

# 2018 Periodic Report

to the  
ACS Committee on Professional Training

Please consult the [ACS Guidelines](http://www.acs.org/cpt) (<http://www.acs.org/cpt>) before completing this report. The information contained in this report should pertain only to your undergraduate program. To facilitate committee review, all responses must be provided on this form. Extra pages for the tables are available under the Templates tab on [CPRS](#).

Name of Institution California State University, Chico

City, State, and Zip Code Chico, CA 95929

Report Prepared by (e.g., Dr. Mary Smith or Juan Ruiz) Dr. Randy Miller, Chair  
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Current Chemistry Department Chair Name Dr. Randy Miller  
 Title Department Chair and Professor  
 E-mail rmmiller@csuchico.edu

Name of Department Department of Chemistry and Biochemistry

## Section 1

1.1 Degrees Offered in Chemistry (check those offered)

Bachelor's	<input checked="" type="checkbox"/>	
Master's	<input type="checkbox"/>	
Ph.D.	<input type="checkbox"/>	

1.2 Number of Calendar Weeks per Term (not counting final exams)

Semester		<u>16</u>
Quarter		<u>                    </u>
4-1-4		<u>                    </u>
Other		<u>                    </u>

1.3 Provide the number of students in the current (most recently completed) academic year:

Entire Campus		<u>16760</u>
Undergraduates		<u>15300</u>
Chemistry Seniors		<u>29</u>
Sum of enrollments in all undergraduate chemistry courses		<u>3050</u>

1.4 Provide the number of bachelor's-degree graduates during the past six years who went on to:

Graduate School in the Chemical Sciences		<u>56</u>
Medical and other Professional Schools		<u>14</u>
Private Sector		<u>36</u>
Teaching		<u>4</u>
Other/Unknown		<u>24</u>

## Section 2: Institutional Environment

2.1 Is the institution accredited by a regional accrediting association? Yes  No   
 Name of Accrediting Association Western Association of Schools and Colleges

2.2 Is the chemistry department organized as an independent administrative unit? Yes  No

a. If no, how is the department or program administered and to whom does the department administrator report?

b. If no, who controls budgetary, personnel, and teaching decisions for the chemistry program, and how are chemistry faculty involved?

2.3 Check the Minimum Salary for each Rank of Chemistry Faculty (Nine Months)

Minimum Salary	Professor	Associate Professor	Assistant Professor	Long-term, non-tenure track
Below \$51K	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
\$51 - \$60K	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
\$61 - \$70K	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
\$71 - \$80K	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
\$81 - \$90K	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Over \$90K	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2.4 Chemistry Expenditures (rough estimates – 2 significant figures):

If your expenditures are over \$60,000 per year, excluding internal and external grants, salaries, and library budget, check here  and go to Item 2.5.

	Current	Annual Average Over the Past Five Years
Operating Expenditures Exclusive of Salaries	_____	_____
Instrument Maintenance and Repair	_____	_____
Student and Faculty Travel	_____	_____
Internal Grants	_____	_____
External Grants	_____	_____

2.5 Describe whether the level of institutional support allows the department to meet its teaching, infrastructure, and faculty development needs.

Yes. The university, through the general fund and student fees, has continued to meet our needs. The budget situation for our system has improved remarkably over the last several years, including significant raises for faculty and staff. Our college is able to provide new faculty release time from teaching their first two years and start-up funds that are sufficient to equip their research labs. A variety of resources exist on-campus and within our system that provide for the innovation in teaching, redesign of courses and acquisition of new instrumentation.

## Section 3: Faculty and Staff

- 3.1 Number of Chemistry Faculty in the Spring 2018 Academic Term (If you have no faculty in a particular category, record a "0"). Please be sure the Total Faculty column sums to the number in the Permanent Total row.

Faculty	Total Faculty	With Ph.D.	Female	Black/AA*	Native American	Asian	Hispanic/Latinx	Other**
<b>Permanent total</b>	12	12	5	0	0	2	0	0
<b>Full-time</b>	12	12	5	0	0	2	0	0
Tenured	8	8	2	0	0	1	0	0
Pre-tenured	4	4	3	0	0	1	0	0
Long-term, non-tenure track	0	0	0	0	0	0	0	0
<b>Part-time</b>	0	0	0	0	0	0	0	0
Tenured	0	0	0	0	0	0	0	0
Pre-tenured	0	0	0	0	0	0	0	0
Long-term, non-tenure track	0	0	0	0	0	0	0	0
<b>Temporary total</b>	18	6	12	0	0	0	0	0
Full-time	0	0	0	0	0	0	0	0
Part-time	18	6	12	0	0	0	0	0

\* AA = African American. \*\*Other includes other ethnicities/diversities beyond Caucasian.

- 3.2 Number of Instructional Staff (Do not include faculty listed in Item 3.1 or Teaching Assistants. If you have no instructional staff in a particular category, record a "0".)

Instructional Staff	Total Staff	With Ph.D.	Female	Black/AA	Native American	Asian	Hispanic/Latinx	Other
<b>Long-term*</b>	0	0	0	0	0	0	0	0
Full-time	0	0	0	0	0	0	0	0
Part-time	0	0	0	0	0	0	0	0
<b>Temporary</b>	0	0	0	0	0	0	0	0
Full-time	0	0	0	0	0	0	0	0
Part-time	0	0	0	0	0	0	0	0

\* Employed for three years or more or expectation of employment for at least three years

- 3.3 The ACS is concerned about the potential overreliance on temporary faculty and temporary instructional staff. If the total number of individuals listed as temporary in Items 3.1 and 3.2 above is more than one-third of the number of permanent faculty and long-term instructional staff, describe the courses the temporary appointments teach and indicate whether those courses are required for certification in the curriculum.

Temp faculty primarily teach courses for non-majors.

- \* CHEM 100: Chemistry and Current Issues (lecture and lab)
- \* CHEM 107: Gen Chem for Applied Sciences (lecture and lab)
- \* CHEM 108: OChem for Applied Sciences (lecture and lab)
- \* CHEM 350/350L: Introductory Biochemistry (lecture and lab)

Temp faculty teach some of the sections that are required for certification

- \* CHEM 111: Gen Chem I (lab only and occasionally 1 of 3 large lectures)
- \* CHEM 112: Gen Chem II (lab only)
- \* CHEM 270: OChem I (lab only)

Of all the CHEM course units required for certification 94% are taught by the permanent faculty for the BS in Chemistry and 93% for the BS in Biochemistry.

3.4 Diversity in the faculty provides valuable perspectives, resources, and knowledge within an academic setting. Examples of diversity include gender identity, people of color, sexual orientation/LGBTQ, religion, ethnicity, multi-racial identity, country of origin, disability status, first-generation college students and military service.

a. Please describe any attributes of the diversity of your faculty and instructional staff that are not captured in Items 3.1 and 3.2.

Most faculty were born in the US, but one is from China. Several are the first in their families to attend college.

b. Please describe any activities the program has engaged in to enhance and promote diversity among faculty and instructional staff in the last five years. You may include strategies used to (1) reach out to applicants from diverse backgrounds, (2) execute the search process, (3) recruit the applicant(s), (4) create an inclusive environment, and (5) retain the recruit(s).

In the past 5 years we have hired 4 new T/TT faculty members, 3 of whom are women. Our search process is organized to reach all PhD-granting institutions. The vacancy announcement gives prominence to our intention to attract and hire a diverse faculty as evidenced by this extract from the opening paragraph.

"CSU, Chico is committed to enriching its educational environment and its culture through the diversity of its staff, faculty, students, and administrators. Persons with interest and experience in helping to set and achieve goals relative to diversity and inclusion are especially encouraged to apply."

3.5	a.	Number of Support Staff:	Administrative	1.5
			Stockroom	3
			Instrument Technicians	.25
			Other	

b. Comment on the adequacy of support staff:

We have outstanding support staff. We recently added a half-time office staff. The university and college have continued to provide the resources need to hire and retain stockroom technicians. The college electronics and instrumentation technician is not exclusively assigned to our department, but is available as needed.

3.6 Describe the professional development opportunities (including sabbaticals) that are available to chemistry faculty and instructional staff.

Tenured faculty are eligible to apply for sabbatical leave every seven years. New faculty receive release from two courses each semester in year 1 and one course each semester in year 2. In addition, our four new faculty have been very successful garnering additional course release in years 3 and 4 from a variety of internal research and curriculum-development grants at the university and system level.

- 3.7 Report the number of chemistry faculty and instructional staff who have taken a sabbatical or professional leave in the last six years.

Requested	<u>3</u>
Granted	<u>3</u>

- 3.8 Teaching Contact Hours for 2017-2018 Academic Year (Classroom and Lab)

Please provide the minimum and maximum numbers that occurred during this academic year. **The ranges reported here should match the numbers reported in Table 3.1.**

- a. Contact Hours/week per semester for Chemistry Faculty (exclusive of research):

Range from 3 to 18 ; Average 11.3

- b. Contact Hours/week per semester for Instructional Staff:

Range from \_\_\_\_\_ to \_\_\_\_\_ ; Average \_\_\_\_\_

- c. If you need to explain how contact hours are counted or if there is a special situation, for example, for online instruction please explain:

- d. Are maximum and/or minimum teaching loads established as an institutional policy?

Yes  No

If yes, explain briefly:

Max teaching loads of 15 weighted teaching units (WTU) are "required" by the CBA of the CalStateUniv system; A typical GenChem lab is 2 WTU and 3 contact hours; a 15 WTU load equates to 22.5 contact hours. The ACS-CPT requirement limiting faculty contact hours to 16 is problematic for most of our temporary faculty members who teach only laboratories. They either agree to teach less than full-time or we violate the ACS-CPT limit.

- 3.9 a. Do you use student teaching assistants? Yes  No

If yes, answer items b. and c.

- b. Describe the formal instruction and assistance in laboratory and/or classroom teaching provided to teaching assistants.

- c. How are teaching assistants supervised in the laboratory?

**Table 3.1 – Teaching Contact Hours**

Provide the **actual contact hours** per week for each individual involved in undergraduate instruction for the 2017-2018 academic year. List one faculty member per row and enter as many faculty per page as possible. List non-tenure-track faculty, temporary faculty, and instructional staff and **identify them with the key below**. Do not include graduate teaching assistants. If the average number of contact hours for your department is less than 12 contact hours per week, complete Table 3.1 only for those individuals with 12 or greater contact hours per week. Please use whole and half numbers only. Additional copies of this table are available under the Template tab on [CPRS](#).

Faculty Member (list according to rank)	Fall Semester/1 <sup>st</sup> Quarter 2017				Spring Semester/2 <sup>nd</sup> Quarter 2018			
	Course Number and Title	1*	2*	3*	Course Number and Title	1*	2*	3*
Curie, Marie (Professor)	CHEM112 – Gen Chem I CHEM 257 – O. Chem I CHEM 258 – O.Chem Lab (2 sections)	3 3 0	0 3 5	14	CHEM259 – Analytical Chemistry CHEM260 – O. Chem II CHEM268 – O.Chem Lab	3 3	3 3 2.5	14.5
Arpin,Carolynn (Asst Prof)					CHEM111-GenChem I (1lec/1lab)	3	3	6
Miller, Randy (Professor)	CHEM381-Int Lab I (1lab/half)	0	3	3	CHEM381-Int Lab I(1lab/half)	0	3	3
Nichols, Christopher (Professor)	CHEM112-GenChem II CHEM370 - OChem II CHEM401-Comm Chem	3 3 4	0 0 0	10	CHE270-OChem I lab(1lec/1lab)	3	3	6
Clark, Dan (Assoc Professor)	CHEM451-Biochem I CHEM453L-Biochem Lab CHEM453M-BiChem Lab	3 0 1	0 3 6	13	CHEM451-Biochem I CHEM453L-Biochem Lab (3 lab)	3 0	0 9	12
Edwards, Dan (Assoc Professor)	CHEM451-Biochem I CHEM453L-Biochem Lab (4 sec)	3 0	0 9	12	CHEM350L-Biochem Lab (1lab) CHEM453L-Biochem Lab (1lab) CHEM453M-Biochem Lab CHEM452-Biochem II	0 0 1 3	3 3 6 0	16
Ott, Lisa (Asst Professor)	CHEM112-GenChemII (1lab) CHEM320-Quant CHEM420-Instrumental	0 2 3	3 6 0	14	CHEM111-GenChemI (1lab) CHEM320-Quant CHEM483-IntChem Lab (1lab)	0 2 0	3 6 6	17
Wasinger, Erik (Asst Professor)	CHEM111-GenChem I CHEM361-Inorganic I CHEM382-IntLab II (1lab/half)	3 3 0	0 0 3	9	CHEM111-Gen Chem I	3	0	3
Zhang, Jinsong (Asst Professor)	CHEM370-OCHEM II CHEM370M OCHEM II Lab(2 labs)	3 0	0 12	15	CHEM112-GenChemII(1lec/3lab)	3	9	12
Postma, James (Professor)	CHEM111-Gen Chem I (1lab)	0	3	3	CHEM112-GenChem II(1lec/1lab)	3	3	6
Everson, Daniel (Asst Professor)	CHEM 270 - O Chem I	3	0	3	CHEM370-O Chem II CHEM370M-OChem II lab (1lab)	3 0	0 6	9
Kendhammer, Lisa (Asst Professor)	CHEM111-GenChem I (2 lec)	6	0	6	CHEM111-GenChem I (1lec/1lab)	3	3	6

\*1 Number of class hours scheduled per week.

\*2 Number of contact hours of lab per week.

\*3 Total of columns 1 and 2 for a grand total for each individual.

# Non-tenure track faculty

@ Temporary faculty and instructional staff

+ Long-term instructional staff

**Table 3.1 – Teaching Contact Hours**

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	Course Number and Title	1*	2*	3*	Course Number and Title	1*	2*	3*
Curie, Marie (Professor)	CHEM112 – Gen Chem I CHEM 257 – O. Chem I CHEM 258 – O.Chem Lab (2 sections)	3 3 0	0 3 5	14	CHEM259 – Analytical Chemistry CHEM260 – O. Chem II CHEM268 – O.Chem Lab	3 3	3 3 2.5	14.5
So, Monica (Asst Professor)	CHEM331-PChem CHEM381-Int Lab I (1lab/half)	3 0	0 3	11	CHEM111-Gen Chem I (1 lab) CHEM381-Int Lab I (1lab/half) CHEM332-PCHEM II	0 0 3	3 3 0	9
Ball, Dave@ (Part-time temp)	CHEM270 - O Chem I CHEM381-Int Lab I (1lab/half) CHEM382-IntLab II(1lab/half)	3 0 0	0 3 3	9	CHEM370-O Chem II CHEM370M-O Chem II Lab (1lab) CHEM381-Int Lab I (1lab/half)	3 0 0	0 6 3	12
Hillyard,S. Luke@ (Part-time temp)	CHEM107-GenChem (1lab) CHEM111-GenChem I(1 Lec/3labs	0 3	3 9	15	CHEM107-GenChem (1Lec/4Lab)	3	12	15
Jones, Ryan@ (Part-time temp)	CHEM270-OChem I Lab (5 lab)	0	15	15	CHEM111-GenChem I (2 lab) CHEM112-GenChem II (3 lab) CHEM270-OChem I (1lab)	0 0 0	6 9 3	18
Mejia, Barbara@ (Part-time temp)	CHEM107-GenChem (2 lab)	0	6	6	CHEM107-GenChem (2 lab)	0	6	6
McBain, Devin@ (Part-time temp)	CHEM107-GenChem (1lab) CHEM108-OChem (2 lab)	0 0	3 6	9	CHEM100-ChemCurrIss CHEM108-OChem (1 lab) CHEM320-Quant (1 lab)	3 0 0	3 6	12
Nuester, Jochen@ (Part-time temp)	CHEM111-GenChem I (2 lab) CHEM320-Quant (1lab)	0 0	6 6	12		0	0	0
Sherry, Sisarie@ (Part-time temp)	CHEM107-GenChem (1lab) CHEM111-GenChem I (5 lab)	0 0	3 15	18	CHEM100- ChemCurrIss (1lab) CHEM111-GenChem I (3 lab)	0 0	2 9	11
Voigtritter, Karl@ (Part-time temp)	CHEM111-GenChem I (4 lab) CHEM270-OChem I (1 lab) CHEM370L-OChem II Lab (1 lab)	0 0 0	12 3 3	18	CHEM270-OChem I (3 lab) CHEM370L-OChem II Lab (2 lab)	0 0	9 6	15
Burgess-Henry, Jana@ (part-time long term)	CHEM270-OChem I (3 lab) CHEM370L-OChem II Lab (2 sec)	0 0	9 6	15				0
Dailey, Kristy@ (part-time temp)				0	CHEM108-OChem (4 lab) CHEM111-GenChem I (1 lab)	0 0	12 3	15

\*1 Number of class hours scheduled per week.

\*2 Number of contact hours of lab per week.

\*3 Total of columns 1 and 2 for a grand total for each individual.

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@ Temporary faculty and instructional staff

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	Course Number and Title	1*	2*	3*	Course Number and Title	1*	2*	3*
Curie, Marie (Professor)	CHEM112 – Gen Chem I CHEM 257 – O. Chem I CHEM 258 – O.Chem Lab (2 sections)	3 3 0	0 3 5	14	CHEM259 – Analytical Chemistry CHEM260 – O. Chem II CHEM268 – O.Chem Lab	3 3	3 3 2.5	14.5
Hanson, Tina@ (Part-time temp)	CHEM107-GenChem (2 lab) CHEM111-GenChem I(1 lab) CHEM350L-BioChem lab (2 lab)	0 0 0	6 3 6	15	CHEM111-GenChem I(2 lab) CHEM350L-BioChem Lab (2 lab)	0 0	6 6	12
Gray, Danielle@ (Part-time temp)	CHEM100-ChemCurIss (1Lec/2lab) CHEM107-GenChem (1 Lec/2 Lab)	2 3	4 6	15	CHEM107-GenChem (1 Lec/4 lab)	3	12	15
Anderson, Tiffani@ (Part-time temp)	CHEM108-OChem (1Lec/3Lab) CHEM370L-OChem II Lab (1 lab)	3 0	9 3	15	CHEM108-OChem (1Lec/1Lab) CHEM370L-OChem II Lab (3 sec)	3 0	3 9	15
Green, Julianne@ (Part-time temp)	CHEM107-GenChem (1Lec/2Lab) CHEM108-OChem (2 lab)	3 0	6 6	15				0
Kirk, Larry@ (Part-time temp)	CHEM350-Biochem	3	0	3	CHEM350-Biochem	3	0	3
Wenham, Jamie@ (Part-time temp)	CHEM107-GenChem (2 Lab)	0	6	6				0
Chatha, Courtney@ (Part-time temp)	CHEM107-GenChem (1lab) CHEM111-GenChem I (4 labs)	0 0	3 12	15	CHEM100-ChemCurIss (1 lab) CHEM107-GenChem (3labs)	0 0	2 9	11
Shaffer, Emily@ (Part-time temp)	CHEM111-GenChem (1 lab) CHEM112-GenChem II (5 labs)	0 0	3 15	18	CHEM111-GenChem (3 labs) CHEM112-GenChem II (2 labs)	0 0	9 6	15

\*1 Number of class hours scheduled per week.

\*2 Number of contact hours of lab per week.

\*3 Total of columns 1 and 2 for a grand total for each individual.

# Non-tenure track faculty

@ Temporary faculty and instructional staff

+ Long-term instructional staff

## Section 4: Infrastructure

- 4.1 Comment on the adequacy and condition of your department's instruments and lab apparatus to meet your program's teaching and research needs. Describe the arrangements for repair, replacement, and maintenance of instruments.

We have a typical variety of instrumentation. Most have been purchased between 2000 and 2018. We continue to partner with local and regional labs to acquire donated, but fully functional equipment and instruments. The university and college are only able to support the upfront purchase of modest instruments in the \$5-50k range, but will provide matching funds for large purchases if/when successful. Repairs under \$1000 are covered by the department; those over \$1000 by the college.

- 4.2 Do you rely on off-site instrumentation to meet your department's research needs? Yes  No   
If yes, please describe the arrangement:

- 4.3 Comment on the adequacy of the facilities and space available for the undergraduate chemistry program.

Each faculty member has a small research lab, approx 300 sq ft, that is adequate for modestly sized research groups (2-3 students) during the academic year. Adjacent instructional labs are available for full-time research during the summer.

- 4.4 a. Indicate the number of chemistry journals to which students have immediate institutional access on your campus.

13 or fewer

14 or more

- b. Do your students and faculty have access to journals that are not available on campus through interlibrary loan? Yes  No

- c. What types of access do undergraduate students and faculty have to chemical information databases on your campus? (Check all that apply.)

Online through ChemSpider

Online through SciFinder

Online through STN

Online through Web of Science

Other access

Specify

- 4.5 What is the maximum number of students in a laboratory section who are directly supervised per faculty member, instructional staff member, or teaching assistant? 24

**Table 4.1 – Instrumentation and Specialized Laboratory Apparatus**

If you have more than one particular instrument, please list up to two. **Only report functioning instrumentation that is used by undergraduate students.** If your department has more than one of a particular instrument type, please list the two newest.

Instrument/Apparatus	Used by Undergraduates		Year Acquired	Manufacturer and Model
	In Chemistry Course Work	In Research		
<b>NMR spectrometer(s)</b>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1999	Varian Mercury VX-300
	<input checked="" type="checkbox"/>	<input type="checkbox"/>	2016	Bruker Avance 400
<b>Optical Molecular Spectroscopy</b>	<input type="checkbox"/>	<input type="checkbox"/>		
IR spectrometer(s)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2004	Nicolet 4700
FT-IR	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2010	Nicolet 380
UV-Vis spectrometer(s)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2000	Agilent 8453
UV-Vis	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1995	Agilent 8453
Other:	<input type="checkbox"/>	<input type="checkbox"/>		
<b>Optical Atomic Spectroscopy</b>	<input type="checkbox"/>	<input type="checkbox"/>		
Atomic absorption/emission	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2004	Thermo Solaar
	<input type="checkbox"/>	<input type="checkbox"/>		
Other:	<input type="checkbox"/>	<input type="checkbox"/>		
<b>Mass Spectrometry</b>	<input type="checkbox"/>	<input type="checkbox"/>		
Mass spectrometer(s)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2005	ThermoFinnegan LCQ
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
GC-Mass spectrometer(s)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2018	Thermo ISQ LT/Tracel300
2 of these	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1998	HP 6890/ MSD
Other:	<input type="checkbox"/>	<input type="checkbox"/>		
<b>Chromatography and separations</b>	<input type="checkbox"/>	<input type="checkbox"/>		
Gas chromatograph(s)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1997	SRI 310
2 more GC	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1997	SRI 310
Liquid chromatograph(s)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2008	HP 1100 HPLC
	<input type="checkbox"/>	<input type="checkbox"/>		
Gel electrophoresis	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2005	Stratagene Joule Box
2 more Gel Electrophoresis	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2005	Biorad Protean 3
Other: Gel Imaging	<input type="checkbox"/>	<input type="checkbox"/>	2018	BioRad EZ Imager
<b>Electrochemistry</b>	<input type="checkbox"/>	<input type="checkbox"/>		
Electrochemical Instrumentation	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2010	BAS epsilon
	<input type="checkbox"/>	<input type="checkbox"/>		
Other:	<input type="checkbox"/>	<input type="checkbox"/>		
<b>Other</b>	<input type="checkbox"/>	<input type="checkbox"/>		
Radiochemistry (including counting equipment and sources)	<input type="checkbox"/>	<input type="checkbox"/>		
	<input type="checkbox"/>	<input type="checkbox"/>		
Thermal analysis equipment	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2003	TA DSC 2010
Bomb Calorimetry	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1990	Parr bomb calorim
Schlenklines and dry box apparatus	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2000	Vacuum Atmos Omni-lab
	<input type="checkbox"/>	<input type="checkbox"/>		
Imaging microscopy	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2016	PemTron PS-230A SEM
	<input type="checkbox"/>	<input type="checkbox"/>		
Other: XRD	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1980	RigakuXRD(upgraded 2018)
<b>Additional Instruments (over \$10,000 in cost):</b>				
Fluorimeter	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	1993	Hitachi F-4500
4 FPLC	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	2005	Pharmaceia LCC 501

#### 4.6 Safety

- a. Are the following laboratory facilities **adequate** for your instructional program and are they routinely **inspected and/or tested**:

Safety Showers	Adequate	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Inspected and/or Tested	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
Eye Washes	Adequate	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Inspected and/or Tested	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
Fire Extinguishers	Adequate	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Inspected and/or Tested	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
Hoods	Adequate	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Inspected and/or Tested	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No
Ventilation	Adequate	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No	Inspected and/or Tested	<input checked="" type="checkbox"/> Yes	<input type="checkbox"/> No

- b. If you do not have any of the above items, or if it is not adequate, inspected and/or tested, please explain.

4.7

	Yes	No
a. Does the department/university have established safety rules?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Does the department/university have emergency reporting procedures?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Does your department have a written chemical hygiene plan?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Are there adequate facilities and arrangements for disposal of chemical waste?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Are safety information and reference materials (e.g., MSDS, SDS, SOPs) readily available to all students and faculty?	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Is appropriate personal protective equipment available and used by all students and faculty?	<input checked="" type="checkbox"/>	<input type="checkbox"/>

- b. If no is checked for any of the above, please explain.

- c. Does the chemistry department or program have a safety committee? Yes  No   
 If yes, how often does it meet? monthly  
 If no, does the chemistry department have a safety officer? Yes  No   
 If you answered no to both checkboxes above, who in the department is responsible for promoting a culture of safety? \_\_\_\_\_

### Section 5: Curriculum

5.1

- a. Are all foundation courses taught annually? Yes  No

- b. If no is checked above, indicate the foundation courses that are **not** taught annually.

- c. If all of the courses required for student certification are not taught annually, describe how students can complete the requirements for a certified chemistry degree within four years.

- d. Are at least four semester-long (or six quarter-long) in-depth courses taught annually, exclusive of research? Yes  No

5.2 Refer to section 5.8 of the ACS Guidelines for the definition of degree tracks and **list only those degree tracks that lead to an ACS-certified bachelor's degree** in chemistry or related field.

Track 1	B.S. in Chemistry
Track 2	B.S. in Biochemistry
Track 3	
Track 4	
Track 5	

Complete Tables 5.1 – 5.4 only for those courses in degree tracks that may lead to an ACS-certified bachelor's degree.

**Table 5.1 – Introductory Course Work**

List all introductory chemistry course work students may use to prepare for the foundation course work listed in Table 5.2. Do not include courses listed in Table 5.2 and 5.3 or courses that are not used for ACS certification purposes. Enter only one course per row.

Dept. & Course Number	Course Title	Total Hours <sup>1</sup>		Textbook and Author	Credit Hours	Tracks <sup>2</sup>				
		Class	Lab			1	2	3	4	5
CHEM 111	General Chemistry I	47	45	General Chemistry, McMurry and Fay	4	R	R	-	-	-
CHEM 112	General Chemistry II	47	45	General Chemistry, McMurry and Fay	4	R	R	-	-	-
						-	-	-	-	-
						-	-	-	-	-
						-	-	-	-	-
						-	-	-	-	-

1. Total Hours refers to the total contact hours per term. Do not record credit hours or contact hours per week in this column.
2. Using the drop-down menu, indicate whether a course is required (R) or one of two or more alternatives (A) that students may choose for each degree track.

5.3 Please report the number of hours in each course listed above in Table 5.1 that reflect remote or virtual laboratory experiences. If none are taught in this matter, please record 0.

0

**Table 5.2 – Foundation Course Work**

List below all course work students may use to satisfy the FOUNDATION requirements in the sequence(s) suggested for ACS certification. Do not include courses listed in Tables 5.1 and 5.3 or courses that are not used for ACS certification purposes. Refer to Section 5.3 of the ACS Guidelines for the definition of a foundation course. Enter only one course per row.

Dept. & Course Number	Course Title	Total Hours <sup>1</sup>		Textbook and Author	CH <sup>2</sup>	Subdisciplinary % Breakdown <sup>3</sup>					Tracks <sup>4</sup>				
		Class	Lab			A	B	I	O	P	1	2	3	4	5
CHEM 270	Organic Chemistry I	47	45	Organic Chemistry, Wade	4				100		<u>R</u>	<u>R</u>	_	_	_
CHEM 320	Quantitative Analysis	32	90	Quantitative Analysis, Harris	4	100					<u>R</u>	<u>R</u>	_	_	_
CHEM 331	Physical Chemistry I	47	0	Physical Chemistry, Engel and Reid	3					100	<u>R</u>	<u>R</u>	_	_	_
CHEM 361	Inorganic Chemistry I	47	0	Inorganic Chemistry, Shriver and Atkins	3			100			<u>R</u>	<u>R</u>	_	_	_
CHEM 451	Biochemistry	47	0	Biochemistry, Nelson, Cox, Lehninger	3		100				<u>R</u>	<u>R</u>	_	_	_
CHEM 381	Integrated Chemistry Lab I		90	Lab handouts and literature	2			30		70	<u>R</u>	<u>R</u>	_	_	_
CHEM 453M	Biochemistry Lab (LAB component)	15	90	Lab handouts and literature	2	15	85				_	<u>R</u>	_	_	_
											_	_	_	_	_
											_	_	_	_	_
											_	_	_	_	_

1. Total hours refers to the total contact hours per term including the final. Do not record credit hours or contact hours per week in this column.
2. Indicate the credit hours (CH) for each course listed.
3. State the approximate percentage of each subdiscipline found in each course (analytical chemistry (A), biochemistry (B), inorganic chemistry (I), organic chemistry (O), and physical chemistry (P)). The percentage coverage must add up to 100% for each course. For example, Biophysics I might be 40% biochemistry and 60% physical or Organic Chemistry I might be 100% organic.
4. Using the drop-down menu, indicate whether a course is required (R) or one of two or more alternatives (A) that students may choose to meet the foundation requirements for each degree track.



**Table 5.3 – In-Depth Course Work**

List the in-depth course work used for ACS certification. Do not include courses listed previously in Tables 5.1 and 5.2. Refer to Section 5.4 of the ACS Guidelines for the definition of an in-depth course. Enter only one course per row.

Dept. & Course Number	Course Title	Total Hours <sup>1</sup>		Textbook and Author	Foundation Prerequisite Course #	CH <sup>2</sup>	Tracks <sup>4</sup>				
		Class	Lab				1	2	3	4	5
CHEM 332	Physical Chemistry II	47	0	Physical Chemistry, Engel and Reid	CHEM 331	3	R	R	_	_	_
CHEM 370	Organic Chemistry II	47		Organic Chemistry, Wade	CHEM270	3	R	R	_	_	_
CHEM 370M	Organic Chemistry II Lab	0	90	Lab handouts and literature	CHEM 270	2	R	R	_	_	_
CHEM 420	Instrumental Analysis	47	0	Principles of Instrumental Analysis, Skoog, Holler and Crouch	CHEM 320	3	R	_	_	_	_
CHEM 483	Integrated Chemistry Lab III	0	90	Lab handouts and literature	CHEM 331	2	R	_	_	_	_
CHEM 452	Biochemistry II	47	0	Biochemistry, Nelson, Cox, Lehninger	CHEM 451	3	E	R	_	_	_
CHEM 382	Integrated Chemistry Lab II		90	Lab handouts and literature	CHEM 331	2	R	R	_	_	_
CHEM 477	Seminar in Organic Spectroscopy	17		Introduction to Spectroscopy, Pavia, Lampman and Kriz	CHEM 370	1	E	E	_	_	_
CHEM 490	Research in Chemistry		45	Lab handouts and literature	CHEM 270, 331, 361, 451	1	E	E	_	_	_
CHEM 491	Research Project		135	Lab handouts and literature	CHEM 270, 331, 361, 451	3	E	E	_	_	_
CHEM 499H	Honors Research Project (2 consecutive semesters required if selected; each semester is 3		135	Lab handouts and literature	CHEM 270, 331, 361, 451	3	E	E	_	_	_

1. Total hours refers to the total contact hours per term including the final. Do not record credit hours or contact hours per week in this column.
2. Indicate the credit hours (CH) for each course listed.
3. Indicate whether a course is required (R) or elective (E) for each track using the drop-down menu.

**Table 5.3 – In-Depth Course Work (continued)**

Dept. & Course Number	Course Title	Total Hours <sup>1</sup>		Textbook and Author	Foundation Prerequisite Course #	CH <sup>2</sup>	Tracks <sup>3</sup>				
		Class	Lab				1	2	3	4	5
CHEM 453M	Biochemistry Lab (LECTURE component)	15	90	Lab handouts and literature	CHEM451	3	-	R	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-
							-	-	-	-	-

1. Total hours refers to the total contact hours per term including the final. Do not record credit hours or contact hours per week in this column.
2. Indicate the credit hours (CH) for each course listed.
3. Indicate whether a course is required (R) or elective (E) for each track using the drop-down menu.

**Table 5.4 – Physics and Mathematics Courses**

List the physics and mathematics course work required for ACS certification. Refer to Section 5.7 of the ACS Guidelines. Enter only one course per row.

Dept. & Course Number	Course Title	Total Hours <sup>1</sup>		Department	Credit Hours	Tracks <sup>2</sup>				
		Class	Lab			1	2	3	4	5
MATH 120	Calculus I	62	0	Math and Statistics	4	<u>R</u>	<u>R</u>	–	–	–
MATH 121	Calculus II	62	0	Math and Statistics	4	<u>R</u>	<u>R</u>	–	–	–
MATH 220	Calculus III	62	0	Math and Statistics	4	<u>R</u>	<u>R</u>	–	–	–
PHYS 204A	Physics I: Mechanics (calculus)	47	45	Physics	4	<u>R</u>	<u>A</u>	–	–	–
PHYS 204B	Physics II: Electricity and Magnetism (calculus)	47	45	Physics	4	<u>R</u>	<u>A</u>	–	–	–
PHYS 204C	Physics III: Heat, Wave, Sound, Light (calculus)	47	45	Physics	4	<u>R</u>	<u>A</u>	–	–	–
PHYS 202A	General Physics I (non-calculus)	47	45	Physics	4	–	<u>R</u>	–	–	–
PHYS 202B	General Physics II (non-calculus)	47	45	Physics	4	–	<u>R</u>	–	–	–
						–	–	–	–	–
						–	–	–	–	–
						–	–	–	–	–

1. Total hours refers to the total contact hours per term including the final. Do not record credit hours or contact hours per week in this column.

2. Indicate whether a course is required (R) or elective (E) for each track using the drop-down menu.

5.5 How do ACS-certified graduates in each degree track meet the in-depth course requirements? List the names, course numbers, and indicate if required or elective. If a course is listed here, ensure it is also entered in Table 5.3. Where a student may choose among two or more courses, clarify the options, and how many courses are required for certification.

B.S. Chemistry

CHEM370/370M: Organic Chemistry II lecture and lab (required)  
CHEM332: Physical Chemistry II (required)  
CHEM382: Integrated Chemistry Lab II-Inorganic focus (required)  
CHEM483: Integrated Chemistry Lab III-Analytical focus (required)  
CHEM420: Instrumental Analysis (required)

Required to choose 1-3 units from the list below

CHEM452: Biochemistry II (3 units)

CHEM490/491/499H: Research in Chemistry (1-3 units; can be taken more than once)

CHEM477: Seminar in Organic Spectroscopy (1 unit)

B.S. Biochemistry

CHEM370/370M: Organic Chemistry II lecture and lab (required)  
CHEM452: Biochemistry II (required)  
CHEM453M: Biochemistry lab (15 hours LECTURE component; required)

REQUIRED to choose 5-6 units from the list below

CHEM 332: Physical Chemistry II

CHEM 420: Instrumental Analysis

CHEM 382: Integrated Chemistry Lab II

CHEM 490/491/499H: Research in Chemistry (1-3 units; can be taken more than once)

CHEM 477: Seminar in Organic Spectroscopy (1 unit)

5.6 How do ACS-certified graduates in each degree track meet the laboratory requirement of 400 hours? Include the subdisciplinary area (ABIOP) covered by each course, the course name, the course number, the number of lab hours devoted to each area, and indicate whether courses are required or elective. Please record the total sum of lab hours for the courses listed in each track. Do not include lab hours from general or introductory lab courses. If a course is listed here, ensure it is also entered in Table 5.2 or 5.3. Example: Organic Chemistry II (CH 232), Organic 45 hours, Required

B.S. Chemistry (540-630 total hours)

Organic Chemistry I (CHEM270), Organic, 45 hours, Required

Organic Chemistry II (CHEM370M), Organic, 90 hours, Required

Quantitative Analysis (CHEM320), Analytical, 90 hours, Required

Integrated Chemistry Lab I (CHEM381), Physical and Inorganic, 90 hours, Required

Integrated Chemistry Lab II (CHEM382), Physical and Inorganic, 90 hours, Required

Integrated Chemistry Lab III (CHEM483), Analytical, 90 hours, Required

Research in Chemistry (CHEM490, 491 or 499H), Could be AIOP, 45-135 hours, Elective

B.S. Biochemistry (450-540 total hours)

Organic Chemistry I (CHEM270), Organic, 45 hours, Required

Organic Chemistry II (CHEM370M), Organic, 90 hours, Required

Quantitative Analysis (CHEM320), Analytical, 90 hours, Required

Integrated Chemistry Lab I (CHEM381), Physical and Inorganic, 90 hours, Required

Biochemistry Lab (CHEM 453M LAB component), Biochemistry, 90 hours, Required

Research in Chemistry (490, 491 or 499H), Biochemistry, 45-135 hours, Elective

5.7a How is the requirement for coverage of at least two of synthetic polymers, biological macromolecules, supramolecular aggregates and/or meso or nanoscale systems, described in Section 5.1 of the Guidelines, satisfied within course work required for certification:

\_\_\_ one or more stand-alone courses that are required for certification

distributed coverage among courses required for certification

5.7b i. If the coverage of biological macromolecules is used to meet up to half of the requirement, list the course numbers and titles of these classes.

CHEM 370: Organic Chemistry II

CHEM 451: Biochemistry

ii. Identify additional areas that are covered, report the approximate number of hours spent in lecture and lab on each topic, and the courses in which these topics are covered in.

Material Classification	Approximate Number of Hours in Lecture	Course Numbers	Approximate Number of Hours in Lab	Course Numbers	Not Covered
Synthetic polymers			35*	CHEM 382	<input type="checkbox"/>
Supra-molecular aggregates					<input checked="" type="checkbox"/>
Meso- or nanoscale materials			35**	CHEM 381	<input type="checkbox"/>

iii. Provide specific examples of how these systems are covered and how the student learning is assessed.

a. Preparation/synthesis

\*\*381: Multi-week project -> prepare perovskite films using spincoating, dipcoating and annealing methods. Written

\*382: Multi-week project -> prepare polyaniline and polypyrrole films using electrochemical polymerization method

\*\*\* Assessment: lecture homework/exams; lab written and oral reports

b. Characterization

\*\*381: Multi-week project -> Record and interpret UV-Vis, fluorescence, XRD, and SEM of perovskite devices

\*382: Multi-week project -> Record and interpret UV-Vis spectra, electrical conductivity, and CV of the polyaniline and polypyrrole polymer films in doped and de-doped states.

c. Physical Properties

\*\*381: Multi-week project -> Confirm crystallinity, structure and solar cell efficiencies of perovskite devices.

\*382: Multi-week project -> Simultaneously probe color changes and redox potentials based on the electrochemical doping-deoping process of the polymers. Measure how much charge is being passed through a given time.

5.7c Provide the course syllabi and exams for any course(s) cited in Items 5.7b.

5.8 Describe the computational chemistry facilities and software (e.g., Gaussian) that students use in their course work and research.

Students have browser-based access to Gaussian 16 through a WebMO interface. Most of our students bring laptop computers to class. Wireless access is available all over campus so that students are able to work on computational projects for courses or research from anywhere. We maintain a small computer lab for those students without a laptop. Formal training in computational work is given as part of CHEM 381: Integrated Chemistry Lab 1 and also as part of our summer research institute.

5.9 How do students gain hands-on experience using chemical instrumentation?

Students first start working with small Spec20-type visible spectrophotometers in the second semester of general chemistry. In sophomore organic students get training and weekly hands-on access to FT-IR, GC-MS and NMR instrumentation. Our quantitative analysis course gives students experience with additional instrumentation like HPLC, fluorescence, atomic absorption and cyclic voltammetry. The most comprehensive experience is in the CHEM 381/382/483 for the B.S. Chemistry majors and CHEM 381/453M for the B.S. Biochemistry majors.

- 5.10 a. Are any classes required for student certification taught wholly online? Yes  No
- b. If you are having problems or concerns with the arrangements for these courses, please describe them.

## Section 6: Undergraduate Research

6.1 Undergraduate Research

- a. Do you use undergraduate research to fulfill certification requirements for lab hours?  
Yes  No
- b. Do you use undergraduate research to fulfill certification requirements for in-depth course work?  
Yes  No
- If yes to either question above, is a comprehensive written report required? Yes  No   
If no, go to Item 6.3.

6.2 Do you have a standard rubric used to evaluate research reports? Yes  No

If yes, please upload the rubric used for evaluation.

6.3 Submit a sample of the comprehensive student research reports or theses representative of multiple disciplines and faculty, with the grade the student received indicated on each report. Also indicate on each report the number of terms (semesters or quarters) and actual student hours per term of research covered by the report.

Number submitted 5 (3-5 reports, 5 maximum)

6.4 Report on the participation in undergraduate research during the last six years.

- a. Number of undergraduate majors (all degrees offered by your program) who participated in a research experience 125
- b. Number of chemistry faculty who were regularly involved in research with undergraduates 10

6.5 If undergraduate research done outside of your institution is used to satisfy certification requirements, are students required to submit a comprehensive written research report that a faculty member at your institution evaluates and approves?

Yes  No  Not applicable

6.6 How are students who are involved in research projects provided with experiment-specific safety education and training?

We have a general orientation meeting then each faculty member goes over the specific safety concerns in their research labs. Faculty review required PPE the safety features. For each new experiment or reagent faculty require students to review the appropriate SDS and then meet to discuss prior to the start of the experiment.

## Section 7: Student Skills

Provide instructional courses and/or laboratories required for the certified degree, **exclusive of research experiences**, where each skill listed below is developed and assessed.

1. Report the course and/or lab where this skill is first introduced
2. If applicable, provide up to two other courses and/or labs where development of this skill is emphasized.
3. Give up to three specific examples of assignments and assessments.

7.1 **Problem solving** (defined as developing testable hypotheses, designing and executing experiments, understanding the fundamental uncertainties in experimental measurements, and drawing appropriate conclusions)

CHEM 370M: Organic Chemistry II lab

CHEM 320: Quantitative Analysis

CHEM 381: Integrated Chemistry Lab I

CHEM 453M: Biochemistry Lab

\* development and implementation of natural product extraction; extraction and quantification of caffeine in beverages; preparation and characterization of MOF thin-films for solar energy conversion.

\* assessment by oral and written report; comparison to accepted values.

7.2 **Reading/searching of primary literature**

CHEM 381: Integrated Chemistry Lab I

CHEM 401: Communicating Chemistry

CHEM 453M: Biochemistry Lab

\* Use SciFinder to locate recent articles on perovskite solar cells, articles for extensive literature review of students choice, green fluorescent protein.

\* assessment by oral and written lab reports; literature review

7.3 **Written communication**

CHEM 370M: Organic Chemistry I

CHEM 381: Integrated Chemistry Lab I

CHEM 401: Communicating Chemistry

CHEM 453M: Biochemistry Lab

\* Written reports on novel natural product extraction, MOF solar cells design and efficiency, GFP project (extraction, purification, characterization)

\* assessment of these reports

## 7.4 Oral Communication

CHEM 370M: Organic Chemistry I  
CHEM 381: Integrated Chemistry Lab I  
CHEM 401: Communicating Chemistry  
CHEM 453M Biochemistry Lab

- \* oral presentations on conformational preferences in bromocyclohexanone systems, MOF solar cells, GFP project, literature review
- \* assessment of these presentations.

## 7.5 Ethics

CHEM 370M: Organic Chemistry I  
CHEM 381: Integrated Chemistry Lab I  
CHEM 401: Communicating Chemistry

- \* proper citation of literature sources, description and examples of plagiarism in lab reports, case studies of high-profile examples of scientific misconduct.
- \* assessment of citation formatting, use of Turnitin to check for plagiarism followed by discussion of specific examples.

## 7.6 Safety

CHEM 111: General Chemistry I  
CHEM 270: Organic Chemistry I  
CHEM 381: Integrated Chemistry Lab I

- \* description of hazards associated with chemicals, proper use of PPE depending on specific lab, biannual evacuation drill of physical science building.
- \* student signature on safety contract, debrief after evacuation drill.

## Section 8: Program Self-Evaluation

### 8.1 Describe the program self-evaluation activities that your department has undertaken over the past five years. Provide quantitative information, if available.

Our department has identified several broadly defined Student Learning Outcomes in areas such as proficiency in chemical theory, laboratory manipulations, quantitative analysis of experimental results and in written and oral communication with several sub-categories in each area. Each year we choose one or two of these broad areas and select some specific aspect to assess in more detail. In most cases we try to identify a sequence of courses over which we can assess, over time, student development.

Below is a brief summary of just a few of the specific results over the last five years.

- \* 2013-14: 50% of the BS Chemistry majors and 88% of BS Biochem majors had a good understanding of organic chemistry in CHEM 370: Organic Chemistry II.
- \* 2014-15: 52% of the BS Biochem students met or exceeded the national average on the standardized biochem exam.
- \* 2015-16: BS Chemistry majors were more proficient than BS Biochemistry majors in analyzing experimental results and categorizing data statistically using computer technology.
- \* 2016-17: 68% of BS Chemistry and BS Biochemistry majors demonstrated proficiency in the concepts in Inorganic Chemistry. Weakness in "solids" and "geometries" were identified.
- \* 2017-18: 36% of the BS Chemistry and 40% of BS Biochemistry majors "mastered" the concepts in Physical Chemistry. Mastery in "electronic structure theory & spectroscopy" and "molecular orbital theory", appeared to be more problematic.

## 8.2 Describe how the results of your department's self-evaluations have been used to improve student learning, student skills, exploration of alternative pedagogies, and the effectiveness of the chemistry program.

The last component of our annual assessment reports include recommendations for improvement, if needed. We discuss these recommendations and work together to implement policies, procedures or pedagogies that address any concerns. For example, "Sanger DNA Sequencing (analysis using gel electrophoresis)" and "Multiple Sequence Alignments", topics in both semesters (CHEM 451 and 452) of our biochemistry sequence were identified as areas needed particular attention. One of our biochemistry faculty members implemented a requirement that all students perform a multiple sequence alignment using the program BioEdit, and interpret the data, as part of a graded assignment.

2017-18 was the last year of the 5-year assessment. 2018-19 is the first year to return to previously assessed topics to evaluate success of modifications motivated by previous assessments.

### Final Comments

Please comment on (in as much detail as you wish) changes in the last five years in faculty, diversity initiatives, professional development, support personnel, facilities, capital equipment, curriculum, and any other items related to your program that you believe would be of interest to CPT. We are especially interested in any new programs you are about to undertake. Use additional sheets, if necessary. Please do not include actual self-evaluation documents or reports.

New faculty - We currently have 12 tenure/tenure-track faculty members, four of whom have been hired since our last report in 2012. Three of these new hires are women. These new faculty have expertise in the areas of Bioorganic (MedChem), Organic, Physical/Materials and Chemical Education opening new areas of research and curriculum design.

Faculty Publications and Grant Activity - The faculty publication list highlights the tremendous success in publishing peer-reviewed articles with undergraduates. The number of publications has increased significantly over the last review cycle not only because of the new faculty hired, but also because of the renewed commitment by mid-career faculty. Faculty have also been successful at garnering primarily internal (on-campus and in-system) funding research and curriculum redesign.

New Building - In 2016 we receive approval and funding for a new science building that will house the Department of Chemistry and Biochemistry. The building is currently under construction with the expectation that we will start the fall 2020 semester in the new facility. The area available to our department in the new building is comparable to or slightly larger than in the current building (built in 1960s), but the design is much more efficient and actually provides more useful space for research. The building provides many areas for student study and collaboration. Our nationally recognized student chapter of the ACS will have nearly 600 sq ft available to provide tutoring and to engage in other activities. We have also designed two, 48 student studio labs for the first semester of General Chemistry.

Chemistry Studio Lab - Our college has committed the resources necessary to completely redesign our first semester GenChem course around a studio model. PhD faculty will have 6 hours per week of contact with students on a 3-day per week, 2-hour per day schedule. We have already started to build a baseline of assessment data regarding faculty and staff workload and current student knowledge and success. We will build on this dataset over the next four years (2 prior and 3 post move to the building).

27 August 2014

Dr. Randy M. Miller, Chair  
Department of Chemistry and Biochemistry  
California State University, Chico  
400 West First Street  
Chico, CA 95929-0210

Dear Dr. Miller:

The Committee on Professional Training reviewed your department's periodic report. Based on the information available, the Committee concluded that the chemistry program meets all of the requirements in the ACS Guidelines and agreed to **continue approval**.

The Committee commended the many positive developments in the chemistry department, including three new faculty appointments, the approval to construct a new science building, and the significant increase in the number of chemistry majors as a result of the new degree tracks that have been instituted to produce high school teachers. The Committee complimented the department for remaining in agreement with the contact-hour requirements for ACS approval through an agreement with the administration and the union.

The Committee made the following suggestions for the continued development of the chemistry program.

**Sabbaticals.** According to the periodic report, only one faculty member took a sabbatical over the five years covered by this report. The Committee urges your eligible faculty members to take advantage of this important opportunity to engage in an extended period of professional renewal in order to maintain the vitality of the faculty and the academic program.

**Research reports.** According to Item 6.1, undergraduate research is used to fulfill certification requirements, and the student research reports submitted were described as good. However, at least one of the reports submitted was referenced as a requirement for CHEM 300, which is not listed in the periodic report form or the college catalog. Please ensure that all research reports provided during the next review are from students enrolled in courses that are used to satisfy certification requirements.

The Committee made the following recommendations that require action by the department.

- **Laboratory experience.** According to Item 5.5, the required laboratory experience covers four of the five foundation areas, as specified in the ACS Guidelines. However, the inorganic lab experience is obtained mainly in Integrated Chemistry Lab II (CHEM 382), which is rather limited in scope and must be improved. A brief description of the changes you have made and all relevant course materials must be included in your department's next periodic report. The enclosed supplement on inorganic chemistry offers guidance on the expectations for instruction in this area.

- **Certification requirements: biochemistry degree track.** Based on the information available, only two in-depth courses are required for student certification in the biochemistry degree track. The other courses listed in Item 5.4 appear to be electives with no indication of the number of courses students must complete. If courses taught outside of the chemistry program are required for certification, you must provide copies of the course materials for CPT review. If you wish to certify graduates from this track, you must confirm that four in-depth courses are required for certification purposes at the time of your department's next review.

As specified in section 5.12 on page 26 of the ACS Guidelines booklet, you must adequately address the recommendations in the next periodic report package that you submit for review by CPT. Your program's next periodic report will be due in **2018**.

Please do not hesitate to contact me if you have any questions about the information in this letter or the expectations for ACS-approved programs.

Sincerely,

Cathy A. Nelson  
Secretary  
Committee on Professional Training

CAN/hdk

c: President Paul J. Zingg

Enclosure: Inorganic Chemistry Supplement

# Chemistry and Biochemistry

Behind the scenes in almost any area—medicine, transportation, agriculture, the environment, computing, entertainment, law, psychology, and the arts—is an army of chemists and chemical technicians who help prepare materials, analyze evidence, create new substances, and answer the "What is it?" questions that are presented each day. They help clean the environment, cure the ill, convict the guilty, and keep us fed, clothed, sheltered, and healthy. And we will continue to need more of these kinds of services to help clean our environment, defeat the next epidemic, and improve our energy efficiency.

The bachelor's degrees in Chemistry and Biochemistry includes a broad selection of courses in the sciences and in mathematics that provides an excellent background for careers in a wide range of fields in science or teaching, or as preparation for professional schools, especially medicine (including dentistry and pharmacy).

Upon completion of the series of courses prescribed by American Chemical Society guidelines, students may be certified as professional chemists and awarded the American Chemical Society Certificate in Chemistry.

## Faculty and Facilities

The Committee on Professional Training of the American Chemical Society has approved the chemistry faculty, facilities, and curriculum. This is a clear statement of the quality of our program and our graduates to anyone in the field.

The permanent faculty have Ph.D.'s in chemistry, representing the major areas of the science. The small size of most major courses assures students of friendly, close contact with the faculty, allowing for hands-on learning of techniques and instrumentation. Short-term research projects with faculty are accessible to all chemistry students. The Department of Chemistry and Biochemistry is housed in the Physical Science Building and includes nine laboratories and a number of specialized instrument and project rooms.

## Career Outlook

A bachelor's degree in chemistry is the minimum requirement for starting a career as a chemist. Graduate training is necessary for most research and college teaching positions. Nearly two-fifths of all chemists are involved in research and development—extending scientific knowledge and creating new products. Nearly one-fifth work in production and inspection activities. Others work as analysts in forensics or environmental laboratories, professors in colleges and universities, as consultants in industry and government agencies, and marketing or sales representatives.

Growth in demand for industrial products (plastics, man-made fibers, pharmaceuticals, and fertilizers), the recognition of the need for pollution control, and improved health care programs

will increase opportunities for chemists. In addition, new and more efficient fuels or fuel cells must be developed to stem energy shortages. Larger enrollments in chemistry education in the future will increase the need for chemists to teach at universities and community colleges. In addition, there is a nationwide shortage of high school chemistry teachers. The California Council on Science and Technology estimates that for every one hundred high school chemistry job openings, there are only sixty qualified applicants. Our department is one of the only eight in the entire CSU system to have a degree program for future chemistry teachers approved by the California Commission on Teacher Credentialing. Plus, our campus has financial incentives for future science teachers that can pay for most of your college expenses.

Our department is uniquely poised to make significant contributions to the training of future scientists, engineers, health practitioners and educators at all levels.

## The Bachelor of Science in Chemistry

### Total Course Requirements for the Bachelor's Degree: 120 units

See [Bachelor's Degree Requirements](#) in the *University Catalog* for complete details on general degree requirements. A minimum of 40 units, including those required for the major, must be upper division.

A suggested Major Academic Plan (MAP) has been prepared to help students meet all graduation requirements within four years. You can view MAPs on the [Degree MAPs](#) page in the *University Catalog* or you can request a plan from your major advisor.

General Education Pathway Requirements: 48 units

See [General Education](#) in the *University Catalog* and the [Class Schedule](#) for the most current information on General Education Pathway Requirements and course offerings.

This major has approved GE modification(s). See below for information on how to apply these modification(s).

- CHEM 401 is an approved major course substitution for Upper-Division Natural Sciences
- CHEM 401 is also an approved GE Writing Intensive substitution.
- CHEM 420 and CHEM 483 together are an approved GE Capstone substitution.
- CHEM 453M is an approved GE Capstone substitution.

Diversity Course Requirements: 6 units

See [Diversity Requirements](#) in the *University Catalog*. Most courses taken to satisfy these requirements may also apply to [General Education](#).

Literacy Requirement:

See [Mathematics and Writing Requirements](#) in the *University Catalog*. Writing proficiency in the major is a graduation requirement and may be demonstrated through satisfactory completion of a course in your major which has been designated as the Writing Proficiency (WP) course for the semester in which you take the course. Students who earn below a C- are required to repeat the course and earn a C- or higher to receive WP credit. See the [Class Schedule](#) for the designated WP courses for each semester. You must complete the GE Written Communication (A2) requirement before you may register for a WP course.

## Course Requirements for the Major: 70-72 units

Completion of the following courses, or their approved transfer equivalents, is required of all candidates for this degree. Additional required courses, depending upon the selected option are outlined following the major core program requirements.

Lower-Division Requirements: 36 units

Chemistry Requirement: 12 units

### 3 courses required:

CHEM 111	General Chemistry	4.0	FS	GE
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Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112	General Chemistry	4.0	FS
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Prerequisites: CHEM 111 with a grade of C- or better.

CHEM 270	Organic Chemistry	4.0	FS
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Prerequisites: CHEM 112.

Mathematics Requirement: 12 units

### 3 courses required:

MATH 120	Analytic Geometry and Calculus	4.0	FS	GE
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Prerequisites: Completion of ELM requirement; both MATH 118 and MATH 119 (or college equivalent); first-year freshmen who successfully completed trigonometry and precalculus in high school can meet this prerequisite by achieving a score that meets department guidelines on a department administered calculus readiness exam.



Prerequisites: CHEM 370, MATH 220; PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, & PHYS 204C.

CHEM 370	Organic Chemistry	3.0	FS
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Prerequisites: CHEM 270 with a grade of C- or higher.

CHEM 370M	Organic Chemistry Laboratory	2.0	FS
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Prerequisites: Concurrent enrollment in or prior completion of CHEM 370.

CHEM 381	Integrated Chemistry Laboratory I	2.0	FS
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Prerequisites: CHEM 331 (may be taken concurrently), CHEM 361 (may be taken concurrently), CHEM 370M.

CHEM 382	Integrated Chemistry Laboratory II	2.0	FA
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Prerequisites: CHEM 331, CHEM 361, CHEM 381.

CHEM 401	Communicating Chemistry	3.0	FA	GW
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Prerequisites: Completion of GE Written Communication (A2) requirement, CHEM 320, CHEM 370; either CHEM 331, CHEM 361, or CHEM 451.

CHEM 420	Instrumental Analysis	3.0	FA
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Prerequisite: CHEM 332.

CHEM 451	Biochemistry	3.0	FS
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Prerequisites: CHEM 370 with a grade of C- or higher.

CHEM 483	Integrated Chemistry Laboratory III	2.0	SP
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Prerequisites: CHEM 381, CHEM 382, CHEM 420.

**1-3 units selected from:**

CHEM 398	Special Topics	1.0 -3.0	FS
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CHEM 399	Special Problems	1.0 -3.0	FS
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Prerequisites: CHEM 112, faculty permission.

CHEM 452	Biochemistry	3.0	SP
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Prerequisites: CHEM 451.

CHEM 453L	Biochemistry Laboratory	1.0	FS
Prerequisite: CHEM 451 (may be taken concurrently). Recommended: CHEM 370L or CHEM 370M.			
CHEM 453M	Biochemistry Laboratory	3.0	FS
Prerequisites: CHEM 320, CHEM 370M. Corequisite: CHEM 451.			
CHEM 477	Seminar in Organic Spectroscopy	1.0	FS
Prerequisites: Concurrent enrollment in or prior completion of CHEM 370.			
CHEM 490	Research in Chemistry	1.0 -2.0	FS
Prerequisites: CHEM 332.			
CHEM 491	Research Project	3.0	FS
Prerequisites: Open by invitation to chemistry majors with a GPA of 3.0 or higher; faculty permission.			
CHEM 499H	Honors Research Project	3.0	FS GW
Prerequisites: Completion of GE Written Communication (A2) requirement, CHEM 320, CHEM 331, CHEM 332, CHEM 370M, MATH 220, PHYS 204A, PHYS 204B, PHYS 204C; faculty permission.			

#### Electives Requirement:

To complete the total units required for the bachelor's degree, select additional elective courses from the total University offerings. You should consult with an advisor regarding the selection of courses which will provide breadth to your University experience and possibly apply to a supportive second major or minor.

#### Grading Requirement:

All courses taken to fulfill major course requirements must be taken for a letter grade except those courses specified by the department as Credit/No Credit grading only.

#### Advising Requirement:

Advising is mandatory for all majors in this degree program. Consult your undergraduate advisor for specific information.

#### Honors in the Major:

Honors in the Major is a program of independent work in your major. It requires 6 units of honors course work completed over two semesters.

The Honors in the Major program allows you to work closely with a faculty mentor in your area of interest on an original performance or research project. This year-long collaboration allows you to work in your field at a professional level and culminates in a public presentation of your work. Students sometimes take their projects beyond the University for submission in professional journals, presentation at conferences, or academic competition. Such experience is valuable for graduate school and professional life. Your honors work will be recognized at your graduation, on your permanent transcripts, and on your diploma. It is often accompanied by letters of commendation from your mentor in the department or the department chair.

Some common features of Honors in the Major program are:

1. You must take 6 units of Honors in the Major course work. All 6 units are honors classes (marked by a suffix of H), and at least 3 of these units are independent study (399H, 499H, 599H) as specified by your department. You must complete each class with a minimum grade of B.
2. You must have completed 9 units of upper-division course work or 21 overall units in your major before you can be admitted to Honors in the Major. Check the requirements for your major carefully, as there may be specific courses that must be included in these units.
3. Your *cumulative* GPA should be at least 3.5 or within the top 5% of majors in your department.
4. Your GPA *in your major* should be at least 3.5 or within the top 5% of majors in your department.
5. Most students apply for or are invited to participate in Honors in the Major during the second semester of their junior year. Then they complete the 6 units of course work over the two semesters of their senior year.
6. Your honors work culminates with a public presentation of your honors project.

While Honors in the Major is part of the Honors Program, each department administers its own program. Please contact your major department or major advisor to apply.

## The Bachelor of Science in Biochemistry

### Total Course Requirements for the Bachelor's Degree: 120 units

See [Bachelor's Degree Requirements](#) in the *University Catalog* for complete details on general degree requirements. A minimum of 40 units, including those required for the major, must be upper division.

A suggested Major Academic Plan (MAP) has been prepared to help students meet all graduation requirements within four years. You can view MAPs on the [Degree MAPs](#) page in the *University Catalog* or you can request a plan from your major advisor.

General Education Pathway Requirements: 48 units

See [General Education](#) in the *University Catalog* and the [Class Schedule](#) for the most current information on General Education Pathway Requirements and course offerings.

This major has approved GE modification(s). See below for information on how to apply these modification(s).

- CHEM 401 is an approved major course substitution for Upper Division Natural Sciences.
- BIOL 371, BIOL 470, and CHEM 401 are approved GE Writing Intensive substitutions.
- CHEM 453M is an approved GE Capstone substitution.

Diversity Course Requirements: 6 units

See [Diversity Requirements](#) in the *University Catalog*. Most courses taken to satisfy these requirements may also apply to [General Education](#).

Literacy Requirement:

See [Mathematics and Writing Requirements](#) in the *University Catalog*. Writing proficiency in the major is a graduation requirement and may be demonstrated through satisfactory completion of a course in your major which has been designated as the Writing Proficiency (WP) course for the semester in which you take the course. Students who earn below a C- are required to repeat the course and earn a C- or higher to receive WP credit. See the [Class Schedule](#) for the designated WP courses for each semester. You must complete the GE Written Communication (A2) requirement before you may register for a WP course.

## Course Requirements for the Major: 76-78 units

Completion of the following courses, or their approved transfer equivalents, is required of all candidates for this degree.

Lower-Division Requirements: 36 units

### 9 courses required:

BIOL 151	Principles of Cellular and Molecular Biology		4.0	FS	GE
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Prerequisites: Recommend CHEM 111 or concurrent enrollment.

CHEM 111	General Chemistry		4.0	FS	GE
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Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112	General Chemistry		4.0	FS	
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Prerequisites: CHEM 111 with a grade of C- or better.





BIOL 412	Bacterial Physiology	4.0	S1
Prerequisites: BIOL 371, BIOL 360, CHEM 270. CHEM 451 is recommended.			
BIOL 414	Plant Physiology	4.0	SP
Prerequisites: BIOL 153 or SCED 102; CHEM 108 or CHEM 270; or faculty permission.			
BIOL 416	Vertebrate Physiology	4.0	FS
Prerequisites: BIOL 152, BIOL 153; CHEM 108 or CHEM 270.			
BIOL 466	Immunology	4.0	SP
Prerequisites: BIOL 153.			
BIOL 470	Medical Bacteriology	5.0	FA GW
Prerequisites: Completion of GE Written Communication (A2) requirement; BIOL 371, BIOL 466, CHEM 270.			
BIOL 472	Microbial Genetics	4.0	FA
Prerequisites: BIOL 360. BIOL 371 is recommended.			
BIOL 476	General Virology	4.0	SP
Prerequisites: BIOL 151, BIOL 371. Recommended: BIOL 360.			
CHEM 332	Physical Chemistry	3.0	SP
Prerequisites: CHEM 331.			

#### Grading Requirement:

All courses taken to fulfill major course requirements must be taken for a letter grade except those courses specified by the department as Credit/No Credit grading only.

#### Advising Requirement:

Advising is mandatory for all majors in this degree program. Consult your undergraduate advisor for specific information.

## The Bachelor of Arts in Chemistry

## **Total Course Requirements for the Bachelor's Degree: 120 units**

See [Bachelor's Degree Requirements](#) in the *University Catalog* for complete details on general degree requirements. A minimum of 40 units, including those required for the major, must be upper division.

A suggested Major Academic Plan (MAP) has been prepared to help students meet all graduation requirements within four years. You can view MAPs on the [Degree MAPs](#) page in the *University Catalog* or you can request a plan from your major advisor.

This degree is appropriate for students pursuing single subject matter preparation in science with a concentration in chemistry. This degree is also an excellent preparation for students considering chemistry-related interdisciplinary fields. Students who choose this program should consult with their major advisor.

General Education Pathway Requirements: 48 units

See [General Education](#) in the *University Catalog* and the [Class Schedule](#) for the most current information on General Education Pathway Requirements and course offerings.

This major has approved GE modifications. See below for information on how to apply these modifications.

- CHEM 401 is an approved major course substitution for Upper-Division Natural Sciences
- CHEM 401 is also an approved GE Writing Intensive substitution.
- CHEM 453M is an approved GE Capstone substitution.

Diversity Course Requirements: 6 units

See [Diversity Requirements](#) in the *University Catalog*. Most courses taken to satisfy these requirements may also apply to [General Education](#).

Literacy Requirement:

See [Mathematics and Writing Requirements](#) in the *University Catalog*. Writing proficiency in the major is a graduation requirement and may be demonstrated through satisfactory completion of a course in your major which has been designated as the Writing Proficiency (WP) course for the semester in which you take the course. Students who earn below a C- are required to repeat the course and earn a C- or higher to receive WP credit. See the [Class Schedule](#) for the designated WP courses for each semester. You must complete the GE Written Communication (A2) requirement before you may register for a WP course.

## **Course Requirements for the Major: 60-64 units**

Completion of the following courses, or their approved transfer equivalents, is required of all candidates for this degree.

Lower-Division Requirements: 32-36 units

**6 courses required:**

CHEM 111	General Chemistry	4.0	FS	GE
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Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112	General Chemistry	4.0	FS
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Prerequisites: CHEM 111 with a grade of C- or better.

CHEM 270	Organic Chemistry	4.0	FS
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Prerequisites: CHEM 112.

MATH 120	Analytic Geometry and Calculus	4.0	FS	GE
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Prerequisites: Completion of ELM requirement; both MATH 118 and MATH 119 (or college equivalent); first-year freshmen who successfully completed trigonometry and precalculus in high school can meet this prerequisite by achieving a score that meets department guidelines on a department administered calculus readiness exam.

MATH 121	Analytic Geometry and Calculus	4.0	FS
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Prerequisites: MATH 120.

MATH 220	Analytic Geometry and Calculus	4.0	FS
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Prerequisites: MATH 121.

**2-3 courses selected from:**

PHYS 202A	General Physics I	4.0	FS	GE
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Prerequisites: High school physics or faculty permission. High school trigonometry and second-year high school algebra or equivalent (MATH 051 and MATH 118 at CSU, Chico).

PHYS 202B	General Physics II	4.0	FS
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Prerequisites: PHYS 202A with a grade of C- or higher.

**Or the following group of courses may be selected:**

PHYS 204A      Physics for Students of Science and Engineering: Mechanics      4.0 FS GE

Prerequisites: High school physics or faculty permission. Concurrent enrollment in or prior completion of MATH 121 (second semester of calculus) or equivalent.

PHYS 204B      Physics for Students of Science and Engineering: Electricity and Magnetism      4.0 FS

Prerequisites: MATH 121, PHYS 204A with a grade of C- or higher.

PHYS 204C      Physics for Students of Science and Engineering: Heat, Wave Motion, Sound, Light, and Modern Topics      4.0 FS

Prerequisites: MATH 121, PHYS 204A with a grade of C- or higher.

Note: One full sequence (PHYS 202AB or PHYS 204ABC) must be completed.

Upper-Division Requirements: 28 units

**8 courses required:**

CHEM 320      Quantitative Analysis      4.0 FS

Prerequisites: CHEM 112 with a grade of C- or higher.

CHEM 331      Physical Chemistry      3.0 FA

Prerequisites: CHEM 370M, MATH 220; PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, & PHYS 204C.

CHEM 361      Inorganic Chemistry      3.0 FA

Prerequisites: CHEM 370, MATH 220; PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, & PHYS 204C.

CHEM 370      Organic Chemistry      3.0 FS

Prerequisites: CHEM 270 with a grade of C- or higher.

CHEM 370M      Organic Chemistry Laboratory      2.0 FS

Prerequisites: Concurrent enrollment in or prior completion of CHEM 370.

CHEM 381      Integrated Chemistry Laboratory I      2.0 FS



# American Chemical Society Certificate in Chemistry

## Course Requirements for the Certificate: 70-82 units

The following courses, or their approved transfer equivalents, are required of all candidates for this certificate.

Students who complete this program will be awarded a degree in chemistry which will be certified by the American Chemical Society as well as a certificate from CSU, Chico. (Note: ACS requirements change only rarely, but interested students should verify requirements with the Chair of the Department of Chemistry and Biochemistry.) Current requirements include either:

Completion of the BS in Chemistry

or

the BS in Biochemistry with at least 4 units from the following list of courses:

### 4 units selected from:

CHEM 332	Physical Chemistry	3.0	SP
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Prerequisites: CHEM 331.

CHEM 382	Integrated Chemistry Laboratory II	2.0	FA
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Prerequisites: CHEM 331, CHEM 361, CHEM 381.

CHEM 477	Seminar in Organic Spectroscopy	1.0	FS
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Prerequisites: Concurrent enrollment in or prior completion of CHEM 370.

CHEM 490	Research in Chemistry	1.0 -2.0	FS
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Prerequisites: CHEM 332.

CHEM 491	Research Project	3.0	FS
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Prerequisites: Open by invitation to chemistry majors with a GPA of 3.0 or higher; faculty permission.

CHEM 499H	Honors Research Project	3.0	FS	GW
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Prerequisites: Completion of GE Written Communication (A2) requirement, CHEM 320, CHEM 331, CHEM 332, CHEM 370M, MATH 220, PHYS 204A, PHYS 204B, PHYS 204C; faculty permission.

# The Minor in Biochemistry

## Course Requirements for the Minor: 27 units

The following courses, or their approved transfer equivalents, are required of all candidates for this minor.

Lower-Division Requirements: 12 units

### 3 courses required:

CHEM 111	General Chemistry	4.0	FS	GE
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Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112	General Chemistry	4.0	FS
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Prerequisites: CHEM 111 with a grade of C- or better.

CHEM 270	Organic Chemistry	4.0	FS
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Prerequisites: CHEM 112.

Upper-Division Requirements: 15 units

### 6 courses required:

CHEM 320	Quantitative Analysis	4.0	FS
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Prerequisites: CHEM 112 with a grade of C- or higher.

CHEM 370	Organic Chemistry	3.0	FS
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Prerequisites: CHEM 270 with a grade of C- or higher.

CHEM 370L	Organic Chemistry Laboratory	1.0	FS
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Prerequisites: CHEM 370 may be taken as a prerequisite or concurrently with CHEM 370L.

CHEM 451	Biochemistry	3.0	FS
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Prerequisites: CHEM 370 with a grade of C- or higher.

CHEM 452	Biochemistry	3.0	SP
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Prerequisites: CHEM 451.

CHEM 453L	Biochemistry Laboratory	1.0	FS
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Prerequisite: CHEM 451 (may be taken concurrently). Recommended: CHEM 370L or CHEM 370M.

# The Minor in Chemistry

## Course Requirements for the Minor: 23 units

The following courses, or their approved transfer equivalents, are required of all candidates for this minor.

*Lower-Division Courses: 12 units*

### 3 courses required:

CHEM 111	General Chemistry	4.0	FS	GE
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Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112	General Chemistry	4.0	FS
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Prerequisites: CHEM 111 with a grade of C- or better.

CHEM 270	Organic Chemistry	4.0	FS
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Prerequisites: CHEM 112.

*Upper-Division Courses: 11 units*

### 3 courses required:

CHEM 320	Quantitative Analysis	4.0	FS
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Prerequisites: CHEM 112 with a grade of C- or higher.



Pre-Dentistry: 34 units recommended

Entrance into dental school requires from two to four years of pre-dental training. Ordinarily a pre-dental student should plan on pursuing a bachelor's degree program. It is not necessary that this degree be in one of the sciences.

Details about entrance requirements differ considerably from one dental school to another. Further information should be sought from one of the pre-dental advisors and from the booklet entitled, *Entrance Requirements of American Dental Schools*.

The following list represents the California State University equivalent of the requirements and recommendations common to practically all of the American Dental Schools.

#### *Recommended Courses*

BIOL 151 Principles of Cellular and Molecular Biology  4.0 FS GE

Prerequisites: Recommend CHEM 111 or concurrent enrollment.

BIOL 152 Principles of Ecological, Evolutionary, and Organismal Biology  4.0 FS GE

Prerequisites: BIOL 151 or faculty permission; recommend CHEM 112 or concurrent enrollment.

CHEM 111 General Chemistry 4.0 FS GE

Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112 General Chemistry 4.0 FS

Prerequisites: CHEM 111 with a grade of C- or better.

CHEM 270 Organic Chemistry 4.0 FS

Prerequisites: CHEM 112.

CHEM 370 Organic Chemistry 3.0 FS

Prerequisites: CHEM 270 with a grade of C- or higher.

ENGL 130I Academic Writing 3.0 FS GE WI

Prerequisites: English Placement Test.

PHYS 202A General Physics I 4.0 FS GE

Prerequisites: High school physics or faculty permission. High school trigonometry and second-year high school algebra or equivalent (MATH 051 and MATH 118 at CSU, Chico).

PHYS 202B General Physics II 4.0 FS

Prerequisites: PHYS 202A with a grade of C- or higher.

### Pre-Medicine

It is recommended that pre-medical students plan to obtain a degree in a field of science, such as chemistry or biology. While students may apply for admission to medical school any time after their junior year, the majority of those admitted have completed a four-year degree, and a sizable number are admitted only after additional graduate work. The bachelors degree in Chemistry or Biochemistry, therefore, is also appropriate for those seeking advanced training in graduate schools or employment in fields related to medicine. See also the Pre-Medicine program under Biological Sciences.

### Lower-Division Courses

BIOL 151 Principles of Cellular and Molecular Biology  4.0 FS GE

Prerequisites: Recommend CHEM 111 or concurrent enrollment.

BIOL 152 Principles of Ecological, Evolutionary, and Organismal Biology  4.0 FS GE

Prerequisites: BIOL 151 or faculty permission; recommend CHEM 112 or concurrent enrollment.

CHEM 111 General Chemistry 4.0 FS GE

Prerequisites: Completion of ELM requirement; second-year high school algebra; one year high school chemistry. (One year of high school physics and one year of high school mathematics past Algebra II are recommended.)

CHEM 112 General Chemistry 4.0 FS

Prerequisites: CHEM 111 with a grade of C- or better.

CHEM 270 Organic Chemistry 4.0 FS

Prerequisites: CHEM 112.

MATH 120 Analytic Geometry and Calculus 4.0 FS GE

Prerequisites: Completion of ELM requirement; both MATH 118 and MATH 119 (or college equivalent); first-year freshmen who successfully completed trigonometry and precalculus in high school can meet

this prerequisite by achieving a score that meets department guidelines on a department administered calculus readiness exam.

MATH 121 Analytic Geometry and Calculus 4.0 FS

Prerequisites: MATH 120.

PHYS 202A General Physics I 4.0 FS GE

Prerequisites: High school physics or faculty permission. High school trigonometry and second-year high school algebra or equivalent (MATH 051 and MATH 118 at CSU, Chico).

PHYS 202B General Physics II 4.0 FS

Prerequisites: PHYS 202A with a grade of C- or higher.

#### *Upper-Division Courses*

CHEM 320 Quantitative Analysis 4.0 FS

Prerequisites: CHEM 112 with a grade of C- or higher.

CHEM 370 Organic Chemistry 3.0 FS

Prerequisites: CHEM 270 with a grade of C- or higher.

CHEM 370L Organic Chemistry Laboratory 1.0 FS

Prerequisites: CHEM 370 may be taken as a prerequisite or concurrently with CHEM 370L.

CHEM 451 Biochemistry 3.0 FS

Prerequisites: CHEM 370 with a grade of C- or higher.

#### *Recommended Upper-Division Electives*

BIOL 360 Genetics 4.0 FS

Prerequisites: BIOL 153 or permission of instructor.

BIOL 416 Vertebrate Physiology 4.0 FS

Prerequisites: BIOL 152, BIOL 153; CHEM 108 or CHEM 270.

BIOL 426 Developmental Biology 4.0 FA

Prerequisites: BIOL 152, BIOL 153, or faculty permission.

BIOL 430 Comparative Anatomy of the Vertebrates 4.0 F1

Prerequisites: BIOL 152, BIOL 153.

#### Pre-Optometry

The requirements for optometry schools vary widely. The student should see the pre-optometry advisor in the Department of Chemistry and Biochemistry and the catalog of the school of his/her choice. The prospective student is encouraged to consult the Department Chair for further information.

#### Pre-Pharmacy

The requirements for pharmacy schools vary widely. The student should see the pre-pharmacy advisor in the Department of Chemistry and Biochemistry and the catalog of the school of his/her choice. The prospective student is encouraged to consult the Department Chair for further information.

#### Pre-Physical Therapy

See the listings under [Biological Sciences](#).

#### Forensic Science and Graduate Programs in Criminalistics

Entry-level employment and graduate programs in criminalistics commonly require a major in one of the physical or biological sciences, including a year of general chemistry and a course in quantitative analysis. Please see the Anthropology section for a program in Forensic Identification.

## **The Single Subject Matter Preparation Program in Science With a Concentration in Chemistry**

*Course requirements for the Single Subject Matter Preparation Program, 72-86 units, in conjunction with the Professional Education Program, lead to a Single Subject Teaching Credential.*

In most majors, candidates for this credential will normally fulfill the single subject matter preparation program by completing the appropriate education option in the major. Any exceptions to this procedure are noted at the end of this section. In addition to the single subject matter preparation program, completion of an additional professional education program is required to qualify for a California teaching credential. Professional education (credential) programs are available through the School of Education. For prerequisites and other admission requirements to professional education programs, see the [Education](#) chapter of this catalog.

Your departmental credential advisor is responsible for verifying that the subject matter preparation program has been completed. If you are interested in obtaining a teaching credential, confer with the appropriate credential advisor early in your University career. Department credential advisors can assist you in planning an educational program that meets both major and credential requirements.

Subject matter preparation requirements are governed by state legislative action and approval of the California Commission on Teacher Credentialing. Requirements may change between catalogs. Please consult with your departmental credential advisor for current information.

*Completion of one of the degree programs, the BA in Chemistry, BS in Chemistry or the BS in Biochemistry, and the additional courses listed below, along with a professional education program, fulfills all requirements for the single subject matter preparation program in science with a concentration in chemistry. Note that the Internship in Chemistry (CHEM 389) must be with a teacher or involve teaching in some capacity.*

### 5 courses required:

BIOL 151 Principles of Cellular and Molecular Biology  4.0 FS GE

Prerequisites: Recommend CHEM 111 or concurrent enrollment.

BIOL 152 Principles of Ecological, Evolutionary, and Organismal Biology  4.0 FS GE

Prerequisites: BIOL 151 or faculty permission; recommend CHEM 112 or concurrent enrollment.

CHEM 389 Internship in Chemistry 1.0 -3.0 FS

CHEM 389 may be taken for 1 unit twice, but must be taken for a total of 2 units.

GEOS 102 Physical Geology  3.0 FS GE

Prerequisites: High school chemistry or physics is recommended; students with no previous science courses are advised to enroll in GEOS 101. No college credit for those who have passed GEOS 101.

GEOS 300 Earth System Science  3.0 FS GW

Prerequisites: Completion of GE Written Communication (A2) requirement; CHEM 107 or CHEM 111; PHYS 202A or PHYS 204A or PHYS 341.



CHEM 112	General Chemistry	4.0	FS
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Prerequisites: CHEM 111 with a grade of C- or better.  
A continuation of CHEM 111. Topics include kinetics, equilibrium, acid-base chemistry, electrochemistry, chemical thermodynamics, coordination chemistry, and nuclear chemistry. The laboratory sequence supports the above topics including both qualitative and quantitative experiments, analysis of data, and error propagation. 3 hours lecture, 3 hours laboratory. (001817)

CHEM 112X	General Chemistry Problem Session	1.0	FS
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Corequisites: CHEM 112.  
Designed to supplement CHEM 112 with additional applications of general chemistry. Provides the student with the opportunity for additional assistance in developing problem-solving abilities. 2 hours activity. Credit/no credit grading. (001832)

CHEM 189	Internship in Chemistry	1.0 -3.0	FS
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9 hours supervision. You may take this course more than once for a maximum of 15.0 units. Credit/no credit grading. (001844)

CHEM 198	Special Topics	1.0 -3.0	FS
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Prerequisites: Department permission.  
This course is for special topics offered for 1.0-3.0 units. Typically the topic is offered on a one-time-only basis and may vary from term to term and be different for different sections. See the Class Schedule for the specific topic being offered. 3 hours lecture. (001846)

CHEM 270	Organic Chemistry	4.0	FS
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Prerequisites: CHEM 112.  
A study of the fundamental principles of organic chemistry: the chemistry of carbon compounds. Lecture topics include structure, bonding, nomenclature, physical properties of organic compounds, stereochemistry, basic spectroscopy, and basic chemical reactions and their mechanisms. Laboratory topics include the discussion and application of organic laboratory techniques, reactions, and an introduction to organic synthesis. 3 hours lecture, 3 hours laboratory. (001840)

CHEM 320	Quantitative Analysis	4.0	FS
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Prerequisites: CHEM 112 with a grade of C- or higher.  
Precision and accuracy in measurements, interpretation of data by statistical analysis, and development of good quantitative techniques. Analysis by gravimetry, titrimetry, potentiometry, chromatography, and spectrometry. 2 hours discussion, 6 hours laboratory. (001847)

CHEM 331	Physical Chemistry	3.0	FA
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Prerequisites: CHEM 370M, MATH 220; PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, & PHYS 204C.  
An introduction to quantum mechanics and spectroscopy, classical and statistical thermodynamics, and dynamics and chemical kinetics. 3 hours discussion. (001882)

CHEM 332	Physical Chemistry	3.0	SP
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Prerequisites: CHEM 331.  
A continuation of CHEM 331. 3 hours discussion. (001883)

CHEM 350	Introductory Biochemistry	3.0	FS
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Prerequisites: CHEM 108.

A survey of biochemistry, principally for agriculture, child development, and nursing students. Normally not open to chemistry or biological sciences majors. 3 hours discussion. (001849)

CHEM 350L Introductory Biochemistry Laboratory 1.0 FS

Prerequisites: Concurrent enrollment in or prior completion of CHEM 350.

Fundamental laboratory studies and examination of the major classes of biological compounds. Principally for agriculture, child development, and nursing students. Normally not open to chemistry or biological sciences majors. 3 hours laboratory. (001850)

CHEM 361 Inorganic Chemistry 3.0 FA

Prerequisites: CHEM 370, MATH 220; PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, & PHYS 204C.

Emphasis on description and theory of inorganic substances: atomic structure; ionic and covalent bonding; acid-base concepts of inorganic substances; structure, bonding, thermodynamics, and reaction mechanisms of transition metal complexes; organometallic chemistry and catalysis; and bioinorganic chemistry. 3 hours lecture. (001887)

CHEM 362 Intermediate Inorganic Chemistry 2.0 SP

Prerequisites: CHEM 361.

A continuation of CHEM 361. 2 hours lecture. (001888)

CHEM 370 Organic Chemistry 3.0 FS

Prerequisites: CHEM 270 with a grade of C- or higher.

A continuation of CHEM 270. Topics include properties and reactions of ethers, conjugated systems, aromatic compounds, aldehydes and ketones, amines, carboxylic acids and derivatives, and biologically relevant molecules. 3 hours discussion. (001852)

CHEM 370L Organic Chemistry Laboratory 1.0 FS

Prerequisites: CHEM 370 may be taken as a prerequisite or concurrently with CHEM 370L.

Laboratory continuation of CHEM 270. Laboratory experiments in organic chemistry focused on topics discussed in CHEM 370. Not applicable towards a degree in chemistry or biochemistry. 3 hours laboratory. (001856)

CHEM 370M Organic Chemistry Laboratory 2.0 FS

Prerequisites: Concurrent enrollment in or prior completion of CHEM 370.

An in-depth laboratory experience in organic chemistry for chemistry and biochemistry majors. Students are introduced to and become competent in modern laboratory techniques, including handling air-sensitive reagents and column chromatography. Students also get hands-on experience with advanced instrumentation. Completes the two-semester organic lab sequence for chemistry majors. 6 hours laboratory. (001853)

CHEM 381 Integrated Chemistry Laboratory I 2.0 FS

Prerequisites: CHEM 331 (may be taken concurrently), CHEM 361 (may be taken concurrently), CHEM 370M.

Integrated application of concepts and techniques in analytical, inorganic, and physical chemistry with supervised studies in individual literature searches, including the use of Chemical Abstracts, Patent Indexes, and other reference compilations. 6 hours laboratory. (001885)

CHEM 382 Integrated Chemistry Laboratory II 2.0 FA

Prerequisites: CHEM 331, CHEM 361, CHEM 381.

A continuation of CHEM 381. 6 hours laboratory. (001886)

CHEM 389 Internship in Chemistry 1.0 -3.0 FS

9 hours supervision. You may take this course more than once for a maximum of 15.0 units. Credit/no credit grading. (001865)

CHEM 390 Special Problems in Science Education 1.0 -3.0 FS

Prerequisites: CHEM 111, faculty permission.

This course is a supervised study in science outreach to K-14 schools and is offered for 1.0-3.0 units. You must register with a supervising faculty member. You may take this course more than once for a maximum of 3.0 units. Credit/no credit grading. (001866)

CHEM 398 Special Topics 1.0 -3.0 FS

This course is for special topics offered for 1.0-3.0 units. Typically the topic is offered on a one-time-only basis and may vary from term to term and be different for different sections. See the Class Schedule for the specific topic being offered. (001872)

CHEM 399 Special Problems 1.0 -3.0 FS

Prerequisites: CHEM 112, faculty permission.

This course is an independent study of special problems and is offered for 1.0-3.0 units. You must register directly with a supervising faculty member. 9 hours supervision. You may take this course more than once for a maximum of 6.0 units. Credit/no credit grading. (001873)

CHEM 400 Senior Seminar in Chemistry 1.0 SP

Presentation and discussion of topics from chemical literature. 2 hours activity. (001869)

CHEM 401 Communicating Chemistry 3.0 FA GW

Prerequisites: Completion of GE Written Communication (A2) requirement, CHEM 320, CHEM 370; either CHEM 331, CHEM 361, or CHEM 451.

This course helps students improve their skills in written communication and oral communication of chemical and biochemical information. The course centers on one particular topic within chemistry and biochemistry (chosen by the instructor) and students are asked to prepare short papers, long papers, and oral presentations focused on that topic. 2 hours discussion, 2 hours activity. This is an approved Graduation Writing Assessment Requirement course; a grade of C- or better certifies writing proficiency for majors. (021609)

CHEM 420 Instrumental Analysis 3.0 FA

Prerequisite: CHEM 332.

Theory and procedures used in separations and instrumental analysis. Emphasis on rational design of instrumental conditions based on experiment goals. Topics include atomic and molecular spectroscopies, separation methods, and electroanalytical chemistry. 3 hours discussion. (001892)

CHEM 445 Environmental Toxicology  2.0 SP

Prerequisites: CHEM 108 or CHEM 270.

A brief introduction to the principles of toxicology and presentation of facts about current issues related to toxic substances, with special expanded emphasis on environmental aspects of topics presented in CHEM 345. 2 hours discussion. (001880)

CHEM 451 Biochemistry 3.0 FS

Prerequisites: CHEM 370 with a grade of C- or higher.

A general study of the chemistry of biomolecules. Conformation and function of enzymes and other proteins; metabolism, energy generation, and storage; brief discussion of important physiological processes. 3 hours discussion. (001900)

CHEM 452 Biochemistry 3.0 SP

Prerequisites: CHEM 451.

Advanced topics in biochemistry. Biosynthesis of lipids, steroids, amino acids, and nucleotides. Comprehensive study of the chemical role of DNA and RNA in replication, transcription, protein synthesis, and viral activity. 3 hours discussion. (001901)

CHEM 453L Biochemistry Laboratory 1.0 FS

Prerequisite: CHEM 451 (may be taken concurrently). Recommended: CHEM 370L or CHEM 370M.

Separation, identification, and/or analysis of biological materials by modern procedures, such as spectrophotometry, chromatography (gas, TLC, column, ion exchange), electrophoresis, enzymology, fluorimetry, and high-speed centrifugation. Fulfills laboratory requirement for certain biological science majors. Does not fulfill requirement for biochemistry major. 3 hours laboratory. (021067)

CHEM 453M Biochemistry Laboratory 3.0 FS

Prerequisites: CHEM 320, CHEM 370M.

Corequisite: CHEM 451.

Separation, identification, and/or analysis of biological materials by modern procedures, such as spectrophotometry, chromatography (gas, TLC, column, ion exchange), electrophoresis, enzymology, fluorimetry, and high-speed centrifugation. This course fulfills laboratory requirements for biochemistry majors. 1 hour lecture, 6 hours laboratory. (021068)

CHEM 477 Seminar in Organic Spectroscopy 1.0 FS

Prerequisites: Concurrent enrollment in or prior completion of CHEM 370.

A course whose objectives is to help students become experts at the structural determination of organic compounds using modern spectroscopic methods, including IR, UV-Vis, mass spectra, and 1D and 2D NMR techniques. 1 hour seminar. (001905)

CHEM 483 Integrated Chemistry Laboratory III 2.0 SP

Prerequisites: CHEM 381, CHEM 382, CHEM 420.

A continuation of CHEM 382, with a specific emphasis on independent experimental design and use of instruments. Students design, carry out, and orally present their findings for 2-3 major projects. 6 hours laboratory. (001889)

CHEM 489 Internship in Chemistry 1.0 -3.0 FS

9 hours supervision. You may take this course more than once for a maximum of 15.0 units. Credit/no credit grading. (001923)

CHEM 490 Research in Chemistry 1.0 -2.0 FS

Prerequisites: CHEM 332.

This course is an independent study offered for 1.0-2.0 units. You must register directly with a supervising faculty member. Original laboratory or library investigation under individual faculty supervision. 6 hours supervision. You may take this course more than once for a maximum of 4.0 units. (001875)



## CHEM 270 CALENDAR FALL 2016

MONDAY	WEDNESDAY	FRIDAY
Aug 21 Intro. Packet 1: Key Concepts	Aug 23 Packet 1: Key Concepts	Aug 25 <b>iClicker Check-in</b> Packet 1/ Packet 2: Strux/Bond.
Aug 28 <b>Key Concepts Quiz</b> Packet 2: Strux/Bond.	Aug 30 Packet 2: Strux/Bond.	Sept 1 <b>iClicker Check-in</b> Packet 3: FGs/IR.
<b>Sept 4 No Class Labor Day</b>	Sep 6 Packet 3: FGs/IR.	Sep 8 <b>iClicker Check-in</b> Packet 4: Kinetics/Thermo.
Sep 11 <b>FG Quiz</b> Workshop: Kinetics	Sep 13 Packet 5: Acids/Bases	Sep 15 <b>iClicker Check-in</b> Packet 5: Acids/Bases Workshop Acids/Bases <b>DROP DEADLINE</b>
Sep 18 Workshop: Acids/Bases	Sep 20 <b>Exam 1</b>	Sep 22 <b>iClicker Check-in</b> Packet 6: Alkanes
Sep 25 Packet 6: Alkanes	Sep 27 Workshop: Conformational Analysis	Sep 29 <b>iClicker Check-in</b> Packet 7: Stereochemistry
Oct 2 Packet 7: Stereochemistry	Oct 4 Packet 8: NMR/MS	Oct 6 <b>Alkanes/Stereochemistry Quiz</b> Packet 8: NMR/MS
Oct 9 Packet 8: NMR/MS	Oct 11 Workshop: Spectroscopy	Oct 13 <b>iClicker Check-in</b> Packet 9: Alkyl Halides/sub.
Oct 16 <b>Exam 2</b>	Oct 18 Packet 9: Alkyl Halides/sub.	Oct 20 <b>iClicker Check-in</b> Packet 9: Alkyl Halides/sub.
Oct 23 Packet 9: Alkyl Halides/sub.	Oct 25 Packet 9: Alkyl Halides/sub.	Oct 27 <b>iClicker Check-in</b> Workshop: Substitution
Oct 30 Packet 10: Alcohols, Ethers, Epoxides	Nov 1 Packet 10: Alcohols, Ethers, Epoxides	Nov 3 <b>iClicker Check-in</b> Packet 10: Alcohols, Ethers, Epoxides
Nov 6 <b>Exam 3</b>	Nov 8 Packet 10: Alkenes	<b>Nov 10 No Class Veteran's Day</b>
Nov 13 Packet 11: Alkenes	Nov 15 Packet 11: Alkenes	Nov 17 <b>iClicker Check-in</b> Packet 11: Alkenes

<b>Nov 20 No Class</b>	<b>Nov 22 No Class</b>	<b>Nov 24 No Class</b>
Nov 27 <b>Alkenes Quiz</b> Packet 12: Alkynes	Nov 29 Packet 12: Alkynes	Dec 1 <b>iClicker Check-in</b> Packet 12: Alkynes
Dec 4 Workshop: Alkynes	Dec 6 Packet 13 Free Radicals	Dec 8 Last Day of Class Packet 13 Free Radicals

Name: \_\_\_\_\_

- Is a C=O present? Check 1660-1820  $\text{cm}^{-1}$  (if absent, proceed to step 3). Base C=O values below:
  - ACIDS – 1710  $\text{cm}^{-1}$
  - AMIDES – 1690  $\text{cm}^{-1}$
  - ESTERS – 1735  $\text{cm}^{-1}$
  - ANHYDRIDES – 1760 and 1810  $\text{cm}^{-1}$
  - ALDEHYDES – 1725  $\text{cm}^{-1}$
  - KETONES – 1715  $\text{cm}^{-1}$
- If a C=O is present, check the type
  - ACIDS – is O–H also present (br, 2400-3400  $\text{cm}^{-1}$ )?
  - AMIDES – is N–H also present (3100-3500  $\text{cm}^{-1}$ )?
  - ESTERS – is C–O also present (1000-1300  $\text{cm}^{-1}$ )?
  - ANHYDRIDES – are there two C=O absorptions near 1810 and 1760  $\text{cm}^{-1}$ ?
  - ALDEHYDES – are there two aldehyde C–H absorptions near 2750 and 2850  $\text{cm}^{-1}$ ?
  - KETONES – the preceding 5 choices have been eliminated
- If C=O is absent:
  - ALCOHOLS/PHENOLS – check for O–H (br, 3200-3650  $\text{cm}^{-1}$ ), and confirm C–O (1000-1300  $\text{cm}^{-1}$ )
  - AMINES – check for N–H near 3400  $\text{cm}^{-1}$
  - ETHERS – check for C–O (1000-1300  $\text{cm}^{-1}$ ) and absence of O–H (br, 3200-3650  $\text{cm}^{-1}$ )
- Is a C=C present?
  - ALKENES – check for C=C (w, near 1650  $\text{cm}^{-1}$ ), and confirm by checking C–H region ( $> 3000 \text{ cm}^{-1}$ )
  - AROMATIC RINGS – check for aromatic C=C at 1475 and 1600  $\text{cm}^{-1}$
- Is a triple bond present?
  - NITRILES (-CN) – check near 2250  $\text{cm}^{-1}$
  - ALKYNES (-CC-) – check near 2150  $\text{cm}^{-1}$  for CC triple bond, if terminal alkyne check acetylene C–H near 3300  $\text{cm}^{-1}$
- Is a –NO<sub>2</sub> present?
  - NITRO – check for two strong bands near 1530-1600 and 1300-1390  $\text{cm}^{-1}$
- Is C–X present?
  - ALKYL IODIDE/ ALKYL BROMIDE – check  $< 667 \text{ cm}^{-1}$
  - ALKYL CHLORIDE – check 540-785  $\text{cm}^{-1}$
- Is the molecule a hydrocarbon?
  - HYDROCARBON – none of the preceding is found, major absorptions near 3000  $\text{cm}^{-1}$

Type of Vibration		Frequency ( $\text{cm}^{-1}$ )	Intensity
C–H	Alkanes (stretch)	3000–2850	s
	–CH <sub>3</sub> (bend)	1450 and 1375	m
	–CH <sub>2</sub> – (bend)	1465	m
	Alkenes (stretch)	3100–3000	m
	(out-of-plane bend)	1000–650	s
	Aromatics (stretch)	3150–3050	s
	(out-of-plane bend)	900–690	s
	Alkyne (stretch)	ca. 3300	s
	Aldehyde	2900–2800	w
		2800–2700	w
C–C	Alkane	Not interpretatively useful	
C=C	Alkene	1680–1600	m–w
	Aromatic	1600 and 1475	m–w
C≡C	Alkyne	2250–2100	m–w
C=O	Aldehyde	1740–1720	s
	Ketone	1725–1705	s
	Carboxylic acid	1725–1700	s
	Ester	1750–1730	s
	Amide	1700–1640	s
	Anhydride	1810 and 1760	s
	Acid chloride	1800	s
C–O	Alcohols, ethers, esters, carboxylic acids, anhydrides	1300–1000	s
O–H	Alcohols, phenols		
	Free	3650–3600	m
	H-bonded	3400–3200	m
	Carboxylic acids	3400–2400	m
N–H	Primary and secondary amines and amides		
	(stretch)	3500–3100	m
	(bend)	1640–1550	m–s
C–N	Amines	1350–1000	m–s
C=N	Imines and oximes	1690–1640	w–s
C≡N	Nitriles	2260–2240	m
X=C=Y	Allenes, ketenes, isocyanates, isothiocyanates	2270–1940	m–s
N=O	Nitro (R–NO <sub>2</sub> )	1550 and 1350	s
S–H	Mercaptans	2550	w
S=O	Sulfoxides	1050	s
	Sulfones, sulfonyl chlorides, sulfates, sulfonamides	1375–1300 and 1350–1140	s
C–X	Fluoride	1400–1000	s
	Chloride	785–540	s
	Bromide, iodide	$< 667$	s

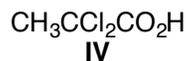
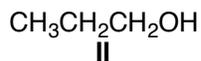
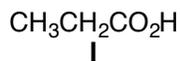
\*\* s = strong; m = medium; w = weak; br = broad

The use of calculators and electronic devices of any kind are prohibited during this examination.



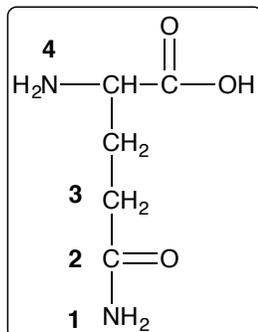


6. (3 pts.) Arrange the following compounds in order of **decreasing** acidity.



- IV, III, I, II
- IV, II, II, I
- II, I, III, IV
- III, IV, I, II

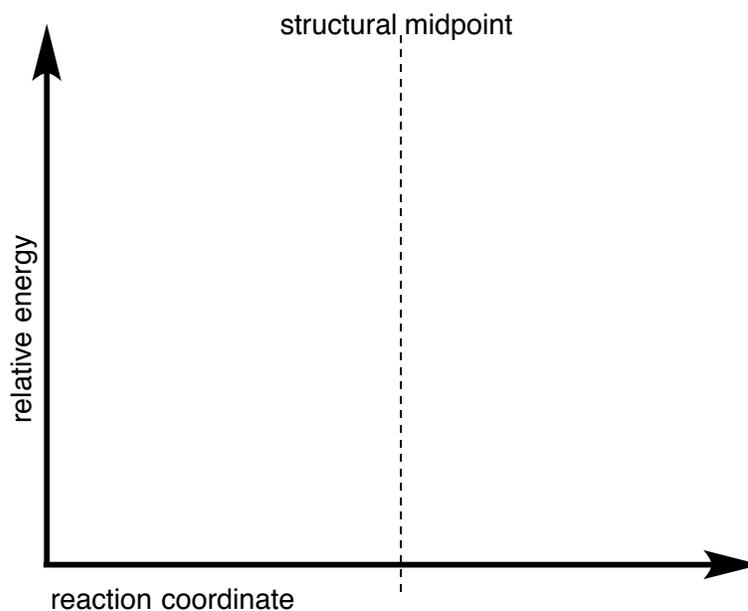
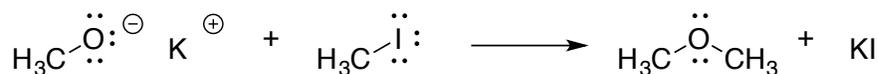
7. (3 pts.) Which hybrid orbital models best describe the atoms labeled **1** to **4** in the amino acid glutamine?



- $\text{sp}^2, \text{sp}^2, \text{sp}^3, \text{sp}^3$
- $\text{sp}^3, \text{sp}^2, \text{sp}^3, \text{sp}^3$
- $\text{sp}^3, \text{sp}, \text{sp}^3, \text{sp}^3$
- $\text{sp}^2, \text{sp}^2, \text{sp}^2, \text{sp}^3$

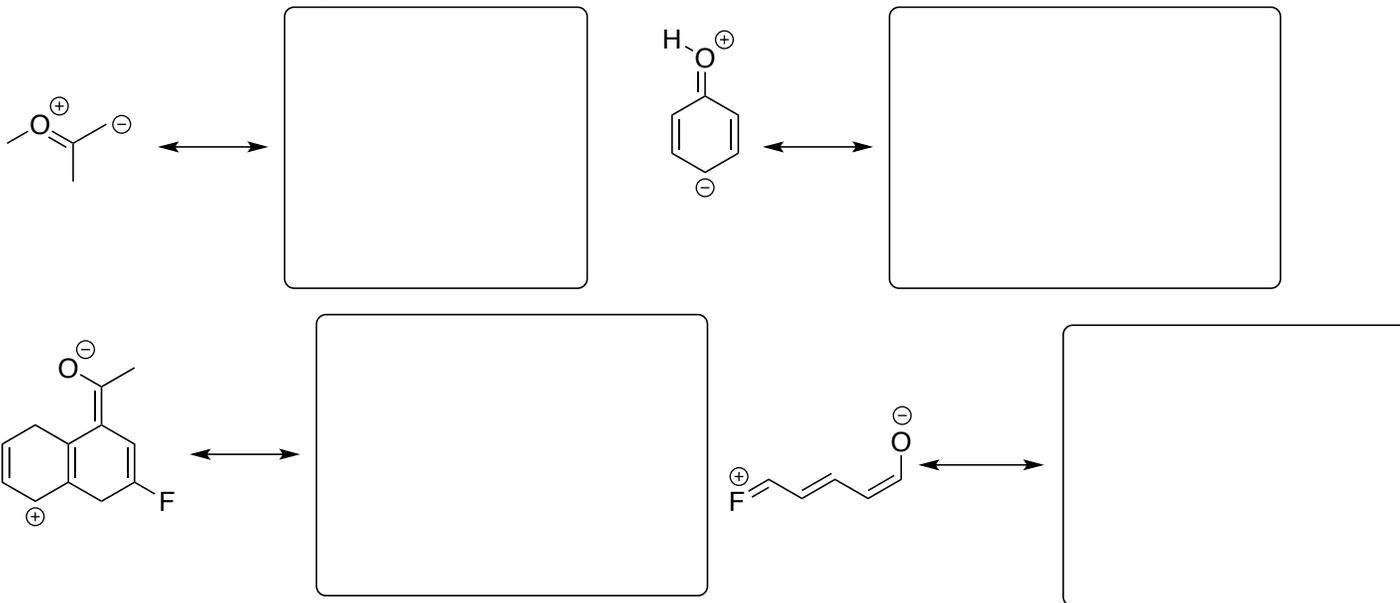
8. (12 pts.) The following reaction is highly exothermic and occurs in a single step. On the reaction coordinate diagram below clearly indicate:

- (3 pts.) The relative energies of the starting materials and the products;
- (3 pts.) Draw a curve that represents the conversion of starting materials into products;
- (3 pts.) Label the point on the curve that indicates the transition state with "TS."
- (3 pts.) Use your knowledge of the Hammond Postulate to place the transition state on the proper side of the structural midpoint line.

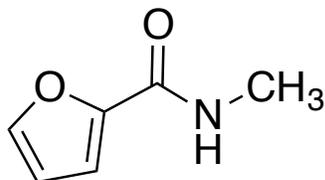


9. (12 pts.) Starting with the charged resonance structures below:

- Fill in **ALL nonbonding electron pairs**;
- Use curved arrows to depict the movement of electrons to make **new resonance structures in which ALL atoms are neutral**;
- Draw the resulting resonance structures in the spaces provided, be sure to **clearly indicate ALL nonbonding electron pairs on the new structures**.



10. (20 pts.) Use the structure of the molecule below as the basis to answer the following questions.



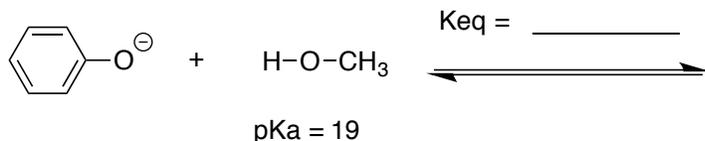
- (3pts.) Indicate all non-bonding electron pairs on the structure above.
- (5 pts.) Label each carbon, nitrogen, and oxygen atom with either  $sp$ ,  $sp^2$ , or  $sp^3$  on the structure above.
- (12 pts.) Use your knowledge of the hybridization model to depict the orbitals for the  $\sigma$ - and  $\pi$ -bonding.

$\sigma$ -bonding

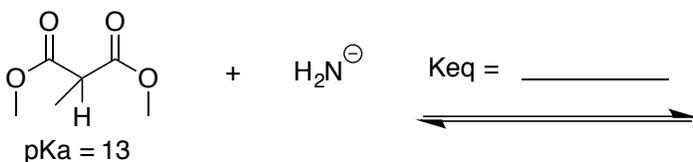
$\pi$ -bonding

11. **Acid/Base Chemistry (28 pts, 7 pts. Ea.)** Complete a-d for each reaction indicated below.

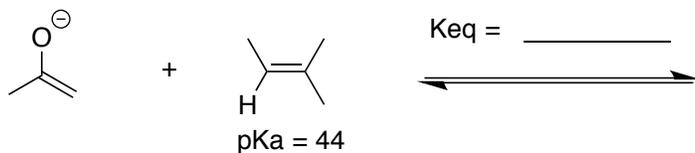
- Designate the acids/electrophiles and the bases/nucleophiles and fill in missing structures as necessary being sure to indicate all nonbonding electron pairs and all nonzero formal charges.
- Use curved arrows to show the flow of electrons as the reaction proceeds from left to right.
- Use the pKa data to calculate/approximate  $K_{eq}$ .
- Circle either the starting materials or products, whichever is favored at equilibrium, and **explain** your reasoning in terms for the stability of the conjugate base, invoking key concepts as necessary. **Simply stating that equilibrium favors the weak acid is NOT enough for full credit.**



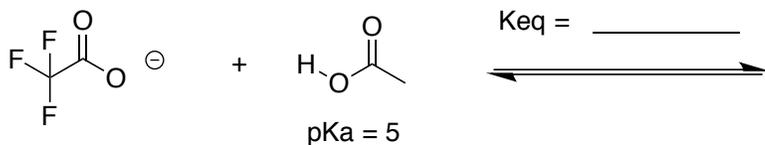
Explain invoking key concepts:



Explain invoking key concepts:

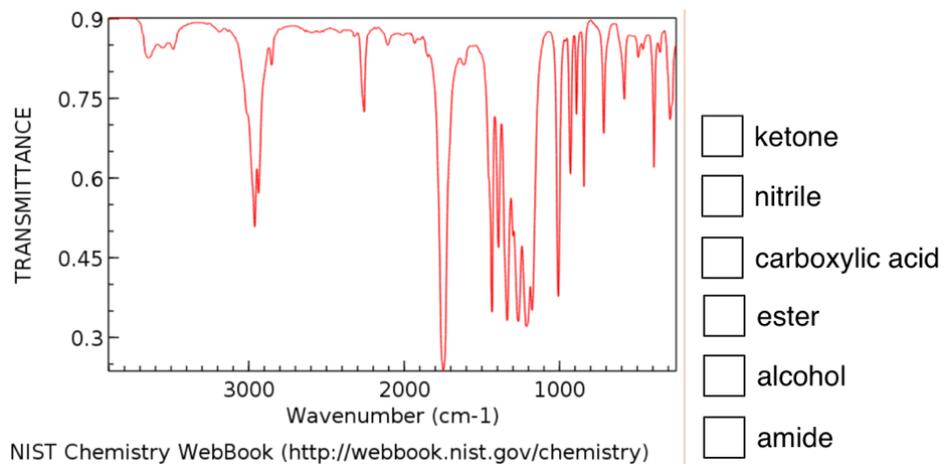


Explain invoking key concepts:



Explain invoking key concepts:

12. (6 pts.) Select all the functional groups in the indicated in the IR spectrum by placing a check mark in the appropriate boxes.



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You may use the space below and on the back for scratch paper.

Name: \_\_\_\_\_

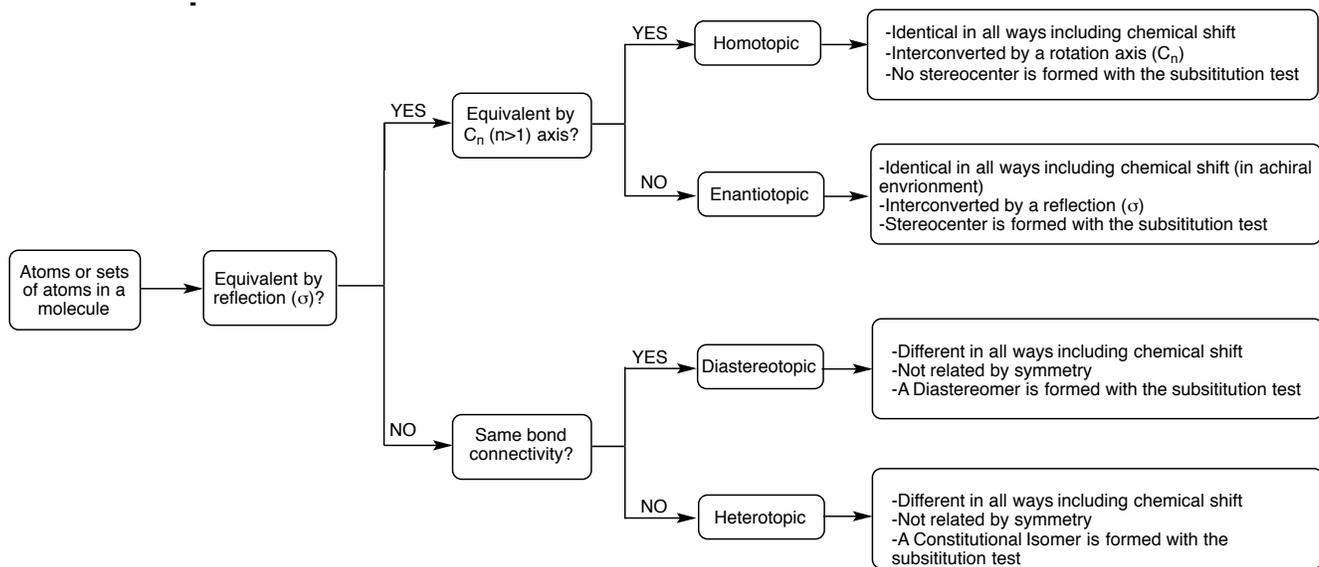
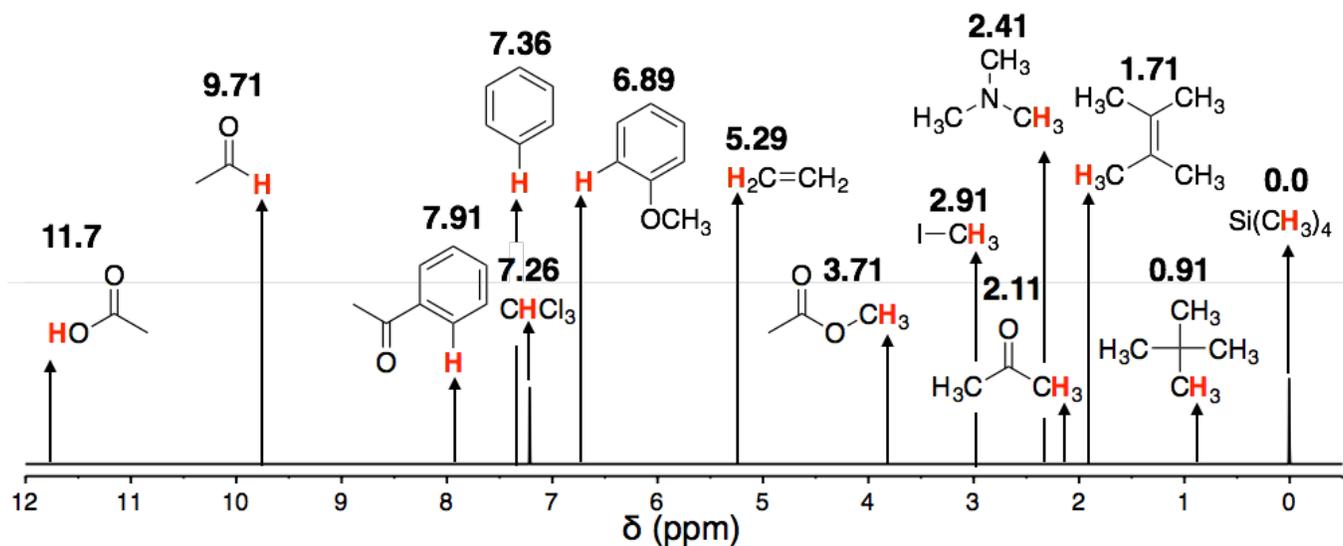
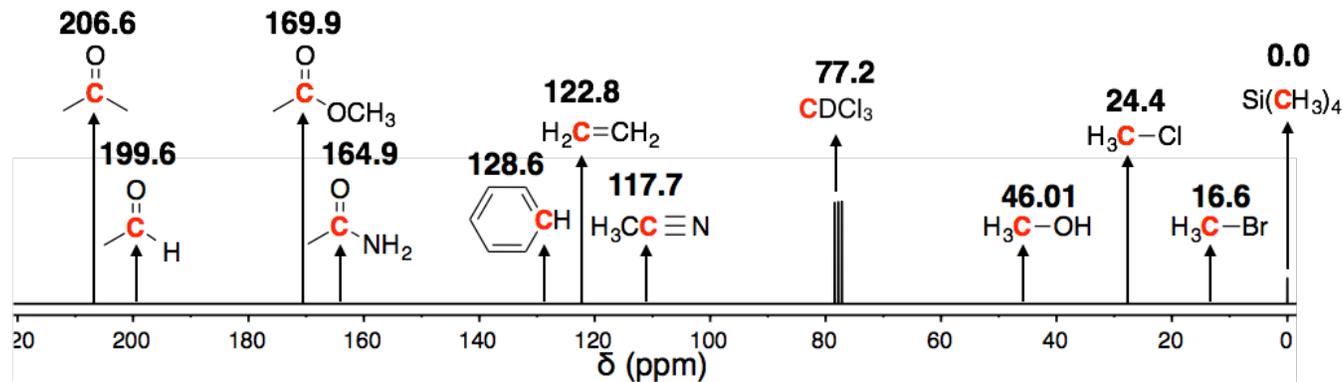
- Is a C=O present? Check 1660-1820  $\text{cm}^{-1}$  (if absent, proceed to step 3). Base C=O values below:
  - ACIDS – 1710  $\text{cm}^{-1}$
  - AMIDES – 1690  $\text{cm}^{-1}$
  - ESTERS – 1735  $\text{cm}^{-1}$
  - ANHYDRIDES – 1760 and 1810  $\text{cm}^{-1}$
  - ALDEHYDES – 1725  $\text{cm}^{-1}$
  - KETONES – 1715  $\text{cm}^{-1}$
- If a C=O is present, check the type
  - ACIDS – is O–H also present (br, 2400-3400  $\text{cm}^{-1}$ )?
  - AMIDES – is N–H also present (3100-3500  $\text{cm}^{-1}$ )?
  - ESTERS – is C–O also present (1000-1300  $\text{cm}^{-1}$ )?
  - ANHYDRIDES – are there two C=O absorptions near 1810 and 1760  $\text{cm}^{-1}$ ?
  - ALDEHYDES – are there two aldehyde C–H absorptions near 2750 and 2850  $\text{cm}^{-1}$ ?
  - KETONES – the preceding 5 choices have been eliminated
- If C=O is absent:
  - ALCOHOLS/PHENOLS – check for O–H (br, 3200-3650  $\text{cm}^{-1}$ ), and confirm C–O (1000-1300  $\text{cm}^{-1}$ )
  - AMINES – check for N–H near 3400  $\text{cm}^{-1}$
  - ETHERS – check for C–O (1000-1300  $\text{cm}^{-1}$ ) and absence of O–H (br, 3200-3650  $\text{cm}^{-1}$ )
- Is a C=C present?
  - ALKENES – check for C=C (w, near 1650  $\text{cm}^{-1}$ ), and confirm by checking C–H region ( $> 3000 \text{ cm}^{-1}$ )
  - AROMATIC RINGS – check for aromatic C=C at 1475 and 1600  $\text{cm}^{-1}$
- Is a triple bond present?
  - NITRILES (-CN) – check near 2250  $\text{cm}^{-1}$
  - ALKYNES (-CC-) – check near 2150  $\text{cm}^{-1}$  for CC triple bond, if terminal alkyne check acetylene C–H near 3300  $\text{cm}^{-1}$
- Is a  $-\text{NO}_2$  present?
  - NITRO – check for two strong bands near 1530-1600 and 1300-1390  $\text{cm}^{-1}$
- Is C–X present?
  - ALKYL IODIDE/ ALKYL BROMIDE – check  $< 667 \text{ cm}^{-1}$
  - ALKYL CHLORIDE – check 540-785  $\text{cm}^{-1}$
- Is the molecule a hydrocarbon?
  - HYDROCARBON – none of the preceding is found, major absorptions near 3000  $\text{cm}^{-1}$

Type of Vibration			Frequency ( $\text{cm}^{-1}$ )	Intensity
C–H	Alkanes	(stretch)	3000–2850	s
		–CH <sub>3</sub> (bend)	1450 and 1375	m
	Alkenes	(stretch)	3100–3000	m
		(out-of-plane bend)	1000–650	s
	Aromatics	(stretch)	3150–3050	s
		(out-of-plane bend)	900–690	s
Alkyne	(stretch)	ca. 3300	s	
Aldehyde		2900–2800	w	
		2800–2700	w	
C–C	Alkane	Not interpretatively useful		
C=C	Alkene	1680–1600	m–w	
	Aromatic	1600 and 1475	m–w	
C≡C	Alkyne	2250–2100	m–w	
C=O	Aldehyde	1740–1720	s	
	Ketone	1725–1705	s	
	Carboxylic acid	1725–1700	s	
	Ester	1750–1730	s	
	Amide	1700–1640	s	
	Anhydride	1810 and 1760	s	
	Acid chloride	1800	s	
C–O	Alcohols, ethers, esters, carboxylic acids, anhydrides	1300–1000	s	
	O–H			
Alcohols, phenols	Free	3650–3600	m	
	H-bonded	3400–3200	m	
	Carboxylic acids	3400–2400	m	
N–H	Primary and secondary amines and amides			
	(stretch)	3500–3100	m	
	(bend)	1640–1550	m–s	
C–N	Amines	1350–1000	m–s	
C=N	Imines and oximes	1690–1640	w–s	
C≡N	Nitriles	2260–2240	m	
X=C=Y	Allenes, ketenes, isocyanates, isothiocyanates	2270–1940	m–s	
N=O	Nitro (R–NO <sub>2</sub> )	1550 and 1350	s	
S–H	Mercaptans	2550	w	
S=O	Sulfoxides	1050	s	
	Sulfones, sulfonyl chlorides, sulfates, sulfonamides	1375–1300 and 1350–1140	s	
C–X	Fluoride	1400–1000	s	
	Chloride	785–540	s	
	Bromide, iodide	$< 667$	s	

\*\* s = strong; m = medium; w = weak; br = broad

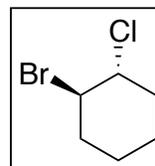
**You may use a calculator on this exam.**

1 1A																18 8A		
1 H 1.008	2 2A															2 He 4.003		
3 Li 6.941	4 Be 9.012												13 3A	14 4A	15 5A	16 6A	17 7A	10 Ne 20.18
11 Na 22.99	12 Mg 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 9B	10 10B	11 11B	12 12B	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95	



1. (3 pts.) What is the IUPAC name for this compound?

- (1*R*, 2*R*)-1-bromo-2-chlorocyclohexane
- (1*S*, 2*S*)-1-bromo-2-chlorocyclohexane
- (1*R*, 2*S*)-1-chloro-2-bromocyclohexane
- (1*R*, 2*R*)-1-chloro-2-bromocyclohexane



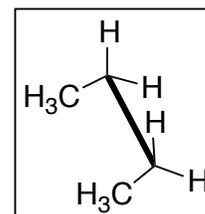
2. (3 pts.) What is the IUPAC name for this compound?

- cis*-1-*tert*-butyl-3-methylcyclohexane
- cis*-1-methyl-3-*tert*-butylcyclohexane
- cis*-1-*tert*-butyl-5-methylcyclohexane
- cis*-1-methyl-5-*tert*-butylcyclohexane

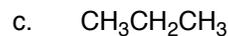


3. (3 pts.) Looking down the bolded bond, how many gauche interactions are present in the following molecule?

- 0
- 1
- 2
- 3

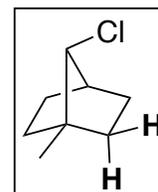


4. (3 pts.) Circle the compound below that will show a doublet as part of its <sup>1</sup>H NMR spectrum.



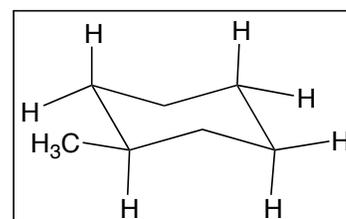
5. (3 pts.) Identify the relationship of the bolded protons by circling the correct term.

- Homotopic
- Enantiotopic
- Diastereotopic
- Heterotopic



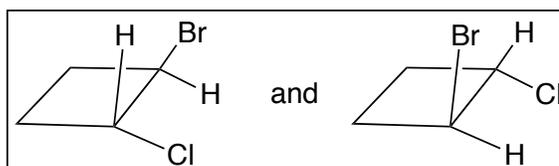
6. (3 pts.) How many <sup>13</sup>C NMR signals would you expect for the following compound?

- 8
- 7
- 6
- 5

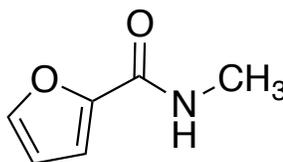


7. (3 pts.) Select the appropriate term that describes the relationship between the following pair of molecules.

- Enantiomers
- Diastereomers
- Constitutional isomers
- The same



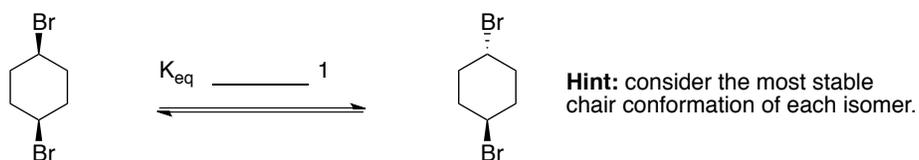
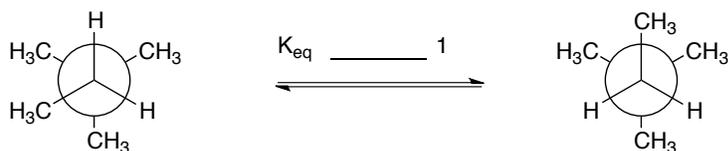
8. **Exam 1 Review question (13 pts.).** Use your knowledge of the hybridization model to depict the orbitals for the  $\sigma$ - and  $\pi$ -bonding.



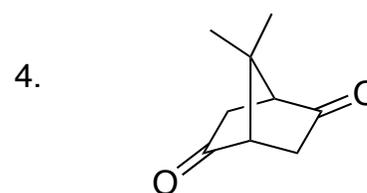
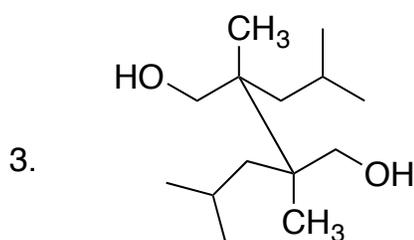
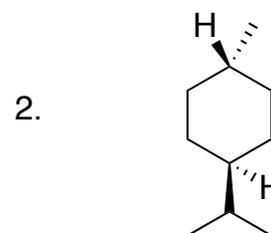
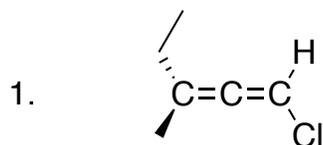
$\sigma$ -bonding

$\pi$ -bonding

9. **(16 pts., 8 pts. Ea.) Conformational Analysis.** Predict whether  $K_{eq}$  is  $<1$ ,  $>1$ , or  $=1$  for the following. Provide a **brief**, but clear explanations for each of your predictions in the provided space.

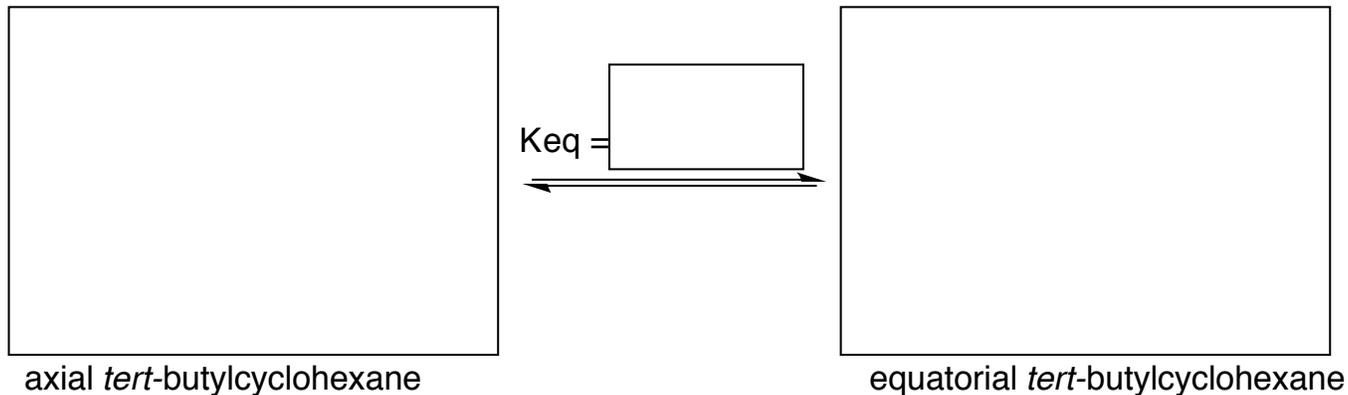


10. **Chiral or achiral? (16 pts., 4 pts. Ea.)** Consider the 4 compounds below. Carefully follow the instructions.
- For each compound label it as chiral or achiral.
  - Only for each achiral compound clearly mark on the symmetry element that requires achirality. You may choose any projection/drawing you find most convenient for this purpose.
  - Only for each chiral compound, when possible, assign the absolute configuration of all asymmetric carbons using the Chan-Ingold-Prelog rules (*R/S*).



11. **Substituted cyclohexanes (14 pts.)**. Use the following information to answer the questions below:  $\Delta G = (G_{\text{product}} - G_{\text{starting material}}) = -RT \ln K_{\text{eq}}$ ;  $R = 0.002 \text{ kcal/mol}\cdot\text{K}$ ; A-value (*tert*-butyl) = 5.4 kcal/mol =  $-\Delta G$ .

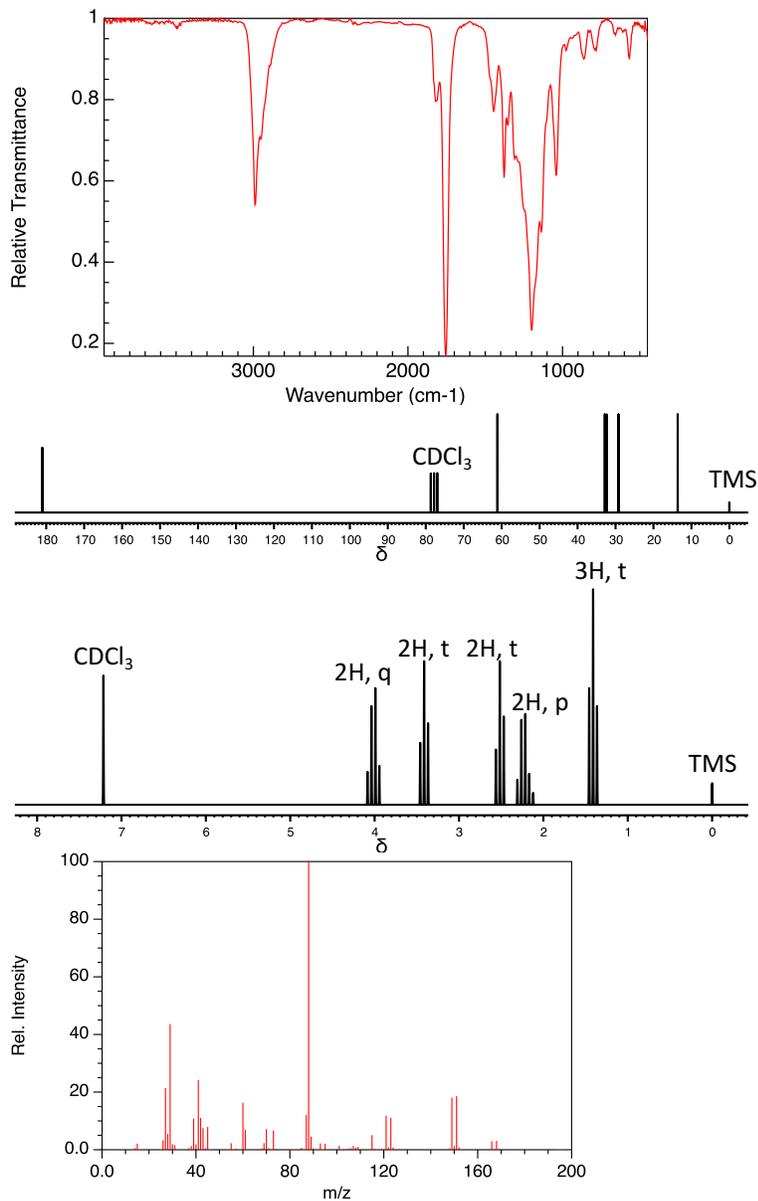
- a. **(6 pts.)**. Draw axial *tert*-butylcyclohexane and its chair flip in the space provided. Your drawing must clearly indicate the difference between axial and equatorial groups.



- b. **(4 pts.)** Calculate  $K_{\text{eq}}$  at 298K and place the value in the box above. Show your work.

- c. **(4pts.)** Based on your calculation in part b, do you expect *tert*-butylcyclohexane to chair flip rapidly at room temperature? **Briefly explain** invoking key concepts in your answer.

12. **Structure elucidation (20 pts.).** Use the information provided to solve for the structure of the unknown compound that is  $C_6H_{11}BrO_2$ . **Hint:** in the  $^{13}C$  there are two carbons at 32 ppm.



- (3 pts.)** Calculate the DoU.
- (3 pts.)** Does the fragment at  $m/z = 121$  contain Br? **Explain.**
- (3 pts.)** What functional group is consistent with the IR spectrum?
- (11 pts.)** Draw the structure below.

**This page has been intentionally left blank. You may use to for scratch paper.**

Name: \_\_\_\_\_

You may use a calculator on this exam.

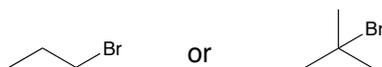
hydrogen 1 <b>H</b> 1.0079																	helium 2 <b>He</b> 4.0026	
lithium 3 <b>Li</b> 6.941	beryllium 4 <b>Be</b> 9.0122											boron 5 <b>B</b> 10.811	carbon 6 <b>C</b> 12.011	nitrogen 7 <b>N</b> 14.007	oxygen 8 <b>O</b> 15.999	fluorine 9 <b>F</b> 18.998	neon 10 <b>Ne</b> 20.180	
sodium 11 <b>Na</b> 22.990	magnesium 12 <b>Mg</b> 24.305											aluminum 13 <b>Al</b> 26.982	silicon 14 <b>Si</b> 28.086	phosphorus 15 <b>P</b> 30.974	sulfur 16 <b>S</b> 32.065	chlorine 17 <b>Cl</b> 35.453	argon 18 <b>Ar</b> 39.948	
potassium 19 <b>K</b> 39.098	calcium 20 <b>Ca</b> 40.078	scandium 21 <b>Sc</b> 44.956	titanium 22 <b>Ti</b> 47.867	vanadium 23 <b>V</b> 50.942	chromium 24 <b>Cr</b> 51.996	manganese 25 <b>Mn</b> 54.938	iron 26 <b>Fe</b> 55.845	cobalt 27 <b>Co</b> 58.933	nickel 28 <b>Ni</b> 58.693	copper 29 <b>Cu</b> 63.546	zinc 30 <b>Zn</b> 65.39	gallium 31 <b>Ga</b> 69.723	germanium 32 <b>Ge</b> 72.61	arsenic 33 <b>As</b> 74.922	selenium 34 <b>Se</b> 78.96	bromine 35 <b>Br</b> 79.904	krypton 36 <b>Kr</b> 83.80	
rubidium 37 <b>Rb</b> 85.468	strontium 38 <b>Sr</b> 87.62	yttrium 39 <b>Y</b> 88.906	zirconium 40 <b>Zr</b> 91.224	niobium 41 <b>Nb</b> 92.906	molybdenum 42 <b>Mo</b> 95.94	technetium 43 <b>Tc</b> [98]	ruthenium 44 <b>Ru</b> 101.07	rhodium 45 <b>Rh</b> 102.91	palladium 46 <b>Pd</b> 106.42	silver 47 <b>Ag</b> 107.87	cadmium 48 <b>Cd</b> 112.41	indium 49 <b>In</b> 114.82	tin 50 <b>Sn</b> 118.71	antimony 51 <b>Sb</b> 121.76	tellurium 52 <b>Te</b> 127.60	iodine 53 <b>I</b> 126.90	xenon 54 <b>Xe</b> 131.29	
caesium 55 <b>Cs</b> 132.91	barium 56 <b>Ba</b> 137.33	57-70 *	lutetium 71 <b>Lu</b> 174.97	hafnium 72 <b>Hf</b> 178.49	tantalum 73 <b>Ta</b> 180.95	tungsten 74 <b>W</b> 183.84	rhenium 75 <b>Re</b> 186.21	osmium 76 <b>Os</b> 190.23	iridium 77 <b>Ir</b> 192.22	platinum 78 <b>Pt</b> 195.08	gold 79 <b>Au</b> 196.97	mercury 80 <b>Hg</b> 200.59	thallium 81 <b>Tl</b> 204.38	lead 82 <b>Pb</b> 207.2	bismuth 83 <b>Bi</b> 208.98	polonium 84 <b>Po</b> [209]	astatine 85 <b>At</b> [210]	radon 86 <b>Rn</b> [222]
francium 87 <b>Fr</b> [223]	radium 88 <b>Ra</b> [226]	89-102 * *	lawrencium 103 <b>Lr</b> [262]	rutherfordium 104 <b>Rf</b> [261]	dubnium 105 <b>Db</b> [262]	seaborgium 106 <b>Sg</b> [266]	bohrium 107 <b>Bh</b> [264]	hassium 108 <b>Hs</b> [269]	meitnerium 109 <b>Mt</b> [268]	unnilium 110 <b>Uun</b> [271]	ununium 111 <b>Uuu</b> [272]	unbibium 112 <b>Uub</b> [277]	ununquadium 114 <b>Uuq</b> [289]					

\* Lanthanide series

lanthanum 57 <b>La</b> 138.91	cerium 58 <b>Ce</b> 140.12	praseodymium 59 <b>Pr</b> 140.91	neodymium 60 <b>Nd</b> 144.24	promethium 61 <b>Pm</b> [145]	samarium 62 <b>Sm</b> 150.36	europium 63 <b>Eu</b> 151.96	gadolinium 64 <b>Gd</b> 157.25	terbium 65 <b>Tb</b> 158.93	dysprosium 66 <b>Dy</b> 162.50	holmium 67 <b>Ho</b> 164.93	erbium 68 <b>Er</b> 167.26	thulium 69 <b>Tm</b> 168.93	ytterbium 70 <b>Yb</b> 173.04
actinium 89 <b>Ac</b> [227]	thorium 90 <b>Th</b> 232.04	protactinium 91 <b>Pa</b> 231.04	uranium 92 <b>U</b> 238.03	neptunium 93 <b>Np</b> [237]	plutonium 94 <b>Pu</b> [244]	americium 95 <b>Am</b> [243]	curium 96 <b>Cm</b> [247]	berkelium 97 <b>Bk</b> [247]	californium 98 <b>Cf</b> [251]	einsteinium 99 <b>Es</b> [252]	fermium 100 <b>Fm</b> [257]	mendelevium 101 <b>Md</b> [258]	nobelium 102 <b>No</b> [259]

\*\* Actinide series

1. (3 pts.) Complete the sentence by circling the appropriate word(s) as they pertain to the following compounds.



1-bromopropane

2-bromo-2-methylpropane

is more reactive in an SN2 reaction because

it is a 3° alkyl bromide

it is a 2° alkyl bromide

it is a 1° bromide

and is therefore

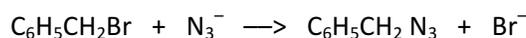
more hindered and less reactive

less hindered and more reactive

more hindered and more reactive

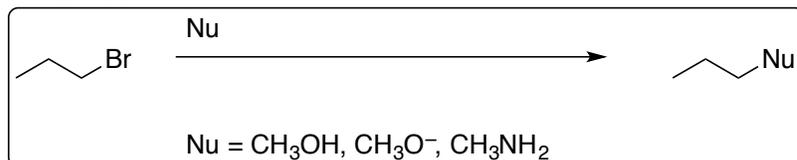
less hindered and less reactive

2. (3 pts.) For the reaction shown, when the concentration of either reactant is doubled while holding the other constant, the rate of the reaction also doubles. What is the rate law for this reaction?



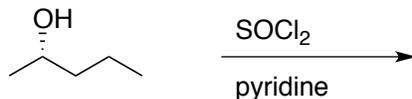
- a)  $\text{rate} = k[\text{C}_6\text{H}_5\text{CH}_2\text{Br}]^2[\text{N}_3^-]^2$   
 b)  $\text{rate} = k[\text{C}_6\text{H}_5\text{CH}_2\text{Br}]^4[\text{N}_3^-]^4$   
 c)  $\text{rate} = k[\text{C}_6\text{H}_5\text{CH}_2\text{Br}]^2[\text{N}_3^-]$   
 d)  $\text{rate} = k[\text{C}_6\text{H}_5\text{CH}_2\text{Br}][\text{N}_3^-]$

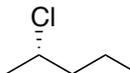
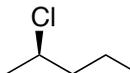
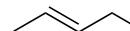
3. (3 pts.) What is the order of rates from *fastest* to *slowest* for the reactions of the three nucleophiles with propyl bromide?



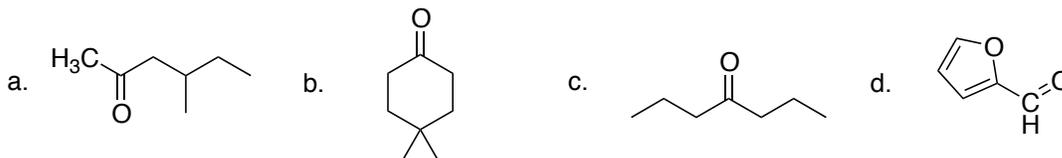
- a) CH<sub>3</sub>OH > CH<sub>3</sub>NH<sub>2</sub> > CH<sub>3</sub>O<sup>-</sup>  
 b) CH<sub>3</sub>NH<sub>2</sub> > CH<sub>3</sub>O<sup>-</sup> > CH<sub>3</sub>OH  
 c) CH<sub>3</sub>O<sup>-</sup> > CH<sub>3</sub>NH<sub>2</sub> > CH<sub>3</sub>OH  
 d) CH<sub>3</sub>O<sup>-</sup> > CH<sub>3</sub>OH > CH<sub>3</sub>NH<sub>2</sub>

4. (3 pts.) Circle the major product from the following reaction.

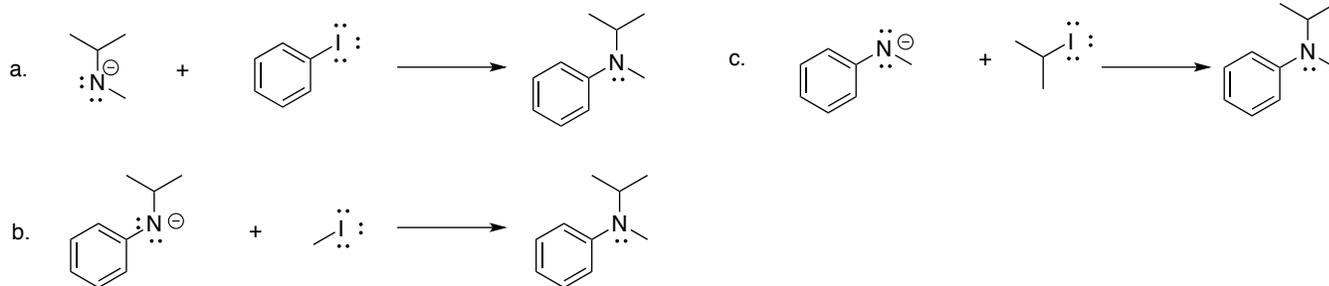


- a.      
 b.      
 c.      
 d. 

5. (3 pts.) Which of the following compounds does **NOT** give a 2° alcohol upon reaction with NaBH<sub>4</sub>?



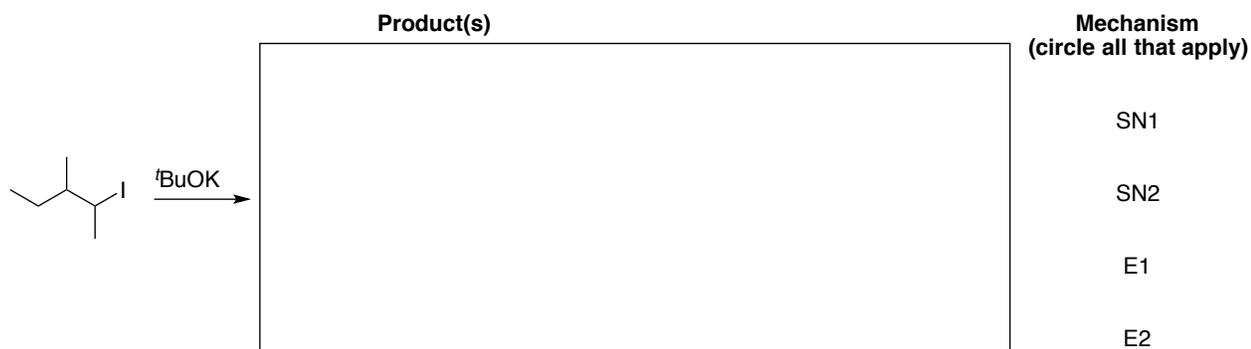
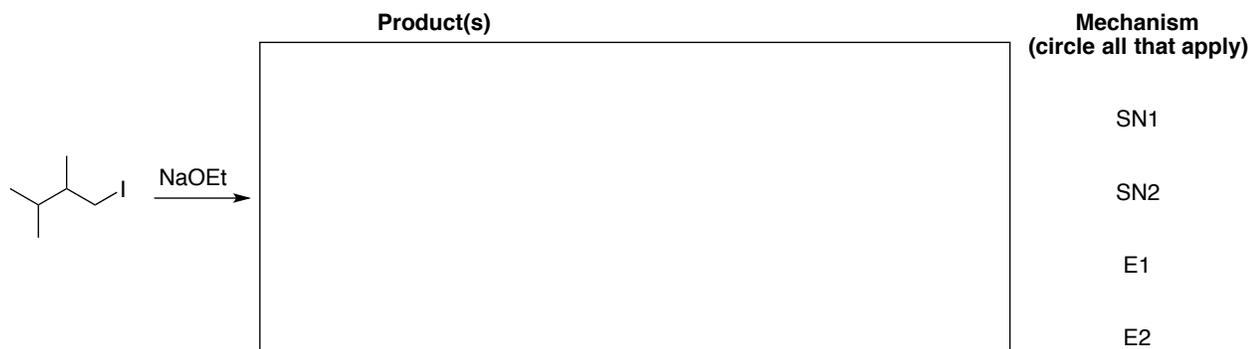
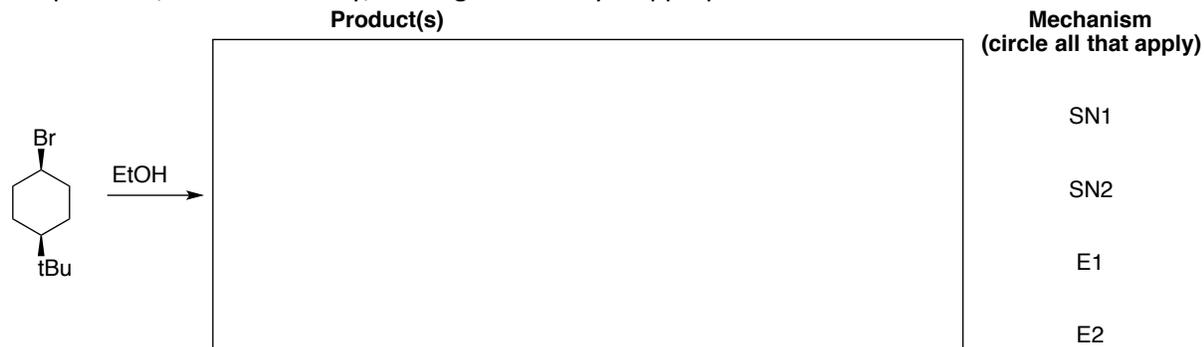
6. (3 pts) Circle the reaction that would give the product compound in the best yield.



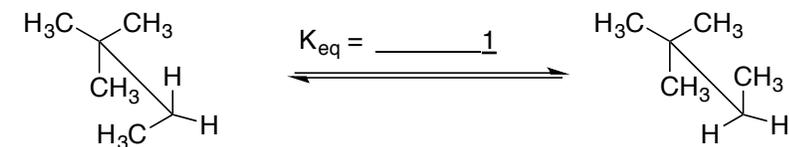
7. (3 pts.) Select only the **major** product that forms when 1,4-dimethylcyclohexanol is subjected to acid-catalyzed dehydration.



8. (15 pts., 5 pts. Ea.) **Identifying reaction components and mechanism type.** For each reaction below draw the product(s) and indicate the mechanism(s). Be sure to take into account major and minor products, stereochemistry, and regiochemistry if appropriate.

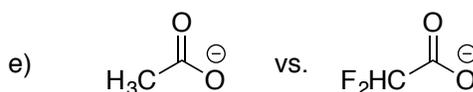


9. (6 pts.) Exam 2 Review Conformational Analysis. Predict whether  $K_{eq}$  is  $<1$ ,  $>1$ , or  $=1$  for the following. Provide a brief, but clear explanation for your prediction in the provided space. **Hint:** Newman Projection.

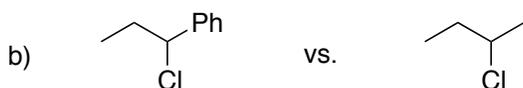


The space below has been left blank if you need space to draw.

10. (12 pts.) In a)–f) below, circle the structure of the stronger nucleophile in each pair.



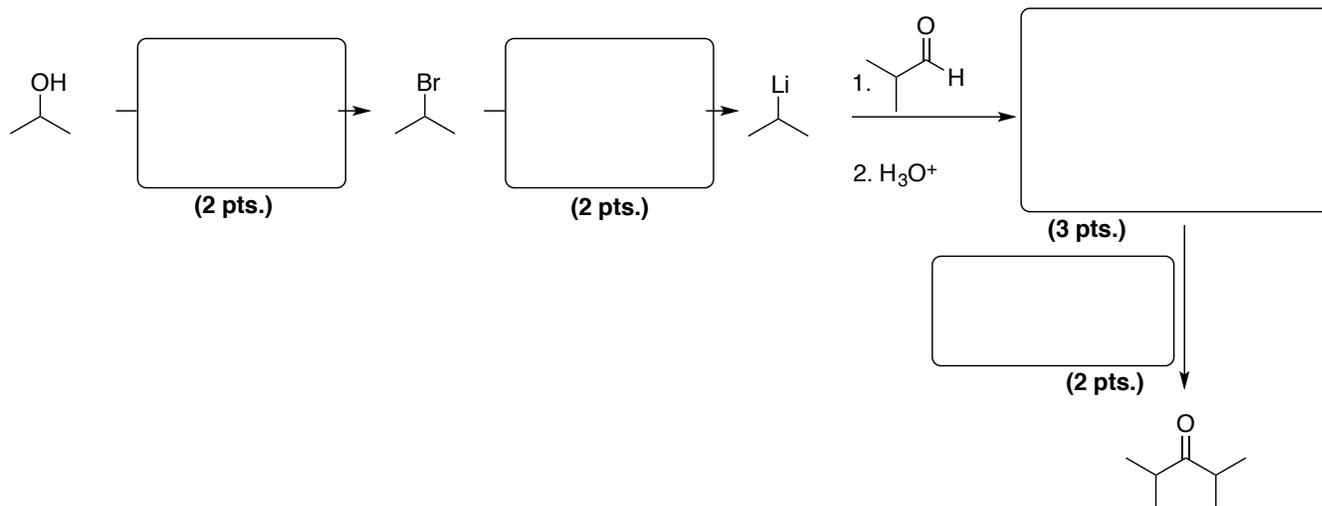
11. (8 pts.) In a)–d) below, circle the structure of the molecule that shows the greater rate of  $\text{S}_{\text{N}}1$  reaction in each pair.



in 9:1 acetone: water

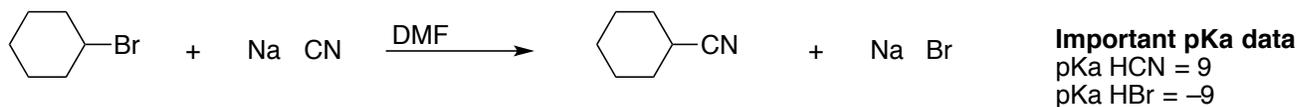
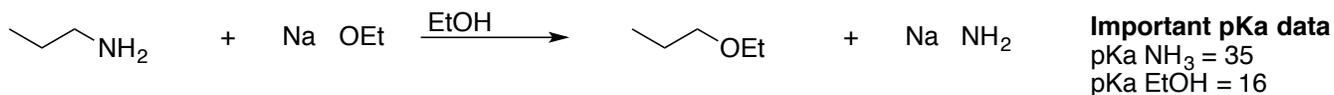
in water

12. (9 pts.) Supply the missing starting material, reagents and reactions conditions, or product(s) in the following synthetic sequence.

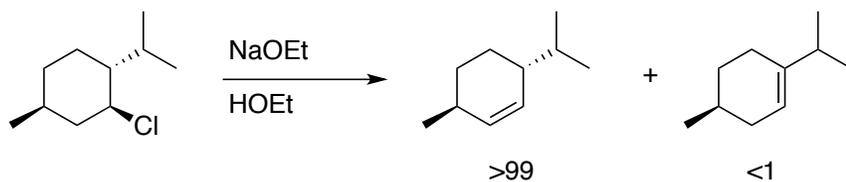


13. (12 pts., 6 pts. Ea.) For each of the potential S<sub>N</sub>2 reactions shown:

- (1 pts.) Fill in all missing lone pairs and formal charges
- (2 pts.) Draw the curved arrows to illustrate how reactants are transformed into products
- (1 pts.) Calculate  $K_{eq}$  from the pK<sub>a</sub> data
- (2 pts.) Explain invoking key concepts whether or not the reaction is likely to proceed



14. (17 pts.) **Data:** The following reaction is highly selective for the Hofmann alkene.



**Explanation:**

(12 pts.) First, draw the two chair conformations of the starting material. Next, based on your knowledge of elimination reactions draw mechanisms that account for both products. If multiple eliminations are possible from a single chair conformation draw them separately.

**Predictions:**

(5 pts.) How would you change the starting material to favor the Zayteff product? Again, draw a reaction mechanism to explain, and show the appropriate chair conformation.

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# Syllabus CHEM 270 Section 1 Fall 2017

## GENERAL INFORMATION

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<u>Instructor:</u>	Dr. Daniel A. Everson <b>Office: PHSC 309A (in the back of the SAACS Club Room)</b> Phone: (530) 898-5728 Email: <a href="mailto:deverson@csuchico.edu">deverson@csuchico.edu</a>
<u>Lecture:</u>	MWF 8:00 – 8:50 am ARTS 112
<u>Office Hours:</u>	TBD: We will discuss during the first class to set office hours that are best for everyone. By appointment and <b>I have an open door policy and generally welcome walk-ins.</b>
<u>Final Exam:</u>	TBD

## REQUIRED MATERIALS

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<u>Text:</u>	Solomons, Fryhle, Snyder <u>Organic Chemistry</u> 12 <sup>th</sup> ed., 2016 Binder ready version with access to WileyPLUS (Wiley, ISBN: 978-1-118-87576-6) available in the bookstore.  Lisa Nichols <u>Organic Chemistry Lab Techniques</u> 2 <sup>nd</sup> ed. (FREE Download!!) <a href="http://organiclabtechniques.weebly.com/">http://organiclabtechniques.weebly.com/</a>
<u>Equipment</u>	Safety goggles, carbonless lab notebook (100 pages), padlock for lab locker; all available through SAACS. <b>Cash only!</b>
<u>Models:</u>	You will need a set of molecular models for in class exercises, homework, and book problems. I recommend Darling Model Kit #1. <a href="http://www.darlingmodels.com/Individual-Orders-Molecular-Model-Kits/KIT-1-ISBN-978-09648837-1-0-Plastic-Box-Organic-Inorg/prod_2.html">http://www.darlingmodels.com/Individual-Orders-Molecular-Model-Kits/KIT-1-ISBN-978-09648837-1-0-Plastic-Box-Organic-Inorg/prod_2.html</a> ) <b>OR</b> you can use the Virtual Model Kit: <a href="http://chemagic.com">http://chemagic.com</a>
<u>iClickers</u>	Available in the bookstore. Bring to class every Friday.

## INTENDED LEARNING OUTCOMES

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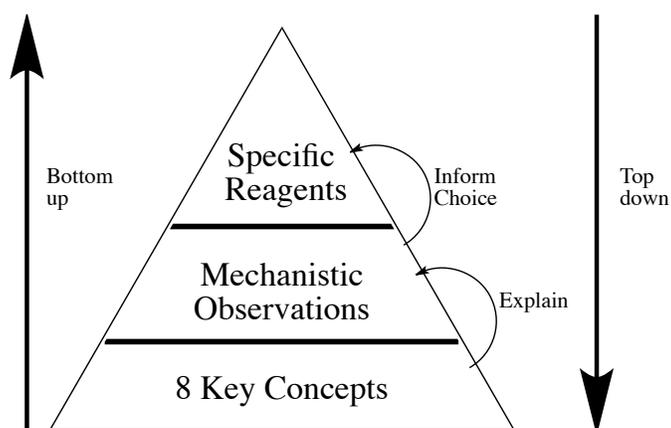
1. To engage my students in the learning process with interactive lectures and in class exercises;
2. To have students master 8 basic concepts, and be able to apply these concepts successfully to *any* organic chemistry problem.
3. To strengthen my students' *critical thinking* and *deductive reasoning* skills, which will be generally useful in the future.

## TIPS FOR SUCCESS

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- Do all the assigned reading and book problems
- Study organic chemistry everyday
- Review the course packets before coming to class and write down your questions

How I Teach



How to Study

### The Process of Studying:

1. Memorize your reagents
  - a. Name
  - b. Structure
  - c. What they do
2. Organize reagents into groups by mechanism; try to see how they relate to each other
3. Rationalize the mechanistic steps with the Key Concepts
4. Practice, Practice, Practice, Practice.

## GRADING

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### Summary notes

2%

The end of every book chapter summarizes key concepts you are expected to have mastered. These summary pages are extremely useful and you will be asked to write your own 1-page summaries, which will be turned in for completion points and returned to you. **ADDITIONALLY, WRITE DOWN THE 'MUDDIEST POINT' FOR YOU AT THE BOTTOM OF THE PAGE.** I will readdress points of confusion before moving on to new material. Stating that you have no muddiest point is strictly prohibited; failure to list a muddiest point will result in a zero for the assignment.

### Mini-Exams

10%

There will be 4 mini-exams evenly spaced through the term, announced a head of time, that will cover important concepts and material. The purpose of these mini-exams are to help you stay on top of the course topics, and to help guide your studying habits. These are not quizzes and you should study for them as if they are regular exams. Please do not underestimate.

**Friday iClicker Check-ins****3%**

These are low-stakes opportunities for you to stay up on the material, and will consist multiple-choice questions. These are participation points and I will drop your lowest two scores (meaning you can forget your iclicker twice). **Even if you are present in class, but forgot your clicker, you will earn a zero for the session.**

**ORION Adaptive Learning Online Assignments****5%**

ORION is an adaptive learning online assessment tool. It will be accessed through the course Blackboard page. The tool will be used to help you assess your strengths and weakness and will guide you to selectively review material to help you improve. Each ORION assignment is ~40 questions and you need not complete it all at once. **You should do the ORION Adaptive Learning Online Assignments BEFORE the WileyPLUS homework (described below)!** The ORION assignments are graded on an ORION Proficiency Scale as follows:

60-100% Proficiency = 10 pts

40-59% Proficiency = 7 pts

20-39% Proficiency = 4 pts

<20% Proficiency = 0 pts

The assignments will be available to you throughout our coverage of the chapter, and **will close at 11:59 PM 2 business days after we complete the material in lecture. I cannot reopen assignments. The due date and time will be clearly indicated.** I will drop your lowest 2 scores. **No exceptions to this policy!**

**Online WileyPLUS Homework****15%**

These online assignments will be accessed through the course Blackboard page. Each question will be accompanied by hints and links to relevant text sections that contain embedded instructional videos. You will be given 3 attempts to earn points on each problem. You may earn 100% of the points on your first and second attempts, 75% of the points on your third attempt, and no points thereafter. The correct answer will be provided by the system. The correct answer will be provided by the system. The assignments will be available to you throughout our coverage of the chapter, and **will close at midnight two business after we complete the material in lecture. I cannot reopen assignments. The due will be clearly indicated. You may submit an assignment up to 2 days late but your total score will be reduced by 50%.** I will drop your lowest 2 scores. **No exceptions to this policy!**

**Lab****20%**

Attendance at the once-a-week labs is mandatory. Since the sections are very full, there will be little opportunity to make up a missed lab – and no labs can be made up once the last section of the week (Thursday) has completed the lab. If you must miss your lab, it is completely up to the discretion of the instructor whether he/she will let you sit in during another section's lab period, this decision is also based on available space. The lab sections tend to be very full, which means we may not be able to accommodate you. Please don't make a habit of switching sections. Missing three (3) lab periods for any reason means automatic failure of the course. Before attending your lab class you must print out a copy of that week's experiment(s), which are found on the Bb Learn site. Lab reports are DUE at the beginning of the lab period in the week following the completion of each experiment. Labs that are late will count for no more than half credit. Labs, which are

more than 1 week late, will not be accepted. You must pass BOTH the lecture part of the class and the lab portion of the class to pass the course overall. Lab grades will be standardized to accommodate for different grading styles among the different lab instructors. You are subject to your lab instructor's grading policy.

### **3 Exams (10% each)**

**30%**

There will be no late exams administered. If you cannot take the exam during the scheduled date and time, then please let me know as soon as possible. ARC students please schedule your exams on the same day as the rest of the class; preferably during the regular examination period. Sponsored University events (e.g. athletics) are valid excuses for missing the exam, but the exam must be taken early; it will not be administered after the majority of the class has taken the exam. If you miss an exam, then I will average the scores of your other two exams and then adjust the average of your scores to accurately reflect your performance against the class average. This WILL NOT help your overall grade, and will merely serve as a placeholder in the grade book for calculations. If you miss two exams, then you will take zeros for both exams.

**Re-grade policy:** Please follow these steps for re-grades:

- 1) You must wait 24h before seeing me with your concerns.
- 2) You must consult the exam answer key.
- 3) Write me a note describing the nature of the correction you feel should be made, and attach it to the exam. (**Do not write on the exam itself.**)
- 4) For me to consider your request, I must receive it no later than one week after the graded exams were returned to the class.

### **Final Exam**

**15%**

The final exam will consist of the American Chemical Society first semester Organic Chemistry Exam.

**Final grades will separate close to the following guidelines:**

- A: above 90%
- A-: 85-90%
- B+: 80-84%
- B: 75-79%
- B-: 70-74%
- C+: 65-69%
- C: 60-64%
- C-: 55-59%

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#### **Minimum grade to move on to CHEM 370**

- D: 46-54%
- F: below 45%

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## **POLICY ON MOVING FORWARD TO CHEM 370**

In order to move onto CHEM 370, the next course in the sequence, you must earn a grade of at least a C-.

## **ADDITIONAL QUIZ AND EXAM POLICIES**

No papers, textbooks, or other written or printed materials may be taken into the seating section of the classroom on the day of examination. These may be left outside the classroom or next to the front or sidewalls. Possession of these during an exam will be considered a violation and will result in a grade of zero for the exam. Periodic tables will be supplied for each exam; possession of other periodic tables, periodic tables with notes, or other written, printed and/or electronic materials (including materials that may be stored on a calculator, computer or other devices), and the use of cell phones or other electronic communication devices during an exam will be considered a violation and will result in a grade of zero for the exam. Communication with any other student or other individual by any means will be considered a violation and will result in a grade of zero for the exam. *Students coming late to exams will not receive any extra time to complete their work*; exams will end at the same time for latecomers as for everyone else. Students absent from an exam will not be able to make it up (and will receive a grade of zero on the exam) unless the absence is a consequence of illness, family emergency, or other major cause.

## **ACADEMIC HONESTY**

I place the highest value on honesty and ethical conduct in my classroom. Instances of cheating will be reported to Student Judicial Affairs, and serious academic penalties could be administered, including failing the course, academic probation, suspension, or disqualification. Please refer to the [catalog](#) for further information. I will take several precautions to help prevent cheating including giving out different versions of exams, which contain different questions, and using a seating chart to record who sits next to whom. If you studied with someone *do not* sit next to that person during the exam; it can lead to suspicion.

## **ADD/DROP POLICY AND CLASSROOM ACCOMADATIONS**

The University policy for the class add and drop request process can be found [here](#). The University policy for classroom accommodations can be found [here](#). You are responsible for knowing these policies and taking appropriate actions. If you will need classroom accommodations, please let me know as soon as possible.

## **CLASSROOM CONDUCT AND PARTICIPATION**

I expect everyone to be respectful of each other during this class. Please, be polite and courteous to everyone. *Please, place your cell phones and other devices on silent. These noises are distracting to me and other students.*

## **TITLE IX**

### **Title IX: Confidentiality and Mandatory Reporting**

As a Chico State instructor, one of my responsibilities is to help create a safe learning environment for Chico State students. It is my goal that you feel able to share information related to your life experiences in classroom discussions, in your written work, and in our one-on-one meetings. I will seek to keep information you share private to the greatest extent possible. **However, I am required to share information regarding sexual misconduct with the University.**

Students may speak to someone confidentially by contacting the Counseling and Wellness Center (898-6345) or Safe Place (898-3030). Information about campus reporting obligations and other Title IX related resources are available here: [www.csuchico.edu/title-ix](http://www.csuchico.edu/title-ix)

## WORDS OF ENCOURAGEMENT FROM ME

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Dear Organic Chemists,

### **A little about myself**

I am originally from Minnesota, the frozen north, and land of 10,000 lakes (actually is 11,842, but 10,000 rolls off the tongue better). I am a first-generation college graduate. My mother was a homemaker who did daycare and worked nights stocking shelves to help make ends meet. My father started in the construction industry and after a decade of dedicated hard work found himself in the right place at the right time. He became a partner in the founding crew of a small commercial contracting firm that eventually brought success to his career and comfort to our lives. I have two younger brothers that, like myself, have inherited our parent's work ethic, and have found success through our diligence. My wife works at Enloe in the Mother-Baby-Center and is a Pediatric Nurse Practitioner. I have two daughters and a yellow lab (mix) that keep me busy. If I ever appear exhausted you can safely assume I had a sleepless night with one or both of my children. ☺

### **A little about the subject matter**

Organic chemistry is the foundation of our material world. Organic chemists played a role in making the tires on your car, the paint on your walls, the dye in your hair, the fabrics in your clothes, the carpet on your floors, and anything plastic. Organic chemistry is also the foundation of biology and medicine. For example, in biology class when you learned about DNA and the bases abbreviated as A, G, C, and T, those letters represent organic molecules! If you have ever taken an over the counter drug, like ibuprofen, or a prescription drug, then you should know that an organic chemist made that drug! In fact, it is a common undergraduate laboratory experiment to synthesize ibuprofen! You might be wondering how organic chemistry can be the foundation of so many different things. Organic chemistry is a unique subject matter, unlike anything you have studied before, that is able to connect seemingly different aspects of our world (from plastics to DNA replication) through the extension of a few key concepts. The primary challenge in this course is learning to make sense of these concepts, and being able to apply them to new situations. Focus your studying on connecting the details into a larger picture. Pay special attention to me when I say things like, "this is just like that." Convince yourself that my statement is true. Write down these analogies and comparisons. You must memorize the details so you can see how they fit together. This class will be a lot like putting together a 1000-piece puzzle, without knowing what the final picture looks like. Each piece is important, but how the pieces fit together is equally important! What we learn (puzzle pieces) on the first day of CHEM 270 is important and must be retained for the final exam (complete picture) in CHEM 370.

### **About my teaching philosophy**

I recognize that the vast majority of my students are NOT going to be professional organic chemists. I also recognize that my courses are "stepping stones" that lead you to the next phases in your journeys (biology major, health professions careers, veterinary medicine, etc.). I believe that critical thinking and deductive reasoning are the most important skills to master in any field and that these skills are generally useful. In the context of my courses critical thinking means being able to analyze problems from multiple perspectives, to be able to extend key concepts to new situations, and to be constantly evaluating your problem-solving process (called metacognition – *'thinking about how you think, solve problems, and learn best.'*). Deductive reasoning means being able to draw conclusions from observations (A.K.A. *data*), which is at the heart of the scientific process. To foster these skills I like to present data ("observations") and to lead class discussions about the data, eventually writing down our deductions. I have prepared empty outline course packets that already have the observations written

down so we can jump straight to the discussions. These packets are at the heart of our classroom experience and you must bring them to class. Everything I write down in class will be available to you through our Black Board page.

### **Embrace your education as an investment in yourself**

College is your opportunity to invest in yourself. You are here to become an educated person capable of thinking critically and acting wisely. Know that every hour of hard work and study that you do is a direct investment in you. When you study, you are making yourself better in the same way that an athlete or musician improves when they practice. I will be the first to admit that GPA and test scores are not always the best measure of a person, but they are the measuring sticks that society has agreed upon. Your GPA and test scores can and will significantly alter your career trajectory, they can open or close doors, and they matter for your first job as a proxy/substitute for work experience. College is your opportunity to invest in you, to propel you on to bigger and better, to open doors and networks, and to look forward to a better tomorrow. Never lose sight of why you are here. The approximate total cost to attend CSU, Chico is \$24,000 per year (<http://www.csuchico.edu/fa/costs/cost.shtml>), which amounts roughly to \$200 per class period for someone taking 12 units and \$150 per class period for someone taking 16 units. Make sure, especially at this price, that you take advantage of all the services that the University provides to help you be successful! Get the most out of your investment!

### **Course resources to help you be successful**

We are in this together. I want you to be successful in organic chemistry! I have tried to design my course with several different resources, and my great hope is that within these resources you will find the magic combination of tools that helps you be successful, enhances your learning experience, and encourages you to have fun with chemistry.

1. **Me.** I am your number one resource. I will hold office hours each week, and if those don't work for you, then be aware that I welcome walk-ins. Feel welcome to stop by, unannounced, to talk chemistry! In class I will try to model the critical thinking and deductive reasoning that I am trying to imprint on you. Pay close attention to the words I use, how I formulate my arguments, and how I analyze data. I make a conscious effort to make my thinking visible so you have a method and an example to follow. Don't hesitate to ask questions, my course materials are designed to promote discussions of real data!
2. **Book/eBook.** We are using an online version of our text that comes with a variety of features we will explore and use. It is vital that you read the book to build your base knowledge of the subject matter, to compare and contrast the readings with what we do in class, and to increase your exposure to example problems. One of the best aspects of our book is that there are instructional videos embedded in the readings! These videos work out examples and provide additional comments and instruction on the reading. I encourage you to watch every video in each chapter that we cover. The ebook is an in-depth and versatile resource.
3. **Packets.** The course is really designed to improve your critical thinking and deductive reasoning skills, and organic chemistry is the subject matter through which I will be trying to achieve these goals. The packets contain all the same information as in your book, but they are organized in a way to promote discussions and data analysis. The examples I present in class may or may not be the same as in the book, and the order of topics that I present may also differ. This is a good thing for your learning. The packets and the book are not meant to be at odds with each other, they are complimentary and represent two different ways of delivering the same subject matter. You should work hard by comparing and contrasting the packets and the book readings to convince yourself that they deliver the same important points in different formats. An important

study tip is to print out blank packets after we covered them in class, and see if you can fill them out on your own.

4. **Summary Notes.** These are completion-based assignments in which you synthesize your own summary of the material from all of the resources available to you (the ebook, the packets, homework, workshops, etc.). This is an extremely valuable learning exercise and it is your opportunity to make sense of the large amount of material we have to cover and to start putting the puzzle pieces into a more cohesive big picture. There is no required format for summary notes, so I encourage you to experiment with what works best for you. Some students make an outline, some draw chemical structures with a few bullet points, some make “reaction webs” (there will be examples of reaction webs in both the book and packets), and some write paragraphs to summarize what they have learned. Figure out what works best for you! Be aware that these will take 1-3 hours to prepare, but your time investment will be worth it for the final exam! These summary notes are great study tools for the final!
5. **Online Homework.** Our ebook also comes with an online homework system. There is simply no substitute for solving problems, and this system gives hints, links to appropriate readings in the book, multiple attempts, and will show you the correct answer! While doing the homework try to organize the individual problems into groups and look for patterns!
6. **Supplemental Instruction.** Supplemental Instruction (SI) is offered for this course. SI sessions are group study opportunities led by an SI leader who has recently completed the course successfully. The SI leaders will attend class and help out in class. Additionally, they will prepare SI sessions based on class content. You can attend SI sessions to ask questions and develop learning strategies that work best for you. SI is not intended as a substitute for going to class! SI attendance is voluntary and anonymous. It has been shown that students who attend SI learn new study strategies and problem solving skills that typically result in better exam scores and higher final grades. If for some reason, you can't make office hours, then please try going to SI for answers to your questions!
7. **Each Other.** Your classmates are a resource. I encourage you to form study groups because we all learn best when we learn together

### **An introduction to the student letters on the following pages**

On the pages that follow are two letters, written to you, from former students in my courses. They offer advice and encouragement. The first letter was entirely unsolicited, meaning I did not ask for it, the student sent it to me and asked that I share it with all my future students. The second letter was solicited. If at the end of this course you would like to pass your words of wisdom on to the next generation of organic chemistry students your letter will be warmly welcomed and appreciated. I will also take any necessary steps to protect your identity so you may speak freely and candidly.

A letter to anyone in any organic chemistry class of Everson's:

Almost all of us are in this course sequence to fulfill some sort of prerequisite for a secondary aspect of our education. Master's goals, doctorate goals, medical school goals, veterinary goals, pharmaceutical goals, and so on. People without these goals look at us and think we're insane for putting ourselves through these intense classes because we are dead set on a certain goal of ours. For me, organic chemistry was my most feared class out of all of my prerequisites. I've been told it's a make or break class that weeds people out who shouldn't move forward. That's kind of bullshit if you ask me.

I took CHEM 270. I passed it... barely, but I passed it. I took CHEM 370 and didn't. Well, I technically was a late drop, but I wasn't going to pass. I could have; very certainly. But I messed up. That happens. That's why they are called scientific *experiments*, and that's why it's called medical *practice*. So I decided to write this open letter to those middle-of-the-road chemistry students who may or may not feel kind of lost for the general remainder of this course sequence.

If I had to offer my advice, it would definitely be:

- Do the homework. You will mathematically be unable to pass without it.
- Make some form of flashcards every day. Even for simple stuff. It will make tests easier to prepare for when you aren't trying to study a giant pile of flashcards with things you don't remember or understand.
- Functional groups are your best friend and the word recognition with it will be your other best friend. You know, the one that follows you around and is kind of annoying, but you love them anyway.
- Figure out how packets work for you! Sometimes printing out the completed notes and annotating them during lecture works for people. Other people learn more by writing everything. Don't choose what is easier, choose what helps you retain the information best. Just make sure you do *actually* bring them.
- Don't you dare skip lecture. Don't even think about it. Especially Fridays. Seriously, free points???
- Go to office hours. Do not be intimidated. *Even if you are very far behind and embarrassed.* Especially then! You not only have one of the nicest chemistry professors, but one who genuinely cares about your success. He will break down anything you need to learn as simply as you need to learn it. And I know this not by asking him, but by having him do this for me. And if I could have done one thing differently, it would have been to ask for help sooner.

No matter where you end up profession wise, I will definitely say that the most important thing you can do is not give up. What is ultimately more important is not your ability to get straight A's, but your ability to persist. Resiliency is a quality that is needed in every single one of your future professions. Doctor's can't give up because a patient's condition gets more complicated. Researchers don't just give up finding cures for diseases. Just because I didn't get through the second semester of organic chemistry, does not mean I am not fit for my career choice. It means I have to enroll in the class again and take it one more time. Never let small circumstances interfere with your goals. And never let anyone tell you that you can't do something.

*"Never give up on a dream because of the time it will take to accomplish it. The time will pass anyway."  
- Earl Nightingale*

P.S.

The Counseling Center is cool and offers free, confidential services and they're helpful when life is hard to figure out. School and career included.

Student Services Center 430

530-898-6345

M-F 8:00am-5:00pm

Best of luck,  
Anonymous

Organic Chemists,

The key to success in any class is to be able to envision and remember the bigger picture, organic chemistry is no exception. Organic Chemistry is the foundation of life! The process by which your DNA is replicated and synthesized is all thanks to organic chemistry. The Asprin your grandparent takes to prevent a heart attack can be accredited to organic chemistry. Even performing a chore as mundane as washing your dishes with soap—organic chemistry is at play. It is easy to forget the larger tasks at hand while studying individual reactions and mechanisms. Your first step towards achieving a favorable outcome in ochem is to remind yourself why you're taking the class.

Of course a healthy and broad mindset alone will not yield good grades. Understanding organic chemistry requires time, effort, and patience: you have to put in the work to reap the benefits. I would study organic chemistry five to six days a week outside of class. Prior to attending class, I would have tried to complete all of the supplemental reading (with note taking) that corresponded to our current "packet" in order to maximize class time. Rather than just copying down the notes, I could understand why reactions would occur and how they occurred. I found the recommended reading particularly helpful in learning the ochem foundations: polarizability, electronegativity, induction etc... "Without a solid foundation, you'll have trouble creating anything of value." Orgo is a "building" subject, understanding it's foundation plays a crucial role in executing organic synthesis. Writing mechanisms and synthesis reactions came naturally to me. HOWEVER, it only felt like second-nature because I had dedicated so much time to learning and practicing the Eight Key Concepts.

While understanding the concepts and mechanisms should always take priority over memorizing, there is a large memorization component in the study of organic chemistry. Many students feel overwhelmed by the sheer number of seemingly "different" reactions and mechanisms. Do not be intimidated. I memorized the general reactions (Rxn webs) with their corresponding names, which enabled me to improvise when I recognized similar reagents, intermediates or products. I would transcribe the integral portions of the packets onto notecards. For instance: a flashcard entitled Alcohol synthesis would include 3-4 different reactions (with arrow pushing) and their associated explanations/deductions-these observations were from both the packets and book. I would draw out these reactions repeatedly until I felt I had a strong understanding of why a reaction would proceed and why I would produce specific products.

With time and dedication your theoretical yield could equal your actual yield,

Best of Luck,  
Anonymous

### **12 organic testing commandments**

The short list is the bible, abide by it

8 key concepts: the bread and butter of ochem

Be able to work through the homework and workshops without aids

Use previous exams and quizzes as practice

Packets > Book

Know the periodic trends

Don't understand a concept or reaction? Do the associated reading

Memorize the reaction webs and generalized reactions with NAMES

Know the ins and outs of functional groups

If Prof. Everson taps his nose and says, "this is an important reaction," memorize it

If you are given links to websites as a study tool, explore them

Print out the packets blank and see if you can fill them out on your own

Name \_\_\_\_\_

Quantitative Analysis, Spring 2018

Exam 1: 75 points

*please show all your work and use the real rule for sig figs*

1. A student wishes to determine the density of a salt solution using volumetric pipets and an analytical balance. She needs to pipet 25.00 mL, but she only has a 20.00 mL and 5.00 mL pipet.
  - a. (5) Using standard tolerances given in the table on the equation sheet, what is her expected error from using two pipets?
  
  - b. (3) What type of error would you expect from using two pipetting steps instead of a single pipetting step?
  
  - c. (7) After pipetting 25.00 mL, the mass of the solution was 28.9743 g ( $\pm 0.0002$  g). Please calculate the density and absolute error on her measurement.
  
2. In experiment 3, you precipitated AgCl from a dilute HNO<sub>3</sub> solution of Cl<sup>-</sup> and an AgNO<sub>3</sub> solution.
  - a. (5) Why did you use dilute HNO<sub>3</sub> instead of deionized water?
  
  
  
  
  
  
  
  
  
  
  - b. (5) Would you have gotten similar results using KNO<sub>3</sub> in place of HNO<sub>3</sub>? Explain.
  
  
  
  
  
  
  
  
  
  
  - c. (5) Why did you stir your solution as you added the AgNO<sub>3</sub>?

3. A student measured the  $\text{Ca}^{2+}$  content in two water samples, city-supplied water and well-supplied water, using two different analytical methods, flame atomic absorption spectrometry (FAAS) and EDTA titration. The results of this experiment are shown below. Each measurement was made 5 times.

	city supplied water		well supplied water	
	average [ ], ppm	std dev, ppm	average [ ], ppm	std dev, ppm
FAAS	58.08	0.72	67.63	0.74
EDTA	58.83	0.92	68.48	0.93

- a. (8) Consider the city-supplied water. Do the two methods produce statistically different results at the 95% confidence level?
- b. (6) The known value of  $\text{Ca}^{2+}$  is 67.25 ppm. Do either of the well supplied water measurements give a result that differs from the known value at the 95% confidence level?
4. Alex in the stockroom has a mixture of 0.0100 M  $\text{Ag}^+$  and 0.0250 M  $\text{Cu}^+$ . He wants to precipitate out the  $\text{Ag}^+$  as  $\text{AgCl}$ , but he doesn't want to coprecipitate  $\text{Cu}^+$  as  $\text{CuCl}$ .
- a. (7) Can Alex precipitate 99.50% of the  $\text{Ag}^+$  without co-precipitating  $\text{Cu}^+$ ?
- b. (4) Suggest a different strategy for Alex that would allow him to precipitate  $\text{Ag}^+$  in the absence of  $\text{Cu}^+$ .

5. Calculate  $\text{pFe}^{2+}$  at each of the following points in the titration of 25.00 mL of 0.02166 M  $\text{Fe}^{2+}$  by 0.03580 M EDTA at  $\text{pH}=6.00$ .
- (5) 12.50 mL
  - (5) the equivalence point
  - (5) 17.00 mL
  - (5) At the equivalence point, would the  $\text{pFe}^{2+}$  increase, decrease, or not change if the solution was instead buffered at  $\text{pH}=10.00$ . **Explain** your answer (no calculations, please).

Chem 320—Exam 1 Equation Sheet, Spring 2018

$$e_4 = \sqrt{e_1^2 + e_2^2 + e_3^2} \quad \%e_4 = \sqrt{(\%e_1)^2 + (\%e_2)^2 + (\%e_3)^2} \quad d = m/v$$

$$\bar{x} = \frac{\sum x_i}{n} \quad s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \quad F_{\text{calc}} = \frac{s_1^2}{s_2^2}$$

$$\mu = \bar{x} \pm \frac{ts}{\sqrt{n}} \quad t_{\text{calc}} = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{\text{pooled}}} \sqrt{\frac{n_1 n_2}{n_1 + n_2}} \quad s_{\text{pooled}} = \sqrt{\frac{s_1^2(n_1-1) + s_2^2(n_2-1)}{n_1 + n_2 - 2}}$$

$$t_{\text{calc}} = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{s_1^2/n_1 + s_2^2/n_2}} \quad \text{degrees of freedom} = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{\frac{(s_1^2/n_1)^2}{n_1-1} + \frac{(s_2^2/n_2)^2}{n_2-1}}$$

$$t_{\text{calc}} = \frac{|\bar{d}|}{s_d} \sqrt{n} \quad s_d = \sqrt{\frac{\sum (d_i - \bar{d})^2}{n-1}} \quad G_{\text{calc}} = \frac{|\text{suspect value} - \text{mean}|}{s}$$

$$\alpha_{Y^{4-}} = \frac{Y^{4-}}{[\text{EDTA}]} \quad K'_f = K_f \cdot \alpha_{Y^{4-}}$$

Table 4-2 Values of Student's t

Degrees of freedom	Confidence level (%)						
	50	90	95	98	99	99.5	99.9
1	1.000	6.314	12.706	31.821	63.656	127.321	636.578
2	0.816	2.920	4.303	6.965	9.925	14.089	31.598
3	0.765	2.353	3.182	4.541	5.841	7.453	12.924
4	0.741	2.132	2.776	3.747	4.604	5.598	8.610
5	0.727	2.015	2.571	3.365	4.032	4.773	6.869
6	0.718	1.943	2.447	3.143	3.707	4.317	5.959
7	0.711	1.895	2.365	2.998	3.500	4.029	5.408
8	0.706	1.860	2.306	2.896	3.355	3.832	5.041
9	0.703	1.833	2.262	2.821	3.250	3.690	4.781
10	0.700	1.812	2.228	2.764	3.169	3.581	4.587
15	0.691	1.753	2.131	2.602	2.947	3.252	4.073
20	0.687	1.725	2.086	2.528	2.845	3.153	3.850
25	0.684	1.708	2.060	2.485	2.787	3.078	3.725
30	0.683	1.697	2.042	2.457	2.750	3.030	3.646
40	0.681	1.684	2.021	2.423	2.704	2.971	3.551
60	0.679	1.671	2.000	2.390	2.660	2.915	3.460
120	0.677	1.658	1.980	2.358	2.617	2.860	3.373
∞	0.674	1.645	1.960	2.326	2.576	2.807	3.291

TABLE 2-4 Tolerances of Class A transfer pipets

Volume (mL)	Tolerance (mL)
0.5	±0.006
1	±0.006
2	±0.006
3	±0.01
4	±0.01
5	±0.01
10	±0.02
15	±0.03
20	±0.03
25	±0.03
50	±0.05
100	±0.08

Number of observations	G (95% confidence)
4	1.463
5	1.672
6	1.822
7	1.938
8	2.032
9	2.110
10	2.176
11	2.234
12	2.285
15	2.409
20	2.557

pH	$\alpha_{Y^{4-}}$
0	$1.3 \times 10^{-23}$
1	$1.4 \times 10^{-18}$
2	$2.6 \times 10^{-14}$
3	$2.1 \times 10^{-11}$
4	$3.0 \times 10^{-9}$
5	$2.9 \times 10^{-7}$
6	$1.8 \times 10^{-5}$
7	$3.8 \times 10^{-4}$
8	$4.2 \times 10^{-3}$
9	0.041
10	0.30
11	0.81
12	0.98
13	1.00
14	1.00

**TABLE 11-2 Formation constants for metal-EDTA complexes**

Ion	$\log K_f$	Ion	$\log K_f$	Ion	$\log K_f$
Li <sup>+</sup>	2.95	V <sup>3+</sup>	25.9 <sup>a</sup>	Tl <sup>3+</sup>	35.3
Na <sup>+</sup>	1.86	Cr <sup>3+</sup>	23.4 <sup>a</sup>	Bi <sup>3+</sup>	27.8 <sup>a</sup>
K <sup>+</sup>	0.8	Mn <sup>3+</sup>	25.2	Ce <sup>3+</sup>	15.93
Be <sup>2+</sup>	9.7	Fe <sup>3+</sup>	25.1	Pr <sup>3+</sup>	16.30
Mg <sup>2+</sup>	8.79	Co <sup>3+</sup>	41.4	Nd <sup>3+</sup>	16.51
Ca <sup>2+</sup>	10.65	Zr <sup>4+</sup>	29.3	Pm <sup>3+</sup>	16.9
Sr <sup>2+</sup>	8.72	Hf <sup>4+</sup>	29.5	Sm <sup>3+</sup>	17.06
Ba <sup>2+</sup>	7.88	VO <sup>2+</sup>	18.7	Eu <sup>3+</sup>	17.25
Ra <sup>2+</sup>	7.4	VO <sub>2</sub> <sup>+</sup>	15.5	Gd <sup>3+</sup>	17.35
Sc <sup>3+</sup>	23.1 <sup>a</sup>	Ag <sup>+</sup>	7.20	Tb <sup>3+</sup>	17.87
Y <sup>3+</sup>	18.08	Tl <sup>+</sup>	6.41	Dy <sup>3+</sup>	18.30
La <sup>3+</sup>	15.36	Pd <sup>2+</sup>	25.6 <sup>a</sup>	Ho <sup>3+</sup>	18.56
V <sup>2+</sup>	12.7 <sup>a</sup>	Zn <sup>2+</sup>	16.5	Er <sup>3+</sup>	18.89
Cr <sup>2+</sup>	13.6 <sup>a</sup>	Cd <sup>2+</sup>	16.5	Tm <sup>3+</sup>	19.32
Mn <sup>2+</sup>	13.89	Hg <sup>2+</sup>	21.5	Yb <sup>3+</sup>	19.49
Fe <sup>2+</sup>	14.30	Sn <sup>2+</sup>	18.3 <sup>b</sup>	Lu <sup>3+</sup>	19.74
Co <sup>2+</sup>	16.45	Pb <sup>2+</sup>	18.0	Th <sup>4+</sup>	23.2
Ni <sup>2+</sup>	18.4	Al <sup>3+</sup>	16.4	U <sup>4+</sup>	25.7
Cu <sup>2+</sup>	18.78	Ga <sup>3+</sup>	21.7		
Ti <sup>3+</sup>	21.3	In <sup>3+</sup>	24.9		

	pK <sub>sp</sub>	K <sub>sp</sub>
Chlorides: L = Cl <sup>-</sup>		
CuL	6.73	$1.9 \times 10^{-7}$
AgL	9.74	$1.8 \times 10^{-10}$
Hg <sub>2</sub> L <sub>2</sub>	17.91	$1.2 \times 10^{-18}$
TlL	3.74	$1.8 \times 10^{-4}$
PbL <sub>2</sub>	4.78	$1.7 \times 10^{-5}$

F table

Degrees of freedom for $s_2$	Degrees of freedom for $s_1$													
	2	3	4	5	6	7	8	9	10	12	15	20	30	$\infty$
2	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5
3	9.55	9.28	9.12	9.01	8.94	8.89	8.84	8.81	8.79	8.74	8.70	8.66	8.62	8.53
4	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.75	5.63
5	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.50	4.36
6	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.81	3.67
7	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.58	3.51	3.44	3.38	3.23
8	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.08	2.93
9	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.86	2.71
10	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.84	2.77	2.70	2.54
11	3.98	3.59	3.36	3.20	3.10	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.57	2.40
12	3.88	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.47	2.30
13	3.81	3.41	3.18	3.02	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.38	2.21
14	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.31	2.13
15	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.25	2.07
16	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.19	2.01
17	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.15	1.96
18	3.56	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.11	1.92
19	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.07	1.88
20	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.04	1.84
30	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.84	1.62
$\infty$	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.46	1.00

Critical values of  $F$  for a one-tailed test of the hypothesis that  $s_1 > s_2$ . There is a 5% probability of observing  $F$  above the tabulated value.

You can compute  $F$  for a chosen level of confidence with the Excel function  $\text{FINV}(\text{probability}, \text{deg\_freedom1}, \text{deg\_freedom2})$ . The statement  $\text{FINV}(0.05, 7, 6)$  reproduces the value  $F = 4.21$  in this table. The statement  $\text{FINV}(0.1, 7, 6)$  gives  $F = 3.01$  for 90% confidence.



3. You prepare a solution by dissolving  $\text{Ag}_2\text{CO}_3(\text{s})$  in water ( $K_{\text{sp}}=8.1 \times 10^{-12}$ ). The major species derived from this solid in aqueous solution are  $\text{Ag}^+$ ,  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$ , and  $\text{AgCO}_3^-$ .
- (5) What are the reactions in aqueous solution?
  - (5) Write the charge balance equation.
  - (5) Write the mass balance equation, simplifying as much as possible.
  - (5) What is the purpose of writing the mass balance and charge balance equations?
4. (10) What is the pH of  $2.5 \times 10^{-7}$  M KOH?



Chem 320—Exam 2 Equation Sheet, Spring 2018

$$c = \lambda\nu$$

$$E = h\nu$$

$$A = \epsilon bc$$

$$K_w = [\text{H}^+][\text{OH}^-] = 1.0 \times 10^{-14}$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+ \gamma_{\text{H}_3\text{O}^+}]$$

$$\text{pOH} = -\log[\text{OH}^- \gamma_{\text{OH}^-}]$$

$$\text{pH} + \text{pOH} = -\log(K_w) = 14.00$$

$$K_w = K_a \cdot K_b$$

$$\text{p}K_a = -\log(K_a)$$

$$\text{p}K_b = -\log(K_b)$$

$$K = \frac{x^2}{F - x}$$

$$\alpha = \frac{x}{F} \times 100$$

$$\text{pH} = \text{p}K_a + \log \frac{[\text{base}]}{[\text{acid}]}$$

$$V_{\text{acid}} \cdot M_{\text{acid}} = V_{\text{base}} \cdot M_{\text{base}}$$

$$F' = [\text{initial}] \cdot \left( \frac{\text{initial volume}}{\text{total final volume}} \right)$$

$$[\text{H}_3\text{O}^+] = \sqrt{\frac{K_{a1}K_{a2}F + K_{a1}K_w}{K_{a1} + F}}$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\log \gamma = \frac{-0.51z^2\sqrt{\mu}}{1 + \left( \frac{\alpha\sqrt{\mu}}{305} \right)}$$

$$\mu = \sum_i \frac{1}{2} c_i z_i^2$$

$$c = 3.0 \times 10^8 \text{ m/s}$$

$$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$$

**TABLE 7-1 Activity coefficients for aqueous solutions at 25°C**

Ion	Ion size ( $\alpha$ , pm)	Ionic strength ( $\mu$ , M)				
		0.001	0.005	0.01	0.05	0.1
<i>Charge = <math>\pm 1</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
H <sup>+</sup>	900	0.967	0.933	0.914	0.86	0.83
(C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> CHCO <sub>2</sub> <sup>-</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>4</sub> N <sup>+</sup>	800	0.966	0.931	0.912	0.85	0.82
(O <sub>2</sub> N) <sub>3</sub> C <sub>6</sub> H <sub>2</sub> O <sup>-</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>3</sub> NH <sup>+</sup> , CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> <sup>-</sup>	700	0.965	0.930	0.909	0.845	0.81
Li <sup>+</sup> , C <sub>6</sub> H <sub>5</sub> CO <sub>2</sub> <sup>-</sup> , HOC <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> <sup>-</sup> , ClC <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> <sup>-</sup> , C <sub>6</sub> H <sub>5</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , CH <sub>2</sub> =CHCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> ) <sub>2</sub> CHCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> CH <sub>2</sub> ) <sub>4</sub> N <sup>+</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup>	600	0.965	0.929	0.907	0.835	0.80
Cl <sub>2</sub> CHCO <sub>2</sub> <sup>-</sup> , Cl <sub>3</sub> CCO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> CH <sub>2</sub> ) <sub>3</sub> NH <sup>+</sup> , (C <sub>3</sub> H <sub>7</sub> )NH <sub>3</sub> <sup>+</sup>	500	0.964	0.928	0.904	0.83	0.79
Na <sup>+</sup> , CdCl <sup>+</sup> , ClO <sub>2</sub> <sup>-</sup> , IO <sub>3</sub> <sup>-</sup> , HCO <sub>3</sub> <sup>-</sup> , H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> , HSO <sub>3</sub> <sup>-</sup> , H <sub>2</sub> AsO <sub>4</sub> <sup>-</sup> , Co(NH <sub>3</sub> ) <sub>4</sub> (NO <sub>2</sub> ) <sub>2</sub> <sup>+</sup> , CH <sub>3</sub> CO <sub>2</sub> <sup>-</sup> , ClCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> ) <sub>4</sub> N <sup>+</sup> , (CH <sub>3</sub> CH <sub>2</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup> , H <sub>2</sub> NCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup>	450	0.964	0.928	0.902	0.82	0.775
<sup>+</sup> H <sub>3</sub> NCH <sub>2</sub> CO <sub>2</sub> H, (CH <sub>3</sub> ) <sub>3</sub> NH <sup>+</sup> , CH <sub>3</sub> CH <sub>2</sub> NH <sub>3</sub> <sup>+</sup>	400	0.964	0.927	0.901	0.815	0.77
OH <sup>-</sup> , F <sup>-</sup> , SCN <sup>-</sup> , OCN <sup>-</sup> , HS <sup>-</sup> , ClO <sub>3</sub> <sup>-</sup> , ClO <sub>4</sub> <sup>-</sup> , BrO <sub>3</sub> <sup>-</sup> , IO <sub>4</sub> <sup>-</sup> , MnO <sub>4</sub> <sup>-</sup> , HCO <sub>2</sub> <sup>-</sup> , H <sub>2</sub> citrate <sup>-</sup> , CH <sub>3</sub> NH <sub>3</sub> <sup>+</sup> , (CH <sub>3</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup>	350	0.964	0.926	0.900	0.81	0.76
K <sup>+</sup> , Cl <sup>-</sup> , Br <sup>-</sup> , I <sup>-</sup> , CN <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup>	300	0.964	0.925	0.899	0.805	0.755
Rb <sup>+</sup> , Cs <sup>+</sup> , NH <sub>4</sub> <sup>+</sup> , Tl <sup>+</sup> , Ag <sup>+</sup>	250	0.964	0.924	0.898	0.80	0.75
<i>Charge = <math>\pm 2</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
Mg <sup>2+</sup> , Be <sup>2+</sup>	800	0.872	0.755	0.69	0.52	0.45
CH <sub>2</sub> (CH <sub>2</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub>	700	0.872	0.755	0.685	0.50	0.425
Ca <sup>2+</sup> , Cu <sup>2+</sup> , Zn <sup>2+</sup> , Sn <sup>2+</sup> , Mn <sup>2+</sup> , Fe <sup>2+</sup> , Ni <sup>2+</sup> , Co <sup>2+</sup> , C <sub>6</sub> H <sub>4</sub> (CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , H <sub>2</sub> C(CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CH <sub>2</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub>	600	0.870	0.749	0.675	0.485	0.405
Sr <sup>2+</sup> , Ba <sup>2+</sup> , Cd <sup>2+</sup> , Hg <sup>2+</sup> , S <sup>2-</sup> , S <sub>2</sub> O <sub>4</sub> <sup>2-</sup> , WO <sub>4</sub> <sup>2-</sup> , H <sub>2</sub> C(CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CHOHCO <sub>2</sub> <sup>-</sup> ) <sub>2</sub>	500	0.868	0.744	0.67	0.465	0.38
Pb <sup>2+</sup> , CO <sub>3</sub> <sup>2-</sup> , SO <sub>3</sub> <sup>2-</sup> , MoO <sub>4</sub> <sup>2-</sup> , Co(NH <sub>3</sub> ) <sub>5</sub> Cl <sup>2+</sup> , Fe(CN) <sub>5</sub> NO <sup>2-</sup> , C <sub>2</sub> O <sub>4</sub> <sup>2-</sup> , Heitrate <sup>2-</sup>	450	0.867	0.742	0.665	0.455	0.37
Hg <sub>2</sub> <sup>2+</sup> , SO <sub>4</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>3</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>6</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> , SeO <sub>4</sub> <sup>2-</sup> , CrO <sub>4</sub> <sup>2-</sup> , HPO <sub>4</sub> <sup>2-</sup>	400	0.867	0.740	0.660	0.445	0.355
<i>Charge = <math>\pm 3</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
Al <sup>3+</sup> , Fe <sup>3+</sup> , Cr <sup>3+</sup> , Sc <sup>3+</sup> , Y <sup>3+</sup> , In <sup>3+</sup> , lanthanides <sup>a</sup>	900	0.738	0.54	0.445	0.245	0.18
citrate <sup>3-</sup>	500	0.728	0.51	0.405	0.18	0.115
PO <sub>4</sub> <sup>3-</sup> , Fe(CN) <sub>6</sub> <sup>3-</sup> , Cr(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup> , Co(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup> , Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O <sup>3+</sup>	400	0.725	0.505	0.395	0.16	0.095
<i>Charge = <math>\pm 4</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
Th <sup>4+</sup> , Zr <sup>4+</sup> , Ce <sup>4+</sup> , Sn <sup>4+</sup>	1 100	0.588	0.35	0.255	0.10	0.065
Fe(CN) <sub>6</sub> <sup>4-</sup>	500	0.57	0.31	0.20	0.048	0.021

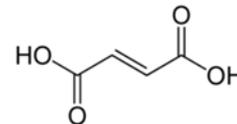
a. Lanthanides are elements 57–71 in the periodic table.  
SOURCE: J. Kielland, *J. Am. Chem. Soc.* 1937, 59, 1675.

Name \_\_\_\_\_

**Quantitative Analysis, Spring 2018**

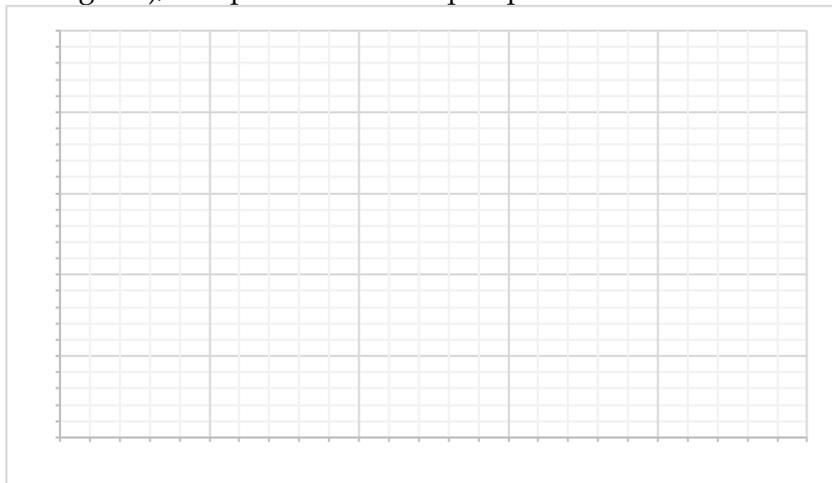
**Exam 3, 75 points**

Please show your work and use good sig figs.



1. You head into the lab to titrate 25.00 mL of 0.0500 M fumaric acid ( $pK_{a1}=3.02$ ,  $pK_{a2}=4.48$ ) with 0.125 M standardized NaOH.
  - a. (16) Please calculate the pH at volumes of 0.00, 5.00, 10.00, and 20.00 mL added NaOH.

- b. (7) Please sketch the expected titration curve. Label your axes, draw an arrow at the equivalence volumes, indicate where you would expect a buffer region (or regions), and put a star where  $pH=pK_{a2}$ .



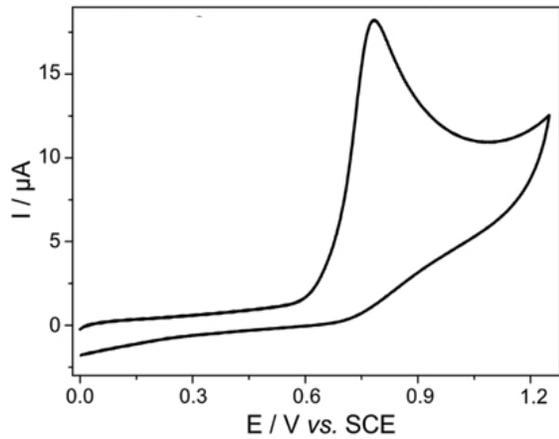
2. (15) Please sketch a glass pH electrode. Please label the important components and briefly describe how this electrode measures the activity of hydronium ion in solution.

3. You would like to extract this compound from 25.00 mL of an aqueous electrolyte solution with 15.00 mL portions of an organic solution ( $K_c=4.50$ ).

a. (8) How many extractions would you need to extract 99% of the compound?

b. (6) How is extraction related to chromatography?

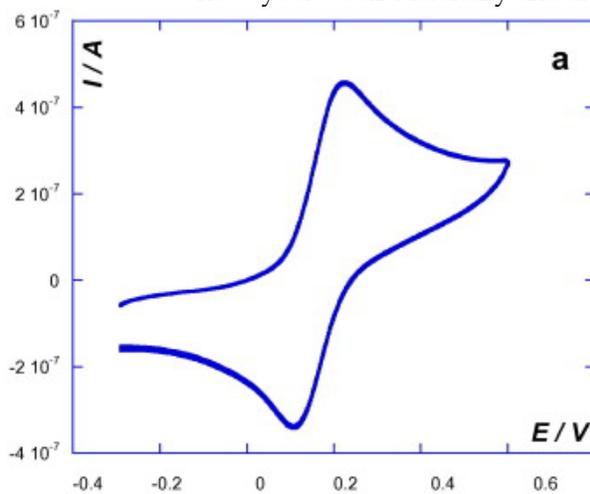
4. You go to the lab to investigate an unknown electroactive species by cyclic voltammetry.
- a. (4) What can you qualitatively conclude from the following voltammogram?



- b. (5) What would the potential of  $i_{pc}$  be if it were measured vs. Ag/AgCl?

- c. (6) What is the purpose of an electrode like SCE or Ag/AgCl?

- d. (8) With a different electroactive species, you measure the following voltammogram vs SHE. How is it different than the one in part (a)? Describe how you would identify the electroactive species investigated in this experiment.



Chem 320 – Exam 3 Equation Sheet, Spring 2018

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$$

$$pH = -\log[H^+ \gamma_{H^+}]$$

$$pOH = -\log[OH^- \gamma_{OH^-}]$$

$$pH + pOH = -\log(K_w) = 14.00$$

$$K_w = K_a \cdot K_b$$

$$pK_a = -\log(K_a)$$

$$pK_b = -\log(K_b)$$

$$K = \frac{x^2}{F - x}$$

$$\alpha = \frac{x}{F}$$

$$pH = pK_a + \log \frac{[\text{base}]}{[\text{acid}]}$$

$$[H_3O^+] = \sqrt{\frac{K_{a1} K_{a2} F + K_{a1} K_w}{K_{a1} + F}}$$

$$pH = \frac{1}{2}(pK_{a1} + pK_{a2})$$

$$V_{\text{acid}} \cdot M_{\text{acid}} = V_{\text{base}} \cdot M_{\text{base}}$$

$$F' = [\text{initial}] \cdot \left( \frac{\text{initial volume}}{\text{total final volume}} \right)$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$E = E^\circ - \frac{RT}{nF} \ln \frac{A_B^b}{A_A^a} = E^\circ - \frac{0.05916}{n} \log Q$$

$$q = It$$

$$\text{moles reacted} = \frac{It}{nF}$$

$$E = E_+ - E_-$$

$$E^\circ = \frac{0.05916}{n} \log K$$

$$E = \text{constant} + \frac{0.05916}{n} \log A_0$$

$$q^n = \left( \frac{V_1}{V_1 + KV_2} \right)^n$$

$$D = \frac{K \cdot K_a}{K_a + [H^+]}$$

$$D = \frac{K \cdot [H^+]}{[H^+] + K_a}$$

$$F = 9.6485 \times 10^4 \text{ C/mol}$$

$$R = 8.314 \text{ J/(K} \cdot \text{mol)} = 8.314 \text{ (V} \cdot \text{C)/(K} \cdot \text{mol)}$$

$$A = C/s$$

$$J = C \cdot V$$

$$W = J/s$$

$$A = V/\Omega$$

$$\text{SHE, } E^\circ = 0.0000 \text{ V}$$

$$\text{SCE, } E^\circ = 0.241 \text{ V vs SHE}$$

$$\text{Ag/AgCl, } E^\circ = 0.197 \text{ V vs SHE}$$

Name \_\_\_\_\_

**Quantitative Analysis, Spring 2018      Final Exam, 150 points**  
Please show your work and use the real rule for sig figs where appropriate.

1. You go to the lab to repeat experiment 2, the titration of a KHP unknown.
  - a. (5) First, you do five replicate titrations of NaOH. Your concentrations are as follows: 0.06333, 0.06334, 0.06336, 0.06299, 0.06335, and 0.06333 M (s=0.000146). Can any of these points be eliminated?

- b. (5) Why were the accuracy and precision standards so high for this lab?

2. (12) In experiment 6, you measured the concentration of Ca and Mg using atomic absorption spectrophotometry. Please calculate the concentration of Ca and propagate the error for the following dataset.

Solution	Vol Ca <sup>+2</sup> /Mg <sup>+2</sup> Stock (mL)	[Ca <sup>+2</sup> ] (ppm)	Absorbance Ca <sup>+2</sup>
blank	0	0	0.000
1	5.00	5.00	0.075
2	10.00	10.00	0.150
3	15.00	15.00	0.226
<b>Preparation of Solutions: Unknowns</b>			
Vol Ca Unknown (mL)	25.00		Absorbance Ca <sup>+2</sup>
Final Volume (mL)	100.00		0.095
<b>Calcium - Linest</b>			
m	0.01506	-0.00020	b
e <sub>m</sub>	3.4641E-05	0.000324037	e <sub>b</sub>
R <sup>2</sup>	0.999989418	0.000387298	e <sub>y</sub>
<b>Calcium</b>			
y-b	(y-b)/m	DF	<b>proper form</b> Conc (ppm)
		0.25	
abs error y-b	rel error (y-b)/m	error DF	abs error Conc
		negligible	



5. You can change the solubility of some salts by changing the pH of the solution. Consider sparingly soluble compound  $\text{Zn}(\text{CN})_2$  ( $K_{\text{sp}}=3.0 \times 10^{-16}$ ). You go to the lab and put this compound in a solution buffered to  $\text{pH}=4.39$ . If the  $K_{\text{a}}$  for  $\text{HCN}$  is  $6.2 \times 10^{-10}$ :
- (6) Write the reactions.
  - (4) Write the charge balance equation.
  - (5) Write the mass balance equation, simplifying as much as possible.
6. In experiment 13, you prepared an acetic acid/acetate buffer and determined its pH using three different methods.
- (5) Your buffer had an acetic acid concentration of 0.060 M and sodium acetate concentration of 0.050 M. Why were those concentrations kept so similar?
  - (8) How would the pH of a buffer prepared from 50.0 mL of 0.060 M acetic acid ( $\text{p}K_{\text{a}}=4.76$ ) and 50.0 mL of 0.050 M sodium acetate change if  $4.0 \times 10^{-4}$  mol  $\text{NaOH}$  was added? Assume no change in volume with the addition of  $\text{NaOH}$ .



9. (10) 30.0 mL of an aqueous ethanolamine,  $\text{HOCH}_2\text{CH}_2\text{NH}_2$ , is extracted once with 145 mL of solvent.  $K_c$  is 3.00 and the  $\text{pK}_a$  of the protonated form of ethanolamine is 9.498. Calculate the fraction remaining in the aqueous phase at  $\text{pH}=8.20$ .

10. (10) On a 150.0 mm long HPLC column with a 2.1 mm diameter, a compound has a retention time of 0.882 min and a full width at half height of 3.24 s. Calculate the number of theoretical plates and the plate height for this column.

11. You are working on a GC method intended to separate two analytes, A and B. All measurements in the table are made in minutes.

	A	B
$t_m$	0.21	0.21
$t_r$	2.23	2.67
$\sigma$	0.0438	0.0525
$w_{1/2}$	0.103	0.123
$w$	0.35	0.42

a. (6) A resolution of 1.0 is required for baseline separation of these peaks. Does your method have this resolution?

b. (10) Briefly compare and contrast the FID and MS detectors for GC.

Final Exam Equations Spring 2018

$$\bar{x} = \frac{\sum x_i}{n} \quad s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

$$\mu = \bar{x} \pm \frac{ts}{\sqrt{n}} \quad t_{calc} = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{pooled}} \sqrt{\frac{n_1 n_2}{n_1 + n_2}} \quad s_{pooled} = \sqrt{\frac{s_1^2(n_1 - 1) + s_2^2(n_2 - 1)}{n_1 + n_2 - 2}}$$

$$F_{calc} = \frac{s_1^2}{s_2^2} \quad t_{calc} = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{s_1^2/n_1 + s_2^2/n_2}} \quad \text{degrees of freedom} = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{\frac{(s_1^2/n_1)^2}{n_1 - 1} + \frac{(s_2^2/n_2)^2}{n_2 - 1}}$$

$$G_{calc} = \frac{|\text{suspect} - \bar{x}|}{s} \quad \alpha_{Y^{4-}} = \frac{Y^{4-}}{[EDTA]} \quad K'_f = K_f \cdot \alpha_{Y^{4-}}$$

$$\mu = \frac{1}{2} \sum_i c_i z_i^2 \quad A_c = [C] \gamma_c$$

$$\frac{\text{unknown } y \text{ interval}}{\Delta y} = \frac{\text{unknown } x \text{ interval}}{\Delta x} \quad \log \gamma = \frac{-0.51 z^2 \sqrt{\mu}}{1 + \left( \frac{\alpha \sqrt{\mu}}{305} \right)}$$

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \quad \text{pH} = -\log(\gamma_{H^+} [H^+]) \quad \text{pOH} = -\log(\gamma_{OH^-} [OH^-])$$

$$\text{pH} + \text{pOH} = -\log(K_w) = 14.00 \quad K_w = K_a \cdot K_b \quad \text{pK}_a = -\log(K_a)$$

$$\text{pK}_b = -\log(K_b) \quad K_a = \frac{x^2}{F - x} \quad \alpha = \frac{x}{F}$$

$$\text{pH} = \text{pK}_a + \log \frac{[\text{base}]}{[\text{acid}]} \quad [H^+] = \sqrt{\frac{K_{a1} K_{a2} F + K_{a1} K_w}{K_{a1} + F}} \quad \text{pH} = \frac{1}{2} (\text{pK}_{a1} + \text{pK}_{a2})$$

$$V_{acid} \cdot M_{acid} = V_{base} \cdot M_{base} \quad F' = [\text{initial}] \cdot \left( \frac{\text{initial volume}}{\text{total final volume}} \right) \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\Delta G = -nFE \quad V = IR \quad A = \epsilon bc \quad c = \lambda \nu \quad E = h\nu$$

$$E = E^\circ - \frac{RT}{nF} \ln \frac{A_B^b}{A_A^a} = E^\circ - \frac{0.05916}{n} \log Q \quad q = It \quad \text{moles reacted} = \frac{It}{nF}$$

$$E = E_+ - E_-$$

$$E^\circ = \frac{0.05916}{n} \log K$$

$$E = \text{constant} + \frac{0.05916}{n} \log A_0$$

$$q^n = \left( \frac{V_1}{V_1 + KV_2} \right)^n$$

$$D = \frac{K \cdot K_a}{K_a + [H^+]}$$

$$D = \frac{K \cdot [H^+]}{[H^+] + K_a}$$

$$K = \frac{A_{S_2}}{A_{S_1}} \quad \alpha = \frac{t'_{R_2}}{t'_{R_1}} = \frac{k'_2}{k'_1} = \frac{K_2}{K_1}$$

$$k = \frac{t_R - t_m}{t_m} = \frac{C_S V_S}{C_M V_M} = K_c \left( \frac{V_S}{V_M} \right)$$

$$R = \frac{\Delta t_R}{w_{av}} = \frac{0.589 \Delta t_R}{w_{\frac{1}{2}^{av}}} = \frac{\sqrt{N}}{4} (\gamma - 1)$$

$$N = \frac{L}{H} = \frac{Lx}{\sigma^2} = \frac{L^2}{\sigma^2} = \frac{16t_R^2}{w^2} = \frac{t_R^2}{\sigma^2} = \frac{5.55t_R^2}{w_{1/2}^2}$$

$$F = 9.6485 \times 10^4 \text{ C/mol}$$

$$R = 8.314 \text{ J/(K}\cdot\text{mol)} = 8.314 \text{ (V}\cdot\text{C)/(K}\cdot\text{mol)}$$

$$A = \text{C/s}$$

$$J = \text{C}\cdot\text{V}$$

$$W = \text{J/s}$$

$$A = \text{V}/\Omega$$

$$\text{SHE, } E^\circ = 0.0000 \text{ V}$$

$$\text{SCE, } E^\circ = 0.241 \text{ V vs SHE}$$

$$\text{Ag/AgCl, } E^\circ = 0.197 \text{ V vs SHE}$$

Table 4-2 Values of Student's t

Degrees of freedom	Confidence level (%)						
	50	90	95	98	99	99.5	99.9
1	1.000	6.314	12.706	31.821	63.656	127.321	636.578
2	0.816	2.920	4.303	6.965	9.925	14.089	31.598
3	0.765	2.353	3.182	4.541	5.841	7.453	12.924
4	0.741	2.132	2.776	3.747	4.604	5.598	8.610
5	0.727	2.015	2.571	3.365	4.032	4.773	6.869
6	0.718	1.943	2.447	3.143	3.707	4.317	5.959
7	0.711	1.895	2.365	2.998	3.500	4.029	5.408
8	0.706	1.860	2.306	2.896	3.355	3.832	5.041
9	0.703	1.833	2.262	2.821	3.250	3.690	4.781
10	0.700	1.812	2.228	2.764	3.169	3.581	4.587
15	0.691	1.753	2.131	2.602	2.947	3.252	4.073
20	0.687	1.725	2.086	2.528	2.845	3.153	3.850
25	0.684	1.708	2.060	2.485	2.787	3.078	3.725
30	0.683	1.697	2.042	2.457	2.750	3.030	3.646
40	0.681	1.684	2.021	2.423	2.704	2.971	3.551
60	0.679	1.671	2.000	2.390	2.660	2.915	3.460
120	0.677	1.658	1.980	2.358	2.617	2.860	3.373
$\infty$	0.674	1.645	1.960	2.326	2.576	2.807	3.291

pH	$\alpha_{Y^{4-}}$
0	$1.3 \times 10^{-23}$
1	$1.4 \times 10^{-18}$
2	$2.6 \times 10^{-14}$
3	$2.1 \times 10^{-11}$
4	$3.0 \times 10^{-9}$
5	$2.9 \times 10^{-7}$
6	$1.8 \times 10^{-5}$
7	$3.8 \times 10^{-4}$
8	$4.2 \times 10^{-3}$
9	0.041
10	0.30
11	0.81
12	0.98
13	1.00
14	1.00

F table

Degrees of freedom for $s_2$	Degrees of freedom for $s_1$													
	2	3	4	5	6	7	8	9	10	12	15	20	30	$\infty$
2	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5
3	9.55	9.28	9.12	9.01	8.94	8.89	8.84	8.81	8.79	8.74	8.70	8.66	8.62	8.53
4	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.75	5.63
5	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.50	4.36
6	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.81	3.67
7	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.58	3.51	3.44	3.38	3.23
8	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.08	2.93
9	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.86	2.71
10	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.84	2.77	2.70	2.54
11	3.98	3.59	3.36	3.20	3.10	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.57	2.40
12	3.88	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.47	2.30
13	3.81	3.41	3.18	3.02	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.38	2.21
14	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.31	2.13
15	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.25	2.07
16	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.19	2.01
17	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.15	1.96
18	3.56	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.11	1.92
19	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.07	1.88
20	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.04	1.84
30	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.84	1.62
$\infty$	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.46	1.00

TABLE 11-2 Formation constants for metal-EDTA complexes

Ion	$\log K_f$	Ion	$\log K_f$	Ion	$\log K_f$
Li <sup>+</sup>	2.95	V <sup>3+</sup>	25.9 <sup>a</sup>	Tl <sup>3+</sup>	35.3
Na <sup>+</sup>	1.86	Cr <sup>3+</sup>	23.4 <sup>a</sup>	Bi <sup>3+</sup>	27.8 <sup>a</sup>
K <sup>+</sup>	0.8	Mn <sup>3+</sup>	25.2	Ce <sup>3+</sup>	15.93
Be <sup>2+</sup>	9.7	Fe <sup>3+</sup>	25.1	Pr <sup>3+</sup>	16.30
Mg <sup>2+</sup>	8.79	Co <sup>3+</sup>	41.4	Nd <sup>3+</sup>	16.51
Ca <sup>2+</sup>	10.65	Zr <sup>4+</sup>	29.3	Pm <sup>3+</sup>	16.9
Sr <sup>2+</sup>	8.72	Hf <sup>4+</sup>	29.5	Sm <sup>3+</sup>	17.06
Ba <sup>2+</sup>	7.88	VO <sup>2+</sup>	18.7	Eu <sup>3+</sup>	17.25
Ra <sup>2+</sup>	7.4	VO <sub>2</sub> <sup>+</sup>	15.5	Gd <sup>3+</sup>	17.35
Sc <sup>3+</sup>	23.1 <sup>a</sup>	Ag <sup>+</sup>	7.20	Tb <sup>3+</sup>	17.87
Y <sup>3+</sup>	18.08	Tl <sup>+</sup>	6.41	Dy <sup>3+</sup>	18.30
La <sup>3+</sup>	15.36	Pd <sup>2+</sup>	25.6 <sup>a</sup>	Ho <sup>3+</sup>	18.56
V <sup>2+</sup>	12.7 <sup>a</sup>	Zn <sup>2+</sup>	16.5	Er <sup>3+</sup>	18.89
Cr <sup>2+</sup>	13.6 <sup>a</sup>	Cd <sup>2+</sup>	16.5	Tm <sup>3+</sup>	19.32
Mn <sup>2+</sup>	13.89	Hg <sup>2+</sup>	21.5	Yb <sup>3+</sup>	19.49
Fe <sup>2+</sup>	14.30	Sn <sup>2+</sup>	18.3 <sup>b</sup>	Lu <sup>3+</sup>	19.74
Co <sup>2+</sup>	16.45	Pb <sup>2+</sup>	18.0	Th <sup>4+</sup>	23.2
Ni <sup>2+</sup>	18.4	Al <sup>3+</sup>	16.4	U <sup>4+</sup>	25.7
Cu <sup>2+</sup>	18.78	Ga <sup>3+</sup>	21.7		
Ti <sup>3+</sup>	21.3	In <sup>3+</sup>	24.9		

Number of observations	G (95% confidence)
4	1.463
5	1.672
6	1.822
7	1.938
8	2.032
9	2.110
10	2.176
11	2.234
12	2.285
15	2.409
20	2.557

**TABLE 7-1 Activity coefficients for aqueous solutions at 25°C**

Ion	Ion size ( $\alpha$ , pm)	Ionic strength ( $\mu$ , M)				
		0.001	0.005	0.01	0.05	0.1
<i>Charge = <math>\pm 1</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
H <sup>+</sup>	900	0.967	0.933	0.914	0.86	0.83
(C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> CHCO <sub>2</sub> <sup>-</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>4</sub> N <sup>+</sup>	800	0.966	0.931	0.912	0.85	0.82
(O <sub>2</sub> N) <sub>3</sub> C <sub>6</sub> H <sub>2</sub> O <sup>-</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>3</sub> NH <sup>+</sup> , CH <sub>3</sub> OC <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> <sup>-</sup>	700	0.965	0.930	0.909	0.845	0.81
Li <sup>+</sup> , C <sub>6</sub> H <sub>5</sub> CO <sub>2</sub> <sup>-</sup> , HOC <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> <sup>-</sup> , ClC <sub>6</sub> H <sub>4</sub> CO <sub>2</sub> <sup>-</sup> , C <sub>6</sub> H <sub>5</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , CH <sub>2</sub> =CHCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> ) <sub>2</sub> CHCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> CH <sub>2</sub> ) <sub>4</sub> N <sup>+</sup> , (C <sub>3</sub> H <sub>7</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup>	600	0.965	0.929	0.907	0.835	0.80
Cl <sub>2</sub> CHCO <sub>2</sub> <sup>-</sup> , Cl <sub>3</sub> CCO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> CH <sub>2</sub> ) <sub>3</sub> NH <sup>+</sup> , (C <sub>3</sub> H <sub>7</sub> )NH <sub>3</sub> <sup>+</sup>	500	0.964	0.928	0.904	0.83	0.79
Na <sup>+</sup> , CdCl <sup>+</sup> , ClO <sub>2</sub> <sup>-</sup> , IO <sub>3</sub> <sup>-</sup> , HCO <sub>3</sub> <sup>-</sup> , H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> , HSO <sub>3</sub> <sup>-</sup> , H <sub>2</sub> AsO <sub>4</sub> <sup>-</sup> , Co(NH <sub>3</sub> ) <sub>4</sub> (NO <sub>2</sub> ) <sub>2</sub> <sup>+</sup> , CH <sub>3</sub> CO <sub>2</sub> <sup>-</sup> , ClCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> , (CH <sub>3</sub> ) <sub>4</sub> N <sup>+</sup> , (CH <sub>3</sub> CH <sub>2</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup> , H <sub>2</sub> NCH <sub>2</sub> CO <sub>2</sub> <sup>-</sup>	450	0.964	0.928	0.902	0.82	0.775
<sup>+</sup> H <sub>3</sub> NCH <sub>2</sub> CO <sub>2</sub> H, (CH <sub>3</sub> ) <sub>3</sub> NH <sup>+</sup> , CH <sub>3</sub> CH <sub>2</sub> NH <sub>3</sub> <sup>+</sup>	400	0.964	0.927	0.901	0.815	0.77
OH <sup>-</sup> , F <sup>-</sup> , SCN <sup>-</sup> , OCN <sup>-</sup> , HS <sup>-</sup> , ClO <sub>3</sub> <sup>-</sup> , ClO <sub>4</sub> <sup>-</sup> , BrO <sub>3</sub> <sup>-</sup> , IO <sub>4</sub> <sup>-</sup> , MnO <sub>4</sub> <sup>-</sup> , HCO <sub>2</sub> <sup>-</sup> , H <sub>2</sub> citrate <sup>-</sup> , CH <sub>3</sub> NH <sub>3</sub> <sup>+</sup> , (CH <sub>3</sub> ) <sub>2</sub> NH <sub>2</sub> <sup>+</sup>	350	0.964	0.926	0.900	0.81	0.76
K <sup>+</sup> , Cl <sup>-</sup> , Br <sup>-</sup> , I <sup>-</sup> , CN <sup>-</sup> , NO <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup>	300	0.964	0.925	0.899	0.805	0.755
Rb <sup>+</sup> , Cs <sup>+</sup> , NH <sub>4</sub> <sup>+</sup> , Tl <sup>+</sup> , Ag <sup>+</sup>	250	0.964	0.924	0.898	0.80	0.75
<i>Charge = <math>\pm 2</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
Mg <sup>2+</sup> , Be <sup>2+</sup>	800	0.872	0.755	0.69	0.52	0.45
CH <sub>2</sub> (CH <sub>2</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub>	700	0.872	0.755	0.685	0.50	0.425
Ca <sup>2+</sup> , Cu <sup>2+</sup> , Zn <sup>2+</sup> , Sn <sup>2+</sup> , Mn <sup>2+</sup> , Fe <sup>2+</sup> , Ni <sup>2+</sup> , Co <sup>2+</sup> , C <sub>6</sub> H <sub>4</sub> (CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , H <sub>2</sub> C(CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CH <sub>2</sub> CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub>	600	0.870	0.749	0.675	0.485	0.405
Sr <sup>2+</sup> , Ba <sup>2+</sup> , Cd <sup>2+</sup> , Hg <sup>2+</sup> , S <sup>2-</sup> , S <sub>2</sub> O <sub>4</sub> <sup>2-</sup> , WO <sub>4</sub> <sup>2-</sup> , H <sub>2</sub> C(CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CH <sub>2</sub> CO <sub>2</sub> <sup>-</sup> ) <sub>2</sub> , (CHOHCO <sub>2</sub> <sup>-</sup> ) <sub>2</sub>	500	0.868	0.744	0.67	0.465	0.38
Pb <sup>2+</sup> , CO <sub>3</sub> <sup>2-</sup> , SO <sub>3</sub> <sup>2-</sup> , MoO <sub>4</sub> <sup>2-</sup> , Co(NH <sub>3</sub> ) <sub>5</sub> Cl <sup>2+</sup> , Fe(CN) <sub>5</sub> NO <sup>2-</sup> , C <sub>2</sub> O <sub>4</sub> <sup>2-</sup> , Heitrate <sup>2-</sup>	450	0.867	0.742	0.665	0.455	0.37
Hg <sub>2</sub> <sup>2+</sup> , SO <sub>4</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>3</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>6</sub> <sup>2-</sup> , S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> , SeO <sub>4</sub> <sup>2-</sup> , CrO <sub>4</sub> <sup>2-</sup> , HPO <sub>4</sub> <sup>2-</sup>	400	0.867	0.740	0.660	0.445	0.355
<i>Charge = <math>\pm 3</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
Al <sup>3+</sup> , Fe <sup>3+</sup> , Cr <sup>3+</sup> , Sc <sup>3+</sup> , Y <sup>3+</sup> , In <sup>3+</sup> , lanthanides <sup>a</sup>	900	0.738	0.54	0.445	0.245	0.18
citrate <sup>3-</sup>	500	0.728	0.51	0.405	0.18	0.115
PO <sub>4</sub> <sup>3-</sup> , Fe(CN) <sub>6</sub> <sup>3-</sup> , Cr(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup> , Co(NH <sub>3</sub> ) <sub>6</sub> <sup>3+</sup> , Co(NH <sub>3</sub> ) <sub>5</sub> H <sub>2</sub> O <sup>3+</sup>	400	0.725	0.505	0.395	0.16	0.095
<i>Charge = <math>\pm 4</math></i>		<i>Activity coefficient (<math>\gamma</math>)</i>				
Th <sup>4+</sup> , Zr <sup>4+</sup> , Ce <sup>4+</sup> , Sn <sup>4+</sup>	1 100	0.588	0.35	0.255	0.10	0.065
Fe(CN) <sub>6</sub> <sup>4-</sup>	500	0.57	0.31	0.20	0.048	0.021

*a. Lanthanides are elements 57–71 in the periodic table.  
SOURCE: J. Kielland, J. Am. Chem. Soc. 1937, 59, 1675.*

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# CHEM 320: QUANTITATIVE ANALYSIS

SPRING 2018

## COURSE INFORMATION

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Class Days: Monday, Wednesday, and Friday

Class Times: 2:00-2:50 pm for 10 weeks

Class Location: PHSC 109

Office Hours (and by appointment)

M, W 9:00-11:00 am

Office Hours Location: PHSC 327

## COURSE OVERVIEW

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In general, this course focuses on measurement in chemistry. Broad topics will include

- statistics and general number crunching (including significant figures)
- complex equilibria (precipitation, acid-base, and others)
- redox chemistry (electrochemical cells, redox titrations, good stuff like that)
- chemical instrumentation (gas and liquid chromatography, ion selective electrodes, etc)

## COURSE MATERIALS

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The required materials for this course are

- Quantitative Chemical Analysis by Daniel C Harris (any edition is fine, but I will assign recommended reading from the 9<sup>th</sup> edition)
- access to Sapling Learning (\$43 fee)
- in-house written lab manual, available for \$10 on your Wildcat Card in the SAACS room
- carbonless copy laboratory notebook, safety eyewear, and a lock

## COURSE ASSESSMENT AND GRADING

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Your grade in this course will be comprised of the following items, which are described in more detail later.

- three in-class exams
- a comprehensive final
- 16 laboratory reports
- 16 short homework assignments, deployed through [Sapling Learning](#)
- Grades will be based on the following percentages: A, >90 %; B >80 %; C, >70 %; D, >60 %. Earning these percentages will guarantee your grade. I reserve the right to adjust the percentages downward as I see fit (for example, an 89 % might earn an A, but do not count on a curve for this course).

## ACADEMIC HONESTY

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The University adheres to a strict [policy regarding cheating and plagiarism](#). Become familiar with the policy and what academic integrity means. Any cheating or plagiarism will result in failing this class and a disciplinary review by the University. These actions may lead to probation, suspension, or expulsion.

## TECHNICAL SUPPORT FOR BLACKBOARD

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Student support for Blackboard is provided by ITSS, located on the first floor opposite from the library main doors.

## COURSE SCHEDULE

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Week of	Topic (chapter in 9 <sup>th</sup> edition)	Other
Jan 22	introduction/review (1) error analysis (3) statistics (4)	homework 1 due 1/26
Jan 29	gravimetric analysis (27) equilibrium and solubility (6)	homework 2 due 1/30 homework 3 due 2/2
Feb 5	activity and systematic treatment of equilibrium (8) EDTA for titrations (12)	homework 4 due 2/6 homework 5 due 2/9
Feb 12	intro to spectroscopy (18) atomic spectroscopy (21)	<b>exam 1</b> , Monday 2/12 homework 6 due 2/16
Feb 19	acids/bases: types and strengths (9) acids/bases: buffers (9)	homework 7 due 2/20 homework 8 due 2/23
Feb 26	acids/bases: polyprotic acids/bases (10) acids/bases: titrations (11)	homework 9 due 2/27 homework 10 due 3/2
Mar 5	acids/bases: titrations (11) electrochemistry (14)	<b>exam 2</b> , Monday 3/5 homework 11 due 3/9
Mar 12	electroanalytical techniques (17) electrodes and potentiometry (15)	homework 12 due 3/13 homework 13 due 3/16 <i>no class Friday 3/16</i>
Mar 19	spring break!	
Mar 26	analytical separations (23) intro to chromatography (23)	homework 14 due 3/27 <i>Friday holiday</i>
Apr 2	gas chromatography (24)	<b>exam 3</b> , Monday 4/2 homework 15 due 4/6 <i>no class Friday 4/6</i>
Apr 6	liquid chromatography (25)	homework 16 due 4/10 M, W class only (makeup)
later		final exam (comprehensive)

## ACCESSIBILITY

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If you are a student who requires or believes you will require accommodations for this class, it is your responsibility to contact the Accessibility Resource Center at (530) 898-5959 or by stopping by SSC 170. You can also learn more about the services provided by visiting the [Accessibility Resource Center](#) website. To avoid any delay in the receipt of your accommodations, you should contact the Accessibility Resource Center as soon as possible.

## EXAMS AND ASSIGNMENTS

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### 16 ONLINE SAPLING LEARNING ASSIGNMENTS @ 5 POINTS EACH =80 POINTS

These assignments will generally be 5-7 problems long and will cover material we have already completed in lecture. Homework is due every Tuesday and Friday, with the exception of Tuesdays following exam days. You can and should retry every problem until the problem is correct. Not only will you gain greater understanding, but there is

no penalty for number of attempts. With that in mind, you should definitely start the homework more than just the night before so you have time to ask me questions and/or try the question multiple times.

### **16 LABORATORY REPORTS @ 20 POINTS EACH = 320 POINTS**

Your laboratory instructor will provide you with MUCH more detail on the requirements for each laboratory report. Please note that gaining proficiency in the laboratory is an integral part of this course; this importance is reflected in the laboratory being a significant portion of your overall class grade.

### **3 IN-CLASS EXAMS @ 75 POINTS = 225 POINTS**

Yep. A week before the exam, I will provide you with a study guide and an equation sheet. You will also receive this equation sheet as part of your exam packet—no use in memorizing all of those beastly long equations. Exams will have some “explain” questions and some calculations. It is in your best interest to try every problem; I’m a big fan of partial credit, as long as you show your work.

### **1 IN-CLASS FINAL @ 150 POINTS = 150 POINTS**

Since this is a condensed lecture schedule, we will decide on a date for the final toward the end of the class. We could always have it during finals week, but most classes like to get it out of the way earlier.

**TOTAL POINTS= 775**

## **SUCCESS IN QUANT**

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I’ve heard through the grapevine that a lot of people dread Quant. Fear not: this class is fantastic. You get to learn a ton of new things, and learn some background detail on concepts you’ve seen before. You’ll reinforce why sig figs were and are so important, and learn why reporting numbers with the correct sig figs properly represents the accuracy and precision of the tools you were using to make the measurement. You’ll learn when it’s important to be “quant-y” and when it’s not. You’ll look at complex equilibria in a whole new light. You will connect with Microsoft Excel in ways that will benefit you for years to come. There’s some math, some art, and some descriptive writing. It’s everything you could hope for in a class, and then some. Rest assured that I am working just as hard for you as you are working for me; I want you to love this stuff like I do. Work hard, form study groups, take advantage of all your resources. It will take a pretty sturdy time commitment from both of us, but that’s okay. That’s what we are here for. Please come to office hours. E-mail me. Call me. Follow me through the halls with your lab notebook. You will be awesome. I can help.



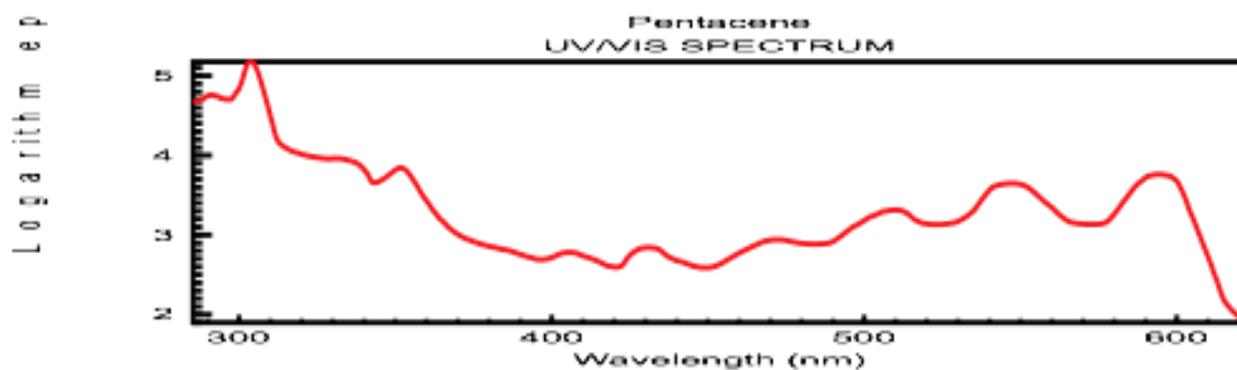


6. (12 pts) Find the result of operating with operator  $\hat{A} = \left(\frac{1}{r^2}\right)\left(\frac{d}{dr}\right)\left(r^2\frac{d}{dr}\right) + 2r$  on the function  $Ae^{-br}$ . Is this an eigenfunction of the operator? If so, write the eigenvalue. If not, explain. **Box your answer.**

7. (14 pts) Sketch  $\psi^2$  for a 1D PIB in the  $n = 2$  state. Determine the probability for finding a particle between  $0.45L$  and  $0.55L$  analytically. **Box your answer.** How does this compare to the classical prediction?

8. (14 pts) Compute  $\langle E \rangle$  for a particle in a 1D box of length  $a$ . **Box your answer.** What does this value say about the energy of a particle?

9. (18 pts) Pentacene is 5 fused benzene rings that can be modeled as a **2D PIB**.



- Sketch pentacene and indicate the number of  $\pi$  electrons. **Box your answer.**
- Sketch the energy diagram in **units of  $\epsilon$**  as used in class. Also, **clearly** indicate the HOMO and LUMO and the **lowest energy transition**.
- Estimate the length and width of pentacene from UV-vis data and 2D PIB theory. **Box your answers.**

- d. Use your best artistic talents to sketch  $\psi$  and  $\psi^2$  for the HOMO. How many total nodes are present? **Indicate using arrows.**

Carefully detach this sheet, if necessary.

$$c = 2.998 \times 10^8 \text{ m s}^{-1} \quad h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} \quad k = 1.381 \times 10^{-23} \text{ J K}^{-1} = 0.695 \text{ cm}^{-1}/\text{K}$$

$$1 \text{ eV} = 1.602 \times 10^{-19} \text{ J} = 8066 \text{ cm}^{-1} \quad N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$$

$$m_e = 9.109 \times 10^{-31} \text{ kg} \quad m_p = 1.672 \times 10^{-27} \text{ kg} \quad 1 \text{ amu} = 1.6605 \times 10^{-27} \text{ kg}$$

$$1 \text{ \AA} = 1 \times 10^{-10} \text{ m}$$

$\hat{x} = x$ (multiply by $x$ )
$\hat{x}^2 = x^2$ (multiply by $x^2$ )
$\hat{p} = \frac{\hbar}{i} \frac{d}{dx}$
$\hat{E}_k = -\frac{\hbar^2}{2m} \frac{d^2}{dx^2}$
$\hat{E}_k = -\frac{\hbar^2}{2m} \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right)$

$$\int \sin bx \cos bx dx = \frac{1}{2b} \sin^2 bx \quad \int \sin ax \sin bx dx = \frac{\sin(a-b)x}{2(a-b)} + \frac{\sin(a+b)x}{2(a+b)}$$

$$\int \sin^2 bx dx = \frac{x}{2} - \frac{1}{4b} \sin(2bx) \quad \int \cos^2 bx dx = \frac{x}{2} + \frac{1}{4b} \sin(2bx)$$

$$\int x \sin^2 bx dx = \frac{x^2}{4} - \frac{x}{4b} \sin(2bx) - \frac{1}{8b^2} \cos(2bx) \quad \int x \cos bx dx = \frac{1}{b^2} \cos bx + \frac{x}{b} \sin bx$$

$$\int x^2 \sin^2 bx dx = \frac{x^3}{6} - \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) - \frac{x}{4b^2} \cos(2bx) \quad \int e^{bx} dx = \frac{1}{b} e^{bx}$$

$$\int x^2 \cos^2 bx dx = \frac{x^3}{6} + \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) + \frac{x}{4b^2} \cos(2bx) \quad \int x e^{bx} dx = e^{bx} \frac{1}{b^2} (bx - 1)$$

$$\int_0^\pi (\cos^n x) (\sin x) dx = \begin{cases} 0 & n \text{ odd} \\ \left( \frac{2}{n+1} \right) & n \text{ even} \end{cases}$$

$$\int (\cos^m ax) (\sin^n ax) dx = \frac{\cos^{m-1} ax \sin^{n+1} ax}{(m+n)a} + \frac{m-1}{m+n} \int (\cos^{m-2} ax) (\sin^n ax) dx$$

$$\int x^2 e^{bx} dx = e^{bx} \left( \frac{x^2}{b} - \frac{2x}{b^2} + \frac{2}{b^3} \right) \quad \int x^m e^{bx} dx = e^{bx} \sum_{k=0}^m (-1)^k \frac{m! x^{m-k}}{(m-k)! b^{(k+1)}}$$

$$\int_0^\infty e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b} \right)^{1/2} \quad \int_{-\infty}^\infty x^2 e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b^3} \right)^{1/2} \quad \int_0^\infty x^n e^{-bx} dx = \frac{n!}{b^{n+1}}, \text{ where } n \neq -1, b > 0$$

$$\int_0^\infty x^{2n} e^{-bx^2} dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1} \cdot b^n} \cdot \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x e^{-bx^2} dx = \frac{1}{2b} \quad \int_0^\infty x^{2n+1} e^{-bx^2} dx = \frac{n!}{2b^{n+1}}$$

#### Bond lengths:

C-C: 1.54 Å

C=C: 1.35 Å

C≡C: 1.20 Å



2. (8 pts) The asymmetric stretch in  $\text{CO}_2$  is IR-active but Raman inactive. Briefly explain with words and sketches.

3. (12 pts) A particular rigid rotor is in a state where the angular momentum vector is perpendicular to the externally applied field and has a length of  $5.48\hbar$ .

a. What are the quantum numbers for this rotor? **Box your answer.**

b. Discuss Bohr's notion of Complementarity for this state. Be sure to use an appropriately labeled sketch in your discussion. **Box your answers.**



5. (8 pts) Compute the displacement,  $x$ , of a simple harmonic oscillator in the  $n = 2$  state. Comment on your result. **Box your answer.**

6. (16 pts) Consider a system in the  $l = 2, m_l = -2$  state.

a. What is the expected energy in units of B? **Box your answer.**

b. Show that the wavefunction for this state is an eigenfunction of the hamiltonian. What is the eigenvalue? Does this agree with your result above? **Box your answer.**

7. (22 pts) Consider a  $2p_z$  electron in hydrogen.

a. Write the wavefunction.

b. Sketch and label the vector diagram for the angular momentum. **Box your answers.**

c. Plot the radial distribution function. Briefly describe.

d. Find the most probable radius. **Box your answer.**

e. Find the radial node(s). **Box your answer(s).**

f. Set up the integrals for calculating the probability that the electron will be found within  $3a_0$  of the nucleus. **Do not evaluate.**

**Carefully detach this sheet.**

$c=2.998 \times 10^8 \text{ m s}^{-1}$        $h=6.626 \times 10^{-34} \text{ J}\cdot\text{s}$        $k=1.381 \times 10^{-23} \text{ J K}^{-1} = 0.695 \text{ cm}^{-1} \text{ K}^{-1}$   
 $m_e=9.109 \times 10^{-31} \text{ kg}$        $1 \text{ amu} = 1.6605 \times 10^{-27} \text{ kg}$   
 $a_0 = 52.9 \text{ pm} = 0.529 \text{ \AA}$  (the bohr radius)     $1 \text{ \AA} = 1 \times 10^{-10} \text{ m}$

$\hat{x}=x$ (multiply by $x$ )	$\nabla^2 = \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right)$	$\nabla^2 = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2}{\partial \phi^2}$
$\hat{x}^2 = x^2$ (multiply by $x^2$ )	$\hat{V} = \frac{1}{2} kx^2$	$\hat{L}^2 = -\hbar^2 \left[ \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2}{\partial \phi^2} \right]$
$\hat{p}_x = -i\hbar \frac{d}{dx}$	$\hat{L}_x = -i\hbar \left( y \frac{\partial}{\partial z} - z \frac{\partial}{\partial y} \right)$	$\hat{L}_x = -i\hbar \left( -\sin \phi \frac{\partial}{\partial \theta} - \cot \theta \cos \phi \frac{\partial}{\partial \phi} \right)$
$\hat{E}_{k,x} = \frac{-\hbar^2}{2m} \frac{d^2}{dx^2}$	$\hat{L}_y = -i\hbar \left( z \frac{\partial}{\partial x} - x \frac{\partial}{\partial z} \right)$	$\hat{L}_y = -i\hbar \left( -\cos \phi \frac{\partial}{\partial \theta} - \cot \theta \sin \phi \frac{\partial}{\partial \phi} \right)$
$\hat{E}_k = \frac{-\hbar^2}{2m} \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right)$	$\hat{L}_z = -i\hbar \left( x \frac{\partial}{\partial y} - y \frac{\partial}{\partial x} \right)$	$\hat{L}_z = -i\hbar \left( \frac{\partial}{\partial \phi} \right)$

$$\int \sin bx \cos bx dx = \frac{1}{2b} \sin^2 bx \quad \sin ax \cos bx = \frac{1}{2} [\cos(a-b)x - \cos(a+b)x]$$

$$\int \sin ax \sin bx dx = \frac{\sin(a-b)x}{2(a-b)} + \frac{\sin(a+b)x}{2(a+b)}$$

$$\int \sin^2 bx dx = \frac{x}{2} - \frac{1}{4b} \sin(2bx) \quad \int \cos^2 bx dx = \frac{x}{2} + \frac{1}{4b} \sin(2bx)$$

$$\int x \sin^2 bx dx = \frac{x^2}{4} - \frac{x}{4b} \sin(2bx) - \frac{1}{8b^2} \cos(2bx) \quad \int x \cos bx dx = \frac{1}{b^2} \cos bx + \frac{x}{b} \sin bx$$

$$\int x^2 \sin^2 bx dx = \frac{x^3}{6} - \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) - \frac{x}{4b^2} \cos(2bx) \quad \int e^{bx} dx = \frac{1}{b} e^{bx}$$

$$\int x^2 \cos^2 bx dx = \frac{x^3}{6} + \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) + \frac{x}{4b^2} \cos(2bx) \quad \int x e^{bx} = e^{bx} \frac{1}{b^2} (bx - 1)$$

$$\int_0^\pi (\cos^n x)(\sin x) dx = \begin{cases} 0 & n \text{ odd} \\ \left( \frac{2}{n+1} \right) & n \text{ even} \end{cases}$$

$$\int (\cos^m ax)(\sin^n ax) dx = \frac{\cos^{m-1} ax \sin^{n+1} ax}{(m+n)a} + \frac{m-1}{m+n} \int (\cos^{m-2} ax)(\sin^n ax) dx$$

$$\int x^2 e^{bx} = e^{bx} \left( \frac{x^2}{b} - \frac{2x}{b^2} + \frac{2}{b^3} \right) \quad \int x^m e^{bx} dx = e^{bx} \sum_{k=0}^m (-1)^k \frac{m! x^{m-k}}{(m-k)! b^{k+1}}$$

$$\int_0^\infty e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x^n e^{-bx} dx = \frac{n!}{b^{n+1}}, \text{ where } n \neq -1, b > 0$$

$$\int_0^\infty x^{2n} e^{-bx^2} dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1} \cdot b^n} \cdot \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x^{2n+1} e^{-bx^2} dx = \frac{n!}{2b^{n+1}}$$

$$\sin^2 \theta + \cos^2 \theta = 1$$

$\psi_0(x) = \left( \frac{\alpha}{\pi} \right)^{1/4} e^{-(1/2)\alpha x^2}$	$Y_0^0(\theta, \phi) = \frac{1}{(4\pi)^{1/2}}$	$R_{10}(r) = 2 \left( \frac{1}{a_0} \right)^{3/2} e^{-r/a_0}$
$\psi_1(x) = \left( \frac{4\alpha^3}{\pi} \right)^{1/4} x e^{-(1/2)\alpha x^2}$	$Y_1^0(\theta, \phi) = \left( \frac{3}{4\pi} \right)^{1/2} \cos \theta$	$R_{20}(r) = \frac{1}{\sqrt{8}} \left( \frac{1}{a_0} \right)^{3/2} \left( 2 - \frac{r}{a_0} \right) e^{-r/2a_0}$
$\psi_2(x) = \left( \frac{\alpha}{4\pi} \right)^{1/4} (2\alpha x^2 - 1) e^{-(1/2)\alpha x^2}$	$Y_1^{\pm 1}(\theta, \phi) = \left( \frac{3}{8\pi} \right)^{1/2} \sin \theta e^{\pm i\phi}$	$R_{21}(r) = \frac{1}{\sqrt{24}} \left( \frac{1}{a_0} \right)^{3/2} \frac{r}{a_0} e^{-r/2a_0}$
$\psi_3(x) = \left( \frac{\alpha^3}{9\pi} \right)^{1/4} (2\alpha x^3 - 3x) e^{-(1/2)\alpha x^2}$	$Y_2^0(\theta, \phi) = \left( \frac{5}{16\pi} \right)^{1/2} (3 \cos^2 \theta - 1)$	$R_{30}(r) = \frac{2}{81\sqrt{3}} \left( \frac{1}{a_0} \right)^{3/2} \left( 27 - 18 \frac{r}{a_0} + 2 \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$
	$Y_2^{\pm 1}(\theta, \phi) = \left( \frac{15}{8\pi} \right)^{1/2} \sin \theta \cos \theta e^{\pm i\phi}$	$R_{31}(r) = \frac{4}{81\sqrt{6}} \left( \frac{1}{a_0} \right)^{3/2} \left( 6 \frac{r}{a_0} - \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$
	$Y_2^{\pm 2}(\theta, \phi) = \left( \frac{15}{32\pi} \right)^{1/2} \sin^2 \theta e^{\pm 2i\phi}$	$R_{32}(r) = \frac{4}{81\sqrt{30}} \left( \frac{1}{a_0} \right)^{3/2} \frac{r^2}{a_0^2} e^{-r/3a_0}$



3. (10 pts) Consider an s-orbital on nucleus 1 and a  $p_x$  orbital on nucleus 2, where the z-axis is the internuclear (bond) axis. Plot the overlap integral,  $S_{12}$  versus  $R$ , for the interaction and discuss with the appropriate sketches.
4. (14 pts) On ONE plot, sketch the 3D Maxwell-Boltzmann distributions for nitrogen gas at 100K and 300K. Briefly explain. (b) On ANOTHER plot, sketch the 3D Maxwell-Boltzmann distributions for nitrogen gas and hydrogen gas at the same temperatures. Briefly explain.
5. (15 pts) Derive the expression for  $v_{\text{avg}}$  from the 3D Maxwell-Boltzmann distribution. Compute for nitrogen gas at 25°C.

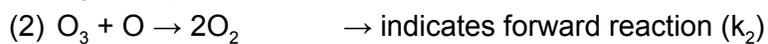
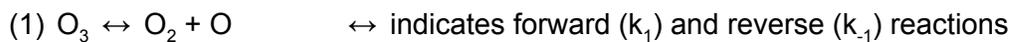
6. (15 pts) Use the integral method to find the expression for the half-life of a reaction  $A \rightarrow P$  that is 2nd order in A. What plot would you make? How would you find the value of k? What is the half-life?

7. (10 pts) An Arrhenius analysis of a certain reaction gives an activation energy of 30 kJ/mol and a pre-exponential of  $1.5 \times 10^8 \text{ M}^{-1}\text{s}^{-1}$ .

a. Compute  $k_{\text{Arr}}$  at 300 K. What is the order of this reaction? Briefly explain.

b. Determine  $\Delta S^\ddagger$  and  $\Delta H^\ddagger$ . Assume  $c$  is  $1 \text{ M}^{-1}$ . Briefly discuss.

8. (15 pts) The experimental rate law for the destruction of ozone is 1st order in ozone only. The reaction is proposed to occur via the following mechanism.



a. What is the overall reaction? Briefly explain.

b. Show that the rate law derived from this mechanism is  $R_{\text{mech}} = \frac{k_1 k_2 [O_3]^2}{k_{-1} [O_2] + k_2 [O_3]}$ .

c. Under what conditions is  $R_{\text{mech}} = R_{\text{exp}}$ ? Briefly discuss.

Carefully detach this sheet.

$$R = 8.314 \text{ J/mol K} = 0.08314 \frac{\text{L bar}}{\text{mol K}} = 0.08206 \frac{\text{L atm}}{\text{mol K}} \quad 1 \text{ atm} = 101.3 \text{ kPa} \quad 1 \text{ bar} = 100.0 \text{ kPa}$$

$$k_B = 1.381 \times 10^{-23} \text{ J/K} \quad h = 6.626 \times 10^{-34} \text{ J s} \quad e = 2.178 \quad N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$$

$$1 \text{ amu} = 1.661 \times 10^{-27} \text{ kg}$$

$$z_{11} = \frac{P_1 N_A}{RT} \sigma \sqrt{2} \left( \frac{8RT}{\pi M_1} \right)^{1/2} \quad z_{12} = \frac{N_2}{V} \sigma \left( \frac{8kT}{\pi \mu} \right)^{1/2} \quad Z_{11} = \frac{1}{2} \frac{N_1}{V} z_{11} \quad Z_{12} = \frac{N_1}{V} z_{12}$$

$$\lambda = \frac{v_{ave}}{z_{11}} \quad \lambda = \frac{v_{ave}}{(z_{11} + z_{12})}$$

**Standard Integrals:**

$$\int \sin bx \cos bx dx = \frac{1}{2b} \sin^2 bx \quad \sin ax \cos bx = \frac{1}{2} [\cos(a-b)x - \cos(a+b)x]$$

$$\int \sin ax \sin bx dx = \frac{\sin(a-b)x}{2(a-b)} + \frac{\sin(a+b)x}{2(a+b)}$$

$$\int \sin^2 bx dx = \frac{x}{2} - \frac{1}{4b} \sin(2bx) \quad \int \cos^2 bx dx = \frac{x}{2} + \frac{1}{4b} \sin(2bx)$$

$$\int x \sin^2 bx dx = \frac{x^2}{4} - \frac{x}{4b} \sin(2bx) - \frac{1}{8b^2} \cos(2bx) \quad \int x \cos bx dx = \frac{1}{b^2} \cos bx + \frac{x}{b} \sin bx$$

$$\int x^2 \sin^2 bx dx = \frac{x^3}{6} - \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) - \frac{x}{4b^2} \cos(2bx) \quad \int e^{bx} dx = \frac{1}{b} e^{bx}$$

$$\int x^2 \cos^2 bx dx = \frac{x^3}{6} + \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) + \frac{x}{4b^2} \cos(2bx) \quad \int x e^{bx} = e^{bx} \frac{1}{b^2} (bx - 1)$$

$$\int_0^\pi (\cos^n x) (\sin x) dx = \begin{cases} 0 & n \text{ odd} \\ \left( \frac{2}{n+1} \right) & n \text{ even} \end{cases}$$

$$\int (\cos^m ax) (\sin^n ax) dx = \frac{\cos^{m-1} ax \sin^{n+1} ax}{(m+n)a} + \frac{m-1}{m+n} \int (\cos^{m-2} ax) (\sin^n ax) dx$$

$$\int x^2 e^{bx} = e^{bx} \left( \frac{x^2}{b} - \frac{2x}{b^2} + \frac{2}{b^3} \right) \quad \int x^m e^{bx} dx = e^{bx} \sum_{k=0}^m (-1)^k \frac{m! x^{m-k}}{(m-k)! b^{k+1}}$$

$$\int_0^\infty e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x^n e^{-bx} dx = \frac{n!}{b^{n+1}}, \text{ where } n \neq -1, b > 0$$

$$\int_0^\infty x^{2n} e^{-bx^2} dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1} \cdot b^n} \cdot \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x^{2n+1} e^{-bx^2} dx = \frac{n!}{2b^{n+1}}$$

$$F(v) dv = 4\pi \left( \frac{M}{2\pi RT} \right)^{3/2} v^2 e^{-Mv^2/2RT} dv$$

$$\text{unimolecular: } E_a = \Delta H^\ddagger + RT; A = \frac{e k_b T}{hc} e^{\Delta S^\ddagger/R}$$

$$\text{bimolecular: } E_a = \Delta H^\ddagger + 2RT; A = \frac{e^2 k_b T}{hc} e^{\Delta S^\ddagger/R}$$

$$\text{termolecular: } E_a = \Delta H^\ddagger + 3RT; A = \frac{e^3 k_b T}{hc} e^{\Delta S^\ddagger/R}$$

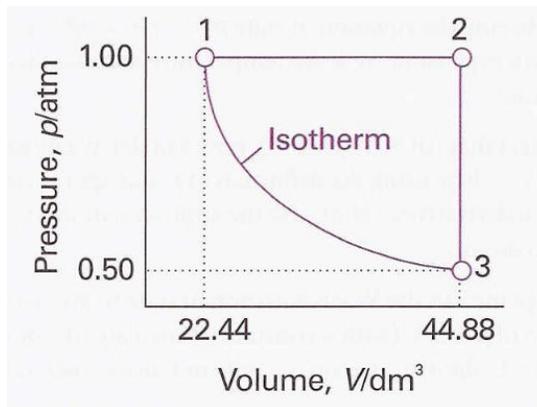


4. (15 pts) A Carnot cycle uses 1.00 mol of a monatomic perfect gas as the working substance from an initial state of 10.0 atm and 600 K. It expands isothermally to a pressure of 1.00 atm (Step 1), and then adiabatically to a temperature of 300 K (Step 2). This expansion is followed by an isothermal compression (Step 3), and then an adiabatic compression (Step 4) back to the initial state. Determine the values of  $q$ ,  $w$ ,  $\Delta U$ ,  $\Delta H$ ,  $\Delta S_{sys}$ ,  $\Delta S_{surr}$ , and  $\Delta S_{tot}$ , for each stage of the cycle and for the cycle as a whole. **Box your answers.**



5. (8 pts) (a) Find an expression for the change in entropy when two blocks of the same substance and of equal mass, one at the temperature  $T_h$  and the other  $T_c$ , are brought into thermal contact and allowed to reach equilibrium at a temperature  $T_f$ . (b) Evaluate the change for two blocks of gold ( $M_w=196.9$  g/mol), each of mass 300 g, with  $C_{p,m} = 24.4$  J K<sup>-1</sup> mol<sup>-1</sup>, taking  $T_h=500$  K and  $T_c=200$  K.
6. (10 pts) The standard enthalpy of formation of the metallocene bis(benzene)chromium was measured in a calorimeter. Assume pressure is not constant. It was found for the reaction  $\text{Cr}(\text{C}_6\text{H}_6)_2(\text{s}) \rightarrow \text{Cr}(\text{s}) + 2 \text{C}_6\text{H}_6(\text{g})$  that  $\Delta_R U^\circ(583\text{K}) = 8.0$  kJ mol<sup>-1</sup> and  $\Delta_f H^\circ(\text{benzene}, 583\text{K}) = 66.8$  kJ mol<sup>-1</sup>. (a) Find the corresponding reaction enthalpy, and (b) estimate the standard enthalpy of formation of the compound at 583 K.
7. (14 pts) Sucrose (table sugar) is a complex sugar ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ ) that consists of a glucose unit ( $\text{C}_6\text{H}_{12}\text{O}_6$ ) covalently bound to a fructose unit ( $\text{C}_6\text{H}_{12}\text{O}_6$ ); a water molecule is given off as a result of the reaction





Determine the temperature at the points 1, 2, and 3. **Box your answers.**

9. (15 pts)  $50.0 \text{ dm}^3$  of dry air was slowly bubbled through a thermally insulated beaker containing 250 g of water initially at  $25^\circ\text{C}$ . The vapor pressure of water is approximately constant at 3.17 kPa throughout, and its

heat capacity is  $75.5 \text{ J K}^{-1} \text{ mol}^{-1}$ . Assume that the air is not heated or cooled and that water vapor is a perfect gas. Calculate the final temperature (in Kelvins).

**Carefully detach this sheet.**

$$\begin{aligned}
 c &= 2.998 \times 10^8 \text{ m s}^{-1} = 2.998 \times 10^{10} \text{ cm s}^{-1} & h &= 6.626 \times 10^{-34} \text{ J}\cdot\text{s} & 1 \text{ eV} &= 1.60 \times 10^{-19} \text{ J} = 8088 \text{ cm}^{-1} \\
 k &= 1.381 \times 10^{-23} \text{ J K}^{-1} = 0.695 \text{ cm}^{-1}/\text{K} & m_e &= 9.109 \times 10^{-31} \text{ kg} & m_p &= 1.672 \times 10^{-27} \text{ kg} \\
 1 \text{ amu} &= 1.6605 \times 10^{-27} \text{ kg} & a_0 &= 52.9 \text{ pm} = 0.529 \text{ \AA} \text{ (the bohr radius)} & 1 \text{ \AA} &= 1 \times 10^{-10} \text{ m}
 \end{aligned}$$

$$R = 8.314 \frac{\text{J}}{\text{mol K}} = 8.314 \frac{\text{kJ}}{\text{K mol}} = 0.08314 \frac{\text{atm dm}^3}{\text{K mol}}$$

$$T_K = T_C + 273.15 \quad \left( \frac{T_f}{T_i} \right) = \left( \frac{V_i}{V_f} \right)^{\gamma} \quad \left( \frac{P_f}{P_i} \right) = \left( \frac{V_i}{V_f} \right)^{\gamma} \quad \gamma = \frac{C_{p,m}}{C_{v,m}}$$

# CHEM 331: Physical Chemistry

Lectures: MWF 9:00-9:50 AM, PHSC 213

## Contact Information:

**Instructor:** Dr. Monica C. So

**Phone**<sup>1</sup>: 530-898-6554

**E-mail**<sup>1</sup>: mso@csuchico.edu

**Office:** PhSc 317A

**Office hours:** Mondays and Fridays 11:00am-12:00pm (and by appointment)

## Course Description and Goals

CHEM 331 is an upper division level physical chemistry course designed for chemistry and biochemistry majors. The purpose of this course is to engage you in the detailed study of the physical principles underlying chemical phenomena. Topics in physical chemistry can generally be grouped in three broad areas (quantum mechanics, thermodynamics, and kinetics). Since many of you may only take one semester of physical chemistry, we will cover many aspects of all three areas in the first semester. Those taking the second semester (CHEM 332) will get more in depth coverage of the same topics.

## Prerequisites

You must have received passing grades for CHEM 320, MATH 220, PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, and PHYS 204C. To be successful, you will have to master the application of concepts and techniques from physics and mathematics to the understanding of chemical principles. Oftentimes during the semester, you may feel as if you are in an applied math rather than a chemistry course, but all is directed toward expanding your understanding of the physical and chemical properties of matter.

## Policy on Recording Lectures

With prior permission written in an email, any student may audio record lecture. Still photography and video recordings of lecture of any kind are prohibited at all times in CHEM 331.

## Student Learning Objectives

Upon successful completion of this course, you will be able to:

1. Understand the criterion which apply to models used in physical chemistry.
2. Understand the physical meanings of models in quantum mechanics, spectroscopy, thermodynamics, and kinetics.
3. Apply mathematical expressions to calculate important values from models.
4. Extend understanding of physical chemistry models to real-life applications.

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<sup>1</sup> I typically check my e-mail and phone messages M-F from 8 am – 4:30 pm. These times will vary somewhat according to my daily teaching schedule. I will not check e-mail and phone messages on weekends and holidays.

## Course Materials

- *Physical Chemistry*, 3<sup>rd</sup> edition, Engel and Reid (ISBN-13: 978-0321812001)
- Solutions manuals and materials from previous semesters are not permitted unless provided to the entire class by me.

## Grading

I will grade using a sliding grade scale, meaning that the highest score in the class will be considered 100% (or the highest score possible). The grading scale will then be 90% and above is a 3.5 – 4.0, 80-89% is 3.0-3.4, 70-79% is 2.0-2.9, and 60-69% is a 1.0-1.9. If necessary, I will lower the A-B and B-C cutoffs to ensure a roughly B-/C+ average in the course.

Item	Points	Dates
4 Exams	400	Fridays of Wks. 4, 8, 11, 14
Final Exam	120	Monday Wk. 16, 10am-12pm
Homework	100	Due Mondays at 4pm
Participation	20	Ongoing
Syllabus Acknowledgement & Student Information Survey	5	Due by Monday Wk. 1
<b>Total Points</b>	<b>645</b>	

## Exams

The nature of the material in physical chemistry makes traditional 1 hour exams difficult, so I will make arrangements to give you 2 hours to complete each exam. Please also bring a calculator for all exams; the use of laptops, smart phones, cell phones, and all other electronic devices will not be allowed. There will be no makeup exam for this class, but if you do miss an exam, please contact Dr. So.

## Homework

Within one hour after each lecture, I will post a homework assignment on BbLearn that will be usually be due at 4pm on Monday. The numerical or short answers for most of the problems are in the back of the text, but to receive full credit, you **must** show your work! After you have turned in all of the homework for a week, I will post my handwritten solutions on BbLearn. After the due date, there will be a one problem per late day penalty.

## Participation

There will be an evaluation of your performance in the course that will include items such as in-class participation and completion of weekly surveys during the course.

## Syllabus Acknowledgement & Student Information Form

This online form will be posted on BBLearn next to the syllabus. It will ensure me that (1) you have read, understand, and agree to content in this syllabus, (2) help me to get to know you better, and (3) it earns you 5 easy points to start your semester off!

## Study Expectations and Tips

I expect that you will need to spend up to 3 hours per lecture outside of class; this means 3 x 3 lectures = 9 hours per week. Adding 3 hours you spend in lecture, you get 12 total hours of physical chemistry per week. Note that lecture attendance is only 25% of the total time you will need to spend thinking about physical chemistry. Therefore, **75% of your preparation in CHEM 331 is up to YOU!** Your preparation should ideally include reading the text prior to lecture, reviewing lecture notes after lecture, reviewing study guides, and the completion of homework. You will be responsible for assimilating all the covered material in the homeworks and lecture notes in a short period of time. To help the process less daunting and help focus your efforts, I have provided a list of helpful tips below. Please know that I am here to help, and that I am your advocate, since I sincerely want to see you succeed!

**1. Develop subject interest.** Do not ask, "What do I need to know for the exam?" Instead, ask questions aimed at improving your understanding of important concepts. Study physical chemistry as if you need it for your job, or even better, as if it were your hobby. Immerse yourself in the subject by reading, working problems, developing skills, speaking physical chemistry to others, and reviewing your text, lecture notes, homework, and study guides. If you do, then your grades will take care of themselves.

**2. Develop understanding.** Focus on understanding key concepts instead of memorizing. Cramming will not work! Take full advantage of the textbook, lecture content, and assigned homework, since these are the sources of my exam questions.

**3. Do the homework.** To be successful in physical chemistry, you must work through relevant homework problems. Students are to be warned that viewing solutions without first struggling and working through problems is a poor study strategy.

**4. Write and draw. A lot.** It takes a lot of practice and patience to get good at physical chemistry. Write out your thought process while working through a problem. Show all your work in both homework and exam questions. Draw pictures to develop and test your understanding of molecular structure, models in quantum chemistry, energy diagrams, phase diagrams, etc.

**5. Seek help.** You can attend my office hours, make appointments for extra office hours, and do homework and study together in groups. Ask lots of questions! Collaborative learning where you have to communicate physical chemistry to each other is an extremely effective way to learn and reinforce the material.

## Students with Disabilities

All efforts will be made to accommodate students with disabilities according to university policy. In the event you require accommodation, be sure to speak with me ASAP, register with the Accessibility Resource Center (ARC) office on campus (<http://www.csuchico.edu/dss/>), and send me the appropriate electronic documentation before each exam. Unless a compelling reason exists, I will only approve ARC exam requests when the exam occurs on the same day (and at the same time) as the exam for the rest of the class; some exceptions may apply. Please see me for other ARC exam policies.

## Academic Integrity

Students are expected to be familiar with the University's Academic Integrity Policy. Your own commitment to learning, as evidenced by your enrollment at California State University, Chico, and the University's Academic Integrity Policy requires you to be honest in all your academic course work. Faculty members are required to report all infractions to the Office of Student Judicial Affairs. The policy on academic integrity and other resources related to student conduct can be found on the [Student Judicial Affairs website](#).

1. (9 pts) Dr. So needs to collect a  $^{11}\text{B}$  NMR spectrum. Tell her what frequency (in MHz) is needed to observe a  $^{11}\text{B}$  NMR transition in the same magnet used for 300. MHz  $^1\text{H}$  NMR experiments, assuming shielding constant of 0.85. **Box your answers.**

2. (7 pts) Imagine a sample that has exactly 1 million  $^2\text{H}$  nuclei. At what temperature (in Kelvins) will the population difference be 1000 in a 1.41 T magnet? **Box your answer.**

3. (6 pts) Describe (in words and sketches) why and how the RF field is used in NMR.

4. (8 pts) Dr. So sees "FID" labeled on a computer screen in the NMR room. You tell her it stands for \_\_\_\_\_. Describe what these words represent using words and pictures.

5. (20 pts) Follow the approach developed in class for a spin-system of two deuterons,  $^2\text{H}$ . For simplicity in labeling, let A =  $^2\text{H}$ , and X =  $^2\text{H}$ . The shielding constants for nucleus A and X are  $1.54 \times 10^{-5}$  and  $1.82 \times 10^{-5}$ , respectively. The coupling constant is 15 Hz.

a) What is the chemical shift difference between these two deuteron resonances? **Box your answer.**

b) Sketch and label the energy diagram including the progression up through the inclusion of spin-spin coupling.

c) Indicate one of the allowed transition in the presence of spin-spin coupling on the diagram above. Compute its frequency, in MHz, in a 7.05 T field. **Box your answer.**

6. (20 pts) A  $^1\text{H}$  NMR experiment was performed with a  $\pi$  pulse, followed by a  $\frac{\pi}{2}$  pulse in an applied field of  $6 \times 10^{-4}$  T.

(a) Compare the pulse times necessary to create flip angles of (a)  $180^\circ$  and (b)  $90^\circ$ . **Box your answers.** What happens to the pulse time as you increase the flip angle? Explain.

(b) Fill in the table below with sketches of the pulse sequence, populations, magnetization in the y,z- and x,y-planes, and FID. Assume  $3\beta/7\alpha$  population ratio to start.

	Before $\pi$ pulse	End of $\pi$ pulse	Before $\frac{\pi}{2}$ pulse	End of $\frac{\pi}{2}$ pulse
Pulse Sequence				
Populations				
y,z plane				
x,y-plane				
FID				

7. (10 pts) Compute the diamagnetic contribution to the local shielding constant of an electron promoted to the  $\psi_{2,1,0}$  orbital. **Box your answer.**

8. (20 pts) The pulse sequence in an actual  $^1\text{H}$  NMR experiment typically uses a  $45^\circ$  ( $\frac{\pi}{4}$ ) pulse to generate a FID. The spectrum is then obtained by FT on an averaged FID.

(a) How is the spectrum obtained with a  $45^\circ$  pulse different from the one obtained with a  $90^\circ$  pulse? Explain using drawings of (a) pulse sequence, (b) populations (start with 70 in  $\alpha$  state and 30 in  $\beta$  state), and (c) plots of the net magnetization vector in the y,z- and x,y-planes.

	Before $\frac{\pi}{4}$ pulse	End of $\frac{\pi}{4}$ pulse	Long time after $\frac{\pi}{4}$ pulse
Pulse Sequence			
Populations			
y,z plane			
x,y-plane			

(b) Why do you think a  $45^\circ$  pulse is used?

### Carefully detach!

$$g_e = 2.0023 \quad \gamma_e = 1.761 \times 10^{11} \text{ rad T}^{-1} \text{ s}^{-1} \quad \mu_B = 9.274 \times 10^{-24} \text{ J/T} \quad c = 2.998 \times 10^8 \text{ m/s}$$

$$a_0 = 52.0 \text{ pm}$$

$$h = 6.626 \times 10^{-34} \text{ J s} \quad m_e = 9.109 \times 10^{-31} \text{ kg} \quad m_p = 1.673 \times 10^{-27} \text{ kg} \quad 1 \text{ amu} = 1.6605 \times 10^{-27} \text{ kg}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ V}\cdot\text{s/A}\cdot\text{m} \quad e = 1.601 \times 10^{-19} \text{ C}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

Nucleus	I	$\gamma$ (rad T <sup>-1</sup> s <sup>-1</sup> )
<sup>1</sup> H	1/2	26.75 x 10 <sup>7</sup>
<sup>2</sup> H	1	4.107 x 10 <sup>7</sup>
<sup>11</sup> B	3/2	8.583 x 10 <sup>7</sup>
<sup>13</sup> C	1/2	6.726 x 10 <sup>7</sup>
<sup>31</sup> P	1/2	10.83 x 10 <sup>7</sup>

$$\int \sin^2 bx \, dx = \frac{x}{2} - \frac{1}{4b} \sin(2bx)$$

$$\int \cos^2 bx \, dx = \frac{x}{2} + \frac{1}{4b} \sin(2bx)$$

$$\int x \sin^2 bx \, dx = \frac{x^2}{4} - \frac{x}{4b} \sin(2bx) - \frac{1}{8b^2} \cos(2bx)$$

$$\int x \cos^2 bx \, dx = \frac{1}{b^2} \cos bx + \frac{x}{b} \sin bx$$

$$\int_0^\pi (\cos^n x) |\sin x| \, dx = \begin{cases} 0 & n \text{ odd} \\ \left(\frac{2}{n+1}\right) & n \text{ even} \end{cases} \quad \int x^2 e^{bx} = e^{bx} \left( \frac{x^2}{b} - \frac{2x}{b^2} + \frac{2}{b^3} \right) \quad \int_0^\infty e^{-bx^2} \, dx = \frac{1}{2} \left( \frac{\pi}{b} \right)^{1/2}$$

$$\int_{-\infty}^\infty x^2 e^{-bx^2} \, dx = \frac{1}{2} \left( \frac{\pi}{b^3} \right)^{1/2} \quad \int_0^\infty x^n e^{-bx} \, dx = \frac{n!}{b^{n+1}}, \text{ where } n \neq -1, b > 0$$

$$\int_0^\infty x^{2n} e^{-bx^2} \, dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1} \cdot b^n} \cdot \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x e^{-bx^2} \, dx = \frac{1}{2b} \quad \int_0^\infty x^{2n+1} e^{-bx^2} \, dx = \frac{n!}{2b^{n+1}}$$

$$R_{1,0} = R_{1s} = 2 \left( \frac{1}{a_0} \right)^{3/2} e^{-r/a_0}$$

$$Y_{0,0} = \left( \frac{1}{4\pi} \right)^{1/2}$$

$$R_{2,0} = R_{2s} = \frac{1}{\sqrt{8}} \left( \frac{1}{a_0} \right)^{3/2} \left( 2 - \frac{r}{a_0} \right) e^{-r/2a_0}$$

$$Y_{1,0} = \left( \frac{3}{4\pi} \right)^{1/2} \cos \theta$$

$$R_{2,1} = R_{2p} = \frac{1}{\sqrt{24}} \left( \frac{1}{a_0} \right)^{3/2} \frac{r}{a_0} e^{-r/2a_0}$$

$$Y_{1,\pm 1} = \left( \frac{3}{8\pi} \right)^{1/2} \sin \theta e^{\pm i\phi}$$

$$R_{3,0} = R_{3s} = \frac{2}{81\sqrt{3}} \left( \frac{1}{a_0} \right)^{3/2} \left( 27 - 18 \frac{r}{a_0} + 2 \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$$

$$Y_{2,0} = \left( \frac{5}{16\pi} \right)^{1/2} (3 \cos^2 \theta - 1)$$

$$R_{3,1} = R_{3p} = \frac{4}{81\sqrt{6}} \left( \frac{1}{a_0} \right)^{3/2} \left( \frac{r}{a_0} \right) \left( 6 - \frac{r}{a_0} \right) e^{-r/3a_0}$$

$$Y_{2,\pm 1} = \left( \frac{15}{8\pi} \right)^{1/2} \sin \theta \cos \theta e^{\pm i\phi}$$

$$R_{3,2} = R_{3d} = \frac{4}{81\sqrt{30}} \left( \frac{1}{a_0} \right)^{3/2} \frac{r^2}{a_0^2} e^{-r/3a_0}$$

$$Y_{2,\pm 2} = \left( \frac{15}{32\pi} \right)^{1/2} \sin^2 \theta e^{\pm 2i\phi}$$

$$a_0 = 52.9 \text{ pm}$$

1. (8 pts) **In words and sketches**, describe the difference in **physical origin** between (a) nonradiative transitions and (b) radiative transitions.

2. (8 pts) **In words and sketches**, explain the differences in **physical origin** between (a) NMR and (b) EPR.

3. (4 pts) On the **same** plot, sketch the PIB model with its (a) simple potential and (b) perturbed potential with  $V = \cos(\frac{\pi x}{L})$ .

4. (10 pts) Can Dr. So simultaneously determine the position of a particle in the x-direction and its squared momentum ( $p^2$ ) in the x-direction? Show her mathematically, and discuss in some detail using the appropriate quantum mechanical language. What should Dr. So conclude about the physical world, based on this answer?

5. (10 pts) Discuss how would you find (**and derive**) the appropriate uncertainty relationship from #4.



7. (20 pts) The Stark Effect refers to the influence of an applied electric field on an atom or molecule. The more polarizable the material, the greater the influence. The Stark Effect can be treated by perturbation theory, where the applied field is the perturbation with the corresponding hamiltonian  $\hat{H} = er E \cos\theta$  where  $e$  is the charge of the electron,  $E$  is the strength of the applied electric field, and  $r$  and  $\theta$  take the usual meaning.

a) Compute the first order correction to the energy of  $\psi_{1,0,0}$ . Briefly discuss.

b) Compute the first order correction to the energy of  $\psi_{2,1,1}$ . Briefly discuss.

c) Compute the mixing (weighting) coefficient between  $\psi_{1,0,0}$  and  $\psi_{2,1,1}$  when the electric field is applied, and discuss your result.

8. (8 pts) We showed in class and in the homework that a spin-echo could be produced by applying a  $\pi$ -pulse. Sketch the pulse sequence, populations, magnetization in the y,z- and x,y-planes.

	Before $\frac{\pi}{2}$ pulse	End of $\frac{\pi}{2}$ pulse	Before $\pi$ pulse	End of $\pi$ pulse	Max of spin echo
Pulse Sequence					
Populations					
y,z plane					
x,y-plane					

9. (17 pts) Sketch the spectrum, and then use Pascal's triangle to identify the likely number of and spin of the nuclei coupled to the unpaired electron in the following cases:

(a) There are 8 total lines in the spectrum. The intensity distribution is the same for all the peaks.

(b) A certain EPR spectrum shows a quadruplet of quadruplets (non-overlapping). The intensity distribution of the more closely spaced quadruplets is 1:2:2:1.

**Carefully detach!**

$h = 6.626 \times 10^{-34} \text{ J s}$      $k = 1.381 \times 10^{-23} \text{ J/K} = 0.695 \text{ cm}^{-1}/\text{K}$      $R = 8.314 \text{ J/mol K}$      $c = 2.998 \times 10^8 \text{ m/s}$   
 $1 \text{ amu} = 1.660 \times 10^{-27} \text{ kg}$      $1 \text{ hartree} = 27.2 \text{ eV}$      $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$      $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$

$\hat{x} = x$ (multiply by x)	$\nabla^2 = \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right)$	$\nabla^2 = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2}{\partial \phi^2}$
$\hat{x}^2 = x^2$ (multiply by $x^2$ )	$\hat{V} = \frac{1}{2} kx^2$	$\hat{l}^2 = -\hbar^2 \left[ \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2}{\partial \phi^2} \right]$
$\hat{p}_x = -i\hbar \frac{d}{dx}$	$\hat{l}_x = -i\hbar \left( y \frac{\partial}{\partial z} - z \frac{\partial}{\partial y} \right)$	$\hat{l}_x = -i\hbar \left( -\sin \phi \frac{\partial}{\partial \theta} - \cot \theta \cos \phi \frac{\partial}{\partial \phi} \right)$
$\hat{E}_{k,x} = \frac{-\hbar^2 d^2}{2m dx^2}$	$\hat{l}_y = -i\hbar \left( z \frac{\partial}{\partial x} - x \frac{\partial}{\partial z} \right)$	$\hat{l}_y = -i\hbar \left( -\cos \phi \frac{\partial}{\partial \theta} - \cot \theta \sin \phi \frac{\partial}{\partial \phi} \right)$
$\hat{E}_k = \frac{-\hbar^2}{2m} \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \right)$	$\hat{l}_z = -i\hbar \left( x \frac{\partial}{\partial y} - y \frac{\partial}{\partial x} \right)$	$\hat{l}_z = -i\hbar \left( \frac{\partial}{\partial \phi} \right)$

$\cos(ax)\sin(bx) = \frac{1}{2}[\sin(a+b)x - \sin(a-b)x]$

$\sin(ax)\sin(bx) = \frac{1}{2}[\cos(a-b)x - \cos(a+b)x]$

$\int \sin bx \cos bx dx = \frac{1}{2b} \sin^2 bx$

$\int \sin ax \sin bx dx = \frac{\sin(a-b)x}{2(a-b)} + \frac{\sin(a+b)x}{2(a+b)}$

$\int \sin^2 bx dx = \frac{x}{2} - \frac{1}{4b} \sin(2bx)$

$\int \cos^2 bx dx = \frac{x}{2} + \frac{1}{4b} \sin(2bx)$

$\int x \sin^2 bx dx = \frac{x^2}{4} - \frac{x}{4b} \sin(2bx) - \frac{1}{8b^2} \cos(2bx)$

$\int x \cos bx dx = \frac{1}{b^2} \cos bx + \frac{x}{b} \sin bx$

$\int x^2 \sin^2 bx dx = \frac{x^3}{6} - \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) - \frac{x}{4b^2} \cos(2bx)$

$\int e^{bx} dx = \frac{1}{b} e^{bx}$

$\int x^2 \cos^2 bx dx = \frac{x^3}{6} + \left( \frac{x^2}{4b} - \frac{1}{8b^3} \right) \sin(2bx) + \frac{x}{4b^2} \cos(2bx)$

$\int x e^{bx} = e^{bx} \frac{1}{b^2} (bx - 1)$

$\int_0^\pi (\cos^n x)(\sin x) dx = \begin{cases} 0 & n \text{ odd} \\ \frac{2}{n+1} & n \text{ even} \end{cases}$

$\sum_{n=0}^\infty x^n = \frac{1}{1-x} \quad \left( \frac{\partial \ln x}{\partial y} \right) = \frac{1}{x} \left( \frac{\partial x}{\partial y} \right)$

$\int_0^\infty e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x^n e^{-bx} dx = \frac{n!}{b^{n+1}}, \text{ where } n \neq -1, b > 0$

$\int_0^\infty x^{2n} e^{-bx^2} dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1} \cdot b^n} \cdot \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x^{2n+1} e^{-bx^2} dx = \frac{n!}{2b^{n+1}}$

$R_{1,0} = R_{1s} = 2 \left( \frac{1}{a_0} \right)^{3/2} e^{-r/a_0}$

$Y_{0,0} = \left( \frac{1}{4\pi} \right)^{1/2}$

$R_{2,0} = R_{2s} = \frac{1}{\sqrt{8}} \left( \frac{1}{a_0} \right)^{3/2} \left( 2 - \frac{r}{a_0} \right) e^{-r/2a_0}$

$Y_{1,0} = \left( \frac{3}{4\pi} \right)^{1/2} \cos \theta$

$R_{2,1} = R_{2p} = \frac{1}{\sqrt{24}} \left( \frac{1}{a_0} \right)^{3/2} \frac{r}{a_0} e^{-r/2a_0}$

$Y_{1,\pm 1} = \left( \frac{3}{8\pi} \right)^{1/2} \sin \theta e^{\pm i\phi}$

$R_{3,0} = R_{3s} = \frac{2}{81\sqrt{3}} \left( \frac{1}{a_0} \right)^{3/2} \left( 27 - 18 \frac{r}{a_0} + 2 \frac{r^2}{a_0^2} \right) e^{-r/3a_0}$

$Y_{2,0} = \left( \frac{5}{16\pi} \right)^{1/2} (3 \cos^2 \theta - 1)$

$R_{3,1} = R_{3p} = \frac{4}{81\sqrt{6}} \left( \frac{1}{a_0} \right)^{3/2} \left( \frac{r}{a_0} \right) \left( 6 - \frac{r}{a_0} \right) e^{-r/3a_0}$

$Y_{2,\pm 1} = \left( \frac{15}{8\pi} \right)^{1/2} \sin \theta \cos \theta e^{\pm i\phi}$

$R_{3,2} = R_{3d} = \frac{4}{81\sqrt{30}} \left( \frac{1}{a_0} \right)^{3/2} \frac{r^2}{a_0^2} e^{-r/3a_0}$

$Y_{2,\pm 2} = \left( \frac{15}{32\pi} \right)^{1/2} \sin^2 \theta e^{\pm 2i\phi} \quad a_0 = 52.9 \text{ pm}$

$\sigma_A \sigma_B \geq \left| \frac{1}{2i} \langle [\hat{A}, \hat{B}] \rangle \right|$

1. (10 pts) Add 2 steps to Einstein's mechanism that depopulates State 2 with molecules undergoing (i) an isomerization to a non-emissive compound at a rate constant  $k_{\text{isomerization}}$  and (ii) an energy transfer to a nearby molecule at a rate constant of  $k_{\text{ET}}$ . (a) Sketch **one energy diagram**, and (b) label all the processes that absorb and/or emit light. (c) Write the **steady-state approximation** for State 2.

2. (10 pts) A thermodynamic process leads to an increase in the partition function. What does this mean? Describe in words, and sketch a likely process.

3. (9 pts) One of your classmates not taking CHEM 332 this semester sees your lecture notes and asks how statistical thermodynamics and thermodynamics differ. What do you tell her? Also, give a specific example of **each** topic you might have used in your conversation.

4. (6 pts) Dr. So observed a natural linewidth of  $1.4 \times 10^{13}$  Hz and another of  $2 \times 10^{15}$  Hz from a He-Ne laser. Which linewidth should she use for her laser measurements? Explain.

5. (20 pts) Imagine you have a 6-atom crystal and 4 quanta of energy available. Each quantum is  $50. \text{ cm}^{-1}$ .

a) Compute the weight for each representative configuration. Clearly label your work. Expect 5 microstates.

b) What is the probability of obtaining the dominant configuration?

c) Is this configuration from part (b) the Boltzmann distribution? Discuss briefly using math.

6. (25 pts) Consider the diatomic molecule NO. The experimental value of the constant volume heat capacity is  $21.53 \frac{J}{mol K}$  at 298 K. The spectroscopic constants are  $\tilde{B} = 1.7 \text{ cm}^{-1}$  and  $\tilde{\nu} = 1904 \text{ cm}^{-1}$ .

	Atomic Number	Atomic Mass (amu)
Nitrogen	7	14
Oxygen	8	16

- Compute the value of the thermal deBroglie wavelength.
- Compute the total molecular partition function in a  $15.00 \text{ cm}^3$  flask at 298 K.
- Compute the value of  $C_{v,m}$  at 298 K expected from equipartition theorem and from statistical thermodynamics, and thoroughly discuss in relation to the experimental value.

7. (20 pts) One mole of  $N_2$  undergoes an isothermal reversible expansion from an initial pressure of 2.00 Pa to 1.00 Pa at 300 K. Calculate the entropy in this process using the:

(a) ideal gas law

(b) van der Waals equation. Assume  $V_2=24.6L$ ,  $V_1=12.3L$ ,  $b=0.0387 \frac{L}{mol}$ , and  $a=1.370 \frac{L^2 atm}{mol}$ .

(c) Maxwell's relations

(d) Compare your results from parts a, b, and c. Explain your observations.

## Carefully detach.

$$k = 1.381 \times 10^{-23} \text{ J/K} = 0.695 \text{ cm}^{-1}/\text{K} \quad R = 8.314 \text{ J/mol K}$$

$$N_A = 6.022 \times 10^{23} \text{ mol}^{-1} \quad c = 2.998 \times 10^8 \text{ m s}^{-1} \quad h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$$

$$1 \text{ amu} = 1.661 \times 10^{-27} \text{ kg}$$

$$\int x^2 e^{bx} = e^{bx} \left( \frac{x^2}{b} - \frac{2x}{b^2} + \frac{2}{b^3} \right) \quad \int x^m e^{bx} dx = e^{bx} \sum_{k=0}^m (-1)^k \frac{m! x^{m-k}}{(m-k)! b^{(k+1)}}$$

$$\int_0^\infty e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b} \right)^{1/2} \quad \int_{-\infty}^\infty x^2 e^{-bx^2} dx = \frac{1}{2} \left( \frac{\pi}{b^3} \right)^{1/2} \quad \int_0^\infty x^n e^{-bx} dx = \frac{n!}{b^{n+1}}, \text{ where } n \neq -1, b > 0$$

$$\int_0^\infty x^{2n} e^{-bx^2} dx = \frac{1 \cdot 3 \cdot 5 \cdots (2n-1)}{2^{n+1} \cdot b^n} \cdot \left( \frac{\pi}{b} \right)^{1/2} \quad \int_0^\infty x e^{-bx^2} dx = \frac{1}{2b} \quad \int_0^\infty x^{2n+1} e^{-bx^2} dx = \frac{n!}{2b^{n+1}}$$

$$\sum_{n=0}^\infty x^n = \frac{1}{1-x} \quad \left( \frac{\partial \ln x}{\partial y} \right) = \frac{1}{x} \left( \frac{\partial x}{\partial y} \right)$$

### Useful Equations

$$\sigma_A \sigma_B \geq \left| \frac{1}{2i} \langle [\hat{A}, \hat{B}] \rangle \right| \quad W_j = \frac{N!}{\prod N_n!} \quad \ln x! \approx x \ln x - x \quad p_i = \frac{g_i e^{-\beta \epsilon_i}}{q} \quad \Lambda = \left( \frac{h^2 \beta}{2\pi m} \right)^{1/2} \quad \langle \epsilon \rangle = -\frac{1}{q} \left( \frac{dq}{d\beta} \right)$$

$$U_m^V = \frac{R \Theta^V}{e^{\Theta^V/T} - 1} \quad C_{v,m}^V = R \left( \frac{\Theta^V}{T} \right)^2 \frac{e^{\Theta^V/T}}{(e^{\Theta^V/T} - 1)^2} \quad \tilde{B} = \frac{\hbar^2}{2Ihc}$$

$$q^T = \frac{V}{\Lambda^3}, \quad \Lambda = \frac{h}{(2\pi mkT)^{1/2}}$$

$$q^R = \frac{T}{\sigma \theta^R},$$

$$q^V = \frac{1}{1 - e^{-\theta^V/T}}$$

$$q^E = \sum_{\text{level } i} g_i e^{-\beta \epsilon_i}$$

**Useful constants:**

$$R = 8.314 \frac{\text{J}}{\text{mol K}} = 0.08314 \frac{\text{L bar}}{\text{mol K}} = 0.08206 \frac{\text{L atm}}{\text{mol K}} \quad 1 \text{ atm} = 760 \text{ torr} = 1.013 \text{ bar} \quad 1 \text{ bar} = 1 \times 10^5 \text{ Pa}$$

1. (15 pts) While running a gas phase experiment, Dr. So forgets the compressibility factors ( $Z$ ) of helium, hydrogen, and carbon dioxide. To inform her, you (a) sketch the  $Z$  vs.  $P$  plots for each gas below, (b) draw and label the plot for ideal gas, and (c) explain your reasoning for each plot, based on van der Waals coefficients,  $a$  and  $b$ .



2. (12 pts) Using sketches and words, describe the process of condensation (a) without ever producing a solid-liquid interface, (b) by producing three phases simultaneously, and (c) by least amount of changes in pressure and temperature. *Hint: Draw a phase diagram first.*



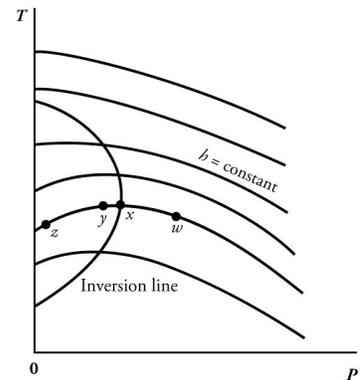
3. (10 pts) In addition to temperature, we can also monitor the chemical potential response of a system to pressure changes by  $\frac{d\mu}{dP} = V_m$ . For water, sketch the plots for gas, liquid, and solid phases.



4. (20 pts) In lab, Dr. So measures isenthalps of various gases using a Joule-Thomson apparatus. The results are shown in the plot below.

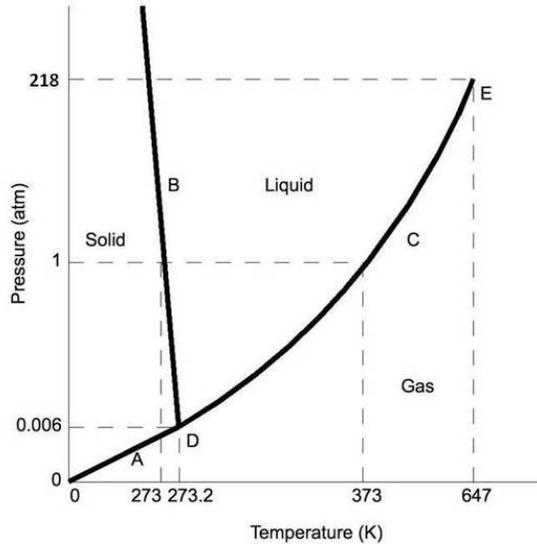
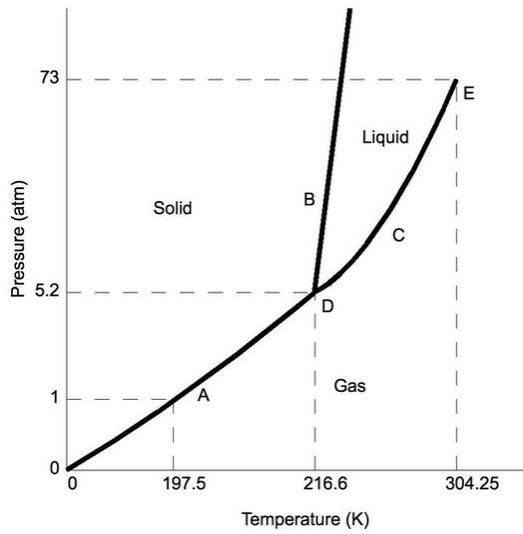
(a) Describe how the gases are behaving in the table.

Point	$\mu_{JT}$ sign	Behavior
w		
x		
y		
z		



(b) Compute the Joule-Thomson coefficient for  $N_2$  at 298 K at 1 atm, where  $C_{p,m} = 29.11 \text{ J/Kmol}$ ,  $a = 1.370 \frac{\text{L}^2 \text{bar}}{\text{mol}^2}$ , and  $b = 0.0387 \frac{\text{L}}{\text{mol}}$ . Identify the most likely point(s) in the isenthalp plot, where  $N_2$  will experience cooling upon expansion.

5. (15 pts) In the phase diagrams below for CO<sub>2</sub> (left) and H<sub>2</sub>O (right), (a) identify A, B, C, D, and E for each.



(b) Label a point on each of the phase diagrams where you may find a supercritical fluid.

(c) Explain why the line slopes to the left for water.

6. (20 pts) (a) Sketch the  $\mu$  vs.  $T$  plot for water in the liquid and gas forms only. Indicate the (i) axes, (ii) chemical potentials of each phase, (iii) relevant temperatures, and (iv) difference in chemical potentials at 95.0°C. Note that water vaporizes at 100°C.

(b) Using  $S_m(g) = 188 \frac{J}{mol K}$ ,  $S_m(l) = 69.9 \frac{J}{mol K}$ , and  $S_m(s) = 38 \frac{J}{mol K}$ , compute this difference in chemical potentials. **Box your answers.**

(c) How does the  $\Delta\mu_{l \rightarrow g}$  compare with  $\Delta\mu_{s \rightarrow l}$ ? Explain briefly.

7. (8 pts) A substance has a molar volume of  $23.68 \frac{L}{mol}$  at 298 K and 1.00 atm and a molar entropy of  $75 \frac{J}{mol K}$ . Compute the change in the chemical potential when the temperature is dropped by 25°C at constant pressure. Be sure to derive, and show your work.

# CHEM 332: Physical Chemistry

*Lectures: MWF 9:00-9:50 AM, PHSC 213*

## Contact Information:

**Instructor:** Dr. Monica C. So

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**E-mail<sup>1</sup>:** mso@csuchico.edu

**Office:** PHSC 304

**Office hours:** Mondays, Wednesdays, & Fridays 11:00am-12:00pm (and by appointment)

## Course Description and Goals

CHEM 332 is an upper division level physical chemistry course designed for chemistry majors. The purpose of this course is to engage you in the detailed study of the physical principles underlying chemical phenomena. Specialized topics in physical chemistry can generally be grouped in three broad areas (quantum mechanics, thermodynamics, and kinetics).

## Prerequisites

You must have received passing grades for CHEM 320, CHEM 331, MATH 220, PHYS 202A & PHYS 202B or PHYS 204A, PHYS 204B, and PHYS 204C. To be successful, you will have to master the application of concepts and techniques from physics and mathematics to the understanding of chemical principles. Oftentimes during the semester, you may feel as if you are in an applied math rather than a chemistry course, but all is directed toward expanding your understanding of the physical and chemical properties of matter.

## Policy on Recording Lectures

With prior permission written in an email, any student may audio record lecture. Still photography and video recordings of lecture of any kind are prohibited at all times in CHEM 332.

## Student Learning Objectives

Upon successful completion of this course, you will be able to:

1. Understand the criterion which apply to models used in physical chemistry.
2. Understand the physical meanings of models in quantum mechanics, spectroscopy, thermodynamics, and kinetics.
3. Apply mathematical expressions to calculate important values from models.
4. Extend and refine understanding of physical chemistry models to real-life applications.

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<sup>1</sup> I typically check my e-mail and phone messages M-F from 8 am – 4:30 pm. These times will vary somewhat according to my daily teaching schedule. I will not check e-mail and phone messages on weekends and holidays.

## Course Materials

- *Physical Chemistry*, 3<sup>rd</sup> edition, Engel and Reid (ISBN-13: 978-0321812001)
- Solutions manuals and materials from previous semesters are not permitted unless provided to the entire class by me.

## Grading

I will grade using a sliding grade scale, meaning that the highest score in the class will be considered 100% (or the highest score possible). The grading scale will then be 90% and above is a 3.5 – 4.0, 80-89% is 3.0-3.4, 70-79% is 2.0-2.9, and 60-69% is a 1.0-1.9. If necessary, I will lower the A-B and B-C cutoffs to ensure a roughly B-/C+ average in the course.

Item	Points	Dates
4 Exams	400	Fridays of Wks. 4, 8, 12, 14
Final Exam	120	Monday of Week 16, 10:00am-12:00pm
Homework	100	Due Mondays at 4pm
Participation	15	Ongoing
Syllabus Acknowledgement & Student Information Survey	5	Due by Monday of Week 1 by 11:59pm
<b>Total Points</b>	640	

## Exams

The nature of the material in physical chemistry makes traditional 1 hour exams difficult, so I will make arrangements to give you 2 hours to complete each exam. Please also bring a calculator for all exams; the use of laptops, smart phones, cell phones, and all other electronic devices will not be allowed. There will be no makeup exam for this class, but if you do miss an exam, please contact Dr. So.

## Homework

Within one hour after each lecture, I will post a homework assignment on BbLearn that will be usually be due at 4pm on Monday. The numerical or short answers for most of the problems are in the back of the text, but to receive full credit, you **must** show your work! After you have turned in all of the homework for a week, I will post my handwritten solutions on BbLearn. After the due date, there will be 10% of total homework points deducted per day that homework is turned in late.

## Participation

There will be an evaluation of your performance in the course that will include items such as ability to answer warm up questions posed during the course and responding to weekly online surveys.

## Syllabus Acknowledgement & Student Information Form

This online form will be posted on BbLearn next to the syllabus. It will ensure me that (1) you have read, understand, and agree to content in this syllabus, (2) help me to get to know you better, and (3) it earns you 5 easy points to start your semester off!

## Study Expectations and Tips

I expect that you will need to spend up to 3 hours per lecture outside of class; this means 3 x 3 lectures = 9 hours per week. Adding 3 hours you spend in lecture, you get 12 total hours of physical chemistry per week. Note that lecture attendance is only 25% of the total time you will need to spend thinking about physical chemistry. Therefore, **75% of your preparation in CHEM 332 is up to YOU!** Your preparation should ideally include reading the text prior to lecture, reviewing lecture notes after lecture, reviewing study guides, and the completion of homework. You will be responsible for assimilating all the covered material in the homeworks and lecture notes in a short period of time. To help the process less daunting and help focus your efforts, I have provided a list of helpful tips below. Please know that I am here to help, and that I am your advocate, since I sincerely want to see you succeed!

**1. Develop subject interest.** Do not ask, "What do I need to know for the exam?" Instead, ask questions aimed at improving your understanding of important concepts. Study physical chemistry as if you need it for your job, or even better, as if it were your hobby. Immerse yourself in the subject by reading, working problems, developing skills, speaking physical chemistry to others, and reviewing your text, lecture notes, homework, and study guides. If you do, then your grades will take care of themselves.

**2. Develop understanding.** Focus on understanding key concepts instead of memorizing. Cramming will not work! Take full advantage of the textbook, lecture content, assigned homework, since these are the sources of my exam questions.

**3. Do the homework.** To be successful in physical chemistry, you must work through relevant homework problems. Students are to be warned that viewing solutions without first struggling and working through problems is a poor study strategy.

**4. Write and draw. A lot.** It takes a lot of practice and patience to get good at physical chemistry. Write out your thought process while working through a problem. Show all your work in both homework and exam questions. Draw pictures to develop and test your understanding of molecular structure, models in quantum chemistry, energy diagrams, phase diagrams, etc.

**5. Seek help.** You can attend my office hours, make appointments for extra office hours, and do homework and study together in groups. Ask lots of questions! Collaborative learning where you have to communicate physical chemistry to each other is an extremely effective way to learn and reinforce the material.

## Students with Disabilities

All efforts will be made to accommodate students with disabilities according to university policy. In the event you require accommodation, be sure to speak with me ASAP, register with the Accessibility Resource Center (ARC) office on campus (<http://www.csuchico.edu/dss/>), and send me the appropriate electronic documentation before each exam. Unless a compelling reason exists, I will only approve ARC exam requests when the exam occurs on the same day (and at the same time) as the exam for the rest of the class; some exceptions may apply. Please see me for other ARC exam policies.

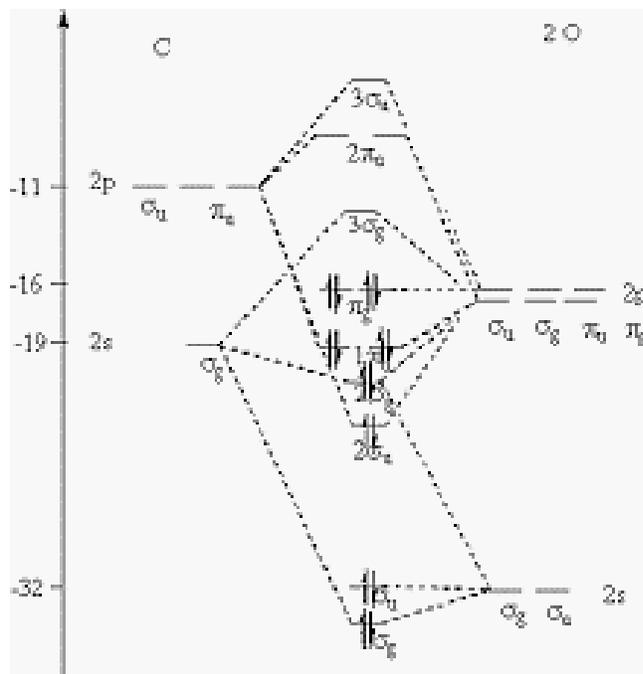
## Academic Integrity

Students are expected to be familiar with the University's Academic Integrity Policy. Your own commitment to learning, as evidenced by your enrollment at California State University, Chico, and the University's Academic Integrity Policy requires you to be honest in all your academic course work. Faculty members are required to report all infractions to the Office of Student Judicial Affairs. The policy on academic integrity and other resources related to student conduct can be found on the [Student Judicial Affairs website](#).



- 3) (15 points, 5 minutes) Draw the complete MO diagram for superoxide ( $\text{CN}^{1-}$ ). What is the bond order for cyanide? Is the ion paramagnetic or diamagnetic (and why)?

- 4) (15 points, 5 minutes) Draw the Lewis structure for the  $\text{CO}_2$  (carbon dioxide) molecule. The MO diagram is given to you at right. Do the two descriptions of the molecule differ? Why or why not? Correlate all electrons in the MO diagram with those in the Lewis Structure.



- 5) (15 points, 10 minutes) Calculate the effective nuclear charge for both a 4s electron and a 3d electron of  $\text{Cu}^0$  (metallic copper). Explain the importance of these values and their relation to the electronic structure of  $\text{Cu}^+$ .
- 6) (15 points, 10 minutes) Give examples of a localized bonding model and a delocalized bonding model and describe the differences between the two models. Is either model more accurate? Why or why not?
- 7) (15 points, 10 minutes) Consider the atomic series Na through Cl. The first ionization energies ( $\text{IE}^{(1)}$ ) for each atom (in kJ/mol) are given as follows. Explain the trend in  $\text{IE}^{(1)}$  including any irregularities.
- |     |      |
|-----|------|
| Li: | 513  |
| Be: | 899  |
| B:  | 801  |
| C:  | 1086 |
| N:  | 1402 |
| O:  | 1314 |
| F:  | 1681 |
| Ne: | 2080 |

8) (15 points, 10 minutes) Potassium crystallizes with a body centered cubic structure with edge length of 532.8 pm. What is the density of potassium?

9) (15 points, 10 minutes) Sketch out a Born-Haber Cycle for the formation of calcium bromide from its elements. Calculate the standard enthalpy of formation for calcium bromide using some of the following information.

Heat of Sublimation (Ca)	178.2 kJ/mol
Heat of Vaporization (Ca)	154.7 kJ/mol
1 <sup>st</sup> Ionization (Ca)	589 kJ/mol
2 <sup>nd</sup> Ionization (Ca)	1145 kJ/mol
3 <sup>rd</sup> Ionization (Ca)	4910 kJ/mol
Electron Affinity (Ca)	2.37 kJ/mol
Heat of Vaporization (Br <sub>2</sub> )	29.96 kJ/mol
Heat of Fusion (Br <sub>2</sub> )	10.57 kJ/mol
Bond Dissociation (Br <sub>2</sub> )	192 kJ/mol
Lattice Enthalpy (CaBr <sub>2</sub> )	2132 kJ/mol
Electron Affinity (Br)	325 kJ/mol
Ionization Energy (Br)	1139.9 kJ/mol

10) (15 points, 10 minutes) Give and explain the three requirements for a substitutional alloy.

11) (5 points, 5 minutes) Explain the utility of Photoelectron Spectroscopy with regards to MO theory.

## Periodic Table of the Elements

1 H 1.008																2 He 4.003	
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
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		90 Th 232.0	91 Pa (231)	92 U 238.0	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)		

## Exam #2

Chemistry 361

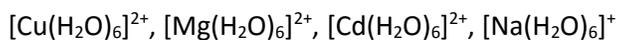
Closed book, closed note, closed friends, closed internet.

Midterm #2

October 11, 2017

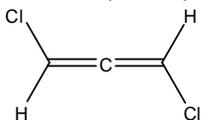
Be **complete** in your explanations. You have two hours.

- 1) (15 pts, 10 mins) Put the following aqua acids in order of acidity, from least acidic to most acidic and *briefly explain* why this is so. **Clearly label which one is least acidic and which is most acidic in your series.** (Assume they are in a non-leveling solvent such as DMSO!)



- 2) (25 pts) Consider the hypothetical  $C_{3v}$  complex  $[\text{Mn}(\text{H}_2\text{O})(\text{CO})_3]^{3+}$ . Determine the reducible representation spanned by the three CO ligands that form sigma bonds with the metal cation, reduce the reducible representation to irreducible representations, and determine (hint: orbitals of the same symmetry....) which d-orbitals are likely to interact with the four CO ligands.

- 3) (15 pts) Consider the molecule drawn below. It has been stated that this molecule contains no stereocenters, and yet is still a chiral molecule. What can you say about its chirality from inorganic chemistry? Why? (Hint: what is its three-dimensional structure?)



- 4) (15 pts, 10 mins) CadR is a member of the MerR family of transcriptional regulatory proteins whose active site - where metal binds - contains three cysteines (a sulfur based thiolate ligand; R-S<sup>-</sup>) and one unknown ligand which is likely oxygen or nitrogen based. When a solution of equal parts Cd<sup>2+</sup> and Co<sup>2+</sup> are added to metal-free CadR, the protein selectively binds one of these metals preferentially (in a 200:1 ratio). **Which** metal is CadR likely to be selective for and **why**?

5) (15 points, 5 mins) Determine the point groups for the follow molecules or ions

a) HCN

b)  $[\text{Fe}(\text{CN})_5\text{Cl}]^{3-}$

c)  $\text{SF}_4$

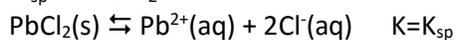
d)  $\text{N}_2\text{O}_4$

e)  $\text{BrCl}_4^{1-}$

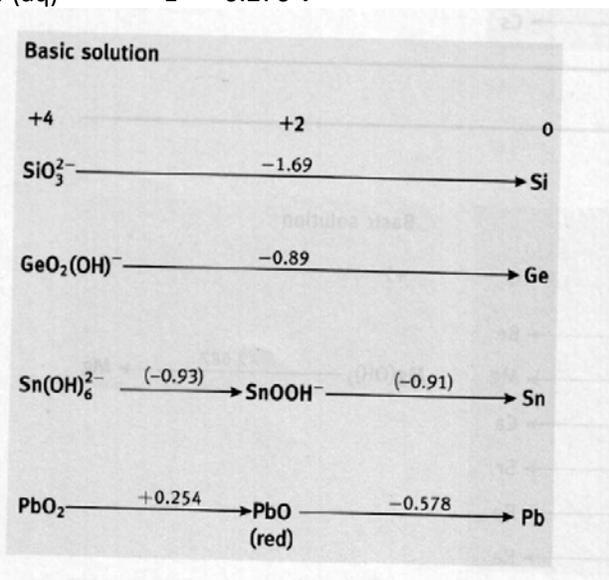
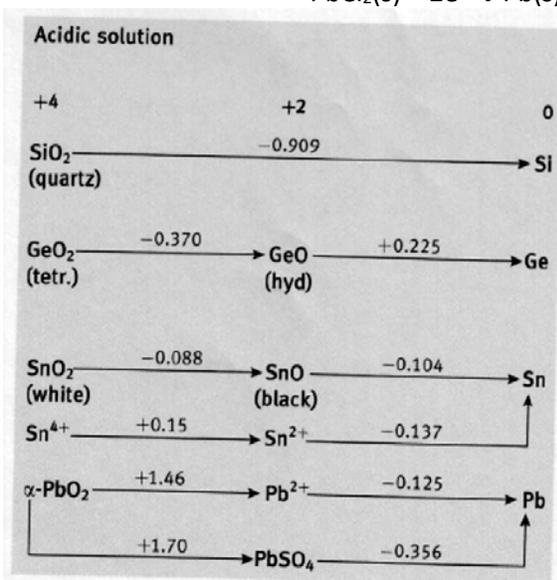
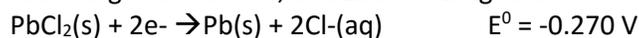
6) (15 pts, 5 mins) **Draw** a molecular orbital diagram of a generic acid/base interaction, and **describe in general terms the interactions** of the frontier orbitals (HOMO & LUMO) between acids and bases.

- 7) (15 points, 15 minutes) You just synthesized aqueous  $\text{PtCl}_2(\text{NH}_3)_2$  in Integrated Lab. Your instructor asks a very simple question: "Did you make the *cis*- or *trans*- form?" How do you answer him? **(Be as specific/mathematically accurate as possible.)**

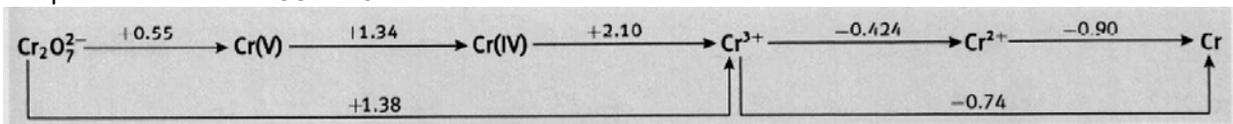
- 8) (10 pts, 5 mins) Calculate the  $K_{sp}$  for  $\text{PbCl}_2$ .



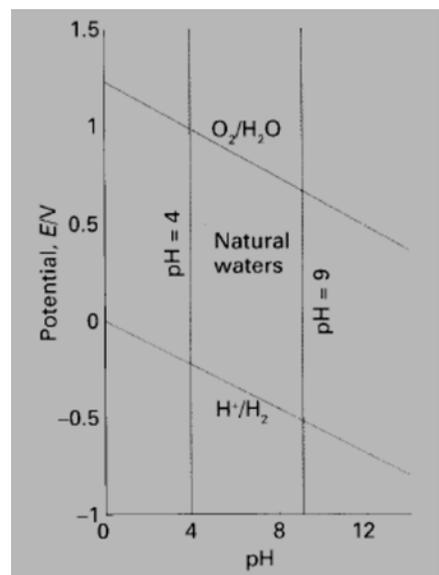
You are given the following half reaction, and Latimer Diagram.



9) (10 pts, 3 mins) The Latimer diagram for chromium in acidic solution is below. Determine the redox potential for  $\text{Cr}^{5+} + 5\text{e}^- \rightarrow \text{Cr}^0$ .



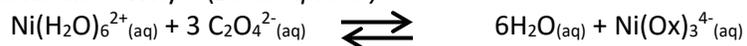
10) (15 pts, 10 mins) Dichromate is routinely used in aqueous conditions, despite the fact that the  $\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+}$  reduction (see problem #9) lies outside the stability field of water (shown at right). Explain how this can be so.



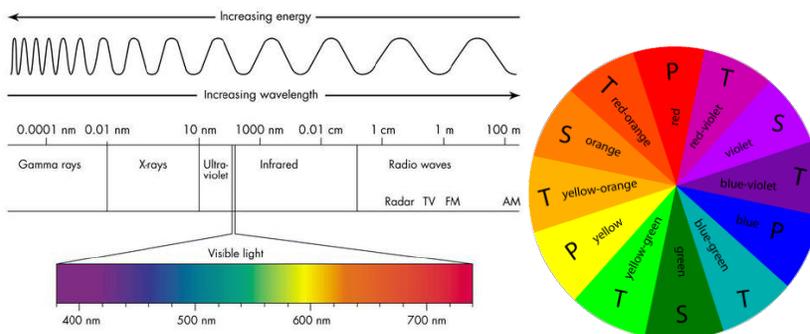
## Periodic Table of the Elements

1 H 1.008																2 He 4.003	
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
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19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
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		90 Th 232.0	91 Pa (231)	92 U 238.0	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)		

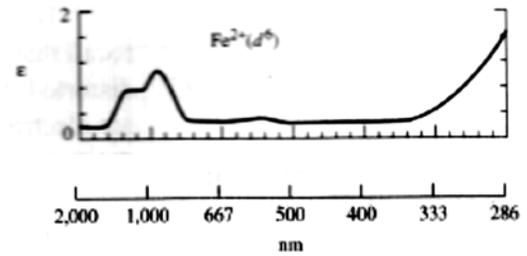
1. (15 pts, 5 minutes) Given the following reaction, what can you say about the value of the equilibrium constant? Why? (*Be complete!*)



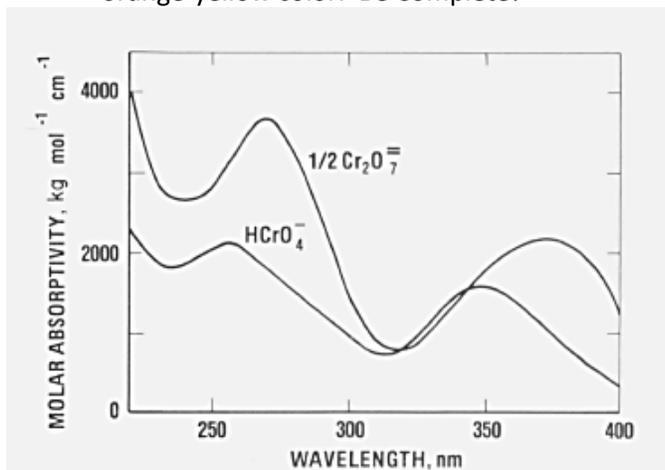
2. (15 pts, 5 minutes)  $\text{Cr}(\text{H}_2\text{O})_6^{3+}$  is blue/violet. Based on this observation, approximately what color do you expect for solid  $\text{CrCl}_3$ ? (The Cr in  $\text{CrCl}_3$  sits in an octahedral array of Cl ions.) The following diagrams may help.



3. (15 pts, 10 minutes) The UV-vis spectrum of ferrous ammonium sulfate  $\{\text{Fe}(\text{H}_2\text{O})_6^{2+}\}$  is shown below. Why are there two features near 1000 nm?



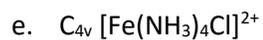
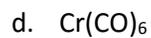
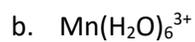
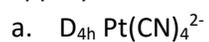
4. (15 pts, 10 minutes) Explain how dichromate ( $\text{Cr}_2\text{O}_7^{2-}$ ; labeled as  $\frac{1}{2} \text{Cr}_2\text{O}_7^{2-}$  below) gets its brilliant orange-yellow color. Be Complete!



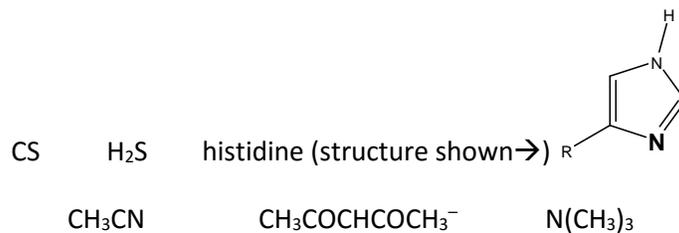
5. (15 pts, 5 minutes) The following stepwise stability constants were found for the reaction of bipyridine with  $\text{Fe}(\text{H}_2\text{O})_6^{3+}$ . What is the explanation for this behavior?

$$\text{Log } K_{f1} = 4.5 \quad \text{Log } K_{f2} = 6.0 \quad \text{Log } K_{f3} = 3.5$$

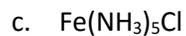
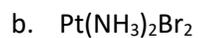
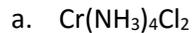
6. (15 pts, 10 minutes) For each of the complexes or ions below, draw and label (e.g.  $d_{xy}$ ) a crystal field splitting diagram (i.e. an energy ordering of the metal d-orbitals), and fill the orbitals with the appropriate number of electrons.



7. (20 pts, 5 minutes) Put the following six ligands in order of increasing  $\Delta$  and briefly suggest a reason for your ordering. (The bold nitrogen in histidine binds to the metal.)



8. (15 pts, 10 minutes) If any of the following compounds have isomers, draw them. If not, write "no isomer".



9. (25 pts, 15 minutes) Your colleagues just isolated a brand new metalloprotein and they \*think\* it is a zinc finger protein. They collect an electronic absorption spectrum (UV-vis) and see nothing. Confused, they turn to EPR to interrogate the system. Later they come to you sad and troubled, yet they leave their meeting with you 10 minutes later happy and with a plan. What did you tell them?

## Periodic Table of the Elements

1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
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37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
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**Possibly Useful Information:**

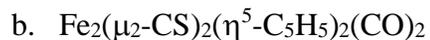
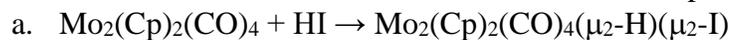
Chemistry 361

Midterm #4

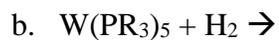
Due 5:00 PM, Monday, December 1, 2017

CLOSED book, CLOSED note, closed friends exam

1) (20 pts) Draw *each* metal complex below (2 in part a, 1 in part b). Also, give the oxidation state and electron count of each metal in each of the complexes. Show your work.

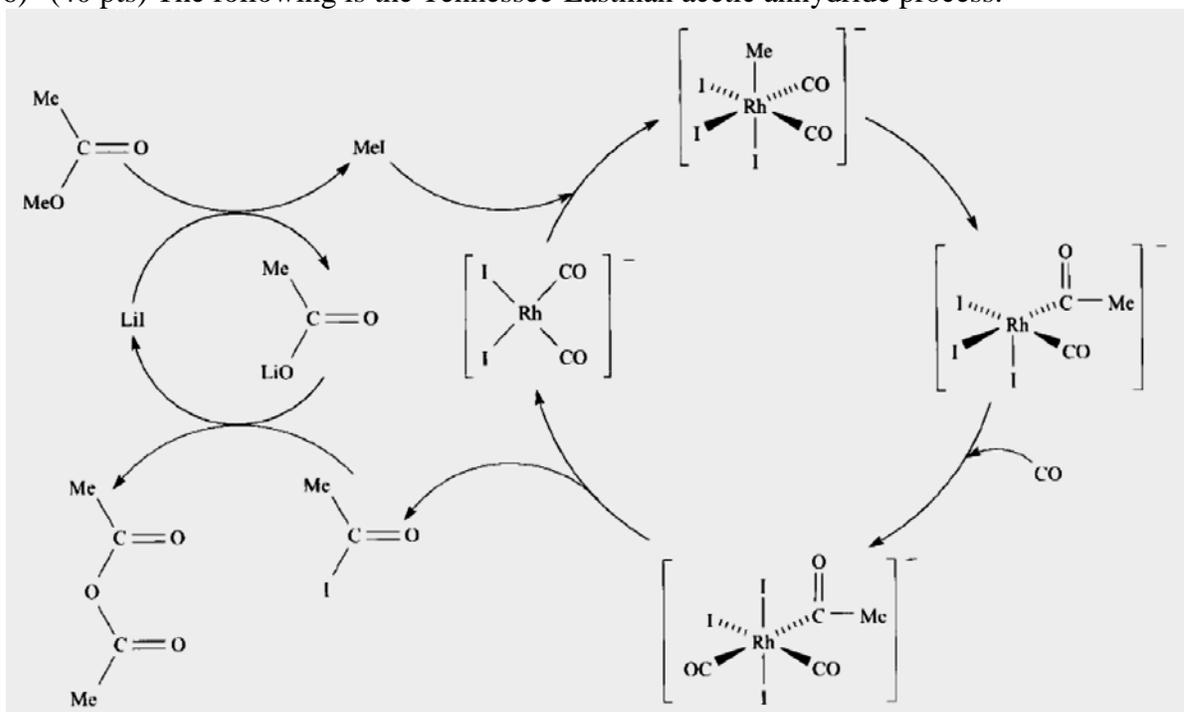


2) (10 pts) Describe the bonding of hydrogen in the *products only* of the following reactions:



- 3) (10 pts) What kind of reactivity might you expect for  $\text{Mn}(\eta^5\text{-C}_5\text{H}_5)_2$ ? Why?
- 4) (10 pts) Explain:  $\text{Ni}(\eta^5\text{-C}_5\text{H}_5)_2$  readily reacts with one molecule of HF to yield the  $[\text{Ni}(\eta^5\text{-C}_5\text{H}_5)(\eta^4\text{-C}_5\text{H}_6)]^+$  cation, whereas  $\text{Fe}(\eta^5\text{-C}_5\text{H}_5)_2$  reacts with strong acid to produce the  $[\text{HFe}(\eta^5\text{-C}_5\text{H}_5)_2]^+$  cation.
- 5) (20 pts) Explain the following. Cyclooctatetraene dianion ( $[\text{C}_8\text{H}_8]^{2-}$ ) is rarely found bound to d-block metals. When it is found bound to a d-block metal, it is often puckered with differing C-C bond lengths, as is the case in  $\text{Ru}(\text{CO})_3(\text{C}_8\text{H}_8)$ . However, it is more commonly found bound to lanthanides or actinides, such as uranocene  $[\text{U}(\text{C}_8\text{H}_8)_2]$ , where all C-C bonds are of equal length. (Hint: Think about different bonding modes...)

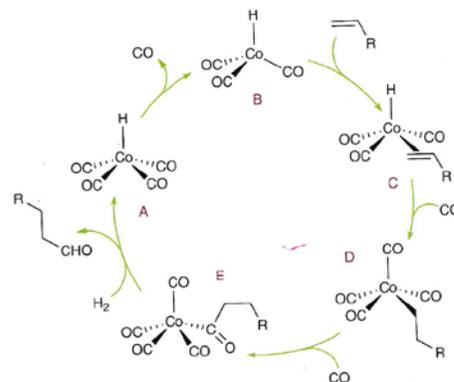
6) (40 pts) The following is the Tennessee-Eastman acetic anhydride process.



- (15 pts) Label each step in the catalytic cycle (i.e. each Rh complex) as to the type of reaction present and give total valence electron counts for each metal complex.
- (5 pts) Give the overall chemical equation for the reaction.
- (10 pts) Is this reaction likely to be run in water? Why or why not?
- (10 pts) Consider and discuss the effects, if any, if the Tennessee-Eastman process above had used  $\text{LiCl}$  instead of  $\text{LiI}$ ?

7) (20 pts) IR investigations of a mixture of CO, H<sub>2</sub> and 1-butene under hydroformylation conditions (catalytic cycle shown) indicate the presence of Compound E.

a. (5 points) what does this observation indicate about the rate determining step of the catalytic cycle?



b. (15 pts) describe the role of gas pressures in the catalytic cycle.

8) (20 pts) Explain the trends (i.e. 1 vs 2 and 3 vs 4, *not* 1/2 vs 3/4) in the following data:

<u>Hydride</u>	<u>pK<sub>a</sub></u>
1) [CoH(CO) <sub>4</sub> ]	8.3
2) [CoH(CO) <sub>3</sub> PPh <sub>3</sub> ]	15.4
3) FeH(Cp*)(CO) <sub>2</sub>	26.3
4) FeH(Cp)(CO) <sub>2</sub>	19.4

## Periodic Table of the Elements

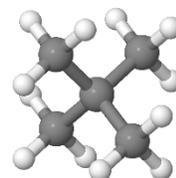
1 H 1.008																2 He 4.003	
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 UDb (262)	106 USg (266)	107 UBh (264)	108 UHs (269)	109 Mt (268)									
		58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (147)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 73.0	71 Lu 175.0		
		90 Th 232.0	91 Pa (231)	92 U 238.0	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (249)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)		



3. (20 pts) You just synthesized  $\text{Fe}(\text{NH}_3)_3(\text{CO})_3$  in integrated lab. You don't know if your product is in the fac- or mer- configuration. Is there a way to tell the difference? If so, be as detailed as possible. (In other words – prove it!)

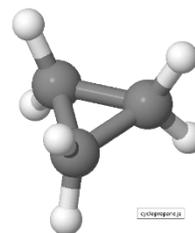
4. (20 pts) Determine the point groups (*not* including Jahn-Teller distortions) for the following molecules or ions:

- a. Neopentane ( $\text{CH}_3\text{C}(\text{CH}_3)_2\text{CH}_3$ , 2,2-dimethylpropane, at right)



- b.  $\text{BrF}_5$

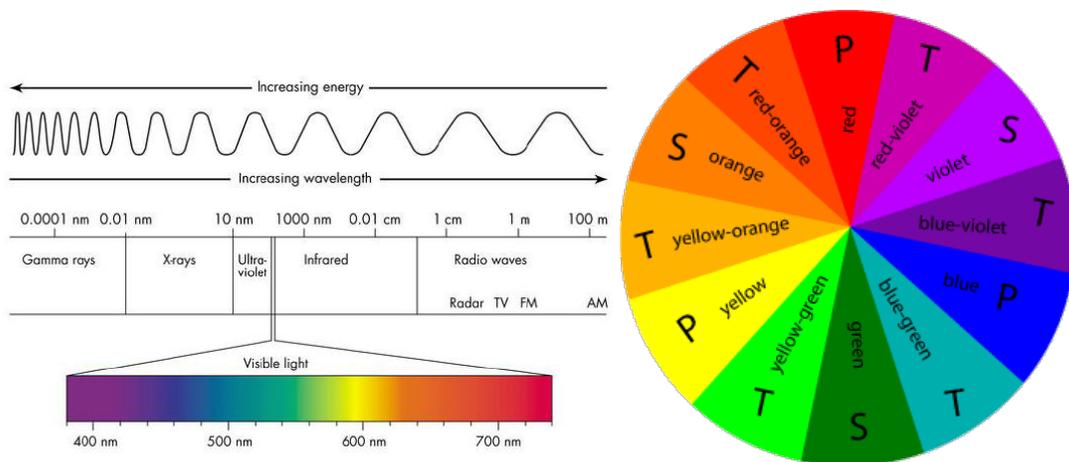
- c. Cyclopropane (at right)



- d.  $\text{SF}_4$

5. (20 pts) Arrange the following aquo acids ions in order of increasing acidity in aqueous solution and explain your choice:  $[\text{Cr}(\text{H}_2\text{O})_6]^{2+}$ ,  $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$ ,  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ ,  $[\text{Tl}(\text{H}_2\text{O})_6]^{3+}$

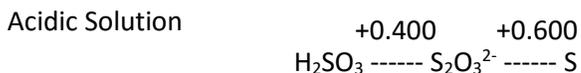
6. (20 pts) In aqueous solution,  $\text{CuSO}_4$  has been found to exist as a 6-coordinate blue-green  $\text{Cu}(\text{H}_2\text{O})_6^{2+}$  complex. What color do you expect  $\text{Cu}(\text{NH}_4)_4(\text{H}_2\text{O})_6^{2+}$  to be? Why? Explain these observations in terms of the electronic structure of the complex, including the metal and ligand contributions. *Be thorough!* The following diagrams may help.



7. (15 pts) Draw energy diagrams representing an A) insulator, B) extrinsic semiconductor, and a C) intrinsic semiconductor.

8. (15 pts) *Briefly explain* the following observation. Gold is typically functionalized for catalysis using sulfur-based linker molecules and not oxygen based linkers. (One sentence is enough!)

9. (10 pts) Given the following Latimer diagrams for chlorine, determine the stability of  $S_2O_3^{2-}$  A) in basic solution and B) in acidic solution.



10. (20 pts) Put the following compounds in order of increasing expected lattice energy from smallest to largest and briefly explain your reasoning:



11. (20 pts) Use symmetry and group theory to determine the symmetry elements present in a linear combination of  $H_{1s}$  orbitals in water. Then couple these with oxygen valence orbitals to draw the MO diagram for water.

12. (10 pts) *Briefly describe* the valence orbital interactions between  $PH_3$  and  $BBr_3$  (One sentence is enough!).

13. (10 pts) Which of the following ions would be EPR active if any? Why or why not?

a. Low-spin  $O_h$   $Fe^{2+}$

b. High-spin  $T_d$   $Co^{2+}$

c. Low-spin  $D_{4h}$   $Pd^{2+}$

14. (15 pts) Draw a crystal field energy diagram for the d-orbitals of each complex and label each d-orbital (i.e.  $d_{xy}$ , etc) for the following ions:

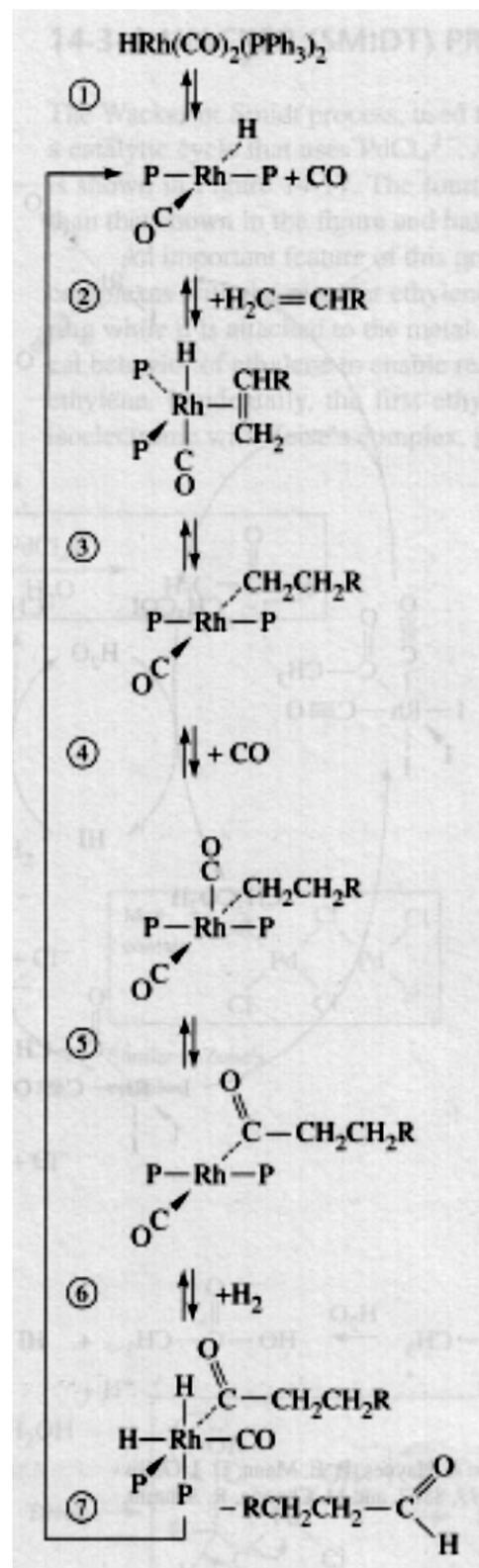
a.  $Pd(CN)_4^{2-}$

b.  $FeCl_4^{2-}$

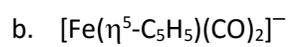
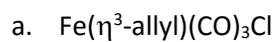
c.  $Co(NH_3)_6^{3+}$

15. (20 points) The carbonyl ligand is a ubiquitous ligand in organometallic chemistry. Using MO theory of the ligand as well as of the ligand attached to a metal center, describe/show/diagram how this ligand can be an important part of chemical reactivity. You may use examples from class if you remember them – but it is not necessary.

16. (25 points) For the catalytic cycle in the diagram at right:  
 a. analyze the types of reactions occurring in each step;  
 b. comment on potential engineering issues.



17. (20 points) Draw the following structures and determine both the valence electron counts and oxidation states for the metal ions in the following complexes:



## Chemistry 361

### Fall 2017 • MWF 10:00-10:50AM • PhSc 213

**Dr. Erik C. Wasinger**

PHSC 325

Office Hours: Monday 2-3 PM, Wednesday 1-2 PM, Thursday 9:00 -11:00 AM, *and by appointment.*

**REQUIRED TEXTS:** *Inorganic Chemistry, 6<sup>th</sup> Ed.*, Shriver & Atkins

**Suggested Materials:** Model kit(s)

#### APPROXIMATE SCHEDULE:

Week	Week of	Material	Important dates
1	August 21	Atomic and Molecular Structure (Chapters 1 & 2)	
2	August 28	Bonding and Structures of Solids (Chapters 2 & 3)	
3	September 4	Acids and Bases (Chapter 4)	9/8/15 Exam 1 (Chpts 1-3)
4	September 11	Redox Chemistry (Chapter 5)	
5	September 18	Symmetry (Chapter 6)	
6	September 25	Symmetry (Chapter 6)	
7	October 2	Coordination Chem. (Chapter 7)	10/6/15 Exam 2 (Chpts 4-6)
8	October 9	Coordination Chem. (Chapter 7)	
9	October 16	Bonding & Physical Methods (Chapters 20 & 8)	
10	October 23	Physical Methods (Chapter 8)	
11	October 30	OM Chemistry (Chapter 22)	11/3/15 Exam 3 (Chpts 7-8, 20)
12	November 6	OM Chemistry & Catalysis (Chapters 22 & 25)	
13	November 13	Catalysis (Chapters 25)	
	November 20	Thanksgiving Week	
14	November 27	Bioinorganic Chemistry (Chapter 27)	12/4/15 Exam 4 (Chpts 22, 25)
15	December 4	Bioinorganic Chemistry (Chapter 27)	“ACS exam” Date TBD
16	December 11	Finals Week	

#### BASIC EXPECTATIONS:

Upon entering this course, you are expected to know a number of topics at a general chemistry (Chem 111 and 112) level. These topics are listed below. If you do not feel comfortable with any of these topics, please see me as soon as possible. We will not be covering them in detail!

1. **Basic atomic structure, protons, neutrons, and electrons**
2. **Atomic number, mass number, isotopes**
3. **Atomic line structure**
4. **Orbital names, shapes, quantum numbers**
5. **Aufbau principle**
6. **Resonance**
7. **Octet rule**
8. **Basic hybridization**

**PLAGIARISM:**

No material may be used by any student other than that which is approved by the instructor. Under no circumstances may a student use any material from any other semester of this or any other inorganic chemistry course. Moreover, no student may use any work from a past student in this course – including his or her own work. Solutions manuals to this or any other textbook are expressly prohibited. Failure to follow these rules may result in expulsion from the course and a concomitant grade of 'F' for the semester.

**HOMEWORK:**

There will be *approximately* one homework assignment every 10 days, assigned from the textbook and other sources. I'll grade them and get them back to you ASAP. You may work together on the homework, especially on conceptual understanding, methodology, etc. *In fact, I encourage it!* ☺ However, the work you turn in should be your own, please. If you have any questions on this, please ask.

The homework in this course is designed less as a measure of what you know, and *more as a learning tool in and of itself*. PLEASE do not hesitate to come and ask questions – I'm counting on it!

**EXAMS:**

The four exams will all be two hour exams. Although I don't anticipate they will take you two hours to do them, I don't want time to be your limiting factor. I will give you more details as to how the two-hour exam will be given (considering we have a one-hour class) as the dates approach. Please note: an average of a passing grade must be achieved on the exams in order to pass this course. You may fail an exam, but your *exam average* must be passing in order to pass the course.

**EVALUATION:**

Homework (10*30 pts)	300 pts
Midterms (4x150)	600 pts
<u>Final</u>	<u>300 pts</u>
Total Course Points	1200 pts

*Approximate* grades will be as follows. The instructor reserves the right to modify this rubric should the need arise. (This is almost always in the favor of the student!)

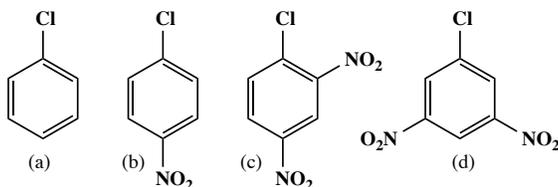
100-85%:	A
84-75%:	B
74-65%:	C
64-55%:	D

Dr. Christopher J. Nichols  
December 11, 2017

NAME \_\_\_\_\_

**Multiple choice (36 points, 3 each).** Put the correct answer in the box at left of each question.

1. Substituted chlorobenzene compounds can be converted into phenols by treatment with KOH at 130 °C. Which of these chlorobenzene compounds would have the fastest rate of reaction with KOH at 130 °C?

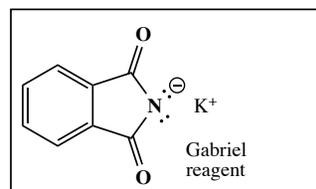


2. What is the name of the process by which the information on mRNA is converted to a particular protein sequence by a ribosome?

- a) Transcription  
b) Translation  
c) Replication  
d) Reverse Transcription

3. Which sequence of steps would convert 1-bromobutane into 1-pentanamine?

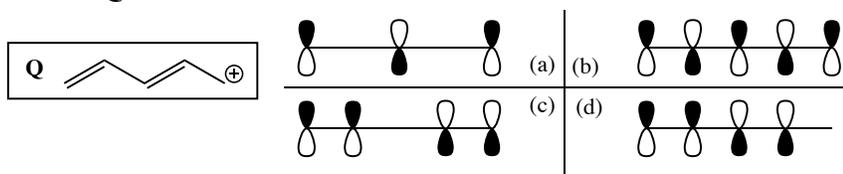
- a) 1. NH<sub>3</sub> (one step)  
b) 1. Gabriel reagent (shown at right); 2. NaOH, H<sub>2</sub>O  
c) 1. NaN<sub>3</sub>; 2. a) LiAlH<sub>4</sub>, b) H<sup>+</sup>, H<sub>2</sub>O  
d) 1. NaCN; 2. a) LiAlH<sub>4</sub>, b) H<sup>+</sup>, H<sub>2</sub>O



4. Which of these compounds would have the slowest hydrolysis reaction with NaOH (aq)?

- a) *N*-methylbenzamide  
b) Methyl benzoate  
c) Benzoyl chloride  
d) Acetic benzoic anhydride

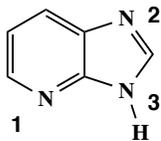
5. Which diagram correctly represents the highest-occupied molecular orbital (HOMO) of carbocation **Q**?



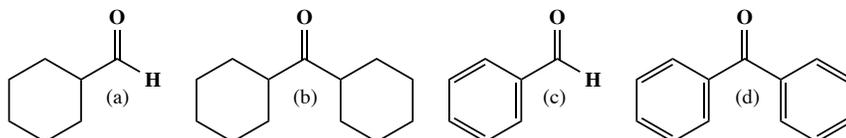
# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 2

6. Which of the N atoms in the molecule shown would be protonated at pH = 3?

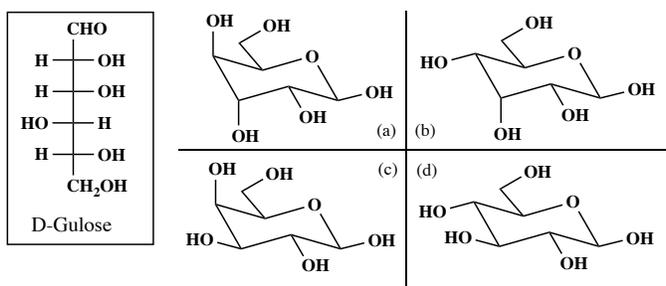
- a) All of them  
 b) Only N2 and N3  
 c) Only N1 and N2  
 d) Only N1 and N3



7. Which of the compounds shown has the highest equilibrium constant of hydration ( $K_{\text{hyd}} = [\text{hydrate}]/[\text{carbonyl}]$ )?



8. The open-chain form of D-gulose is shown here. Which is the correct chair form of  $\beta$ -D-gulopyranose?

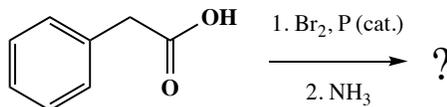


9. Complete hydrolysis of a triglyceride with  $\text{NaOH}_{(\text{aq})}$  produces glycerol and what other product?

- a) Biodiesel  
 b) Bleach  
 c) Soap  
 d) Cooking oil

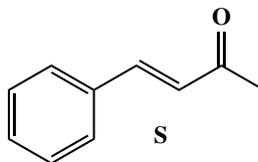
10. What is the product of the sequence of reactions shown here?

- a) An amide  
 b) A compound including aniline  
 c) An amine  
 d) An amino acid



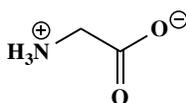
11. What starting materials would you need to make compound **S** using an aldol reaction?

- a) Acetophenone and acetaldehyde  
 b) Benzene and 2-butenoyl chloride  
 c) Benzaldehyde and acetone  
 d) Toluene and hydroxyacetone



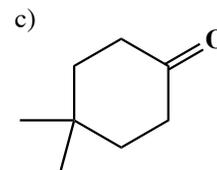
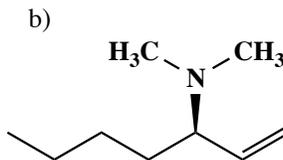
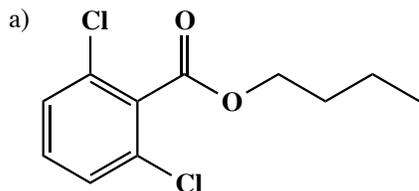
12. What is the name of the compound shown here?

- a) Glyceraldehyde  
 b) Glucose  
 c) Guanine  
 d) Glycine

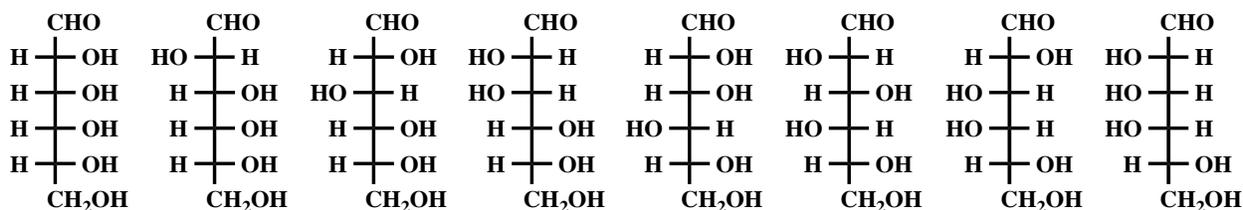


# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 3

1. (12 points, 4 each) Provide complete NAMES for these compounds.



2. (18 points, 6 each) Below are the 8 D-aldohexoses. Answer these questions about them.



D-Allose    D-Altrose    D-Glucose    D-Mannose    D-Gulose    D-Idose    D-Galactose    D-Talose

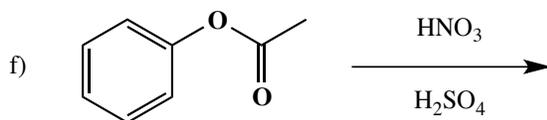
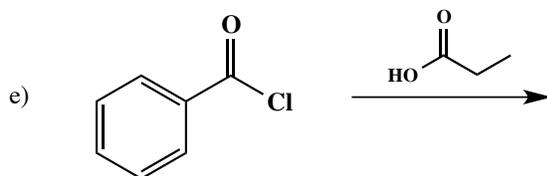
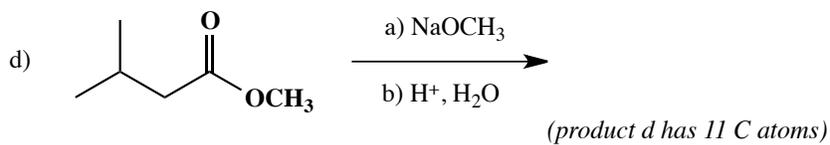
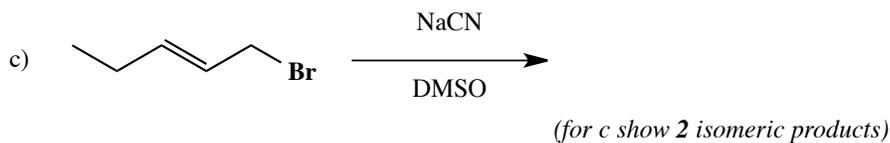
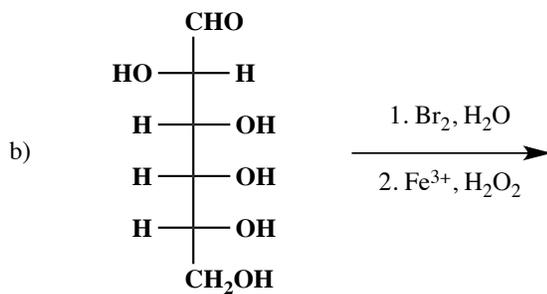
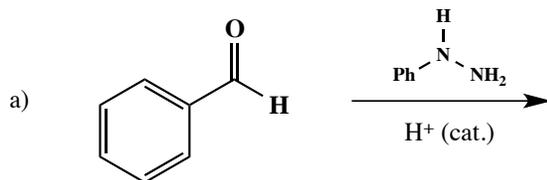
a) Draw the structure of methyl  $\beta$ -D-altropyranoside in a Haworth projection and a chair.

b) Draw the product of reaction of D-glucose with  $\text{HNO}_3$  at  $0^\circ\text{C}$ . There is another aldohexose which would give the same product upon reaction with  $\text{HNO}_3$ . Draw and name that aldohexose and explain why it gives the same product.

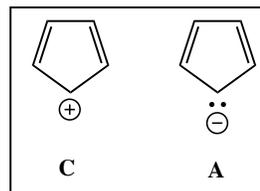
c) Draw a segment (at least 3 monosaccharides long) of a polymer of glucose with each monosaccharide connected to the next by an  $\alpha$ -(1,6')-linkage.

# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 4

3. (24 points, 4 each) Draw the correct structure of the major organic product of each reaction. Pay close attention to stereochemistry.

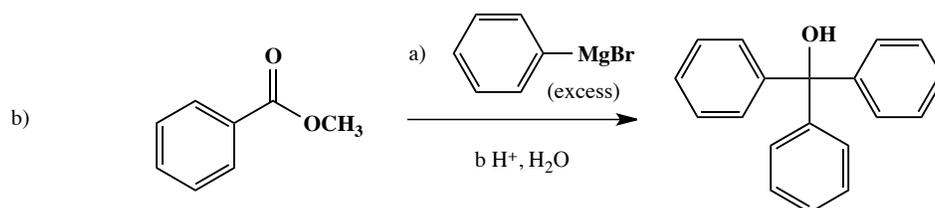
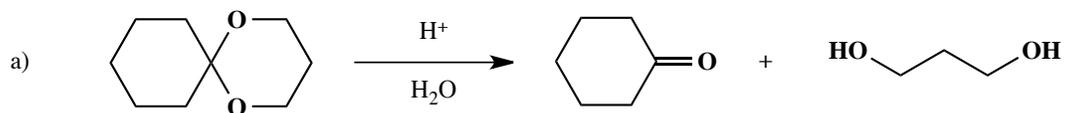


4. (6 points) Which should have a greater stability, the cation **C** or the anion **A**? Explain your answer.



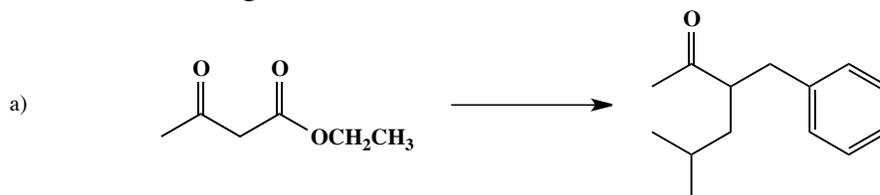
# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 5

5. (24 points, 14 for a and 10 for b) Write a complete arrow-pushing mechanism for BOTH reactions shown below. Draw all important resonance structures and be sure all formal charges are correct.

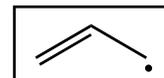


# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 6

6. (24 points, 12 each) For each of the transformations below, devise a complete multi-step synthesis. Show all synthetic intermediates (don't show mechanisms) and write out the names or formulas of the reagents.



7. (6 points) Draw the resonance structures and the  $\pi$  molecular orbital diagram of the allyl radical (shown). Explain in what way the two models agree with each other.



# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 7

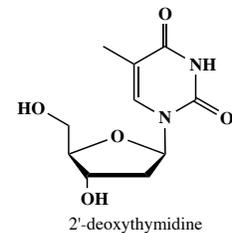
8. (22 points, as indicated) Miscellaneous questions

a, 5 pts) Draw the structure of the tripeptide GGK as you would find it at pH = 8.  
(K = lysine whose side chain is  $-(\text{CH}_2)_4\text{NH}_2$ ). The pKa of COOH groups in amino acids is around 2.0 and the pKa of  $\text{NH}_3^+$  groups in amino acids (and the side-chain in lysine) is 9.5 or higher.

b, 4 pts) Draw an  $\alpha,\beta$ -diglyceride which includes the natural fatty acids 10:0 and 18:2.

c, 5 pts) Explain how some proteins form  $\beta$ -sheets. Include diagrams in your answer.

d, 4 pts) Shown below is the nucleoside 2'-deoxythymidine. Draw the structure of the polynucleotide 5'-TTT-3' made from 2'-deoxythymidine.

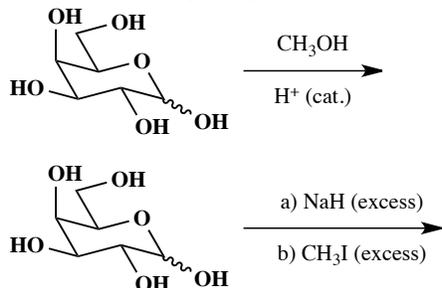


e, 4 pts) List two differences between the structures of DNA and mRNA.

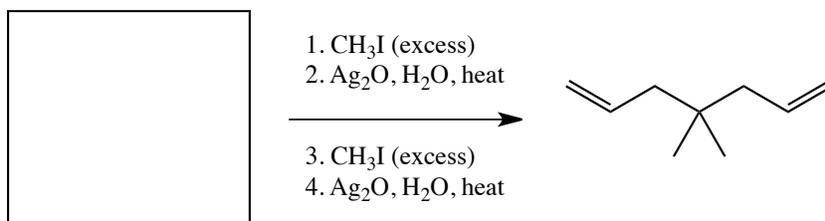
# CHEMISTRY 370 – Fall 2017 – FINAL EXAM – PAGE 8

9. (28 points, as indicated) More miscellaneous questions

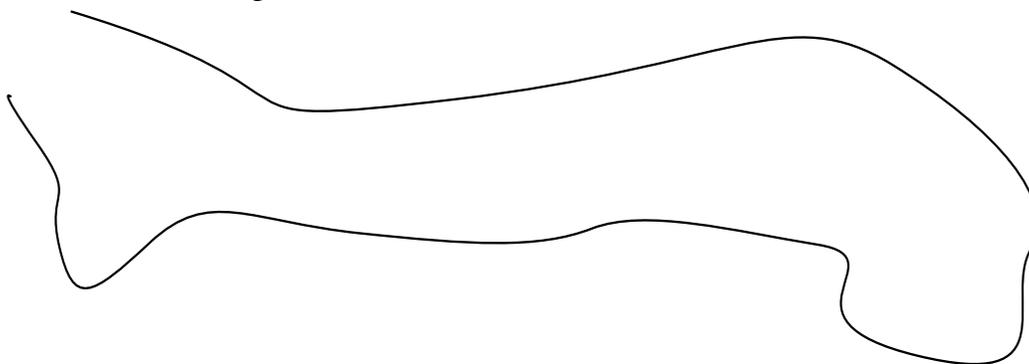
a, 8 pts) When this sugar is reacted with methanol and  $H^+$ , NMR of the product shows only one  $CH_3$  group. However, when the same sugar is reacted with excess NaH and then  $CH_3I$ , NMR of that product shows many  $CH_3$  groups. Draw the products and explain why they are different.



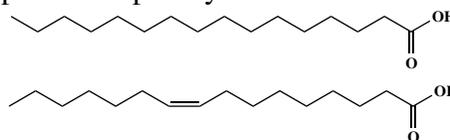
b, 6 pts) After two cycles of the Hofmann elimination, the diene **Z** is formed. The formula of the original starting material was  $C_9H_{19}N$ . What was a possible structure for it?



c, 8 pts) Below is the backbone of a long protein. Draw in some side chains, and show (and label) ALL of these  $3^\circ$  interactions: a hydrogen-bond, a hydrophobic interaction, and a disulfide linkage.



d, 6 pts) Which of these compounds has the lower melting point? Explain your answer.



# CHEMISTRY 370 – Fall 2017

## Organic Chemistry

Dr. Christopher J. Nichols  
PHSC 308  
Ph 898-5541  
e-mail: [cjnichols@csuchico.edu](mailto:cjnichols@csuchico.edu)  
Internet: <http://www.csuchico.edu/~cjnichols>



### Office Hours

M 2-3; W/F 10-11:30

### Prerequisites

CHEM 370 is the second part of a 2-semester sequence of organic chemistry for chemistry, biochemistry, and biology majors as well as many pre-professional programs. CHEM 270 is the first part of that sequence and so a grade of **C-minus or better** in CHEM 270 (or an equivalent class at another institution) is the prerequisite for CHEM 370. Please come and see Dr. Nichols if you are not sure if the classes you have taken meet this prerequisite. CHEM 370 will be taught assuming everyone has completed and understood the material from general chemistry and from CHEM 270.

### Textbooks:

- Solomons, Fryhle, and Snyder, "Organic Chemistry", **12<sup>th</sup> edition, (2016)** ISBN 978-1-118-87576-6 **REQUIRED**. Available at bookstore or online. This is the same book as was used in CHEM 270. *Older editions of this same textbook are acceptable.*
- Nichols, "Chemistry 370: Clicker Questions, Handouts, and Problem Sets" (2017, 3<sup>rd</sup> ed.) ISBN 9781524936914 **REQUIRED**. Available through the bookstore only.
- i>clicker2 – **REQUIRED**. Available at the bookstore.

### Curriculum

CHEM 370 is intended for majors in chemistry, biology, and for most students who will attend medical, dental, veterinary, and chiropractic colleges.

CHEM 370 covers topics included in Chapters 13-25 in Solomons. We will not be doing Chapter 21. The topics are listed on the lecture schedule page. By the end of the semester you will have learned about the structure, function, and reactivity of all of the major functional groups in organic chemistry as well as some biological applications of organic chemistry.

### Laboratory

CHEM 370 does NOT have a lab component. Two stand-alone organic lab courses are offered. They can be taken either concurrently with CHEM 370 or after completion of CHEM 370.

- CHEM 370L is a 3-hour per week (1 unit) lab course. It is required for chemistry minors and microbiology majors. Chemistry and biochemistry majors should NOT take CHEM 370L.
- CHEM 370M is a 6-hour per week (2 units) lab course. It is required for chemistry and biochemistry majors. Other students are welcome to take it but please note that it has a fairly heavy workload for a 2-unit course.

### i>clickers

- You are required to purchase an i>clicker (the standard one used by our campus) for CHEM 370. Every class day (except for exams and the first 2 days of class) I will use them multiple times to get feedback from you – to determine whether or not most students understand a particular chemical concept.
- Your clicker must be registered through the Bb Learn link provided on the home page.
- I expect everyone to bring their clicker to class each day and answer questions when prompted. One point is given for participation with the clicker each day.
- The second day of class we will have a short tutorial on how to use the clicker. Starting the following class, students will accumulate points based on their participation with the clickers.

## Homework and Participation

- To help keep everyone in the class learning as the semester progresses, homework sets will be assigned for each chapter.
- The homework sets are in the “Chemistry 370: Clicker Questions, Handouts, and Homework Sets” book.
- Assignments and due dates will be announced in class and posted on the “calendar” section of Bb Learn. Click on the due date for details on the assignment.
- Answers will be made available after the homework is due.
- There are a total of 12 homework assignments, worth 5 points each.
- Homework is due IN CLASS on the due date: it will be considered late if handed in after class.
- Late homework is accepted up to 1 week past the due date but for no more than half credit.

## Bb Learn

The Bb Learn site will be used for a calendar of assignments and to post answers to the homework, quizzes, and exams. You will also find copies of old exam questions that you can download to help you prepare for the exams this semester.

**Exams:** MIDTERM I – Friday, September 8  
MIDTERM II – Monday, October 2  
MIDTERM III – Friday, October 20  
MIDTERM IV – Monday, November 13  
FINAL EXAM – TBA

- Please show up on time for each exam. You do not get extra time if you arrive late.
- Notes and textbooks are not permitted on exams.
- Students who need special accommodations for exams must have proper authorization from Disability Support Services (DSS). Contact the DSS office 898-5959 for more information.
- Questions from exams from previous years will be posted on the Bb Learn site for you to download. The answers to those questions will also be posted in the days preceding each exam.
- There will be no opportunity for a make-up exam once the class has taken the exam. Please *don't ask*.
- *Early exam-taking* will only be permitted under rare circumstances. If you will be unable to take an exam as scheduled please contact Dr. Nichols as soon as possible. All reasons for early exam-taking must be verified in writing. Acceptable reasons include road trips for intercollegiate athletics. Unacceptable reasons include doctor's appointments and multiple exams on the same day.
- Requests for re-grading questions on exams are limited to 1 week after the exam is returned.

<b>Evaluation:</b>	Homework	60 points
	Clickers	40 points
	Midterms (4 @ 100 pts each)	400 points
	<u>FINAL</u>	<u>200 points</u>
	TOTAL	700 points

<b>Grading</b>	85-100%	A	60-64%	C+
	80-84%	A-	55-59%	C
	75-79%	B+	50-54%	C-
	70-74%	B	40-49%	D
	65-69%	B-	0-39%	F

*Important note! A grade of C-minus or better in CHEM 370 is a prerequisite for Biochemistry, CHEM 451. If you earn a D or an F in CHEM 370 you will not be allowed to enroll in CHEM 451.*

## What I Expect in Chemistry 370

- ✓ Keep up! Falling behind early will lead to real trouble, particularly since the final exam is comprehensive.
- ✓ Attend all lectures. Even though no credit is directly given for attending lectures, studies show that attendance directly affects performance. Don't forget your clicker.
- ✓ Do the assignments and do them on time. The assignments are worth only a few points, but more importantly they are practice for the exams, which are worth plenty of points. *Copying homework answers* from your friends may get you the 5 points the homework assignment is worth, but since you wouldn't be taking the time to learn the material, your performance on the exams will suffer. Don't fall into the *trap* of not actively doing homework.
- ✓ Read the textbook and keep up with the lectures. The topics under discussion each week are laid out in the calendar so there is no excuse for not being prepared for class.
- ✓ Plan to invest *6-8 hours per week* out of class to studying for CHEM 370 in order to succeed. Successful studying involves ACTIVE learning: by doing problems, asking questions, and so on.
- ✓ Turn your cell phones and pagers OFF during class hours. A cell phone which rings during class or lab is disruptive and impolite. If there is a circumstance (emergency) that requires you to leave your phone on please inform me at the beginning of the class.
- ✓ Be prepared to participate in class. You may be invited to the board occasionally to do problems.
- ✓ If you are confused about something in class, ASK! If you are still confused after class, ask again, in office hours, in lab, by e-mail, or however, until you are satisfied.
- ✓ Work together! Obviously on exams you are working on your own, but studies show that studying together and doing homework together are excellent ways for everyone to earn higher grades. You and the other students are not competing with each other: the grades in the class are not on a "curve".
- ✓ Be honest. Copying answers during exams and other forms of academic dishonesty are serious offenses and will not be tolerated. Instances of cheating will be reported to Student Judicial Affairs, and serious academic penalties are possible. Please refer to the catalog for further information. I will take several precautions to help prevent cheating, including:
  - Giving out different versions of exams and quizzes, which contain different questions.
  - Noting who sits next to whom in an exam setting and cross-checking answers. If you studied with someone *do not* sit next to them in the exam: it can lead to suspicion.
  - Checking ID of students during exams.
- ✓ The largest part of the subject matter in this class deals with reactions in which one organic molecule is transformed into another: how well you understand these transformations at the end of the semester will be directly reflected in the grade you earn:
  - To earn a D, you will need to know some of the reactions.
  - To earn a C, you will need to know all of the reactions.
  - To earn a B, you will need to know the mechanisms of all of the reactions.
  - To earn an A, you will need to UNDERSTAND all of the reactions, and be able to explain aspects of a reaction like stereoselectivity, kinetic vs. thermodynamic control, etc.

## CHEMISTRY 370 CALENDAR Fall 2017

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Aug 21 Intro & Review		Aug 23 Chapter 13 Conjugation		Aug 25 Chapter 13 Conjugation
Aug 28 Chapter 13 Conjugation		Aug 30 Chapter 14 Aromaticity		Sept 1 Chapter 14 Aromaticity
<b>LABOR DAY NO SCHOOL</b>		Sept 6 Chapter 14 Aromaticity		Sept 8 <b>EXAM I</b>
Sept 11 Chapter 15 Aromatic Rxns		Sept 13 Chapter 15 Aromatic Rxns		Sept 15 Chapter 15 Aromatic Rxns
Sept 18 Chapter 15 Aromatic Rxns		Sept 20 Chapter 15 Aromatic Rxns		Sept 22 Chapter 16 Aldehyde/Ketone
Sept 25 Chapter 16 Aldehyde/Ketone		Sept 27 Chapter 16 Aldehyde/Ketone		Sept 29 Chapter 16 Aldehyde/Ketone
Oct 2 <b>EXAM II</b>		Oct 4 Chapter 17 C.A./Derivs		Oct 6 Chapter 17 C.A./Derivs
Oct 9 Chapter 17 C.A./Derivs		Oct 11 Chapter 17 C.A./Derivs		Oct 13 Chapter 17 C.A./Derivs
Oct 16 Chapter 17 C.A./Derivs		Oct 18 Chapter 17 C.A./Derivs		Oct 20 <b>EXAM III</b>
Oct 23 Chapter 18 Alpha-C Rxns		Oct 25 Chapter 18 Alpha-C Rxns		Oct 27 Chapter 18 Alpha-C Rxns
Oct 30 Chapter 19 Condensations		Nov 1 Chapter 19 Condensations		Nov 3 Chapter 20 Amines
Nov 6 Chapter 20 Amines		Nov 8 Chapter 20 Amines		<b>VETERANS DAY NO SCHOOL</b>
Nov 13 <b>EXAM IV</b>		Nov 15 Chapter 22 Carbohydrates		Nov 17 Chapter 22 Carbohydrates
	<b>Thanksgiving</b>		<b>Break</b>	
Nov 27 Chapter 22 Carbohydrates		Nov 29 Chapter 23 Lipids		Dec 1 Chapter 24 Amino Acids
Dec 4 Chapter 24 Proteins		Dec 6 Chapter 25 Nucleic Acids		Dec 8 Review for Final
		<b>EXAM WEEK</b>		

## Organic Chemistry II, CHEM 370-01

Fall 2016

Mondays, Wednesdays and Fridays; 9:00am – 9:50am; PLMS 205

### Instructor

Dr.Carolynn Arpin, carpin@csuchico.edu, carolynnarpin.com

### Office Hours

Mondays, Wednesdays, and Thursdays 12:00-1:00pm, and by appointment; in PHSC 316

### Course Materials

Primary Text: *Organic Chemistry* by L.G. Wade, Jr., 8th Edition, 2012 (older editions of this same textbook will suffice); Pearson Education Inc.; ISBN: 0321768140

Suggested Text: *Preparing for Your ACS Examination in Organic Chemistry: The Official Guide*; ACS Division of Chemical Examinations Institute; ISBN: 0-9708042-1-0

i>Clicker2: Participation points will be assessed via use of the i>Clicker2; this will aid in class engagement for students and immediate feedback for the instructor

Molecular Models: A very useful study aid; the Molecular Visions kit by Darling Models is recommended

Paper(!) for Notes: Plain computer paper (not notebook paper) is recommended

Blackboard: Daily notes (designed to be printed and brought to class), due dates, homework sets, additional study aids, learning assessment solutions, and other materials will be posted for the course via Blackboard; be sure to check the course site daily

### Course Content

- CHEM 370 is the second course of a 2-semester sequence of organic chemistry
- CHEM 270 is the prerequisite for this course
- The grade of a C- or better in CHEM 370 is a prerequisite for CHEM 451 – Biochemistry
- Chapters 14-24 of the primary text, Wade's *Organic Chemistry*, will be covered
- Efforts will be made to stick to the following *tentative* schedule:

Week	Dates	Chapter	Important
1	Aug. 22, 24, 26	Ch.14: Ethers & Epoxides	
2	Aug. 29, 31, Sep. 2	Ch.14 & Ch.15: Conjugated Systems	Quiz #1 Fri.
3	Sep. 5, 7, 9	Ch.15: Conjugated Systems	
4	Sep. 12, 14, 16	Ch.16: Aromatics	<b>Test #1 Wed.</b>
5	Sep. 19, 21, 23	Ch.16: Aromatics	
6	Sep. 26, 28, 30	Ch.17: Rxns w/ Aromatics	Quiz #2 Fri.
7	Oct. 3, 5, 7	Ch.17: Rxns w/ Aromatics	
8	Oct. 10, 12, 14	Ch.18: Killer Ketones & Aldehydes	<b>Test #2 Fri.</b>
9	Oct. 17, 19, 21	Ch.18: Killer Ketones & Aldehydes	
10	Oct. 24, 26, 28	Ch.22a: $\alpha$ - & $\beta$ -Carbon Rxns	Quiz #3 Fri.
11	Oct. 31, Nov. 2, 4	Ch.22a & Ch.19: Amazing Amines	
12	Nov. 7, 9, 11	Ch.19: Amazing Amines	
13	Nov. 14, 16, 18	Ch.20 & 21: Carboxylic Acids & Derivatives	<b>Test #3 Mon.</b>
14	Nov. 28, 30, Dec. 2	Ch.20, 21 & Ch.22b: Ester $\alpha$ -Carbon Rxns	Quiz #4 Fri.
15	Dec. 5, 7, 9	Ch.23 & 24: Beautiful Biochemistry	

- Students can expect to work toward achieving these (very) general learning objectives:
  - o How compounds react to break and form chemical bonds and yield reaction products with new chemical properties
  - o How chemical changes can be controlled by choices of reactants, reaction conditions, or use of catalysts
  - o How the geometric structures of chemical compounds influence their chemical and physical behaviors
  - o How to interpret and utilize different forms of spectroscopy

### Learning Assessment

#### **Point Breakdown**

Attendance/Participation:	177 total points (~11.5%)
• Pre-lecture	78 points
• In-Class	78 points
• Wrappers	21 points
Homeworks (9):	20 points each = 180 total points (~11.5%)
Quizzes (4):	50 points each = 200 total points (~13%)
Tests (3):	250 points each = 750 total points (~48%)
<u>Final Exam:</u>	<u>250 points (~16%)</u>
Total Possible:	1557 points

#### **Attendance/Participation**

- Attendance/Participation points will be assessed based on the completion of various activities before, during and after lecture:
  - Pre-lecture assignments will be posted on Blackboard and due *before* the start of lecture (answers must be correct for full credit)
  - In-class participation will be assessed via responses made using the i>Clicker2 during lecture (all answers will receive full credit)
  - “Wrappers” for quizzes and tests will be posted on Blackboard after these assessments are returned; completed wrappers will be due before the start of the following lecture (all answers will receive full credit)

#### **Homework**

- Homework problems for each unit will be posted on Blackboard
- Homework will be collected at the beginning of the lecture following the last day of the unit’s discussion (*e.g.*, we finish covering the chapter on Monday, that chapter’s homework problems will be due on Wednesday)
- Not all of the assigned homework problems will be graded, however, answers to all of the assigned problems will be posted on Blackboard immediately after class on the due date
- Upon return of graded homework, students have the opportunity to earn up to *5 extra credit points* (not surpassing the maximum points allotted) on each assignment by correcting all of their incorrect work and then re-submitting the assignment *one week* later

#### **Quizzes, Tests and the Final Exam**

- Four 20-minute **quizzes** will be held in class throughout the semester: Friday, September 2<sup>nd</sup>; Friday, September 30<sup>th</sup>; and Friday, October 28<sup>th</sup>; and Friday, December 2<sup>nd</sup>
- Three 50-minute **tests** will be given in class throughout the semester: Wednesday, September 14<sup>th</sup>; Friday, October 14<sup>th</sup>; and Monday, November 14<sup>th</sup>
- The **Final Exam** will be a 110-minute final exam covering all of the course content; it will be the standardized multiple choice ACS organic chemistry exam covering BOTH semesters
- Notes and textbooks are not permitted during quizzes, tests or the final exam

### Grading Scale

- The *approximate* grading scale below will be followed; the instructor reserves the right to modify this scale should the need arise, but ONLY in the student's favor

		77-79%	B+	67-69%	C+		
85-100%	A	73-76%	B	63-66%	C	50-59%	D
80-84%	A-	70-72%	B-	60-62%	C-	0-49%	F

### Late or Missed Work

- If a student misses a pre-lecture assignment, quiz or exam wrapper, or i>Clicker2 session, he/she will receive a zero (0) for these Attendance/Participation points; these points cannot be made up
- Late homework will not be accepted since answers will be posted immediate after the lecture in which the homework is due, however, homework may be turned in early or on-time via scanned images sent by e-mail
- If a student is absent when a quiz is given, he/she will receive a zero (0) for these points; these points cannot be made up
- If a student misses a test, he/she will receive a zero (0) for the test; extenuating circumstances will be considered
- Students may take quizzes and tests early under certain circumstances, only if the instructor is contacted well in advance
- As soon as a student knows that he/she will have to turn in homework late or miss a test, students must notify the instructor immediately

### Student Conduct

- Students are expected to follow CSU, Chico's Code of Student Conduct
- Students are encouraged to work together for the completion of homework but what is submitted must be each student's own work
- Any form of cheating will result in a zero (0) on the entire assessment and likely further penalties
- Students are encouraged to speak up and participate during class meetings; because the class will represent a diversity of individual beliefs, backgrounds, and experiences, every member of this class must show respect for every other member of this class
- We will all work to promote an anti-discriminatory environment where everyone feels safe and welcome by being committed to providing equality of opportunity for all by eliminating any and all discrimination, harassment, bullying, or victimization; the success of this policy relies on the support and understanding of everyone in this class

### Disabilities

- If a student has a disability/health consideration that may require accommodations, please feel free to approach the instructor and/or the [Accessibility Resource Center](#) (ARC) as they are the designated department responsible for approving and coordinating reasonable accommodations and services for students with disabilities
- ARC will help you understand your rights and responsibilities under the Americans with Disabilities Act and provide you further assistance with requesting and arranging accommodations
- Students can contact the ARC by calling (530) 898-5959, by visiting Student Services Center 170, or by e-mailing arcdept@csuchico.edu

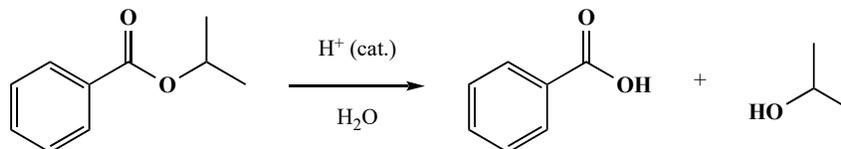
### Other Course Policies

- The laboratory course for Organic Chemistry II is a separate and stand-alone class, thus, your performance in lab is not part of your lecture grade
- Appealing the grading of homework, quizzes or tests requires a written, detailed complaint; please feel free to take advantage of this opportunity
- No extra points will be given to any student after the course is over; the grade a student receives is the grade he/she earned in the course

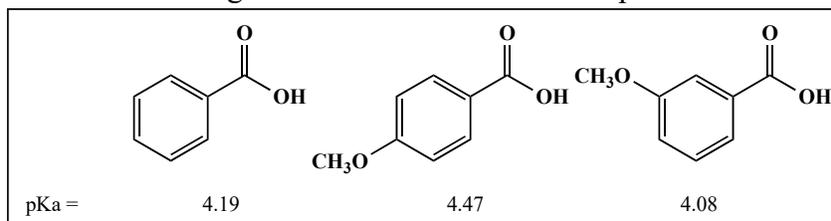
Dr. Christopher J. Nichols  
October 20, 2017

NAME \_\_\_\_\_

1. (12 points) Draw the complete *mechanism* for this reaction. Show all intermediates and important resonance structures. Make sure all formal charges are correct.

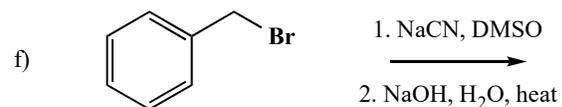
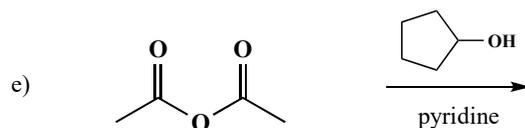
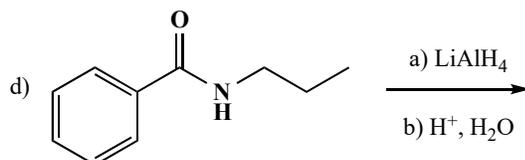
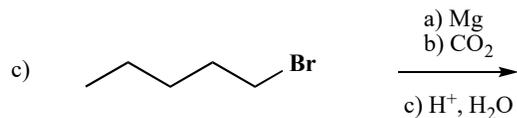
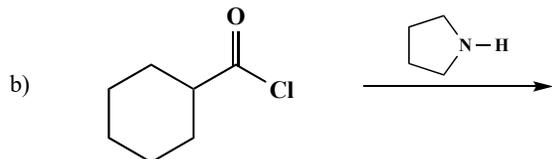
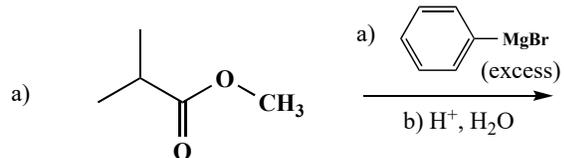


2. (8 points) *p*-Methoxybenzoic acid is a weaker acid than benzoic acid. However, *m*-methoxybenzoic acid is a stronger acid than benzoic acid. Explain in detail.

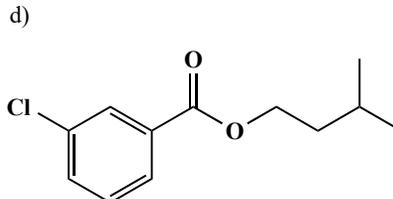
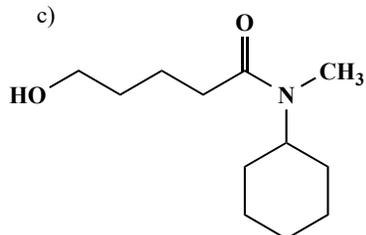
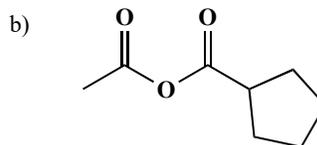
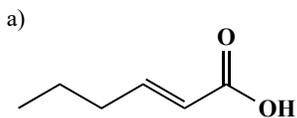


# CHEMISTRY 370 – Fall 2017 – Midterm 3 – PAGE 2

3. (24 points, 4 each) Draw the major organic product of each of the following reactions.

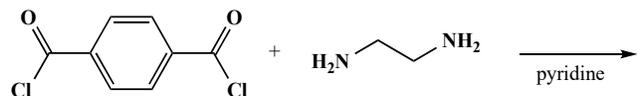


4. (14 points, 3 for a/b; 4 for c/d) Provide complete names for these compounds.

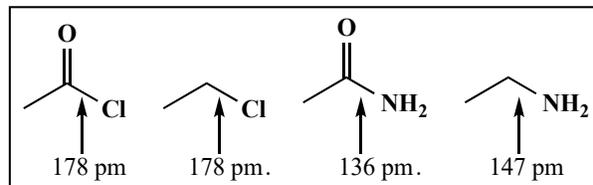


# CHEMISTRY 370 – Fall 2017 – Midterm 3 – PAGE 3

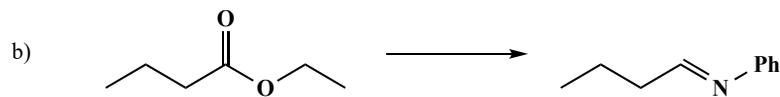
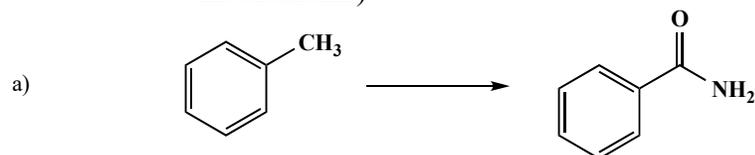
5. (4 points) Draw a short segment of the polymer formed in the reaction below.



6. (6 points) The C-Cl bonds in acetyl chloride and chloroethane are both the same length (178 pm). However, the C-N bonds in acetamide and ethylamine are very different. Explain.



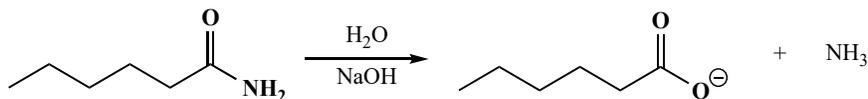
7. (12 points, 6 each) Each of these transformations requires at least two steps to convert the starting material to the product. Propose multi-step synthesis of these compounds, showing all synthetic intermediates and all reagents (don't show mechanisms).



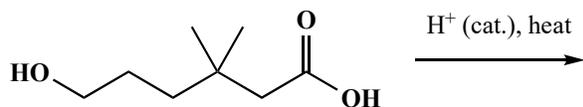
# CHEMISTRY 370 – Fall 2017 – Midterm 3 – PAGE 4

8. (8 points) Methyl benzoate has six (6) signals in its  $^{13}\text{C}$  NMR spectrum. *N,N*-dimethylbenzamide has seven (7) signals in its  $^{13}\text{C}$  NMR spectrum. Draw the structures of these molecules, and explain in detail why their  $^{13}\text{C}$  NMR spectra have different numbers of signals.

9. (8 points) Draw the complete *mechanism* for this reaction. Show all intermediates and important resonance structures. Make sure all formal charges are correct.



10. (4 points) A lactone is a cyclic ester. Draw the structure of the lactone that would be formed in the Fischer esterification shown below.



# CHEM 370-01

Fall 2016

## Test #1

By signing below you are agreeing to the following statement: I will not cheat.

Signed: \_\_\_\_\_

Printed Name: \_\_\_\_\_

Student Number: \_\_\_\_\_

Although you may use scratch paper, answers on additional sheets will not be graded. Please write your last name at the top of each page in this test packet in case it comes apart.

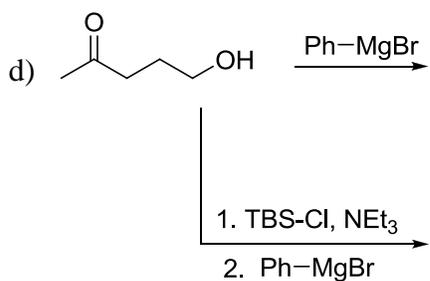
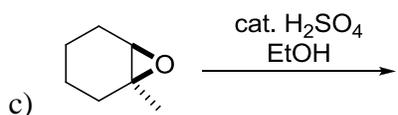
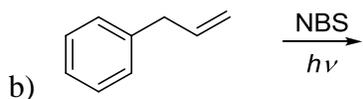
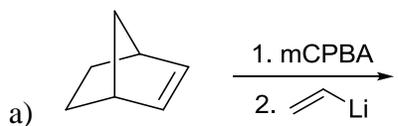
GOOD LUCK!!

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

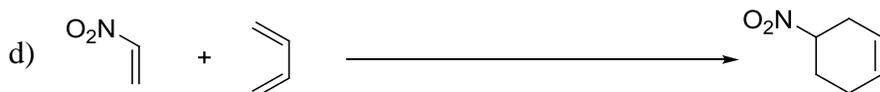
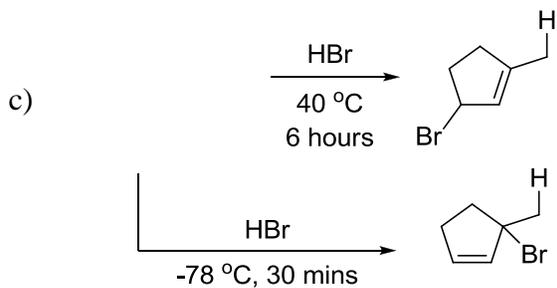
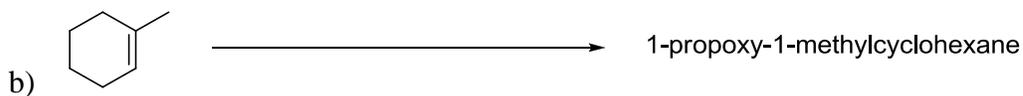
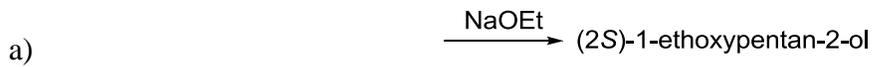
September 14<sup>th</sup>, 2016  
Time Limit: 50 minutes

Page 2: 24 points  
Page 3: 32 points  
Page 4: 27 points  
Page 5: 27 points  
**Total Possible: 110 points**  
**Scaled to 250 points**

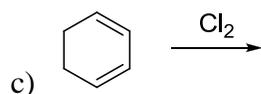
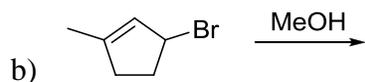
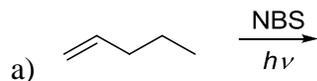
1. Provide the major product(s) of the reactions below. Assume work-ups when appropriate, and be sure to include *stereochemistry* and note *racemic* mixtures. (15 points)



2. Provide the missing reactant or starting material for the reactions below. Assume work-ups when appropriate and be sure to include *stereochemistry* where appropriate. (9 points)

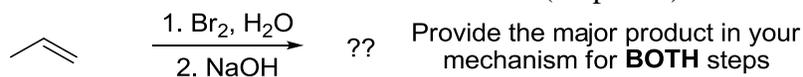


3. Each of the following reactions yields **two** constitutionally isomeric **major products** (products with different substitution, not stereochemistry). Provide the structures of **both** major products for each reaction. You do NOT need to consider stereochemistry. (16 pts)

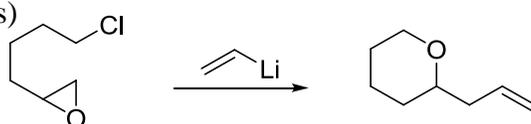


- d) Which one of the products you provided in part c) would form *faster*? Why?

4. Determine the major product of the reaction below by drawing the mechanism for its formation using curved arrows to show the movement of electrons. (10 points)



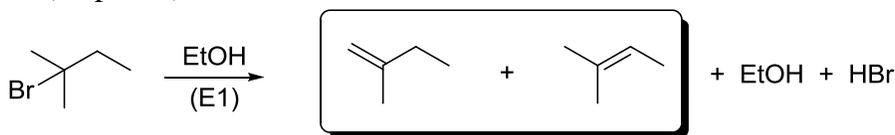
5. Using curved arrows to show the movement of electrons, provide a plausible mechanism for the reaction below. (6 points)



6. **Draw** what you would expect the  $^1\text{H}$  NMR spectrum for methyl ethyl ether ( $\text{CH}_3\text{-O-CH}_2\text{-CH}_3$ ) to look like. Be sure to label the x-axis in PPM and indicate the anticipated integration for each signal. Re-draw methyl ethyl ether onto your spectrum and label *each* proton signal with its corresponding set of hydrogens on the structure. (12 points)

7. The most abundant peak (the base peak) in the mass spectrum of methyl ethyl ether (mol. wt. = 60 g/mol) corresponds to an ion with an  $m/z$  of 45. Show where methyl ethyl ether was cleaved to form this ion. (3 pts)

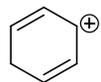
8. E1 elimination of 1-bromo-1-methylbutane with ethanol gives a mixture of alkene products as shown below. (12 points)



- a) Which alkene would be the major product after 12 hours at 35 °C? *Explain.*

- b) Which alkene would be the major product after an hour at -20 °C? *Explain.*

9. Using Hückel MO Theory, explain why the cation shown below is a *more reactive electrophile* than the radical below. In your explanation: (11 pts)
- a) Provide the Hückel MO diagram for each intermediate. (You don't need to provide drawings of each orbital; all that's required is the diagram of the orbital energies with appropriate labels and filled with electrons).
- b) Using your answers to part a), explain why the cation below is a more reactive (reacts faster) as an electrophile than the radical.



cation

or

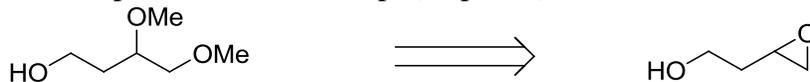


radical

Explain why the cation is a more reactive electrophile

10. Also using your answer to #9a, provide *full MO drawings* of the LUMO for the cation and the LUMO for the radical in #9. Label your drawings with "Cation LUMO" and "Radical LUMO". (6 pts)

11. Using a series of synthetic reaction steps, how could you carry out the following synthesis? Write the reagents and products for each step. (10 points)



# CHEM 370-01

Fall 2016

## Test #2

By signing below you are agreeing to the following statement: I will not cheat.

Signed: \_\_\_\_\_

Printed Name: \_\_\_\_\_

Student Number: \_\_\_\_\_

Although you may use scratch paper, answers on additional sheets will not be graded. Please write your last name at the top of each page in this test packet in case it comes apart.

GOOD LUCK!!

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

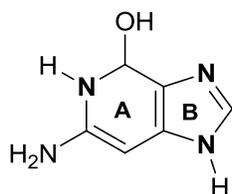
October 14<sup>th</sup>, 2016  
Time Limit: 50 minutes

Page 2: 30 points  
Page 3: 20 points  
Page 4: 28 points  
Page 5: 37 points  
**Total Possible: 115 points**

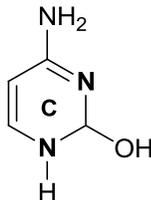
1. Draw the full MO diagram, complete with drawings of all the MOs, for the cyclopentadienyl *cation*. **Using** your MO diagram, *explain* the stability of this ion and determine whether it is aromatic, antiaromatic or nonaromatic. (14 points)

2. The compounds below are derivatives of RNA base pairs. (10 points)

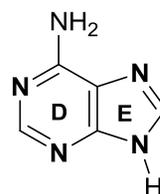
guanine derivative



uracil derivative



adenine

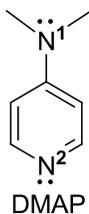


- a) Which of the labeled rings of these compounds are aromatic: A, B, C, D and/or E?

- b) On the figures above, circle which of the **bold** nitrogen atoms are *weak* bases.

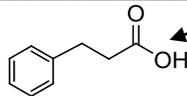
3. Explain *how* the boat shape of cyclooctatetraene prevents the compound from being antiaromatic. (3 points)

4. Amine nitrogens (such as N<sup>1</sup>) are generally good bases, however, in DMAP the pyridine nitrogen (N<sup>2</sup>) is a stronger base. Explain why. (3 points)



Last Name: \_\_\_\_\_ Think about rxn

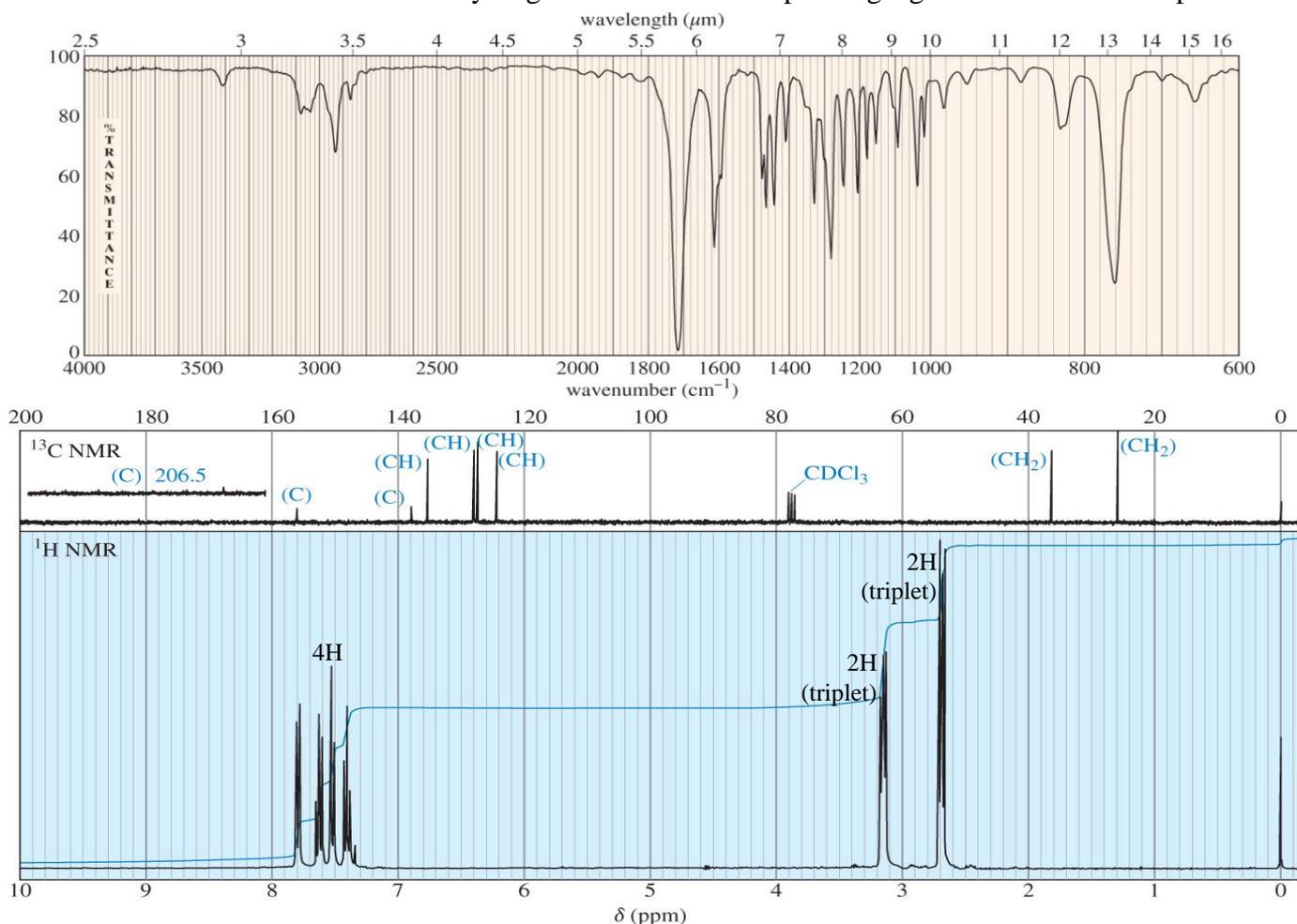
CHEM 370-01 Test #2



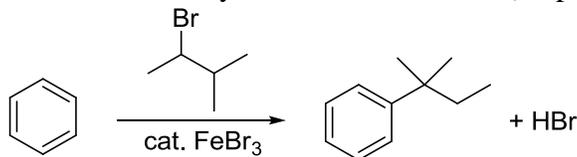
with this SM

(10 points)

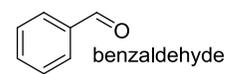
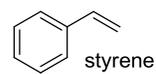
5. 3-Phenylpropanoic acid ( c1ccc(cc1)CCC(=O)O ) was subjected to a 1:1 mixture of NaCl and AlCl<sub>3</sub> and heated to 170 °C to yield an interesting product with the following spectra and a molecular weight corresponding to C<sub>9</sub>H<sub>8</sub>O<sub>2</sub>. **Calculate** the degrees of unsaturation, **label** the IR, **provide** the structure and **label** each set of hydrogens with their corresponding signal on the <sup>1</sup>H NMR spectrum.



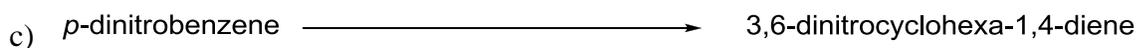
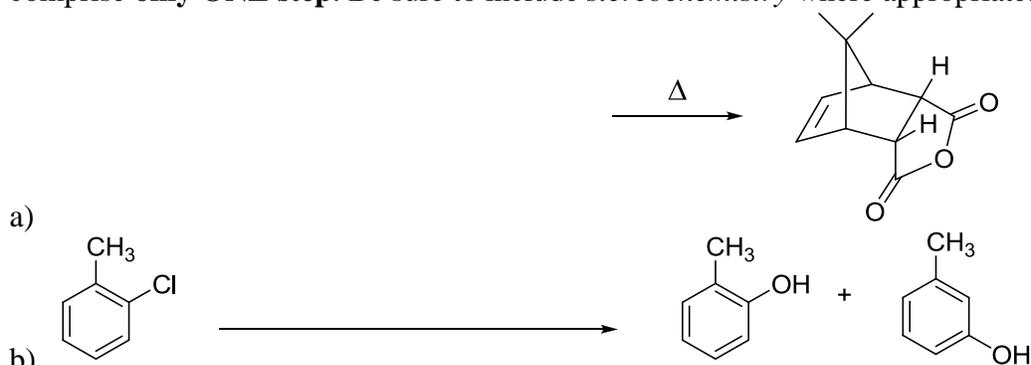
6. Provide a plausible mechanism for the reaction below using curved arrows for the movement of electrons. You do NOT need to show every resonance structure. (10 points)



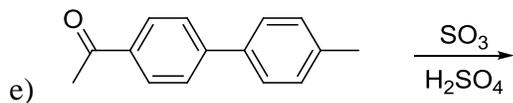
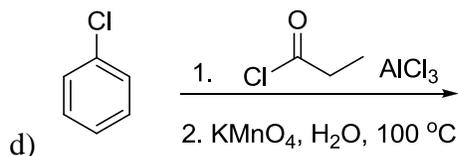
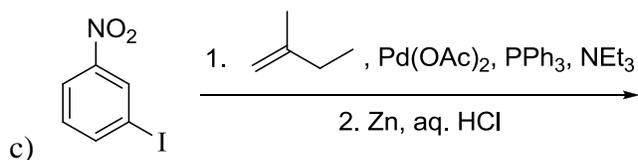
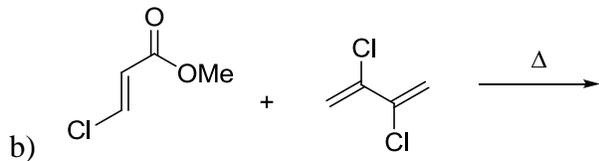
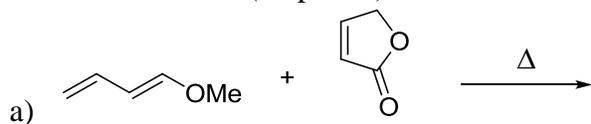
7. Show the formation of the  $\sigma$ -complex intermediate for any EAS reaction using benzene, styrene, *and* benzaldehyde on the **SAME** reaction-energy diagram, **labeling** each curve. Which starting material is slowest and which is fastest? *Explain* using important resonance structures. (15 points)



8. Provide the missing reactant(s) or starting material(s) for the reactions below. Missing reactant(s) comprise **only ONE step**. Be sure to include *stereochemistry* where appropriate. (13 points)

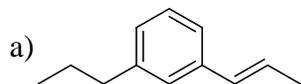


9. Provide the major product(s) of the reactions below. Be sure to include *stereochemistry* and note *racemic mixtures*. (16 points)

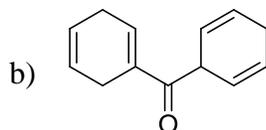


(21 points)

10. Show how you would synthesize the products below beginning with benzene and any inorganic or any organic reagents of **less than six carbons**. Write the reagents and products for each step.



(I take more than 3 steps to make, and I look like a spider!)



(One of these rings was made by a Birch Reduction!)

# CHEM 370-01

Fall 2016

## Test #3

By signing below you are agreeing to the following statement: I will not cheat.

Signed: \_\_\_\_\_

Printed Name: \_\_\_\_\_

Student Number: \_\_\_\_\_

Although you may use scratch paper, answers on additional sheets will not be graded. Please write your last name at the top of each page in this test packet in case it comes apart.

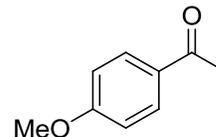
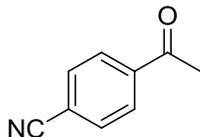
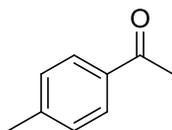
GOOD LUCK!!

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

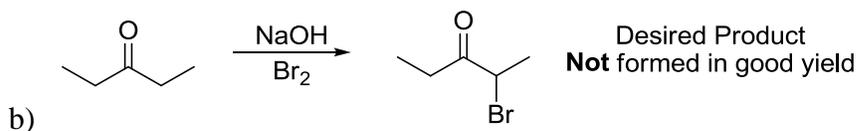
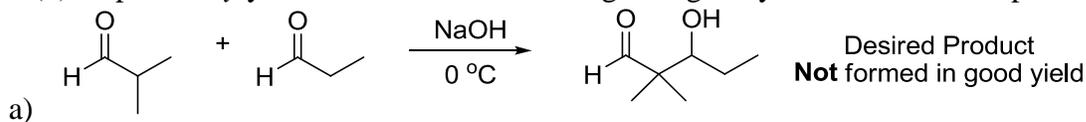
November 14<sup>th</sup>, 2016  
Time Limit: 50 minutes

Page 2: 24 points  
Page 3: 28 points  
Page 4: 24 points  
Page 5: 25 points  
**Total Possible: 101 points**  
**Scaled to 250 points**

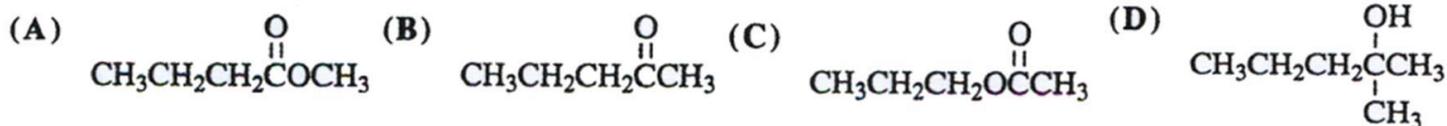
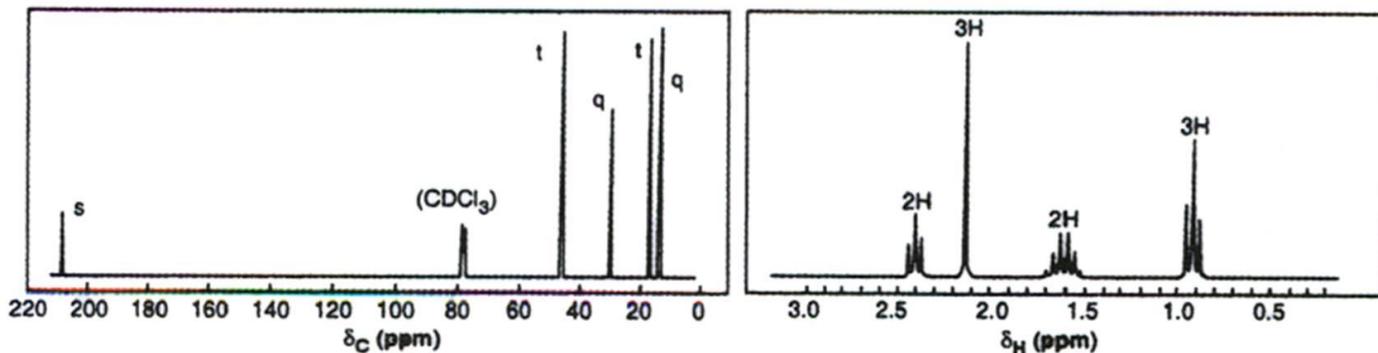
1. Rank the following *para*-substituted acetophenones regarding how fast they would react with KCN in ethanol: 1=fastest, 3=slowest. *Explain* your ranking, **and** provide the product of this reaction for *one* starting material. (11 pts)



2. The reactions below do not give the desired product in good yield. For each reaction: (13 pts)
- (1) Explain why the desired product is not formed in good yield.
  - (2) Provide new reaction conditions that would give the desired product in good yield.
  - (3) Explain *why* your new conditions would give a good yield of the desired product.

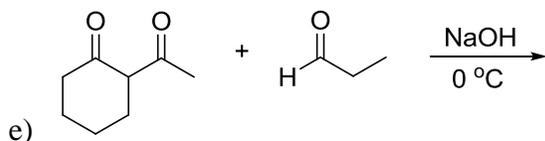
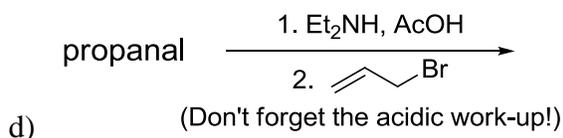
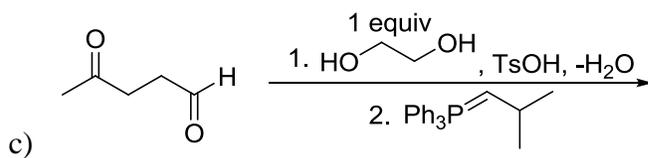
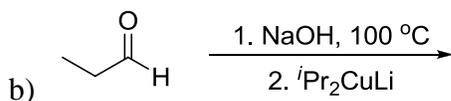
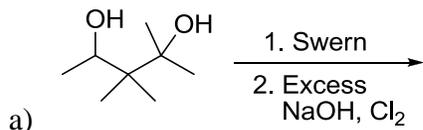


3. (1) Label the carbonyl carbon on the  $^{13}\text{C}$  NMR spectrum. (10 pts for entire problem)  
 (2) Indicate which structure matches the  $^{13}\text{C}$  and  $^1\text{H}$  NMR shown below.  
 (3) Label each set of protons on the chosen structure and their corresponding signal on the  $^1\text{H}$  NMR spectrum.

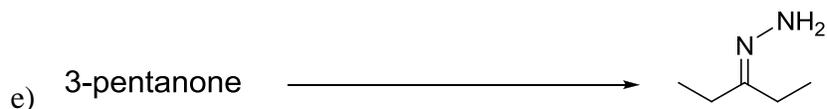
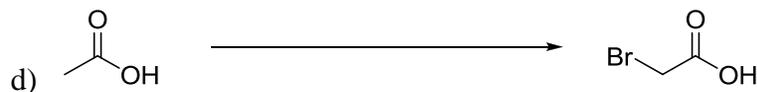
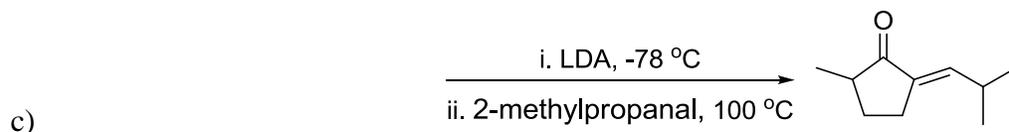
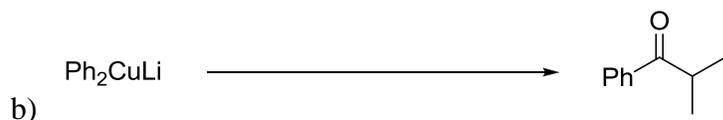
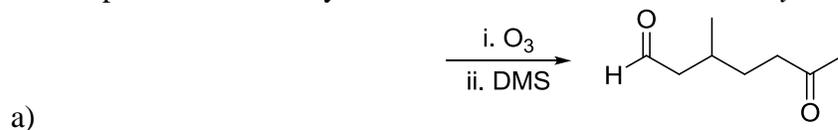


- (4) Provide a characteristic signal in this compound's IR spectrum.

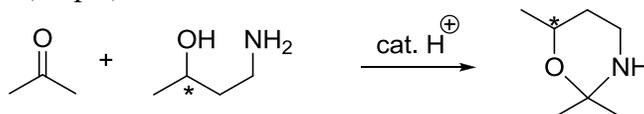
4. Provide the major product(s) of the reactions below. Assume acidic work-ups when necessary. Be sure to include *stereochemistry* and note *racemic* mixtures. (18 pts)



5. Provide the missing reactant(s) or starting material(s) for the reactions below. Assume acidic work-ups when necessary. Be sure to include *stereochemistry* where appropriate. (11 pts)

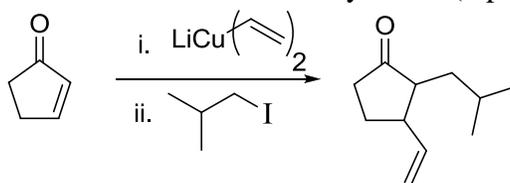


6. a) Using curved arrows to show the movement of electrons, provide a plausible mechanism for the reaction below. (13 pts)

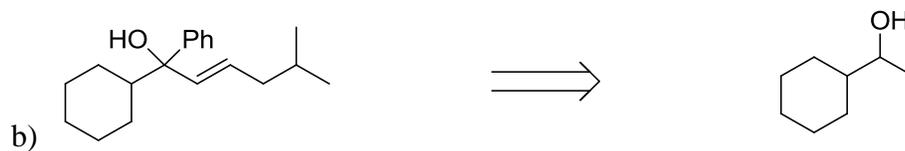
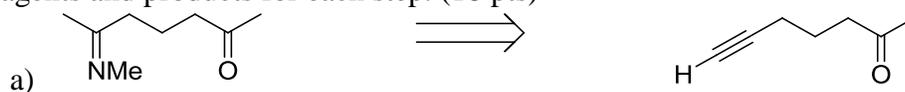


- b) In the reaction above, if the starred carbon in the starting material has an (*R*)-configuration, what is the starred carbon in the product: *R*, *S* or racemic?

7. Again, using curved arrows to show the movement of electrons, provide a plausible mechanism for the reaction below. HINT: This mechanism is very short! (7 pts)



8. Using a series of synthetic reaction steps, how could you carry out the following syntheses? Write the reagents and products for each step. (18 pts)



# CHEM 381: Integrated Lab 1

Labs: T/Th 2:00-4:50 PM, PHSC 320

## Contact Information:

**Instructor:** Dr. Monica C. So

**Phone**<sup>1</sup>: 530-898-6554

**E-mail**<sup>1</sup>: mso@csuchico.edu

**Office:** PHSC 317A

**Office hours:** Mondays, Wednesdays, and Fridays 11:00am-12:00pm (and by appointment)

## Course Description and Goals

This is the first semester of a three semester lab sequence for CHEM majors. The main goals are (1) to engage you in the laboratory application of the concepts from several of your upper division courses, (2) introduce you to the library and online tools available for searching the chemically related literature, and (3) provide a variety of opportunities for you to master the different types of writing relevant to our discipline. Both of the projects will be integrated in terms of the specific chemistry disciplines. Overall the intent is to give you a realistic view of the scientific endeavor with an opportunity to participate as “colleagues” with your classmates and instructors. Both 381 labs, taught by Drs. Miller, Ball, and So will focus on topics in physical organic and materials chemistry, respectively. In order to accomplish these goals you will have different instructors in various components; Drs. Miller/Ball will teach the first half of the semester, while Dr. So will teach the latter half.

## Grading

“The Elucidation of Conformational Preferences in Cyclohexanone by Spectroscopy” (Miller/Ball) 50%

“Fabrication and Characterization of Solution Processed Perovskite Solar Cells” (So) 50%

For Dr. So's portion of the semester, the following will be evaluated:

Item	Points
Quad Charts & Assignments	200
Oral Presentation of Results	100
Lab Performance	350
Final Lab Report	350
<b>Total Points</b>	<b>1000</b>

<sup>1</sup> I typically check my e-mail and phone messages M-F from 8 am – 4:30 pm. These times will vary somewhat according to my daily teaching schedule. I will not check e-mail and phone messages on weekends and holidays.

## Quad Charts & Assignments

During specific weeks, you will be asked to create a 2x2 chart to describe your hypotheses, experimental procedure, results, and main findings/contingency plans for this lab project. These assignments will be due on **Thursdays of Weeks 9-14**. You will also have weekly surveys to complete.

## Oral Presentation

After completing your experiment, you will be asked to present your results to the class. Although this is worth only 10% of your overall grade, this is one of the first periods to get feedback on your work. You are expected to present your fabrication, characterization, results, and any other experiments you have been able to perform at the time. This presentation will be on **Thursday of Week 15** during lab period.

## Lab Performance

As stated above, you will be graded on your performance in lab. This includes timeliness, mastery of techniques and work with instrumentation, safety, and cleanliness.

## Final Lab Report

You will be responsible for a final lab report at the end of the semester which will be graded according to the following rubric:

Item	Points
Abstract	20
Introduction	70
Experimental	30
Results/Discussion	140
Conclusions	50
Grammar/Punctuation	20
Figures/Tables/Formatting	10
References	10
<b>Total Points</b>	<b>350</b>

Late lab reports will not be accepted and will result in failure of the course and a consequential extra year toward your graduation. Reports will be due **Thursday of Week 16 (finals week) at 5pm** by emailing me a PDF.

# CHEM 382: Integrated Lab 2

Lectures: TR 2:00-4:50 PM, PHSC 320

## Contact Information:

**Instructor:** Dr. Monica C. So

**Phone**<sup>1</sup>: 530-898-6554

**E-mail**<sup>1</sup>: mso@csuchico.edu

**Office:** PHSC 304

**Office hours:** Mondays and Fridays 11:00am-12:00pm (and by appointment)

## Course Description and Goals

This is the second semester of a three semester lab sequence for CHEM majors. The main goals are (1) to engage you in the laboratory application of the concepts from several of your upper division courses, (2) introduce you to the library and online tools available for searching the chemically related literature, and (3) provide a variety of opportunities for you to master the different types of writing relevant to our discipline. Both of the projects will be integrated in terms of the specific chemistry disciplines. Overall the intent is to give you a realistic view of the scientific endeavor with an opportunity to participate as “colleagues” with your classmates and instructors. Both 382 labs, taught by Drs. So and Wasinger will focus on topics in materials and inorganic chemistry, respectively. In order to accomplish these goals you will have different instructors in various components; Dr. So will teach the first half of the semester, while Dr. Wasinger will teach the latter half.

## Grading

“Fabrication and Characterization of Polymer Battery” (So) 50%

“Synthesis and Characterization of Ruthenium (II) Tetrakis(pyridine) Complexes” (Wasinger) 50%

For Dr. So's portion of the semester, the following will be evaluated:

Item	Points
Quad Charts & Assignments	200
Oral Presentation of Results	100
Lab Performance	350
Final Lab Report	350
<b>Total Points</b>	<b>1000</b>

<sup>1</sup> I typically check my e-mail and phone messages M-F from 8 am – 4:30 pm. These times will vary somewhat according to my daily teaching schedule. I will not check e-mail and phone messages on weekends and holidays.

## Quad Charts & Assignments

During specific weeks, you will be asked to create a 2x2 chart to describe your hypotheses, experimental procedure, results, and main findings/contingency plans for this lab project. These assignments will be due on Fridays on Weeks 2-5.

## Oral Presentation

After completing your experiment, you will be asked to present your results to the class. Although this is worth only 10% of your overall grade, this is one of the first periods to get feedback on your work. You are expected to present your syntheses, characterization, results, and any other experiments you have been able to perform at the time. This presentation will be on Tuesday, March 1, 2016 during lab period.

## Lab Performance

As stated above, you will be graded on your performance in lab. This includes technique, perseverance, timeliness, thoroughness, safety, work with instrumentation, and cleanliness.

## Final Lab Report

You will be responsible for a final lab report at the end of the semester which will be graded according to the following rubric:

Item	Points
Abstract	10
Introduction	30
Experimental	80
Results/Discussion	150
Conclusions	20
Grammar/Punctuation	20
Figures/Tables/Formatting	30
References	10
<b>Total Points</b>	<b>350</b>

Late lab reports will not be accepted and will result in failure of the course and a consequential extra year toward your graduation. Reports will be due **Friday of Week 8** by emailing PDF.



3. (18) Sketch the basic setups for single beam vs. double beam absorption spectrophotometers. If you could choose one, which one would you pick? Please detail three reasons for your choice.

4. (12) Please describe the basic functioning of the hollow cathode lamp. Why do we use a hollow cathode lamp instead of a D<sub>2</sub> lamp for AA?

5. (16) You are a field chemist performing analysis for Hg in mine tailings. You collect a solid sample of soil from the mine. Please detail the **complete** atomic absorption instrument you would use to quantitate the Hg found in the soil.

6. (16) You have a liquid sample with a variety of second row transition metals which need to be identified and quantitated. Please detail the **complete** instrumental setup you would use.

7. (12) Why are reverse-bias p/n junctions used as detectors more commonly than forward bias p/n junctions? Please describe how a reverse-bias p/n junction works. Why might you choose a p/n junction over a photomultiplier tube?

**Equations, if you want them**

$$A = -\log T = \log \frac{P_0}{P} = \epsilon bc \quad \left(\frac{S}{N}\right)_n = \sqrt{n} \left(\frac{S}{N}\right)_i$$

$$n\lambda' = \frac{2d}{\cos\theta} \quad \lambda = \lambda' n_D$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1} \quad v_i = v\lambda_i \quad R = \lambda/\delta\lambda \quad R=nN$$

$$\delta=2(M-F) \quad P(\delta) = B(v)\cos(2\pi\delta v) \quad n\lambda=d(\sin i \pm \sin \theta)$$



3. (10) Please describe your favorite source for IR spectroscopy. Offer two reasons why your source might be preferred over other sources.

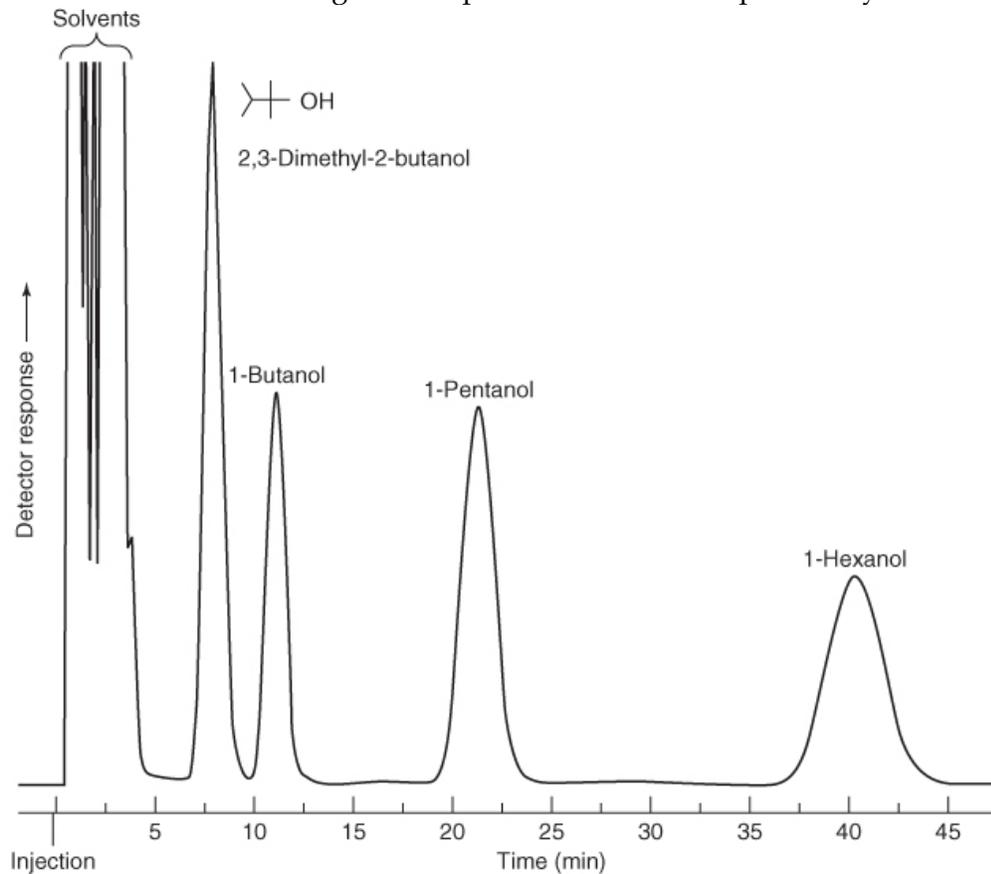
4. (15) What are the key differences between transmission and reflectance IR spectroscopies? Please sketch the instrumental setups that are used. Can you use the same detector? Why might you choose reflectance over transmittance?

5. (10) Why are lasers often used for the irradiation source for Raman spectroscopy? Could a tungsten bulb be used instead? Why or why not?

6. (15) You need to analyze a caustic liquid for dissolved  $\text{SO}_2$  content without modifying the existing sample. Please describe the **complete** instrumental setup that you would use.

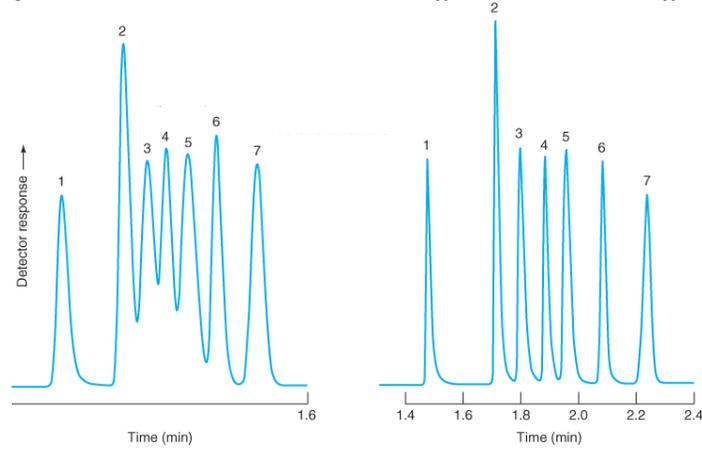
7. (10) You are doing mass spec and you need to understand the structure of a polymer with an approximate molecular mass of 15,000 Da. Which ionization source would you use? Why? Please briefly describe how it works.
8. (15) Please draw, label, and describe your favorite mass analyzer. Be sure to include approximate values for resolution and mass range.

1. The mixture of organic compounds below was separated by GC.

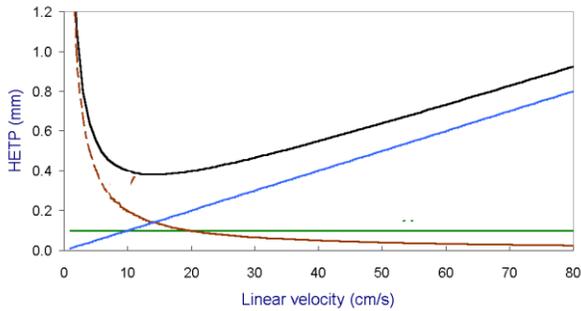


- (5) Estimating retention times to the best of your ability, what is the resolution between 2,3-dimethyl-2-butanol and 1-butanol?
- (5) Based on 1-pentanol, what is the number of theoretical plates for the column?
- (5) Propose a reason why the 1-hexanol peak is so broad.

2. An unknown mixture was analyzed, resulting in the chromatogram on the left. The analyst then optimized the conditions, resulting in the chromatogram on the right.



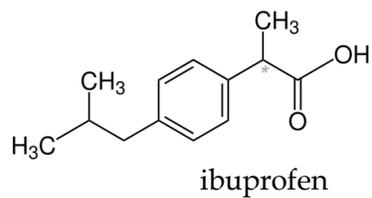
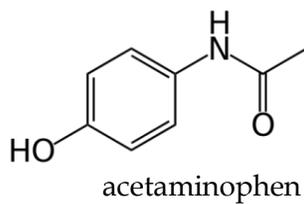
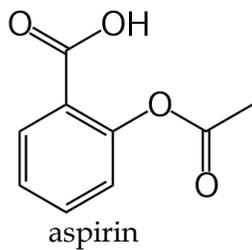
- a. (5) Why were the conditions optimized?
- b. (8) Propose two different ways the analyst could have changed the conditions to give the chromatogram on the right.
3. (15) Please label the van Deemter plot below with the correct parameters. Briefly explain each term. Using this plot, what average linear velocity would you select to run this column? Why?



4. (15) Please describe the general characteristics of an open tubular GC column (length, diameter, etc). Please describe two possible stationary phases, and why you might pick each of the two you described.

5. (10) You need to analyze samples of diesel fuel by GC. Which detector would you choose? Why? Please draw the detector and label its important components.

6. (17) You need to separate and quantitate a mixture of headache medicines (see below). Please propose a mobile phase, stationary phase, and a detector that would be suitable for this separation. How might you change the conditions if the acetaminophen and ibuprofen peaks overlapped?



7. (15) Why do most HPLC/UPLC columns use silica porous particles for support particles? What are some limitations of using silica particles? Describe one alternative to silica and why it is used.

### Equations and constants

$$t_R = t_S + t_m \quad \bar{v} = \frac{L}{t_R} \quad u = \frac{L}{t_M} \quad H = A + B/u + c_s u + c_m u$$

$$K = \frac{A_{S_2}}{A_{S_1}} \quad \alpha = \frac{t'_{R_2}}{t'_{R_1}} = \frac{k'_2}{k'_1} = \frac{K_2}{K_1} \quad k = \frac{t_R - t_m}{t_m} = \frac{C_S V_S}{C_M V_M} = K_c \left( \frac{V_S}{V_M} \right)$$

$$R = \frac{\Delta t_R}{w_{av}} = \frac{0.589 \Delta t_R}{w_{\frac{1}{2}^{av}}} = \frac{\sqrt{N}}{4} (\gamma - 1) \quad N = \frac{L}{H} = \frac{Lx}{\sigma^2} = \frac{L^2}{\sigma^2} = \frac{16t_R^2}{w^2} = \frac{t_R^2}{\sigma^2} = \frac{5.55t_R^2}{w_{1/2}^2}$$

**TABLE 24-2** Eluotropic series and ultraviolet cutoff wavelengths of solvents for adsorption chromatography on silica

Solvent	Eluent strength ( $\epsilon^\circ$ )	Ultraviolet cutoff (nm)
Pentane	0.00	190
Hexane	0.01	195
Heptane	0.01	200
Trichlorotrifluoroethane	0.02	231
Toluene	0.22	284
Chloroform	0.26	245
Dichloromethane	0.30	233
Diethyl ether	0.43	215
Ethyl acetate	0.48	256
Methyl <i>t</i> -butyl ether	0.48	210
Dioxane	0.51	215
Acetonitrile	0.52	190
Acetone	0.53	330
Tetrahydrofuran	0.53	212
2-Propanol	0.60	205
Methanol	0.70	205

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# CHEM 420: INSTRUMENTAL ANALYSIS

FALL 2017

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## COURSE INFORMATION

Class Days: Monday, Wednesday, and Friday  
Class Times: 8:00-8:50 am (you know you love it)  
Class Location: PHSC 213

Office Hours (and by appointment):  
M, W 9:00-11:00 am  
Office Hours Location: PHSC 327

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## COURSE OVERVIEW

What have our atoms and molecules been doing in our instruments all these years?

- why we made you take PHYS 204C
- atomic spectroscopy (absorption, emission, mass spec)
- molecular spectroscopy (UV-vis, IR, Raman, mass spec)
- chromatography (gas, liquid, supercritical fluid)

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## COURSE MATERIALS

The required materials for this course are

- [Instrumental Analysis](#) by Granger, Yochum, Granger, and Sienerth (ISBN 978-0-19-994231-2)
- coffee

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## COURSE ASSESSMENT AND GRADING

Your grade in this course will be comprised of the following items, which are described in more detail later.

- three in-class exams
- a comprehensive final
- weekly homework sets from the textbook
- Grades will be based on the following percentages: A, >90 %; B >80 %; C, >70 %; D, >60 %. Earning these percentages will guarantee your grade. I reserve the right to adjust the percentages downward as I see fit (for example, an 89 % might earn an A, but do not count on a curve for this course).

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## CAPSTONE SUBSTITUTION

This course combined with Chem 483 is a GE Capstone Substitution. Students who successfully complete this duo of classes have met their GE Capstone requirement, and will not have to take a different GE Capstone course. Note that completing this course does not exempt you from taking three upper-division GE courses, only that those upper-division GE courses would not have to include a capstone course.

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## ACADEMIC HONESTY

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The University adheres to a strict [policy regarding cheating and plagiarism](#). Become familiar with the policy and what academic integrity means. Any cheating or plagiarism will result in failing this class and a disciplinary review by the University. These actions may lead to probation, suspension, or expulsion.

## COURSE SCHEDULE

Week of	Topic (chapter)	Other
Aug 21	introduction (1.1) absorption and emission of light (2.2) introduction to optics (3.1-3.2)	
Aug 28	introduction to optics (3.3-3.4) signals and noise (5.1-5.3)	
Sept 4	UV/vis molecular spectrometry (6.1-6.7)	Monday holiday
Sept 11	atomic absorption spectrometry (7.1-7.2, 7.4-7.5)	
Sept 18	luminescence spectroscopy (8.1, 8.3-8.4)	exam 1, 9/22
Sept 25	atomic emission spectroscopy (all of chapter 9)	
Oct 2	x-ray techniques (10.1-10.5, 10.9)	
Oct 9	infrared spectroscopy (11.1-11.5, 11.8)	
Oct 16	Raman spectroscopy (12.1-12.3)	exam 2, 10/20
Oct 23	mass spectrometry (all of chapter 13)	
Oct 30	mass spectrometry (all of chapter 13)	
Nov 6	liquid chromatography (all of chapter 15)	
Nov 13	liquid chromatography (all of chapter 15)	exam 3, 11/17
Nov 20	fall break	get some rest
Nov 27	gas chromatography (all of chapter 16)	
Dec 4	gas chromatography (all of chapter 16)	
Dec 11	likely Friday 8 am final – fun times!	finals week

I will definitely stick with exam dates and the chapters we cover will certainly stay in this order, but the time spent on each chapter might change somewhat.

## EXAMS AND ASSIGNMENTS

### 15 HOMEWORK ASSIGNMENTS @ 10 POINTS EACH = 150 POINTS

These assignments will generally be 10-15 problems long and will cover material we have already completed in lecture. Homework is due every Wednesday in class and will generally be assigned from the book.

### 3 IN-CLASS EXAMS @ 100 POINTS = 300 POINTS

A week before the exam, I will provide you with a study guide and an equation sheet (if needed). The exams are much more about description and explanations; drawings are encouraged and occasionally required. In most cases, you should not need a calculator.

### 1 IN-CLASS FINAL @ 200 POINTS = 200 POINTS

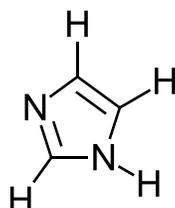
You can choose: I can write a final, or you can take the instrumental ACS final. We'll talk.

**TOTAL POINTS= 650**

Name: \_\_\_\_\_

**Chem 451**  
**February 17, 2017**  
**Exam 1 (Chapter 1-3)**  
**100 pts possible**

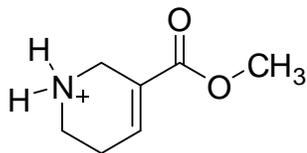
- 1) What is the  $[\text{OH}^-]$  in a  $\text{pH}=2.3$  solution? **(5 pts)**
  
- 2) Which of the twenty amino acids contain sulfur atoms? \_\_\_\_\_ and \_\_\_\_\_ **(2 pts)**
- 3) Which amino acid contains a phenol group? \_\_\_\_\_ **(1 pt)**
- 4) The conjugate acid of  $\text{H}_2\text{PO}_4^-$  is \_\_\_\_\_ **(2 pts)**
  
- 5) Shown below is the structure of imidazole. Show lone pairs of electrons and draw water hydrogen bonded at all potential hydrogen bonding sites in this molecule? **(5 pts)**



- 6) Amino acids and peptides. Please read the whole question (a-d) first and put your answer in one diagram. **(15 points)**
  - a) Write the covalent structure of the tetrapeptide Phe-Pro-Lys-His, with all functional groups in their predominant ionic forms at  $\text{pH} 7$ . **(8 pts)**
  - b) Write the 1-letter code and of the four amino acids below the structure. **(2 pts)**
  - c) Show the bond cleaved by trypsin with a dotted line. **(2 pts)**
  - d) What is net charge on this peptide at a  $\text{pH}=1$ ? **(3 pts)**

Name: \_\_\_\_\_

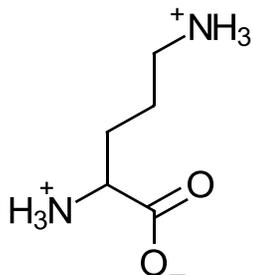
- 7) Betel nut is humanity's fourth most widely used drug after nicotine, ethanol and caffeine, and is chewed by millions of people living between the east coast of Africa and the western Pacific. Betel Nut contains the active ingredient arecoline, a natural product alkaloid that acts to stimulate the central nervous system. Arecoline has structural similarity to nicotine.



Arecoline  
 $pK_a=7.6$

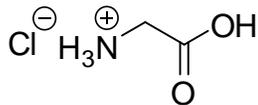
- a) Starting with arecoline, as shown above, show the acid dissociation equilibrium reaction for arecoline in water. Label HA and  $A^-$  species in this reaction. **(3 pts)**
- b) The average pH of saliva is 6.8. Calculate the **percentage** of arecoline in the HA form in typical saliva. **(6 pts)**
- c) Betel nut is usually chewed with slaked lime  $Ca(OH)_2$ . Provide a reason why you think slaked lime increase the oral uptake of arecoline in the mouth. **(4 pts)**

- 8) Ornithine is an amino acid similar to Lysine its structure at pH=7 is shown below. Based on the provided pka values ( $pK_{a1}=1.94$ ,  $Pka_2=8.65$ ,  $pK_{a3}=10.76$ ) determine the pI of this amino acid. Briefly explain your calculated pI. **(7 pts)**



Name: \_\_\_\_\_

9) (20 pts) a) You would like to make 1 liter of a 0.1 M buffer for an experiment at pH=9.6. You have solid glycine hydrochloride (MW=111.5 g/mol) and **1.0 M NaOH** on hand. Describe how to prepare this buffer. (8 pts)



Glycine-HCl

Acid	pK <sub>a1</sub>	pK <sub>a2</sub>
Glycine	2.34	9.60

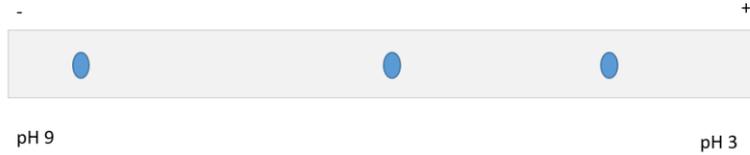
b) Draw the conjugate acid and base pair in your pH 9.6 buffer, indicating which is the acid and which is the base. (3 pts)

c) During the course of an experiment 20 millimoles of H<sup>+</sup> is generated. What would the pH be in the absence of any buffer? (Assume 1 liter volume) (3 pt)

d) If 20 millimoles of H<sup>+</sup> is generated in presence of the glycine buffer (part A) what would be the final pH? (6 pts)

10) The following three peptides are separated by isoelectric focusing. Assign the peptides to the following spots. Briefly explain your assignments.

- 1) Ala-Ser-Val-Thr
- 2) Ala-Arg-His-Val
- 3) Ala-Glu-Gly-Ser

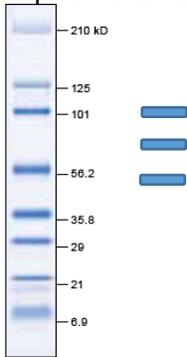


Spot Assignments: \_\_\_\_\_

**Explanation:**

11) Three proteins are analyzed by gel filtration (size exclusion) chromatography. By Gel Filtration chromatography, Protein A is determined to be 150 kD, protein B is 100 kD, and protein C is 50 kD.

- A) Which protein would you expect to elute first off the column? \_\_\_\_\_ (1.5 pts)
- B) Which protein would you expect to elute last off the column? \_\_\_\_\_ (1.5 pts)
- C) Approximately how many amino acids is protein C? \_\_\_\_\_ (3 pts)
- D) The sample containing the proteins A, B, and C are then analyzed by SDS PAGE in the presence of the reducing agent  $\beta$ -mercaptoethanol. On the left shows the MW standard. On the right shows the sample. What new information is learned about the proteins from this analysis? Briefly explain. (6 pts)



E) \_\_\_\_\_

Name: \_\_\_\_\_

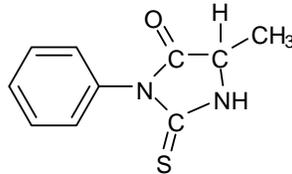
**13) Determine the sequence of the following hexapeptide from the following results. (12 pts)**

The amino acid determination by hydrolysis with 6 M HCl at 110° C indicates the peptide contains the following amino acids.

Ser Lys Met Phe Ala

a) Trypsin has no effect on the heptapeptide.

b) One cycle of Edman degradation renders:



c) Chymotrypsin treatment yields three fragments a dipeptide, a tripeptide, and Lys.

d) Cyanogen bromide treatment generates a tetrapeptide and a positively charged dipeptide.

Follow-up: Is there any uncertainty in your sequence assignment? If yes, what further analysis would you propose to eliminate the uncertainty?

1 (30)	2 (20)	3 (20)	4 (18)	5 (12)	Total (100)

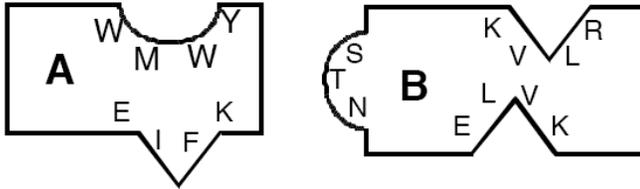
**Chem 451**  
**October 17, 2018**  
**Exam 3**  
100 pts possible

**Multiple Choice (3 pts each, 15 pts total)**

- 1) Which of the following is a type of **covalent bond** that links small subunits together in larger proteins?
  - a) Van der Waals interactions
  - b) Hydrogen bonds
  - c) Ionic interactions
  - d) Hydrophobic interactions
  - e) Disulfide bonds
  
- 2) Which group of amino acids are **most likely** found on the exterior of a water soluble globular protein?
  - a) His, Glu, Ser
  - b) Val, Phe, Trp
  - c) Ile, Met, Tyr
  - d) Leu, Val, Phe
  
- 3) What do  $\alpha$ -helices and  $\beta$ -sheets have in common?
  - a) Both are stabilized by hydrogen bonding involving carbonyl oxygens and amide nitrogens.
  - b) The same amino acids stabilize both forms of secondary structure.
  - c) The physical length of a 10-amino acid  $\alpha$ -helix and  $\beta$ -sheet strand will be the same.
  - d) Both are stabilized by glycine and proline residues.
  - e) All of the above.
  
- 4) Which of the following forces are primarily involved in maintaining the secondary structure of a protein?
  - a) Hydrogen bonds
  - b) Covalent bonds
  - c) Ionic interactions
  - d) Hydrophobic interactions
  
- 5) When a protein is denatured
  - a) Its secondary and tertiary structure is disrupted but its primary structure remains intact.
  - b) Its primary structure is disrupted but its secondary and tertiary structure remains intact.
  - c) It is broken apart into its constituent amino acids.
  - d) It becomes all  $\alpha$ -helix.
  - e) Both A and C are correct
  
- 6) Predict which amino acid substitution would show the greatest effect (circle choice) and briefly describe the possible effect on a globular protein's structure (Be specific). **(8 pts)**  
**(a) Gly** (Buried inside a large globular protein)  $\rightarrow$  Phe or Ala

(b) Valine (in  $\alpha$ -helix)  $\rightarrow$  Proline or Leucine

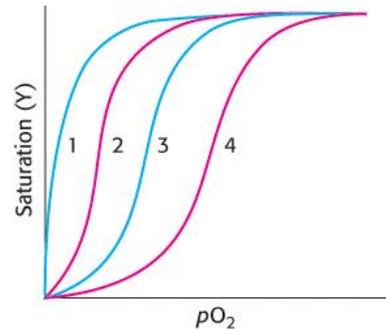
- 7) For proteins A and B below, draw the most likely A:B dimer and briefly explain sources of specificity in quaternary structure. (8 pts)



- 8) In *E. coli* an estimated 10-15% of cellular proteins require the resident chaperonin system, called GroEL/GroES, for folding under normal conditions. Binding partially folded protein by GroEL/GroES leads to the hydrolysis of ATP. What are two problems that proteins encounter when folding and why might a chaperonin system be required? (8 pts)
- 9) The  $pK_a$  of an acid depends partly on its environment. Predict the effect of the following environmental changes on the  $pK_a$  of a glutamic acid side chain. Explain your reasoning. (6 pts)

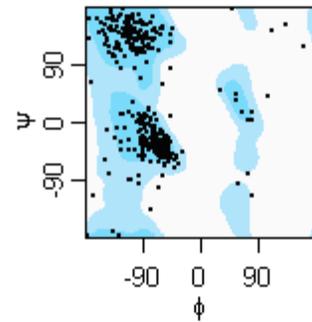
The glutamic acid side chain is shifted from the exterior of the protein where it is exposed to aqueous solvent to a nonpolar pocket.

10) The illustration below shows several oxygen-dissociation curves. Assume that curve 3 corresponds to hemoglobin with physiological concentrations of  $\text{CO}_2$  and 2,3-BPG at pH 7. Which curves represent each of the following perturbations? (8 pts)



- |                                 |              |
|---------------------------------|--------------|
| a) Decrease in $\text{CO}_2$    | Curve: _____ |
| b) Increase in 2,3-BPG          | Curve: _____ |
| c) Increase in pH               | Curve: _____ |
| d) Loss of quaternary structure | Curve: _____ |

11) On the right is a Ramachandran plot showing dots for each amino acid in a protein (assume the protein is about 250 amino acids). (10 pts)



a) What can you conclude about the secondary structure of this protein?

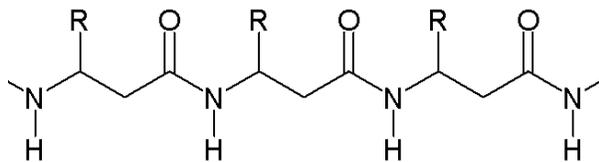
b) What do the two axis on the plot represent? Be specific.

c) What do the shaded regions represent?

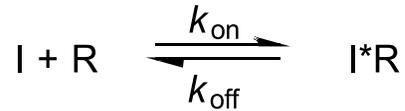
12) Peptides comprised of  $\beta$ -amino acids are also possible, but are not synthesized via the genetic code. (4 pts, +3 bonus points)

On the structure below, clearly label the backbone bond(s) in the structure that are expected to have restricted rotation at room temperature with an **X**.

Bonus Question: Consider how a Ramachandran plot of a protein made of  $\beta$ -amino acids would be fundamentally different. Provide an explanation of the key difference.



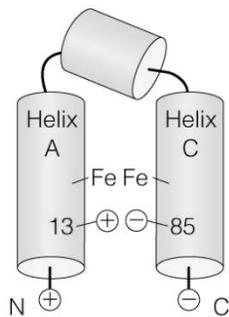
13) (18 pts) Consider the following equilibrium between insulin (I) and its receptor (R) to form the insulin receptor complex (I•R).



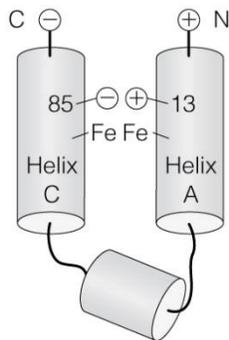
- (a) Write the rate expression for the association of the I•R complex and the dissociation of the I•R complex. (4 pts)
- (b) Derive an expression that relates  $K_d$  (dissociation constant) to the rate constants ( $k_{\text{on}}$  and  $k_{\text{off}}$ ). (4 pts)
- (c) The  $K_d$  for the insulin receptor-insulin interaction is 0.1 nM. In what concentration range of insulin would you expect greater than 50% of the receptor sites to be bound to insulin? (3 pts)
- (d) Binding of Insulin to the insulin receptor is important for triggering uptake of glucose into cells. Individuals with type I diabetes do not produce enough insulin to stimulate this response and their cells starve for glucose. Mutant insulin syndrome is a rare genetic disease where individuals produce insulin with a mutation of leucine in place of alanine at position three of the insulin peptide. This amino acid substitution significantly decreases insulin's affinity for the receptor. **What would be the resulting effect on the  $K_d$ ? Provide a hypothesis for why this mutation might have this effect.** (7 pts)

14) A new oxygen-transport protein has been discovered. X-ray diffraction of the deoxy protein reveals that it has the dimeric structure shown here. Each subunit contains a salt bridge between residues histidine 13 and aspartic acid 85. The two monomers interact by salt bridges between the C- and N- termini. The O<sub>2</sub>-binding site lies between the two iron atoms shown, which are rigidly linked to helices A and C (figure (b)). In the deoxy form, the space between the iron atoms is too small to hold O<sub>2</sub>, and so the Fe atoms must be forced apart when O<sub>2</sub> is bound. Answer the following questions, **explaining your answer in each case in terms of the structures below.** (15 pts)

- a) Is this molecule likely to show cooperative oxygen binding?
- b) Is this molecule likely to exhibit a Bohr Effect?
- c) Predict the likely effect of a mutation that replaced aspartic acid 85 by a lysine residue.



(d)



(b) Detail of the oxygen-binding site in the oxy form.

(a) Structure of homodimeric deoxy protein. N and C denote N-termini and C-termini.

1 (15)	2 (30)	3 (22+3)	4 (18)	5 (15)	Total (100) 103 possible

**Chem 451**  
**October 29, 2015**  
**Exam 3**  
 100 pts possible

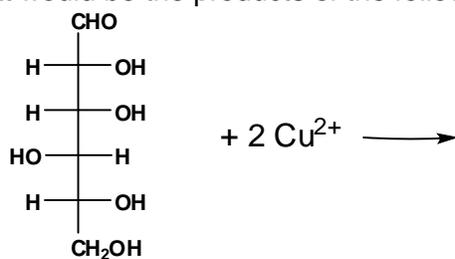
1) (a) Draw the Fischer projection for D-Mannose, the C-2 epimer of D-glucose. (4 pts)

(b) Draw a disaccharide which is  $\beta$ -D-mannopyranosyl (1 $\rightarrow$ 4) D-Glucopyranose. Circle the two anomeric carbons (6 pts)

(c) Is  $\beta$ -D-mannopyranosyl (1 $\rightarrow$ 1)  $\beta$ -Glucopyranose a reducing sugar? Explain why or why not. (4 pts)

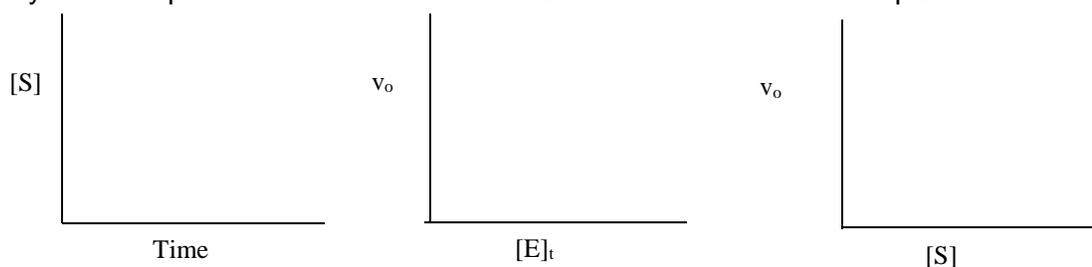
2) In reference to their stereochemistry,  $\alpha$ -D-glucose and  $\beta$ -D-glucose, are considered to be \_\_\_\_\_ of each other. The process that interconverts to two is \_\_\_\_\_. (3 pts)

3) What would be the products of the following reaction? (5 pts)



**4) (6 pts)** (a) Compare and contrast the structure and biological function of glycogen and cellulose. In what ways are they similar, and in what ways do they differ?

**5) (6 pts)** For a typical enzymatic reaction, draw curves that show the appropriate relationships between the variables in each plot. The trend and shape of the curve are important.  $[E]_t$  relates to enzyme amount in assay. For the plots with time on x-axis assume the reaction reaches equilibrium over the time scale shown.



**6) (3 pts)** Binding of a water molecule to the zinc ion on carbonic anhydrase induces

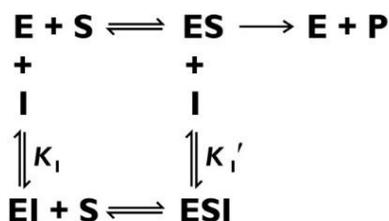
- a hydronium ion to form.
- a large conformation change in the binding site.
- ionization of a his residue, which functions as a strong nucleophile.
- a lowered  $pK_a$  for water, which leads to formation of a zinc bound hydroxide ion.
- an altered  $K_M$  value.

**7) (8 pts)** For a reaction that can take place with or without catalysis by an enzyme, what would be the effect of the enzyme on the:

- standard free energy change of the reaction?
- activation energy of the reaction?
- initial velocity of the reaction?
- equilibrium constant of the reaction?

**8) (6 pts)** Enzyme A catalyzes the reaction  $S \rightarrow P$  and has a  $K_m$  of  $50 \mu\text{M}$  and a  $V_{max}$  of  $100 \text{ nM s}^{-1}$ . Enzyme B catalyzes the reaction  $S \rightarrow Q$  and has a  $K_m$  of  $5 \text{ mM}$  and a  $V_{max}$  of  $120 \text{ nM s}^{-1}$ . When  $100 \mu\text{M}$  of S is added to a mixture containing equivalent amounts of enzyme A and B, after one minute which reaction product will be more abundant: P or Q and why?

9) (5 pts) On the scheme below, identify which interconversions (i.e. steps) are relevant to (a) pure competitive inhibition and (b) pure uncompetitive inhibition.



10) (4 pts) In many enzyme assays, the natural substrate and product are not used. Why?

11) (3 pts) Riboflavin is a water-soluble organic substance that is not synthesized by humans. Metabolically, it is chemically converted into a substance called flavin adenine dinucleotide, which is required by succinate dehydrogenase. Which of the following statements is **most** correct?

- Riboflavin is a coenzyme.
- Flavin adenine dinucleotide is a vitamin.
- Succinate dehydrogenase is a coenzyme.
- Flavin adenine dinucleotide is a coenzyme.

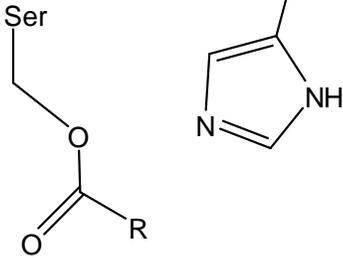
12) (8 pts) Enzyme binding energy is important to understanding the catalytic power of enzymes. Provide a specific example of how binding energy plays an important role in the specificity and huge rate enhancement in enzymatic catalysis?

**11) (15 pts)** A modified enzyme active site is shown below. **A)** Most likely this acyl enzyme intermediate belongs to this class of enzymes.

- a) isomerase
- b) oxidoreductase
- c) lyases
- d) hydrolase

**b)** From this intermediate show clearly by the way of a detailed electron arrow pushing mechanism how the active enzyme could be regenerated.

Acyl Enzyme Intermediate



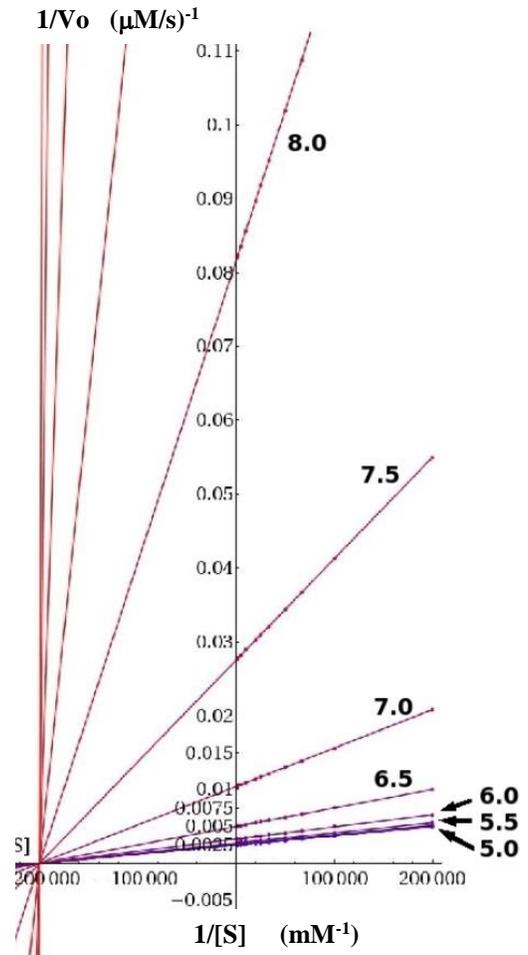
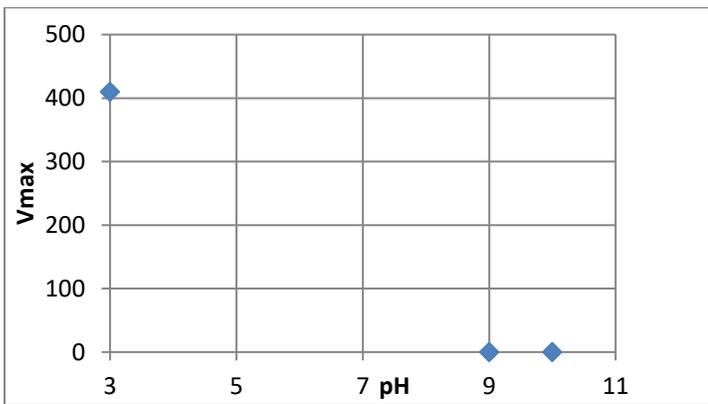
c) Provide a brief explanation how an oxyanion hole might be beneficial to this enzyme?

Name: \_\_\_\_\_

**12) (14 pts) (a)** You are studying an enzyme and find that its activity is influenced by pH. At right are double-reciprocal plots of  $1/V_o$  vs.  $1/[S]$  at different values of pH. The enzyme concentration is the same in all cases. **(6 pts)**

pH	Apparent $V_{max}$
pH 5.0	
pH 5.5	
pH 6.0	
pH 6.5	
pH 7.0	
pH 7.5	
pH 8.0	

**(b) Fill** Plot your estimates of the apparent  $V_{max}$  as a function of pH on the graph below. **(3 pts)**



**(c)** Does pH exert its effect on  $k_{cat}$ , on  $K_m$ , both, or neither? Explain your reasoning. **(5 pts)**

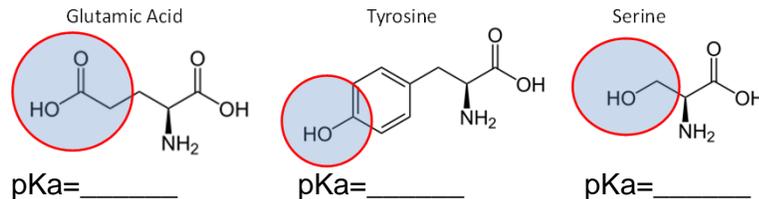
**(d)** Propose a specific explanation for the mechanism of inhibition by pH. Explain your reasoning. **(5 pts)**

1 ( 22 pts)	2( 29 pts)	3 (20 pts)	4 (15 pts)	5 (14 pts)

**Chem 451**  
**September 22, 2017**  
**Exam 1**  
**100 pts possible**

**Identification and fill in blank (13 points)**

- Which of the following solutions would you expect to have the **highest** pH? Circle your choice.  
 0.1 M HCl                      0.1 M Acetic Acid (pKa= 4.76)                      0.1 M Formic Acid (pKa=3.75)
- Which of the twenty amino acids is achiral? \_\_\_\_\_
- Which amino acid residue in protein commonly forms disulfide bonds? \_\_\_\_\_
- What are the normal species in a phosphate buffer at pH=7 (The three pKa values for H<sub>3</sub>PO<sub>4</sub> are 2.1, 6.8, 12.3)? \_\_\_\_\_ and \_\_\_\_\_
- Methanol can be expected to form a maximum number of \_\_\_\_\_ hydrogen bonds with water.
- For the following amino acid R-groups provide approximate pKa values.



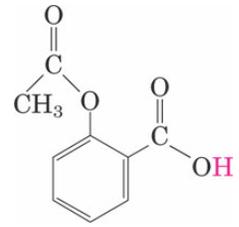
**7) Amino acids and peptides. Please read the whole question (A-C) first and put your answer in one diagram. (10 points)**

- Write the covalent structure of the tetrapeptide Gln-Pro-Arg-His, with all functional groups in their predominant ionic forms at pH 7. **(6 pts)**
- Write the 1-letter code and of the four amino acids below the structure. **(2 pts)**
- Show the bond cleaved by trypsin with a dotted line. **(2 pts)**

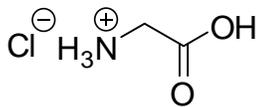
- What is approximate pI of this peptide? Show your work for full credit. *Using a table to tabulate charge at different pH values is recommended but not necessary.* (pKa<sub>carboxy terminus</sub>=3.0, pKa<sub>His R</sub>=6.0, pKa<sub>amino terminus</sub>=8.0, pKa<sub>Arg R</sub>=12.5) **(5 pts)**

Name: \_\_\_\_\_

8) Aspirin is a weak acid with a  $pK_a$  of 3.5 (the ionizable H is shown in red). The pH of the stomach contents is about 1.5, and the pH of the contents of the small intestine is about 6. Is more aspirin absorbed into the bloodstream from the stomach or from the small intestine? Clearly justify your choice. (5 pts)



9) (20 pts) a) You would like to make 1 liter of a 0.1 M buffer for an experiment at pH=9.6. You have solid glycine hydrochloride (MW=111.5 g/mol) and either **2.0 M NaOH** or **2.0 M HCl** on hand. Describe how to prepare this buffer. (8 pts)



Glycine-HCl

Acid	$pK_{a1}$	$pK_{a2}$
Glycine	2.34	9.60

b) Draw the conjugate acid and base pair in your pH 9.6 buffer, indicating which is the acid and which is the base. (3 pts)

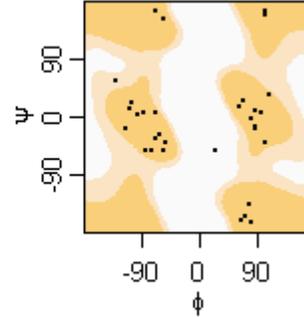
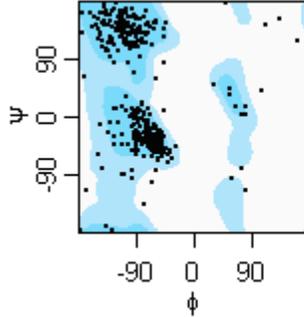
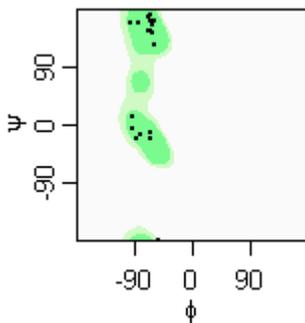
c) During the course of an experiment 20 millimoles of  $H^+$  is generated. What would the pH be in the absence of any buffer? (Assume 1 liter volume) (3 pt)

d) If 20 millimoles of  $H^+$  is generated in presence of the glycine buffer (part A) what would be the final pH? (6 pts)

**10)** All of the L-amino acids have an S-absolute configuration except L-cysteine, which has the R configuration. Draw L-cysteine and explain why cysteine is different? Why do the L- and D- designations continue to be used in biochemistry although we use R- and S- throughout organic chemistry? **(7 pts)**

**11)** Ramachandran plots are often used by X-ray crystallographers to evaluate how reasonable a protein model is. **(10 pts)**

- a) Shown are three separate Ramachandran plots. Each plot represents data for a single amino type in typical globular proteins. Assign these plots to Glycine, Glutamine, and Proline residues and briefly explain your assignments.



- b) Draw the amino acid that corresponds to the plot on the left and explain why the Ramachandran plot for this amino acid looks this way.

**12)** The following reagents are often used in protein chemistry: **(8 pts)**

CNBr	Trypsin	Ninhydrin	Urea	Chymotrypsin
Performic Acid	6M HCl	Mercaptoethanol	Phenyl isothiocyanate (Edman's Reagent)	

Which one is the best suited for accomplishing each of the following tasks?

- (a) Determination of the amino acid sequence of a small peptide.  
 (b) Reduction of disulfide bonds?  
 (c) Hydrolysis of peptide bonds on the carboxyl side of aromatic residues?  
 (d) Cleavage of peptide bonds on the carboxyl side of methionine.

Name: \_\_\_\_\_

13) A biochemist is attempting to separate a DNA-binding protein (protein X) from other proteins in a solution. Only three other proteins (A, B, and C) are present. The proteins have the following properties: (6 pts)

	pI	Size (kD)	Bind to DNA?
Protein A	7.4	82,000	Yes
Protein B	3.8	21,500	Yes
Protein C	7.9	23,000	No
Protein X	7.8	22,000	Yes

What type of protein separation techniques might she use to separate

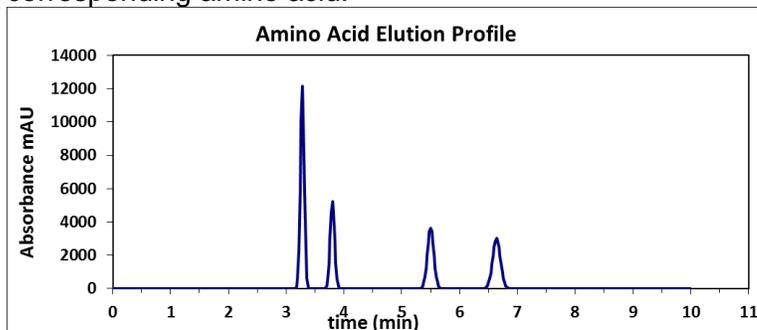
- a) protein X from protein A? \_\_\_\_\_  
 b) protein X from protein B? \_\_\_\_\_  
 c) protein X from protein C? \_\_\_\_\_

14) Draw a short segment of the peptide backbone for two parallel  $\beta$ -strands that are part of a  $\beta$ -sheet and show the primary way these strands interact with each other. (R groups can be omitted for clarity) (8 pts)

15) The following peptide is completely hydrolyzed with 6 M HCl at 110°C overnight. (8 pts)



The amino acid hydrolysis products are reacted with ninhydrin to label the amino acids then analyzed by cation exchange chromatography (sulfonated polystyrene resin) with a pH gradient elution with citrate buffer. The following chromatogram is obtained (note: only the amino acid products are shown). Label the peaks with the corresponding amino acid.



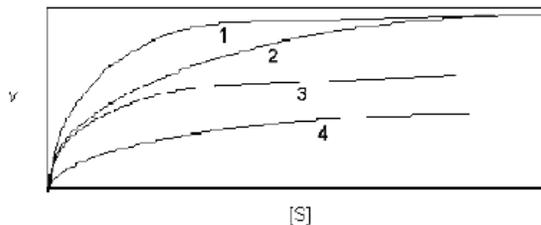
a) Briefly explain your elution order and why only four peaks are obtained.

1 (28)	2 (25)	3 (25)	4 (22)	Total (100)

**Chem 451**  
**Dec 15, 2017**  
**Final Exam**  
 150 pts possible

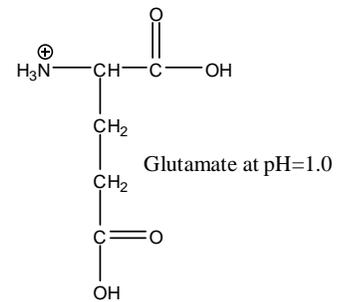
Multiple Choice (50 pts total, 2.5 pts each)

- Which of the following is a type of covalent bond that links small subunits together in larger proteins?
  - Van der Waals interactions
  - hydrogen bonds
  - ionic interactions
  - hydrophobic interactions
  - disulfide bonds
- What would be the approximate pH of a buffer solution prepared by mixing 50 mL of 1.0 M acetic acid and 5 mL of 1.0 M sodium acetate. ( $pK_a$  acetic acid=4.8)
  - 1.8
  - 3.8
  - 4.8
  - 5.8
  - 7.0
- The  $K_m$  is:
  - Equal to the product concentration at initial reaction conditions.
  - Equal to the substrate concentration when the reaction rate is half its maximal value.
  - Proportional to the standard free energy
  - Equal to the reaction rate when the enzyme is half saturated.
  - None of the above
- Which group of amino acids are **most likely** found on the exterior of a protein?
  - His, Glu, Ser
  - Val, Phe, Trp
  - Ile, Met, Tyr
  - Leu, Val, Phe
- In the Michaelis-Menten plot below, the uninhibited reaction is described by curve 1. **The effect of a competitive inhibitor is best represented by curve:**
  - 1
  - 2
  - 3
  - 4



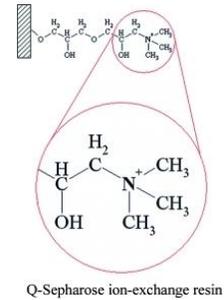
- When the concentration is much larger than the  $K_m$  the rate of an enzyme reaction with respect to substrate concentration is most nearly
  - zero order
  - first order
  - second order
  - cannot be determined
- Choose the correct path taken by a pair of electrons as it travels down the electron-transport chain.
  - NADH  $\rightarrow$  complex I  $\rightarrow$  complex II  $\rightarrow$  Complex III  $\rightarrow$  Cyt c  $\rightarrow$  complex IV  $\rightarrow$  O<sub>2</sub>
  - FADH<sub>2</sub>  $\rightarrow$  complex I  $\rightarrow$  CoQ  $\rightarrow$  Complex III  $\rightarrow$  Cyt c  $\rightarrow$  complex IV  $\rightarrow$  O<sub>2</sub>
  - NADH  $\rightarrow$  complex I  $\rightarrow$  CoQ  $\rightarrow$  Complex III  $\rightarrow$  Cyt c  $\rightarrow$  complex IV  $\rightarrow$  O<sub>2</sub>

- 4)  $\text{FADH}_2 \rightarrow \text{complex II} \rightarrow \text{CoQ} \rightarrow \text{Complex III} \rightarrow \text{Cyt c} \rightarrow \text{complex IV} \rightarrow \text{O}_2$
- 1 and 2
  - 1 and 4
  - 2 and 3
  - 3 and 4
  - 1 and 3
8. What do  $\alpha$ -helices and  $\beta$ -sheets have in common?
- Both are stabilized by hydrogen bonding involving carbonyl oxygens and amide nitrogens.
  - The same amino acids stabilize both forms of secondary structure.
  - The length of a 10-amino acid  $\alpha$ -helix and  $\beta$ -sheet strand will be the same.
  - Both are stabilized by glycine and proline residues.
  - All of the above.
9. A single methanol  $\text{CH}_3\text{OH}$  molecule can form a maximum of this number of hydrogen bonds:
- 2
  - 3
  - 4
  - 5
  - 6
10. In what pH range would you expect glutamate to have a net charge = -1.  
( $\text{pK}_a \text{COOH}=2.19$ ,  $\text{pK}_a \text{NH}_3^+=9.67$ ,  $\text{pK}_a \text{COOH side chain}=4.25$ )
- Less than 2.19
  - From 2.19-4.25
  - From 4.25-9.67
  - Greater than 9.67
11. Which of the following forces are primarily involved in maintaining the secondary structure of a protein?
- Hydrogen bonds
  - Covalent bonds
  - ionic interactions
  - hydrophobic interactions
12. Which of the following is false?
- Enzymes force reactions to proceed in only one direction.
  - Enzymes speed up reaction rates.
  - Enzymes alter activation energy of the reaction.
  - Enzymes allow reactions to reach equilibrium faster.
  - Enzyme do not alter the standard free energy change of a reaction.
13. Which of following is an anomeric pair?
- D-glucose and D-fructose
  - D-glucose and L-fructose
  - D-glucose and L-glucose
  - $\beta$ -D-glucose and  $\alpha$ -D-glucose
  - $\beta$ -D-glucose and  $\alpha$ -L-glucose
14. Which of the following is NOT a coenzyme necessary in the function of pyruvate dehydrogenase complex?
- Lipoic acid
  - Thiamine pyrophosphate
  - $\text{NAD}^+$



Name: \_\_\_\_\_

- d) Ubiquinone
- e) Coenzyme A

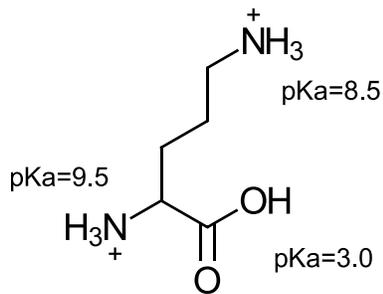


15. Which protein would be expected to bind most tightly to a (Q-sepharose) anion exchange resin at a pH=8.0?
- a) Protein A, MW=100 kD, and pI=8.0
  - b) Protein B, MW=50 kD, and pI=6.0
  - c) Protein C, MW=75 kD, and pI=4.0
  - d) Protein D, MW=200 kD, and pI=10.0
16. The enzyme that catalyzes the committed step at an early stage in an ATP producing pathway is under allosteric control. What effect would you expect ATP to have on this enzyme?
- a) ATP would bind at the active site and would activate the enzyme.
  - b) ATP would bind to the active site and would inhibit the enzyme.
  - c) ATP would bind at an allosteric site and would activate the enzyme.
  - d) ATP would bind at an allosteric site and would decrease the activity of the enzyme.
17. Of the electron transfer complexes associated with the inner mitochondrial membrane, which is not involved in generation of a proton gradient?
- a) Cytochrome oxidase (complex IV)
  - b) Cytochrome bc1 (complex III)
  - c) Succinate-Q reductase (complex II)
  - d) NADH-Q reductase (complex I)
18. Acyl groups generated during metabolic processes involving carbohydrates and fatty acids are activated by attachment to
- a) Glyceraldehyde-3-phosphate
  - b) pyruvate
  - c) coenzyme A
  - d) thiamine pyrophosphate
19. For a given reaction of A (substrate) being converted to B (product), how might this reaction in the cell still proceed from A to B even if the  $\Delta G'^{\circ}$  is positive?
- a) Deplete substrate A to produce more product B
  - b) Deplete product B to facilitate more B production
  - c) You cannot alter the  $\Delta G'^{\circ}$ , and as such, the reverse reaction will always dominate
  - d) Increase the kinetic energy to drive more molecules to the transition state
  - e) Add an enzyme specific for this reaction
20. Oxygen is not used at any point in the citric acid cycle. However, the cycle will not work without oxygen because
- a) Molecular O<sub>2</sub> will regulate many of the enzyme steps.
  - b) Oxygen is necessary to transcribe and translate enzyme for the reactions.
  - c) Oxygen is needed to regenerate electron carriers.
  - d) Not enough energy is generated without O<sub>2</sub> to run the cycle.

**Part 2 (100 pts) Choose 10 of 12 to Answer (The best 10 will count towards your final score)**

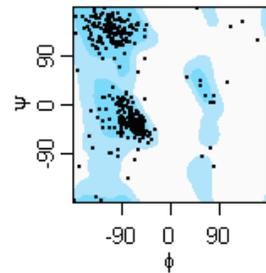
1) a) Draw the structure of the following peptide at pH=7. Cys-Val-Pro (5 pts)

b) Ornithine is an amino acid that is an important intermediate in the Urea cycle. It has the following structure in the fully protonated form (pKa values are provided). Determine the pI of ornithine and show predominant structure at the isoelectric pH. (4 pts)

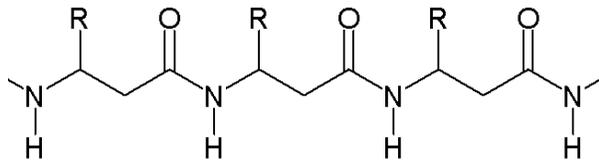


c) What common amino acid is Ornithine most similar to? \_\_\_\_\_ (three letter code) (1 pt)

2) a) On the right is a Ramachandran plot showing dots for each amino acid in a protein (assume the protein is about 250 amino acids). What are the two axis on the plot and what do the blue shaded regions represent? (5 pts)



b) Peptides comprised of  $\beta$ -amino acids are also possible, but are not synthesized via the genetic code. Consider how a Ramachandran plot of a protein made of  $\beta$ -amino acids would be fundamentally different. Provide an explanation of the key difference. (5 pts)



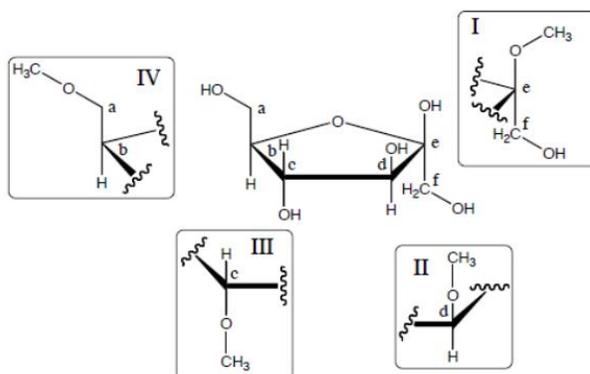
Name: \_\_\_\_\_

3) a) Draw the Fischer projection structures of the three possible trioses. Also, provide names. (3 pts)

b) Describe the primary structural difference between starch and cellulose? How do these structural differences impact the physical properties and digestibility of these polysaccharides? (5 pts)

c) Which one of the following chemical modifications (I-IV) would result in the conversion of D-fructofuranose from a reducing carbohydrate to a non-reducing carbohydrate? (2 pts)

- A) I
- B) II
- C) III
- D) IV
- E) None of the above



4) The kinetic parameters of three different liver esterases thought to be the main cocaine metabolizing enzymes in the liver are shown. The substrate used was cocaine.

Enzyme	K <sub>m</sub>	k <sub>cat</sub>
Gut esterase	0.64 μM	7 s <sup>-1</sup>
hCE-1 (human liver esterase-1)	0.39 mM	7 min <sup>-1</sup>
hCE-2 (human liver esterase-2)	0.12 mM	10 min <sup>-1</sup>

a) Which of the esterases is more active towards cocaine? Briefly explain how you know. (5 pts)

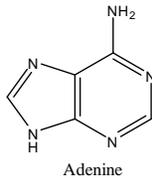
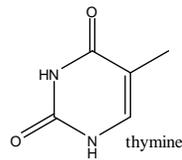
b) If the *in vivo* concentration of cocaine = 5 μM. What would be the rate of hCE-1 be as a percentage of V<sub>max</sub>? (5 pts)

Name: \_\_\_\_\_

5) Given the structure of the thymine and adenine bases

a) Draw the structure for 2'-deoxythymidine 3'-monophosphate. (3 pts)

b) Draw an AT base pair showing hydrogen bonding and the location of the major and minor grooves on the base pair. (3 pts).



a)

b)

c) Provide a specific justification for why DNA synthesis uses nucleoside triphosphates (dATP, dTTP, dCTP, dGTP) instead of nucleoside monophosphates (dAMP, dTMP, dCMP, dGMP). (4 pts)

6) a) Hemoglobin binds  $O_2$  with high affinity. In fact, it is over 95% saturated with  $O_2$  in the lungs. Provide two specific factors that contribute to efficient  $O_2$  offloading in the tissue. Relate these factors to **specific structural features** within the hemoglobin protein. (5 pts)

b) Genetic testing of a newborn baby has found that a specific Arg residue in the central cavity Hb is mutated to an Ala. Crystal structures show this Arg residue normally interacts with 2,3-BPG. Propose a physiological effect of this mutation. Explain why this would affect Hb in this way. (5 pts)

Name: \_\_\_\_\_

**7) a)** Indicate the highest level of protein structure that is most applicable to each of the following **(4 pts)**:

- \_\_\_\_\_ : A protein with three subunits
- \_\_\_\_\_ : Amino acid sequence
- \_\_\_\_\_ : A hydrogen bond between the R-groups of two serines
- \_\_\_\_\_ : Peptide backbone hydrogen bonding

b) Predict which amino acid substitution would show the greatest effect (circle choice) and briefly describe the possible effect on a globular protein's structure (Be specific). **(6 pts)**

**(a)** Aspartate (involved in binding  $Mg^{2+}$ ) → Glutamate or Lysine

**(b)** Valine (in  $\alpha$ -helix) → Proline or Leucine

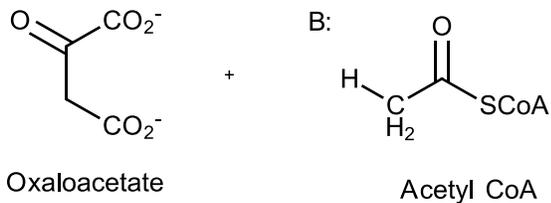
**8)** Starting with glucose draw out the first five steps of glycolysis providing structures of intermediates, co-substrates (i.e. ATP, ADP, etc) and enzyme names. **(10 pts)**

Name: \_\_\_\_\_

9) a) Under aerobic conditions lactate can act as a metabolic fuel for the production of ATP. How much net ATP can be produced by one molecule of lactate. Assume where appropriate  $1 \text{ NADH} = 2.5 \text{ ATP}$  and  $1 \text{ FADH}_2 = 1.5 \text{ ATP}$ . Outline the pathways involved and show all work for full credit. (6 pts)

b) Under anaerobic conditions yeast will consume glucose faster and will start producing  $\text{CO}_2$  and ethanol. Why does glucose consumption increase and how does this relate to production of  $\text{CO}_2$  and ethanol. (4 pts)

10) a) Given the structure of Oxaloacetate and Acetyl CoA provide a stepwise mechanism showing the formation of citrate by citrate synthase. (7 pts)



b) The citric acid cycle is an amphibolic pathway. What does that mean? (3 pts)

11) a) Substrate level phosphorylation is fundamentally different from oxidative phosphorylation. Provide a specific example of each and identify the source of free energy (through energy coupling) that provides the driving force for ATP production for each. **(5 pts)**

b) What happens to the ratio of ATP produced versus the amount of O<sub>2</sub> consumed when electron transfer and ATP synthase are uncoupled? Explain. **(5 pts)**

12) The following reaction is catalyzed by a single enzyme and is an important step in the biosynthesis of cholesterol. NADP<sup>+</sup> is like NAD<sup>+</sup> and NADPH is like NADH. Answer the following.

A) Is this an oxidation or reduction? **(2 pts)** \_\_\_\_\_

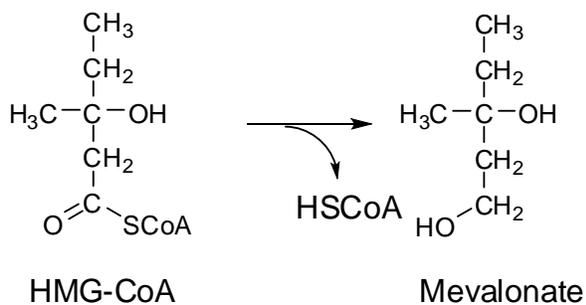
B) How many electrons are transferred (Hint: use oxidation numbers)? **(2 pts)** \_\_\_\_\_

C) In the direction shown does this enzyme use NADP<sup>+</sup> or NADPH? **(2 pts)** \_\_\_\_\_

D) How many would be necessary? **(2 pts)** \_\_\_\_\_

E) When NAD<sup>+</sup> or NADH is used in an enzymatic reaction what is transferred? **(2 pts)**

\_\_\_\_\_



The most interesting thing I learned this semester was: (1 pt extra)

What I wished we spent more time on in class was: (1 pt extra)

Name: \_\_\_\_\_

### Useful Equation and Constants

$$\Delta G^{\circ} = -n\bar{F} \Delta E^{\circ}$$

$$\bar{F} = 96.480 \frac{\text{kJ}}{\text{V}\cdot\text{mol}}$$

$$v_0 = V_{\max} [S] / (K_m + [S])$$

$$\text{pH} = \text{pK}_a + \log [A^-] / [HA]$$

$$\Delta G = \Delta G^{\circ} + RT \ln Q$$

$$\theta = [L] / ([L] + K_d)$$

$$N_a = 6.022 \times 10^{23} / \text{mole}$$

$$R = 0.008315 \frac{\text{kJ}}{\text{mol}\cdot\text{K}}$$

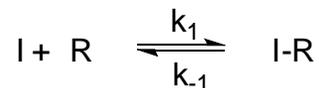
**Chem 451**  
**October 23, 2017**  
**Exam 2-100 pts possible**

1) Draw the structure of 4-hydroxyproline residue as part of a polypeptide (label the polypeptide chains as R<sub>1</sub> and R<sub>2</sub>). **(5 pts)**

2) What does 4-hydroxyproline have to do with collagen and how does it get incorporated into a protein? Why might this be important for diet considerations? **(5 pts)**

3) When performing his experiments on protein refolding, Christian Anfinsen obtained a quite different result when reduced ribonuclease was reoxidized while it was still in 8 M urea and the preparation was then dialyzed to remove the urea. Ribonuclease reoxidized in this way had only 1% of the enzymatic activity of the native protein. Why were the outcomes so different when reduced ribonuclease was reoxidized in the presence and absence of urea? **(7 pts)**

4) Consider the following equilibrium between insulin (I) and its receptor (R) to form the insulin receptor complex (I-R).



a) Write the equilibrium expression for K<sub>d</sub>. **(4 pts)**

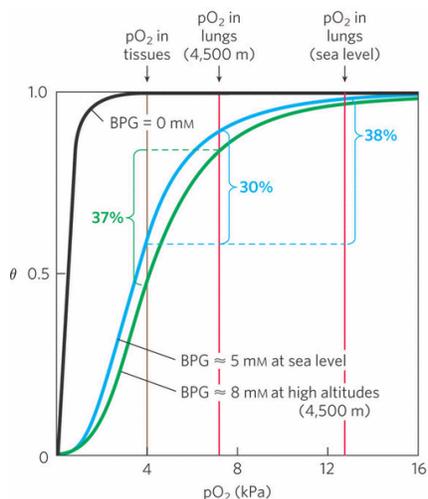
b) What is K<sub>d</sub> in terms of the rate constants. **(4 pts)**

c) The  $K_d$  for the insulin receptor-insulin interaction is 0.1 nM. In what concentration range of insulin would you expect greater than 90% of the receptor sites to be bound to insulin? (5 pts)

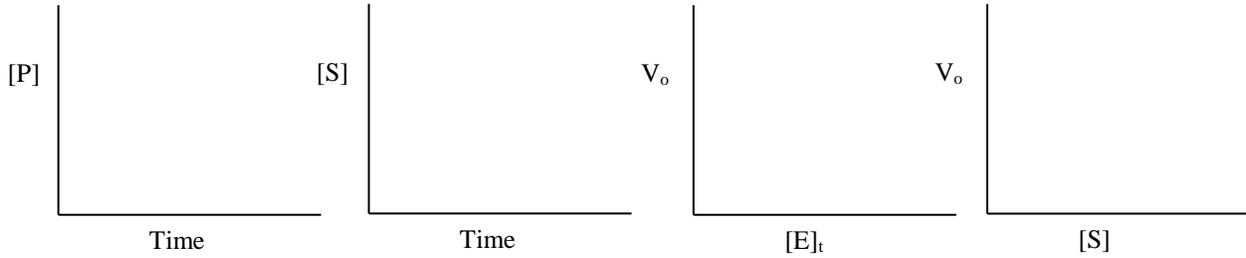
5) Does myoglobin exhibit a Bohr effect? Why or why not? (6 pts)

6) All following molecules when present in the blood impede the ability of hemoglobin to bind oxygen: CO, CO<sub>2</sub>, H<sup>+</sup>, and 2,3-bisphosphoglycerate (BPG). What is the principal difference in the mechanism of how they affect oxygen binding? (8 pts)

7) BPG is not only important for our adaptation to higher altitudes, but it is also critical for oxygen transport by the blood at the sea level. Based on the Figure below, explain why it is essential that a certain level of BPG is maintained in human blood. What would happen if BPG concentration drops to 1 mM? (6 points)

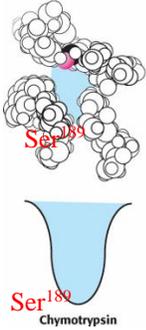


8) For a typical enzymatic reaction ( $S \rightarrow P$ ), sketch curves that show the appropriate relationships between the variables in each plot. *For the time based plots assume the reaction proceeds to equilibrium and the  $K_{eq}=1$ .* (10 pts)



- 9) (3 pts) Binding of a water molecule to the zinc ion on carbonic anhydrase induces
- a hydronium ion to form.
  - a large conformation change in the binding site.
  - ionization of a his residue, which functions as a strong nucleophile.
  - a lowered  $pK_a$  for water, which leads to formation of a zinc bound hydroxide ion.
  - an altered  $K_M$  value.

10) In chymotrypsin, a mutant was constructed with Ser 189, which is in the bottom of the **substrate-specificity pocket (S1 site of proteases)**, changed to Asp. How might this alter the specificity of Chymotrypsin? (6 pts)



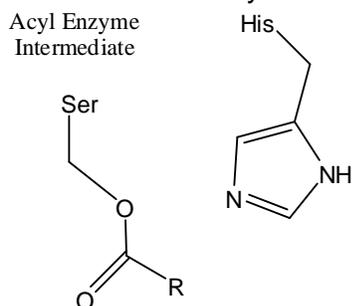
11) Define what is meant by enzymatic rate enhancement. (3 pts)

12) What is the range of values for enzymatic rate enhancements? (3 pts)

13) (20 pts) An acyl enzyme intermediate is shown below. **A)** This type of intermediate is mostly commonly found in which class of enzymes?

- a) isomerase
- b) oxidoreductase
- c) lyases
- d) hydrolase

**b)** From this intermediate show by the way of a step-wise electron arrow pushing mechanism how the active enzyme could be regenerated.



c) A Gln145 residue positioned next to the acyl intermediate is hypothesized to play a role in the “oxyanion hole” of this enzyme. To test this hypothesis two mutant forms of the enzyme were generated and tested. What is an oxyanion hole?

d) Do these results support this role of Gln145? Explain the results.

Enzyme	$k_{cat}$
Wild Type Enzyme	$30 \text{ s}^{-1}$
Gln145→Ala145	$3 \times 10^{-4} \text{ s}^{-1}$
Gln145→Thr145	$10 \text{ s}^{-1}$

14) One hydrogen bond has a measured strength of 10-20 kJ/mol. A globular protein can contain more than 100 hydrogen bonds; however, the  $\Delta G_{\text{folding}}$  is typically in the range of -40 to -70 kJ/mol. Explain how these numbers can make sense? (7 pts)

Useful Equations:  $\theta = \frac{[L]}{K_d + [L]}$        $V_o = \frac{V_{max}[S]}{K_m + [S]}$

1 ( 25 pts)	2( 25 pts)	3 (25 pts)	4 (20 pts)	5 (7 pts)	Total (100 pts) (102 possible)

**Chem 451**

November 29, 2017

**Exam 3**

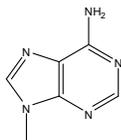
100 pts possible

**1) Multiple Choice 3 pts each (18 pts total)**

1. Starting with Fructose-6-phosphate how much **net** ATP is generated in glycolysis to lactate.
  - a) 0 ATP
  - b) 1 ATP
  - c) 2 ATP
  - d) 3 ATP
  - e) 4 ATP
2. Aldolase belongs to what class of enzymes?
  - a) oxidoreductase
  - b) hydrolase
  - c) isomerase
  - d) transferase
  - e) lyase
3. An example of oxidoreductase is?
  - a) hexokinase
  - b) glyceraldehyde-3-phosphate dehydrogenase
  - c) triose phosphate isomerase
  - d) lactase
  - e)  $\alpha$ -amylase
4. The role of NADH in metabolism is?
  - a) carrier of high energy phosphate
  - b) activated carrier of two-carbon fragments
  - c) activated carrier of electrons for fuel oxidation
  - d) important for carboxylation reactions
  - e) important for decarboxylation reactions
5. Which of following is an anomeric pair?
  - a) D-glucose and D-fructose
  - b) D-glucose and L-fructose
  - c) D-glucose and L-glucose
  - d)  $\beta$ -D-glucose and  $\alpha$ -D-glucose
  - e)  $\beta$ -D-glucose and  $\alpha$ -L-glucose
6. Which steps in Glycolysis are REVERSIBLE?
  - a) Hexokinase
  - b) Glucophosphate isomerase
  - c) Glyceraldehyde phosphate dehydrogenase
  - d) All of the above
  - e) B and C
- 7) Xylose has the same structure as that of glucose except that xylose has a hydrogen atom at C-5 in place of a hydroxymethyl group. The rate of ATP hydrolysis by hexokinase is markedly enhanced by the addition of xylose. Why? **(5 pts)**

Name: \_\_\_\_\_

8) Complete the entire chemical structure of 2',3'-deoxyadenosine triphosphate using the provided structural part (3 pts)

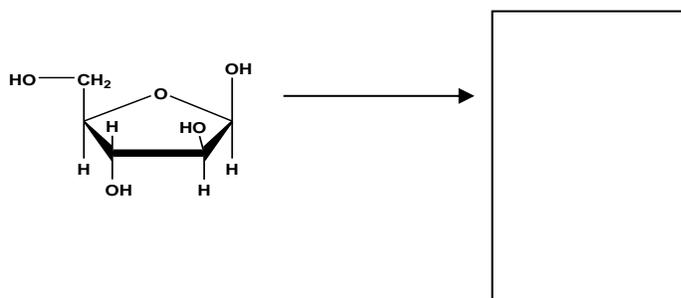


9) 2',3'-deoxy ATP can be incorporated into a growing strand but then DNA synthesis is terminated. This chemistry is the basis for a method of DNA sequencing developed by Fredrick Sanger. Propose why this nucleotide would terminate DNA synthesis when incorporated opposite a thymine base? (7 pts)

10) What effect will addition of an enzyme have on the following? Circle your choice for each (6 pts)

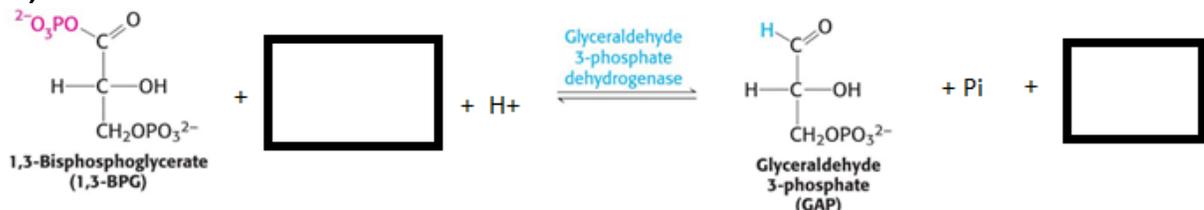
$\Delta G'^{\circ}$	increase	stay the same	decrease
$K_{eq}'$	increase	stay the same	decrease
$\Delta G^{\ddagger}$	Increase	stay the same	decrease
$V_o$	Increase	stay the same	decrease

11) From the usual ring structure of D-arabinose shown, deduce the Fischer projection formula of its straight chain form. (4 pts)



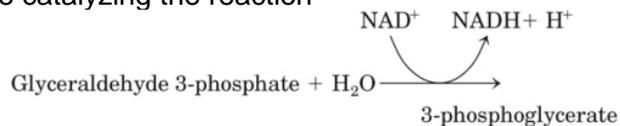
12) How is it possible that a starch molecule can have only one reducing end, but many non-reducing ends? Explain. (5 pts)

13) The following is an incomplete reaction found in metabolism. Answer the following questions. (8 pts)



- The oxidation state of carbon 1 in 1,3-BPG is? \_\_\_\_\_
- The oxidation state of carbon 1 in GAP is? \_\_\_\_\_
- Which substance is more oxidized 1,3-BPG or GAP \_\_\_\_\_
- Fill in the boxes with the expected necessary coenzymes (cosubstrate).

14) Suppose you discovered a mutant yeast whose glycolytic pathway was shorter because of the presence of a new enzyme catalyzing the reaction

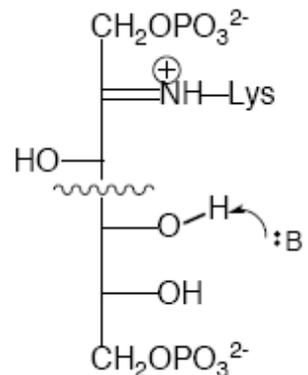


Would shortening the glycolytic pathway in this way benefit the cell? Explain. (6 pts)

15) The structure at the right shows a key intermediate in the aldolase reaction. The squiggly line indicates the C-C bond to be broken.

a) (3 pts) Draw the three additional electron-pair arrows that will take us to the next step in the mechanism

b) (5 pts) Draw the two products of the aldolase reaction.



16) Creatine is a popular, but not completely tested, dietary supplement. **(6 pts)**

a) What is the biochemical rationale for the use of creatine?

b) Would weight lifters or marathon runners be most likely to benefit more from creatine supplementation? Explain why from a biochemical perspective.

17) The standard free energy of hydrolysis for ATP is  $-30.5 \text{ kJ mol}^{-1}$  ( $-7.3 \text{ kcal mol}^{-1}$ ). In typical cells the free energy of hydrolysis is closer to  $-50 \text{ kJ mol}^{-1}$ . Why are the values so different? **(5 pts)**

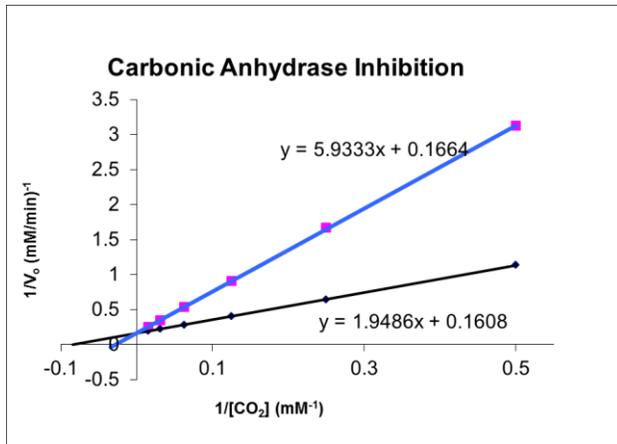
18) Aspirin, penicillin, and sarin gas are all examples of irreversible inhibitors. For **one of these compounds** explain how the compound inhibits its target. Details such as compound structure, target enzyme name, or mechanism of inhibition will be important to get full credit. **(8 pts)**

## 19) Acetazolamide (AZA) is a widely-used drug in the treatment of glaucoma. (13 pts)

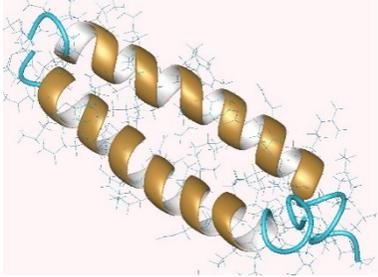
It acts by competitively inhibiting carbonic anhydrase II, thereby reducing pressure in the affected eyes. The kinetics of the reaction was determined in a series of reactions with 25 mM Aza and without Aza. The data from each set of experiments was plotted and fit by linear regression using a double reciprocal analysis.

- Label corresponding lines (with 25mM Aza or without Aza) on the plot.
- Determine the  $K_i$  for the Aza inhibitor.

$$\text{For competitive inhibition: } V_o = \frac{V_{max}[S]}{\alpha K_m + [S]} \text{ and } \alpha = \left(1 + \frac{[I]}{K_i}\right)$$



<b>1</b> <b>(23)</b>	<b>2</b> <b>(20)</b>	<b>3</b> <b>(27)</b>	<b>4</b> <b>(19)</b>	<b>5</b> <b>(13)</b>	<b>Total</b> <b>(100)</b>
					<b>102 possible</b>

<p><b>CHEMISTRY 451</b> <b>Biochemistry</b> <b>Fall 2017</b></p> <p><b>MWF 8:00-8:50 Plumas 201</b></p> <p><b>Dr. Dan Edwards</b> <b>California State University, Chico</b> <b>Department of Chemistry</b></p>	
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**OFFICE HOURS:** Tues 11 AM-noon, Thurs 1-3 PM, Fri 10-11AM, or by appointment

**OFFICE:** PHSC 329

**PHONE:** 898-5226

**EMAIL:** [djedwards@csuchico.edu](mailto:djedwards@csuchico.edu)

**COURSE OBJECTIVE:**

The objective of this course is to provide a one semester overview of the fundamentals of biochemistry. A primary goal will be to develop an understanding of the relationship between the structure and function of biological molecules. We will also focus on the underlying chemical and physical principles that dictate energy and material flow in living organisms. The following general topics will be emphasized:

1. Structural and chemical features of the main classes of biomolecules (proteins, carbohydrates, lipids, and nucleic acids)
2. The basis for self-assembly of macromolecules and the interactions between biomolecules
3. Thermodynamic and kinetic aspects of biochemical processes
4. Chemical mechanisms of bioorganic reactions
5. The dynamics and regulation of metabolic pathways
6. Modern methods for the separation and characterization of biological macromolecules
7. Quantitative aspects of biochemistry

**REQUIRED MATERIAL:**

- **Nelson & Cox, Lehninger Principles of Biochemistry, 6th edition**
- **Scientific calculator:** A calculator that can do logs and natural logs (ln) will be required for many problem sets, exams and quizzes. *Smart phones or programmable calculators are not allowed for exams!*
- **Electronic course access:** Blackboard will be used to distribute class information and access assignments.
- **iClicker**

**PREREQUISITES:**

Completion of two semesters of general chemistry (CHEM 111/112) and two semesters of organic chemistry (CHEM 270/370) is required. **You must have received a C- or better in CHEM 370 or instructor permission to continue on to CHEM 451.** Biochemistry is a very integrative subject dealing with how biological processes occur at the molecular level. A solid foundation in general chemistry, organic chemistry, biology, and mathematics will make it easier for success in this course. Expect to spend some time on your own reviewing topics.

**KEY REVIEW TOPICS:**

- Mathematics – exponents, logarithms, simple algebra, graphs of linear equations (slope and intercept)
- Acids and Bases- pH,  $K_a$ ,  $pK_a$ , titration, and buffers
- Thermodynamics, equilibrium constants ( $\Delta H$ ,  $\Delta S$ ,  $\Delta G$ ,  $\Delta G^\circ$ ,  $K_{eq}$ )
- Organic chemistry
  - Functional groups
  - Physical organic chemistry aspects
  - Reaction types and electron arrow pushing mechanisms

**GRADE ASSESSMENT:**

Clicker participation and attendance	50 pts
Quizzes (Ten x 10 pt modules)	100 pts
Mid-Term Exams	3 x 100 pts = 300 pts
Final Exam	150 pts
<b>TOTAL:</b>	<b>Approximately 600 pts</b>

Grades will be assigned based on an approximate breakdown of:

A	85.0-100 %
B	70.0-85 %
C	55-70 %
D	50-55 %
F	Below 49.9 %

**i>clicker:**

We will be using the i>clicker student response system in class this term. The use of clickers will help me access student understanding of topics and to facilitate classroom engagement with students. 50 Clicker points will be assigned based on submitted responses and not on correctness. When you respond to at least 50% of the questions in a class period, you will receive credit for that day. At the end of the semester, you points are assigned based on the percentage of days that you responded to the clicker questions. All students will be granted two free absences.

**The following models are acceptable:**

The original i>clicker  
i>clicker +  
i>clicker 2

**How to register:**

To receive credit for the responses you submit with i>clicker, you are **required to have a registered clicker by the second class period on Wednesday August 23**. See Blackboard Learn for details.

**Cheating:**

I consider bringing a fellow student's i>clicker to class to be cheating and a violation of the University Honor Code. If you are caught with a remote other than your own or have votes in a class that you did not attend, you will forfeit all clicker points and may face additional disciplinary action.

**HOMEWORK AND PROBLEM SETS:**

Although homework will not be collected, it is expected that students will complete the assigned homework problems and case studies.

**QUIZZES:**

During the semester, there will be ten in class quiz modules (See schedule below). Each 10 pt quiz module will be graded on mastery of a concept and getting all parts of each module correct will be required to get credit. If you miss any part of a 10 pt quiz module you will be given up to three opportunities to retake the module at designated times outside of class time to get full credit.

**Quiz Modules**

A-Gen Chem Review: pH scale, pH of strong acid/base solutions, pKa/Ka and acid strength  
B-Preparation of buffers  
C-Amino acid and peptide structure  
D-Amino ionization/Titration curves  
E-Hemoglobin structure-Bohr Effect, BPG Effect  
F-Kd values, Ligand binding equilibrium, Ligand binding curves  
G-Michaelis Menten Kinetics  
H-Serine protease mechanism  
I-Electron transfer in oxidation and reduction  
J-Electron pushing for NAD<sup>+</sup>/NADH dependent dehydrogenases

**EXAM AND QUIZ POLICIES:**

Makeup exams will only be given for "serious and compelling reasons" as described in the University Catalog. Your makeup exam score will be counted no higher than the average of other exam scores. For example, if you receive an 80% on the make-up exam, but your average on all of the other exams is only 70%, then your makeup exam score will be adjusted to 70% at the end of the course; however, if you receive the same or lower than your average then the makeup exam score stands. **Only one makeup exam is allowed per semester.** The final exam will be comprehensive and **will only be given during the scheduled time so please plan ahead.**

Quizzes will not be scheduled outside of the scheduled times. If you miss one of the scheduled quiz days you will have up to three other opportunities to complete the quiz for full credit.

**STUDYING EXPECTATIONS:**

- Prepare for class by completing the assigned daily reading and homework problems.
- Plan to spend 2-4 quality hours per lecture outside of class to be successful.
- On exams, you are accountable for all assigned reading material, even though **I will not cover all the material in lecture.** Lecture will expose you the most difficult concepts and we will work through some of the more difficult problems and material in class. Terminology and structures of key biomolecules are examples of two items that you will need to learn on your own outside of class.
- **You are expected to read the textbook.**

**HELPFUL HINTS:**

*Focus on concepts* –When studying ask yourself questions aimed at improving your understanding of important concepts, not questions like, "Is this going to be on the exam?"

*Stay on top of the material and prepare for lecture*- You will have access to my lecture material before class so you will know what material I will be covering before you arrive. Try to spend some time on biochemistry every day.

*Don't try to memorize everything, instead focus on understanding and applying key chemical concepts*- This class is not about memorizing every biochemical piece of information we encounter. However, there is a substantial vocabulary as well as knowledge of chemical functional groups and structures that you will need to know. A lot of your success in this course will depend on your ability to apply fundamental chemical concepts learned in previous chemistry courses.

*Get into a study group! (This is probably the most important hint.)*- At the beginning of the semester form small groups of two to five students. Collaborative learning where you have to communicate biochemistry to each other is an extremely effective way to learn the material. From my experience, both as a student and an instructor, students that work together outside the classroom in preparation for lecture and in particular examinations score better in the course.

**ACADEMIC HONESTY:**

The copying of answers on homework, quizzes, and exams will not be tolerated. You are entirely responsible for your own work on exams and no outside sources are allowed. In all instances such occurrences will be reported to Student Judicial Affairs, where serious academic penalties may result.

**STUDENTS WITH DISABILITIES:**

All efforts will be made to accommodate students with disabilities according to university policy. In the event you require accommodation, be sure to speak with me ASAP, register with the Accessibility Resource Center (ARC) office on campus (<http://www.csuchico.edu/dss/>), and send me the appropriate electronic documentation before each exam. Unless a compelling reason exists, I will only approve ARC exam requests when the exam occurs on the same day (and at the same time) as the exam for the rest of the class. Please see me for other ARC exam policies.

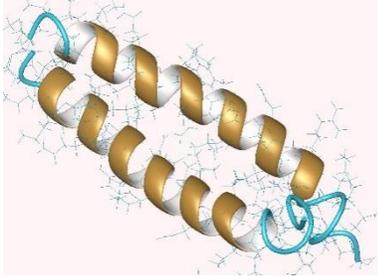
**COURSE SCHEDULE:**

Date(s)	Day	Reading	Topics	Quiz
Aug 21	M	1	Course Introduction	
Aug 23	W	2.1	Noncovalent Interactions	
Aug 25	F	2.2	Ionization in Water, Acids and Bases	
Aug 28	M	2.3	Buffers	
Aug 30	W		Wrap up Chap. 2	<b>Quiz A &amp; B</b>
Sept 1	F	3.1	Amino Acids	
Sept 4	M	<b>Labor Day Holiday</b>		
Sept 6	W	3.2	Peptides	Retake A or B*
Sept 8	F	3.2	Peptides cont.	<b>Quiz C &amp; D</b>
Sept 11	M	3.3	Protein Purification Methods	Retake A or B*
Sept 13	W	3.4	Protein Sequencing and Analysis Techniques	Retake C or D*
Sept 15	F	4.1 & 4.2	Secondary Structure of Proteins	
Sept 18	M	4.2	Secondary Structure of Proteins	Retake C or D*
Sept 20	W	4.3	3° and 4° Structure of Proteins	Retake A, B, C, or D*
Sept 22	F	<b>Exam 1</b>		
Sept 25	M	4.4	Protein Folding	
Sept 27	W	4.3	4° Structure and Fibrous Proteins	
Sept 29	F	5.1	Protein Function-Protein Ligand Interactions	
Oct 2	M	none	Myoglobin and Cooperativity of Hemoglobin	
Oct 4	W	none	Hemoglobin cont.	
Oct 6	F	6.1-6.2	Enzymes	<b>Quiz Module E, F</b>
Oct 9	M	6.3	Enzymes	
Oct 11	W	6.4	Enzymes	Retake E or F*
Oct 13	F	none	Enzymes	
Oct 16	M	6.4	Enzymes	Retake E or F*
Oct 18	W	7.1	Carbohydrates	<b>Quiz Module G</b>
Oct 20	F	7.2, 7.3, 7.5	Carbohydrates	
Oct 23	M	<b>Exam 2</b>		
Oct 25	W	8.1 & 8.4	Nucleic Acids	
Oct 27	F	13.1-13.2	Introduction to Metabolism	
Oct 30	M	13.3	Bioenergetics-Phosphoryl Transfer Reactions	
Nov 1	W	13.4	Electron Transfer in Metabolism	
Nov 3	F	None	Bioenergetics and Metabolic Pathways	
Nov 6	M	14.1	Glycolysis	<b>Quiz Module I, J</b>
Nov 8	W	14.2	Glycolysis	
Nov 10	F	<b>Veterans Day</b>		
Nov 13	M	14.3	Glycolysis and Fermentation	Retake I or J*
Nov 15	W	14.4	Gluconeogenesis	
Nov 17	F		Catch up day or start Ch. 16	Retake I or J*
Nov 20-24	M-F	<b>Thanksgiving Break</b>		
Nov 27	M	16.1-16.2	Citric Acid Cycle	Retake I or J*
Nov 29	W	<b>Exam 3</b>		
Dec 1	F	19.1-19.2	Oxidative Phosphorylation	
Dec 4	M	10.1-10.3	Lipids	
Dec 6	W	10.4 & 11.1	Lipids and Biological Membranes	
Dec 8	F	11.2-11.3	Biological Membranes	
Dec 15	F	<b>Final Exam 8:00-9:50</b>		

\*Quiz retakes start at 7:30 AM Sharp and must be completed by 7:55.

<b>Assigned Reading</b>	<b>Recommended Textbook Problems 6<sup>th</sup> Edition</b>
Chapter 1 (All)	6-9, 11, 12, 14, 16 a-f
Chapter 2 (All)	1-9, 10-33, 35
Chapter 3 (All)	All
Chapter 4 (All)	1, 2, 4-14, 16
Chapter 5 (pp 157-174)	1-10, 15, 16
Chapter 6 (All)	1, 3-13, 15, 17-19, 21-23
Chapter 7 (All)	1, 2, 4-9, 11-17, 22, 23, 27, 28
Chapter 8 (All)	1, 2, 10, 13
Chapter 10 (All)	1, 2, 8-14, 16-20
Chapter 11 (pp 385-395; 402-426)	4, 5, 7-13, 15, 19, 20
Chapter 13 (All) and (pp 501-504)	2-21
Chapter 14 (pp 543-575)	1, 2, 5-27, 29, 31
Chapter 16 (All)	1-19, 20, 23, 24, 30, 31, 34, 36
Chapter 19 (pp 731-762)	4-8, 13, 14

\* Additional problems, handouts, and journal articles may also be assigned

<p><b>CHEMISTRY 451</b>  <b>Biochemistry</b>  <b>Fall 2018</b></p> <p><b>MWF 2:00-2:50 Modoc 220</b></p> <p><b>Dr. Dan Edwards</b>  <b>California State University, Chico</b>  <b>Department of Chemistry</b></p>	
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**OFFICE HOURS:** Mon 10:30-noon ; Wed 11-noon ; Thurs 9:00-10:30 or by appointment

**OFFICE:** PHSC 329

**PHONE:** 898-5226

**EMAIL:** [djedwards@csuchico.edu](mailto:djedwards@csuchico.edu)

#### COURSE OBJECTIVE:

The objective of this course is to provide a one semester overview of the fundamentals of biochemistry. A primary goal will be to develop an understanding of the relationship between the structure and function of biological molecules. We will also focus on the underlying chemical and physical principles that dictate energy and material flow in living organisms. The following general topics will be emphasized:

1. Structural and chemical features of the main classes of biomolecules (proteins, carbohydrates, lipids, and nucleic acids)
2. The basis for self-assembly of macromolecules and the interactions between biomolecules
3. Thermodynamic and kinetic aspects of biochemical processes
4. Chemical mechanisms of bioorganic reactions
5. The dynamics and regulation of metabolic pathways
6. Modern methods for the separation and characterization of biological macromolecules
7. Quantitative aspects of biochemistry

#### REQUIRED MATERIAL:

- **Nelson & Cox, Lehninger Principles of Biochemistry, 7<sup>th</sup> edition or other recent edition 5<sup>th</sup> or later**
- **Scientific calculator:** A calculator that can do logs and natural logs (ln) will be required for problem sets, exams and quizzes. *Smart phones or programmable calculators are not allowed for exams!*
- **Electronic course access:** Blackboard will be used to distribute class information and access assignments.
- **iClicker**

#### PREREQUISITES:

Completion of two semesters of general chemistry (CHEM 111/112) and two semesters of organic chemistry (CHEM 270/370) is required. **You must have received a C- or better in CHEM 370 or instructor permission to continue on to CHEM 451.** Biochemistry is a very integrative subject dealing with how biological processes occur at the molecular level. A solid foundation in general chemistry, organic chemistry, biology, and mathematics will make it easier for success in this course. Expect to spend some time on your own reviewing topics.

#### KEY REVIEW TOPICS:

- Acids and Bases- pH,  $K_a$ ,  $pK_a$ , titration, and buffers
- Thermodynamics, equilibrium constants ( $\Delta H$ ,  $\Delta S$ ,  $\Delta G$ ,  $\Delta G^\circ$ ,  $K_{eq}$ )
- Organic chemistry
  - Functional groups
  - Physical organic chemistry aspects
  - Reaction types and electron arrow pushing mechanisms
- Mathematics – exponents, logarithms, simple algebra, graphs of linear equations (slope and intercept)

**GRADE ASSESSMENT:**

Engagement Points	100 pts	14.2%
Mid-Term Exams	4 x 100 pts = 400 pts	57.1%
Final Exam	200 pts	28.4%
<b>TOTAL:</b>	<b>Approximately 700 pts</b>	

Grades will be assigned based on an approximate breakdown of:

A	85.0-100 %
B	70.0-85 %
C	55-70 %
D	50-55 %
F	Below 49.9 %

**ENGAGEMENT POINTS:**

Engagement points will be assessed to provide incentive to prepare for class and to be an active participant in class.

**1) Up to a maximum of 50 engagement points will be available by in class clicker participation.**

Clicker points will be assigned based on submitted responses and not on correctness. When you respond to at least 50% of the questions in a class period, you will receive credit for that day. At the end of the semester, points are assigned based on the percentage of days that you responded to the clicker questions. All students will be granted two unexcused absences. There will be no make-ups for lost days.

**2) Up to a maximum of another 50 engagement points will be available by:**

- Random in class assignments/questions that will be handed in (5 points each (20 pts max), cannot be made up).
- Class Participation: (up to 20 points based on asking or answering questions in class).
- Office hours visits (+5 pts for first visit, up to 15 additional points possible)
- Participation in online discussion board (Up to 20 points max)
- Book report on: (up to 20 points)
  - [The Great Influenza](#)
  - [Alzheimer's Disease Decoded: The History, Present, And Future Of Alzheimer's Disease And Dementia 1st Edition](#)
  - [DNA: The Story of the Genetic Revolution](#)
  - Other?

**I>CLICKER:**

We will be using the i>clicker student response system in class this term. The use of clickers will help me assess student understanding of topics and to facilitate classroom engagement with students.

**The following models are acceptable:**

The original i>clicker  
i>clicker +  
i>clicker 2

**How to register:**

To receive credit for the responses you submit with i>clicker, you are **required to have a registered clicker by the second class period on Wednesday August 29.** See Blackboard Learn for details.

**CHEATING:**

I consider bringing a fellow student's i>clicker to class to be cheating and a violation of the University Honor Code. If you are caught with a remote other than your own or have votes in a class that you did not attend, you will forfeit all clicker points and may face additional disciplinary action.

**HOMEWORK AND PROBLEM SETS:**

Although homework will not be collected, it is expected that students will complete the assigned homework problems and case studies. This work is a necessary component of the course and will be essential for success on exams.

**EXAM POLICIES:**

Makeup exams will only be given for "serious and compelling reasons" as described in the University Catalog. Your makeup exam score will be counted no higher than the average of other exam scores. For example, if you receive an 80% on the make-up exam, but your average on all of the other exams is only 70%, then your makeup exam score will be adjusted to 70% at the end of the course; however, if you receive the same or lower than your average then the makeup exam score stands. **Only one makeup exam is allowed per semester.** The final exam will be comprehensive and **will only be given during the scheduled time so please plan ahead.**

**STUDYING EXPECTATIONS:**

- Prepare for class by completing the assigned daily reading and homework problems.
- Plan to spend 2-4 quality hours per lecture outside of class to be successful.
- On exams, you are accountable for all assigned reading material, even though **I will not cover all the material in lecture.** Lecture will expose you the most difficult concepts and we will work through some of the more difficult problems and material in class. Terminology and structures of key biomolecules are examples of two items that you will need to learn on your own outside of class.
- **You are expected to read the textbook.**

**HELPFUL HINTS:**

*Stay on top of the material and prepare for lecture-* You will have access to my lecture material before class so you will know what material I will be covering before you arrive. Try to spend some time on biochemistry every day.

*Don't try to memorize everything, instead focus on understanding and applying key chemical concepts-* This class is not about memorizing every biochemical piece of information we encounter. However, you will need to learn relevant vocabulary. A knowledge of chemical functional groups, important biochemical structures, and common reaction types will also be necessary.

*Focus on concepts* –When studying ask yourself questions aimed at improving your understanding of important concepts, not questions like, "Is this going to be on the exam?". Your ability to integrate more than one concept to answer questions and explain your answers will be necessary for success.

*Get into a study group! (This is probably the most important hint.)-* At the beginning of the semester form small groups of two to five students. Collaborative learning where you have to communicate biochemistry to each other is an extremely effective way to learn the material. From my experience, both as a student and an instructor, students that work together outside the classroom in preparation for lecture and in particular examinations score better in the course.

**ACADEMIC HONESTY:**

The copying of answers on homework, quizzes, and exams will not be tolerated. You are entirely responsible for your own work on exams and no outside sources are allowed. In all instances such occurrences will be reported to Student Judicial Affairs, where serious academic penalties may result.

**STUDENTS WITH DISABILITIES:**

All efforts will be made to accommodate students with disabilities according to university policy. In the event you require accommodation, be sure to speak with me ASAP, register with the Accessibility Resource Center (ARC) office on campus (<http://www.csuchico.edu/dss/>), and send me the appropriate electronic documentation before each exam. Unless a compelling reason exists, I will only approve ARC exam requests when the exam occurs on the same day (and at the same time) as the exam for the rest of the class. Please see me for other ARC exam policies.

**COURSE SCHEDULE:**

Date(s)	Day	Reading	Topics
Aug 27	M	1	Course Introduction-Themes of Biochemistry
Aug 29	W	2.1	Noncovalent Interactions
Aug 31	F	2.2	Ionization in Water, Acids and Bases
Sept 3	M	<b>Labor Day Holiday</b>	
Sept 5	W	2.3	Buffers
Sept 7	F	3.1	Buffers/Amino Acids
Sept 10	M	3.1	Amino Acids
Sept 12	W	3.2	Peptides
Sept 14	F	3.2	Peptides cont.
Sept 17	M	3.3	Protein Purification Methods
Sept 19	W	<b>Exam 1</b>	
Sept 21	F	3.4	Protein Sequencing and Analysis Techniques
Sept 24	M	4.1 & 4.2	Secondary Structure of Proteins
Sept 26	W	4.2	Secondary Structure of Proteins
Sept 28	F	4.3	3° and 4° Structure of Proteins
Oct 1	M	4.4	Protein Folding
Oct 3	W	4.3	4° Structure and Fibrous Proteins
Oct 5	F	5.1	Protein Function-Protein Ligand Interactions
Oct 8	M	none	Myoglobin and Cooperativity of Hemoglobin
Oct 10	W	none	Hemoglobin cont.
Oct 12	F	6.1-6.2	Enzymes
Oct 15	M		Catch up day
Oct 17	W	<b>Exam 2</b>	
Oct 19	F	6.3	Enzymes
Oct 22	M	6.4	Enzymes
Oct 24	W	none	Enzymes
Oct 26	F	6.4	Enzymes
Oct 29	M	6	Enzymes
Oct 31	W	7.1	Carbohydrates
Nov 2	F	7.2, 7.3, 7.5	Carbohydrates
Nov 5	M	8.1 & 8.4	Nucleic Acids
Nov 7	W	<b>Exam 3</b>	
Nov 9	F	8.1 & 8.4	Nucleic Acids
Nov 12	M	<b>Veterans Day</b>	
Nov 14	W		Introduction to Metabolism
Nov 16	F	13.3	Bioenergetics-Phosphoryl Transfer Reactions
Nov 19-23	M-F		<b>Thanksgiving Break</b>
Nov 26	M	13.4	Electron Transfer in Metabolism
Nov 28	W	14.1	Glycolysis
Nov 30	F	14.2	Glycolysis
Dec 3	M	14.3	Glycolysis and Fermentation
Dec 5	W	<b>Exam 4</b>	
Dec 7	F	14.4	Gluconeogenesis
Dec 10	M	16.1-16.2	Citric Acid Cycle
Dec 12	W		Oxidative Phosphorylation
Dec 14	F	10.1-10.3	Lipids
Dec 21	F	<b>Final Exam 12:00-1:50</b>	

**Engagement Rubric**

<b>ENGAGEMENT</b>	<b>PREPARATION (outside of class)</b>	<b>PARTICIPATION (in class)</b>
<b>I am fully engaged</b>	<p><b><u>Exemplary Preparation</u></b>                      I read carefully assigned readings and problems.                      I review background (foundational information) on the topic ahead of time.                      I attempt to make connections to the text/topics covered in previous chemistry and biology courses. I always try to connect the material to the big picture and try to understand the relevance of the topics.                      I look over assigned homework problems in advance of class discussion and complete some of the problems.</p>	<p><b><u>Animated Participation</u></b></p> <ul style="list-style-type: none"> <li>• I attend class and I ask and/or answer questions daily.</li> <li>• I actively take notes and attempt all problems presented in class.</li> <li>• I jot down muddy points, questions, and key topics to investigate as they arise in class.</li> <li>• I email instructor questions on material or ask questions after class or in office hours.</li> </ul>
<b>I am occasionally engaged</b>	<p><b><u>Novice Preparation</u></b>                      I read assignments ahead of time. I do sometimes look up things I should know, but I do not go beyond the obvious.                      Sometimes I consider how this is important and relevant and see the connections.</p>	<p><b><u>Occasional Participation</u></b>                      I attend class daily.                      I speak occasionally—mainly when called upon by the professor.                      Sometimes I present general evidence to support my position.</p>
<b>I'm not sure how to be engaged; I need some direction</b>	<p><b><u>Inadequate preparation</u></b>                      Sometimes I do the reading.                      I don't research to understand the material, nor do I go beyond the obvious.                      I do not look up terms I do not know.</p>	<p><b><u>Inadequate participation</u></b>                      My attendance is inconsistent.                      I participate only when prompted.</p>
<b>I am Disengaged</b>	<p><b><u>No Preparation</u></b>                      I neither read nor research before class.</p>	<p><b><u>No Participation</u></b>                      My attendance is inconsistent.                      I do not speak in class.</p>

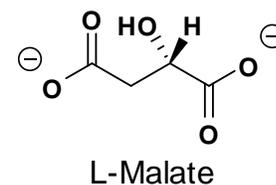
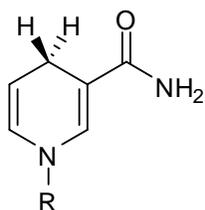
**Exam 1**  
**February 16, 2018**  
**100 pts possible**

1) Malate dehydrogenase converts oxaloacetate to L-malate by transferring the pro-R hydride of NADH

(a) On the provided nicotinamide ring of NADH and clearly label the pro-R hydride.

(b) Draw oxaloacetate and identify the face (Re or Si) to which the hydride would add to generate L-malate.

(c) Draw a mechanism to show the conversion of oxaloacetate to L-malate. **(10 pts)**



2) Match the cofactors below with their roles in metabolism. **(10 pts)**

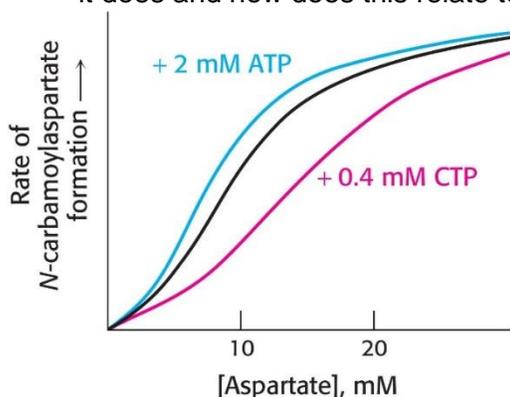
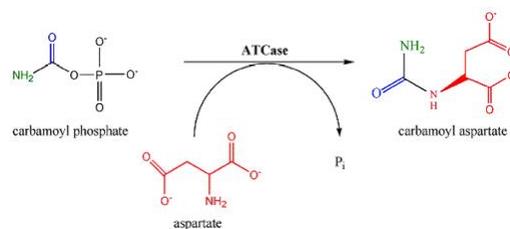
Cofactors:

- A. Coenzyme A (CoA-SH)
- B. Coenzyme B<sub>12</sub>
- C. NAD<sup>+</sup>
- D. Thiamine pyrophosphate (TPP)
- E. FAD
- F. Lipoic acid in oxidized form
- G. Biotin

Roles:

- \_\_\_\_\_ Attacks and attaches to the central carbon in pyruvate in the pyruvate dehydrogenase complex
- \_\_\_\_\_ Oxidizes FADH<sub>2</sub> in the pyruvate dehydrogenase complex
- \_\_\_\_\_ Accepts the acetyl group from reduced lipoic acid in the pyruvate dehydrogenase complex
- \_\_\_\_\_ Oxidizes the reduced form of lipoic acid in the pyruvate dehydrogenase complex
- \_\_\_\_\_ Initial electron acceptor in oxidation of pyruvate in the pyruvate dehydrogenase complex
- \_\_\_\_\_ Involved in the activation of HCO<sub>3</sub><sup>-</sup> in pyruvate carboxylase
- \_\_\_\_\_ Involved in homolytic bond cleavage in the methylmalonyl-CoA mutase reaction

- 3) Aspartate transcarbamoylase an important enzyme in pyrimidine biosynthesis. Shown below is the activity of enzyme without ATP or CTP (black line), with 2 mM ATP (blue line), and with 0.4 mM CTP (red line). Answer the following questions. (12 pts)



- a) Why does the activity curve have the shape it does and how does this relate to the T/R equilibrium (just consider black curve)?
- b) Where do you expect ATP or CTP to bind to ATCase and how does the binding of ATP or CTP affect the T/R ratio of ATCase?
- c) Considering the role of this enzyme in metabolism, why does ATP and CTP affect the enzyme in the way that it does?

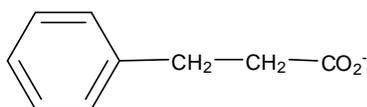
- 4) An actively respiring bacterial culture is briefly incubated with [3-<sup>14</sup>C]pyruvate, and the citric acid cycle intermediates are isolated. Clearly show by drawing the structures where the <sup>14</sup>C will be found in each of the intermediates listed below in the first pass through the cycle. Consider only the initial incorporation of <sup>14</sup>C, in the first pass of labeled glucose through the citric acid cycle. (12 pts)

(a) Acetyl-CoA

(b)  $\alpha$ -Ketoglutarate

(c) Oxaloacetate

- 5) The  $\beta$ -oxidation pathway was elucidated in part by Franz Knoop in 1904. He fed dogs fatty acid phenyl derivatives and then analyzed their urine for the resulting metabolites.
- Show the reactions that phenylpropionate would undergo in  $\beta$ -oxidation.
  - How much **net** ATP would be produced from the catabolism of this molecule by  $\beta$ -oxidation and subsequent metabolism of the resulting acetyl-CoA(s).
  - Predict what metabolite would be found in the urine when the dogs were fed phenylpropionate. **(15 pts)**

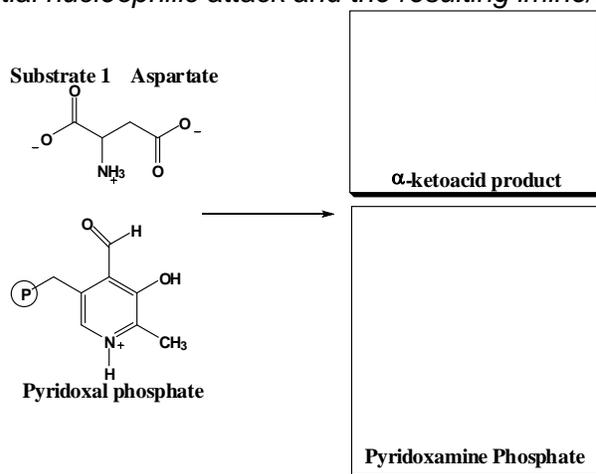


Phenylpropionate

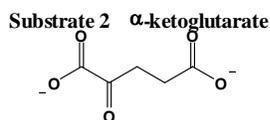
- 6) Suppose that, for some bizarre reason (maybe you get stranded on an arctic island) you decide to exist on a diet of whale and seal blubber (Fat) exclusively.
- How would the lack of carbohydrates affect your ability to utilize this food source? Be specific in your explanation.
  - What would your breath smell like? Explain.
  - One of your best friends, after trying unsuccessfully to convince you to abandon this diet, makes you promise to consume a healthy dose of an odd-chain fatty acid supplement. Does your friend have your best interests at heart? Explain providing **(10 pts)**

7) (15 pts) Pyridoxal phosphate participates in the transfer of amino groups of amino acids to an  $\alpha$ -keto acid acceptor such as  $\alpha$ -ketoglutarate by a ping pong reaction mechanism.

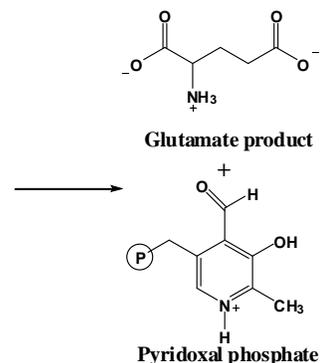
- a) Show the  $\alpha$ -ketoacid product and the structure of pyridoxamine after the first phase of transamination.
- b) Using the pyridoxamine phosphate from phase one, show the stepwise arrow pushing mechanism outlining the second phase of transamination showing the transfer of an amino group from pyridoxamine phosphate to  $\alpha$ -ketoglutarate. (For imine formation or hydrolysis simply show the initial nucleophilic attack and the resulting imine/keto product respectively)



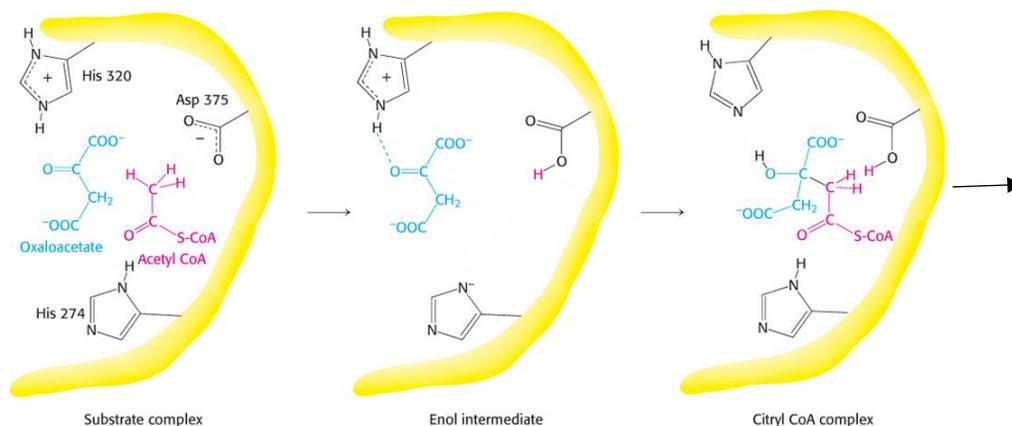
**Mechanism of amino transfer to  $\alpha$ -ketoglutarate:**



Pyridoxamine  
Phosphate

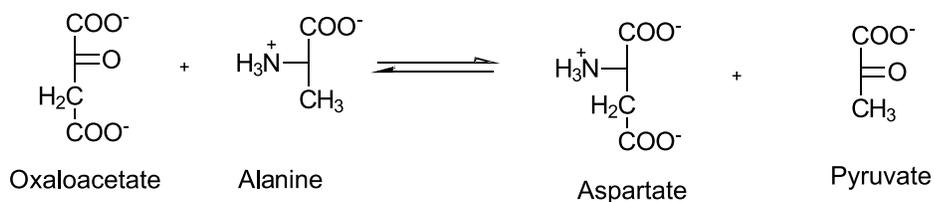


8) Propose a reaction mechanism (with appropriate electron arrows) for the condensation of acetyl CoA with oxaloacetate to generate citrate by Citrate Synthase. In the mechanism provide the structure of the enol intermediate and the final reaction products. (10 pts)



b) What aspect of this reaction provides the energetic driving force?

9) Describe how the transamination reaction below could function as an anaplerotic reaction for the citric acid cycle. (6 pts)



1 (20)	2 (24)	3 (25)	4 (15)	5 (16)	Total

**CHEM 452**

**Exam 2**

**Name:** \_\_\_\_\_

**March 16, 2018**

**100 pts possible**

1) Almost all of the oxygen ( $O_2$ ) one consumes in breathing is converted to:

- A) acetyl-CoA.
- B) carbon dioxide ( $CO_2$ ).
- C) carbon monoxide and then to carbon dioxide.
- D) water
- E) none of the above.

2) When the  $\Delta G^\circ$  of the ATP synthesis reaction is measured on the surface of the ATP synthase enzyme, it is found to be close to zero. This is thought to be due to:

- A) a very low energy of activation.
- B) enzyme-induced oxygen exchange.
- C) stabilization of ADP relative to ATP by enzyme binding.
- D) stabilization of ATP relative to ADP by enzyme binding.
- E) none of the above.

3) If malonyl-CoA is synthesized from  $^{14}CO_2$  and unlabeled acetyl-CoA, and the labeled malonate is then used for fatty acid synthesis, the final product (fatty acid) will have radioactive carbon in:

- A) every C.
- B) every even-numbered C-atom.
- C) every odd-numbered C-atom.
- D) no part of the molecule.
- E) only the omega-carbon atom (farthest carbon from C-1).

4) The type of membrane transport that uses ion gradients as the energy source is:

- A) facilitated diffusion
- B) passive transport.
- C) primary active transport.
- D) secondary active transport.
- E) simple diffusion.

5) In the reoxidation of  $QH_2$  by purified ubiquinone-cytochrome c reductase (Complex III) from heart muscle, the overall stoichiometry of the reaction requires 2 mol of cytochrome c per mole of  $QH_2$  because:

- A) cytochrome c is a one-electron acceptor, whereas  $QH_2$  is a two-electron donor.
- B) cytochrome c is a two-electron acceptor, whereas  $QH_2$  is a one-electron donor.
- C) cytochrome c is water soluble and operates between the inner and outer mitochondrial membranes
- D) heart muscle has a high rate of oxidative metabolism, and therefore requires twice as much cytochrome c as  $QH_2$  for electron transfer to proceed normally.
- E) two molecules of cytochrome c must first combine physically before they are catalytically active.

**Part Two: Amino Acid Catabolism (25 pts)**

Choose one of the following two problems **(6 or 7)** (15 pts)

- 6) In a study conducted some years ago, cats were fasted overnight then given a single meal complete in all amino acids except arginine. Within 2 hours, blood ammonia levels increased from a normal level of  $18 \mu\text{g/L}$  to  $140 \mu\text{g/L}$ , and the cats showed the clinical symptoms of ammonia toxicity. A control group fed a complete amino acid diet or an amino acid diet in which arginine was replaced by ornithine showed no unusual clinical symptoms.

*Answer all parts below.*

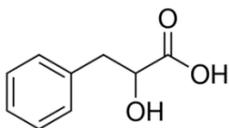
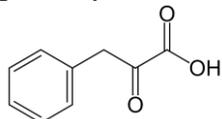
- (a) What was the role of fasting in the experiment?
- (b) What caused the ammonia levels to rise in the experimental group? Why did the absence of arginine lead to ammonia toxicity? Is arginine an essential amino acid in cats? Why or why not?
- (c) Why can ornithine be substituted for arginine?

7. A two-year-old child was taken to the hospital. His mother said that he vomited frequently, especially after feedings. The child's weight and physical development were below normal. His hair, although dark, contained patches of white. A urine sample treated with ferric chloride ( $\text{FeCl}_3$ ) gave a green color characteristic of the presence of phenylpyruvate. Quantitative analysis of urine samples gave the results shown in the table.

Substance	Concentration (mM)	
	Patient's urine	Normal urine
Phenylalanine	7.0	0.01
Phenylpyruvate	4.8	0
Phenyllactate	10.3	0

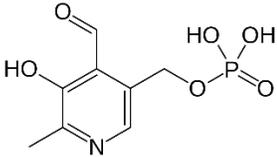
Answer all parts below.

- (a) Suggest which enzyme might be deficient in this child. Propose a treatment.  
(b) Why does phenylalanine appear in the urine in large amounts?  
(c) What is the source of phenylpyruvate and phenyllactate (structures shown below)? Why does this pathway (normally not functional) come into play when the concentration of phenylalanine rises?



- (d) Why does the boy's hair contain patches of white?

8) Many enzymes catalyze reactions with amino acids as substrate utilize pyridoxal phosphate (PLP) as a necessary coenzyme (shown below). Typically these reactions proceed via covalent catalysis where an amino acid (AA) covalently attaches to PLP as an imine (Schiff's Base). **Sketch this common AA-PLP intermediate with a generic amino acid  $\text{NH}_2\text{-CHR-CO}_2^-$**  From this intermediate the subsequent enzymatic reaction (transamination, racemization, decarboxylation, dehydration) is largely influenced by the Stereoelectronic effect. Describe what the stereoelectronic effect is and how it plays a role in determining the reaction outcome. *A reaction mechanism is not necessary but can be helpful in explaining the concept.* (10 pts)



**Part Three: Membrane Transport (15 pts)**

9) Give the structure of the modified residue that is involved as an intermediate of P-type ATPases like sarcoplasmic reticulum  $\text{Ca}^{2+}$  ATPase (SERCA). (5 pts)

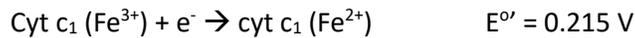
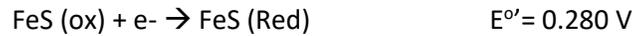
10) What is the free-energy change of pumping  $\text{Ca}^{2+}$  out of a cell when the cytoplasmic concentration is  $0.4 \mu\text{M}$ , the extracellular concentration is  $1.5 \text{ mM}$ , and the membrane potential is  $-60 \text{ mV}$  at  $25^\circ\text{C}$ . (*outside of the cell is (+) relative to inside*) (7 pts)

11) Glut4 is responsible for glucose transport into skeletal muscle cells and operates by: (3 pts)

- a) primary active transport
- b) secondary active transport
- c) simple diffusion
- d) facilitated diffusion

**Part Four:** Electron Transport/ATP synthase (25 pts)

12) An iron-sulfur protein in Complex III donates an electron to cytochrome  $c_1$ . The reduction half reactions and standard reduction potentials ( $E^{\circ}$  values) are shown below. **Write a balanced equation for the electron transfer reaction and calculate the standard free energy change.** How can you account for the fact that this reaction occurs spontaneously in the cell? (10 pts)



13) In class we have previously assigned an ATP equivalent value of 1.5 ATP per  $\text{FADH}_2$  and 2.5 ATP per NADH. Account for the difference with how oxidative phosphorylation works. (5 pts)

14) Isolated ATP Synthase  $F_1$  subunit catalyzes ATP hydrolysis. Why? What does the ATP Synthase  $F_o$  subunit provide that make ATP synthesis possible. (5 pts)

15) Compound X is an inhibitor of mitochondrial ATP synthesis. It was observed that when compound X was added to cells, the  $\text{NAD}^+/\text{NADH}$  ratio decreased. Would you expect X to be an uncoupling agent or an inhibitor of respiratory electron transfer? Explain. (5 pts)

**Part Five: Lipid Synthesis (20 pts)**

16) Starting with acetyl-CoA, malonyl-CoA, and NADPH describe enzyme loading and show by way of reactions one round of chain elongation (carbon-carbon bond forming reaction) and modification by fatty acid synthase to generate a four carbon intermediate.(10 pts)

b) If [2-<sup>13</sup>C] acetyl-CoA was used where would the label end up in a C-10 fatty acid? Draw this product. (5 pts)

c) Although clinical trials have not yet been carried out to document benefits or side effects, some physicians have suggested that patients being treated with statins also take a supplement of coenzyme Q. Suggest a rationale for this recommendation. (5 pts)

**Possibly Useful Equation and Constants**

$E = E^{\circ} + \frac{RT}{nF} \ln \frac{[\text{electron acceptor}]}{[\text{electron donor}]}$	$\Delta G^{\circ} = -nF \Delta E^{\circ}$
$\text{pH} = \text{pK}_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$	$\Delta G = \Delta G^{\circ} + RT \ln Q$
$N_a = 6.022 \times 10^{23} / \text{mole}$	$\Delta G = RT \ln \left( \frac{C_2}{C_1} \right) + ZF \Delta \psi$
$R = 0.008315 \frac{\text{kJ}}{\text{mol} \cdot \text{K}}$	$F = 96.480 \frac{\text{kJ}}{\text{V} \cdot \text{mol}}$

**Exam 3****May 6, 2016****100 pts (103 pts possible)****Multiple Choice Three points each**

- 1) A domain in polyketide synthases that is responsible for the selection and loading of a correct extender unit is:
- A) KS
  - B) AT
  - C) KR
  - D) ER
  - E) ACP
- 2) For a closed-circular DNA molecule of 10,000 base pairs in the fully relaxed form, the linking number ( $Lk$ ) is about:
- A) 10,000.
  - B) 950.
  - C) 100.
  - D) 9.5.
  - E) 2.
- 3) Formation of the ribosomal initiation complex for bacterial protein synthesis does *not* require:
- A) EF-Tu.
  - B) formylmethionyl tRNA<sup>fMet</sup>.
  - C) GTP.
  - D) initiation factor 2 (IF-2).
  - E) mRNA.
- 4) It is possible to convert the Cys that is a part of Cys-tRNA<sup>Cys</sup> to Ala by a catalytic reduction. If the resulting Ala-tRNA<sup>Cys</sup> were added to a mixture of (1) ribosomes, (2) all the other tRNAs and amino acids, (3) all of the cofactors and enzymes needed to make protein *in vitro*, and (4) mRNA for hemoglobin, where in the newly synthesized hemoglobin would the Ala **from Ala-tRNA<sup>Cys</sup>** be incorporated?
- A) Nowhere; this is the equivalent of a nonsense mutation
  - B) Wherever Ala normally occurs
  - C) Wherever Cys normally occurs
  - D) Wherever either Ala or Cys normally occurs
  - E) Wherever the dipeptide Ala-Cys normally occurs
- 5) The PCR reaction mixture does *not* include:
- A) all four deoxynucleoside triphosphates.
  - B) DNA containing the sequence to be amplified.
  - C) DNA ligase.
  - D) heat-stable DNA polymerase.
  - E) oligonucleotide primer(s).
- 6) Indicate whether the following statements are true (T) or false (F). (4 pts)
- \_\_\_ The linking number ( $Lk$ ) of a closed-circular DNA molecule can be changed only by breaking one or both strands.
- \_\_\_ DNA of all organisms is overwound (i.e., positively supercoiled).

7) Match the factor or enzyme at the right with the stage(s) of protein synthesis at which it acts. If a factor or enzyme participates in two stages of protein synthesis, indicate both of them. (6 pts)

- |                           |                             |
|---------------------------|-----------------------------|
| ___ Amino acid activation | (a) RF <sub>1</sub>         |
| ___ Initiation            | (b) EF-Tu                   |
| ___ Elongation            | (c) aminoacyl-tRNA          |
| ___ Termination           | (d) Shine-Dalgarno sequence |

8) The sequence of part of an mRNA is: (6 pts)

5' AUGGGGGAACG 3'

- a) What is the sequence of the DNA coding strand? \_\_\_\_\_
- b) Of the DNA template strand? \_\_\_\_\_

**Part II. Choose one of the next two questions to answer; (10 pts total)**

- 1) The gram-negative bacterium *Vibrio cholerae* produces a protein, cholera toxin ( $M_r$  90,000), that is responsible for the characteristic symptoms of cholera: extensive loss of body water and Na<sup>+</sup> through continuous, debilitating diarrhea. If body fluids and Na<sup>+</sup> are not replaced, severe dehydration results; untreated, the disease is often fatal. The toxin catalyzes the covalent attachment of an ADP-ribose group to the  $\alpha$  subunit of the G protein. This results in the inhibition of the intrinsic GTPase activity of the G protein.
- a) Sketch a diagram of the key components of a GPCR signaling system that acts through cAMP.

b) What is the effect of cholera toxin on [cAMP] in intestinal epithelial cells? Explain.

c) Based on the information above, suggest how cAMP normally functions in intestinal epithelial cells.

- 2) Figure 12-8 (left, below) shows the interaction between  $\beta$ -arrestin and the  $\beta$ -adrenergic receptor. How would you use FRET (Right, below) to demonstrate this interaction in living cells? Which proteins would you fuse? Which wavelengths would you use to illuminate the cells, and which would you monitor? What would you expect to observe if the interaction occurred? If it did not occur? How might you explain the failure of this approach to demonstrate this interaction?

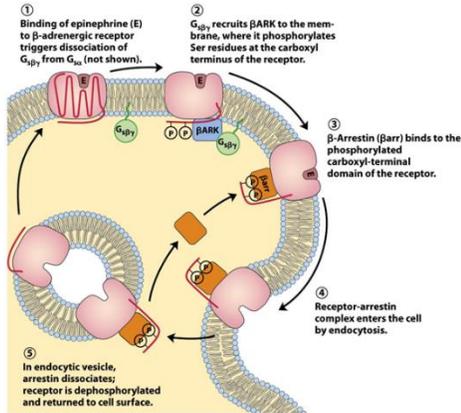
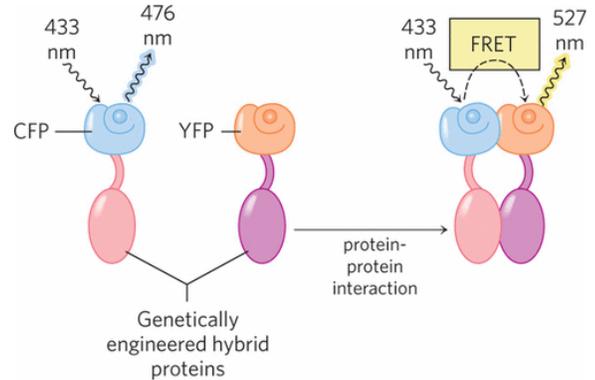


Figure 12-8  
Lehninger Principles of Biochemistry, Fifth Edition  
© 2008 W.H. Freeman and Company



### Part III. Choose four of the next five questions to answer; 8 pts each (32 pts total)

- 3) *Going Wobbly*. Explain how it is possible that some tRNA molecules recognize more than one codon. How does this impact the number of unique tRNAs required in a cell? (8 pts)

- 4) What is the role of EF-Tu in protein synthesis? Predict the effect on protein synthesis if EF-Tu were able to recognize and form a complex with fMet-tRNA<sup>Met</sup>. (8 pts)

- 5) One strand of a chromosomal DNA sequence is shown below. An investigator wants to amplify and isolate a DNA fragment defined by the segment shown in red, using the polymerase chain reaction. Design two PCR primers, each 15 nucleotides long, that can be used to amplify this DNA segment. (8 pts)

5' --- AATGCCGTCAGCCGATCTG**CCTCGAGTCAATCGA**  
**TGCTGGTAACTTGGGGTATAAAGCTTACCCATGGTATCG**  
**TAGTTAGATTGATTGTTAGGTTCTTAGGTTTAGGTTTC**  
**TGGTATTGGTTTAGGGTCTTTGATGCTATTAATTGTTTGG**  
**TTTTGATTTGGTCTTTATATGGTTTATGTTTTAAGCCGGT**  
**TTTGTCTGGGATGGTTCGTCTGATGTGCGCGTAGCGTGCG**  
 GCG --- 3'

Primer 1: 5' \_\_\_\_\_ 3'

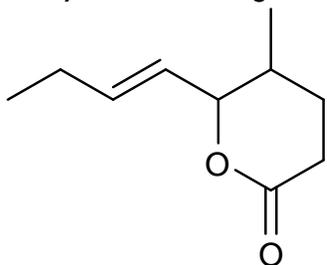
Primer 2: 5' \_\_\_\_\_ 3'

- 6) (a) Describe two structural features required for a DNA molecule to maintain a negatively supercoiled state. (b) What enzyme, with the aid of ATP, can generate negative superhelicity in DNA? (c) Describe the physical mechanism by which this enzyme acts. (8 pts)

- 7) The restriction enzymes *AclI* cleaves at the sequence 5'-AGCT-3', and *NotI* cleaves at 5'-GCGGCCGC-3'. What would be the average distance between cleavage sites for each enzyme on digestion of double stranded DNA? Assume that the DNA contains equal proportions of A, G, C, and T. (8 pts)

**Part IV. Answer Both of the Following Questions: 15 pts each; 30 pts total**

- 8) The following compound is assembled by a polyketide synthase (PKS) pathway.



- (a) Clearly mark which carbons would be labeled if [2-<sup>13</sup>C] acetate was fed to the producing organism. Label these carbons with an asterisks in the structure. (3 pts)
- (b) Four modules and a TE domain are found from the biosynthetic genes that encode for the PKS. Arrange these modules in the correct order for the assembly of this product. Circle the AT domain(s) in you arranged system that would be specific for methyl malonyl CoA. (8 pts)

KS AT DH ER KR ACP

AT ACP

TE

KS AT KR ACP

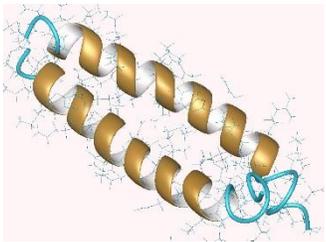
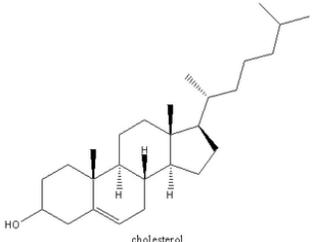
KS AT DH KR ACP

- (c) In one sentence describe the function of the following domains in fatty acid synthase. (4 pts)

ACP

Ketosynthase



	<p><b>CHEMISTRY 452</b>  <b>Biochemistry II</b>  <b>Spring 2018</b></p> <p><b>MWF 8-8:50am      PHSC 301</b></p> <p><b>Dr. Dan Edwards</b>  <b>California State University, Chico</b>  <b>Department of Chemistry</b></p>	 <p style="text-align: center;">cholesterol</p>
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**OFFICE HOURS:** Tues and Thurs 2-3 PM, Wed and Fri 10-11 AM or by Appointment

**OFFICE:** PHSC 329

**PHONE:** 898-5226

**EMAIL:** [djedwards@csuchico.edu](mailto:djedwards@csuchico.edu)

**REQUIRED MATERIAL:**

- **Nelson & Cox, Lehninger Principles of Biochemistry, 6th edition**
- **Scientific calculator**
- **Electronic course access:** Blackboard Learn will be used to distribute class information, assignments, keys, etc.

**PREREQUISITES:**

- Completion of Biochemistry I (CHEM 451) is required
- C- Grade or better is highly recommended

**WHO SHOULD TAKE THIS COURSE:**

- Biochemistry majors-Required for major
- Professional Chemistry, Biology (molecular and cell biology emphasis), and Microbiology majors that are interested in biochemistry and may desire a comprehensive understanding of biochemistry for career preparation, career advancement, and/or for preparation for graduate school in a chemistry, biochemistry, molecular biology, or a cellular biology field.
- Pre-professionals that want an excellent preparative course for medical, dental, and pharmacy school.

**DESIRED COURSE OUTCOMES:**

- Develop a solid biochemical foundation in key areas of metabolism, molecular biology, and molecular disease.
- Become familiar with the key chemical, biochemical, and molecular genetic techniques used to study biological chemistry.
- Learn to explore biochemical topics independently by becoming familiar with the biochemical literature and how to use these resources.
- Learn to communicate biochemical topics by discussing and presenting biochemical material in a small classroom setting.
- Gain an appreciation of what is currently known in biochemistry and what are the current hot research areas in the field.

**KEY REVIEW TOPICS:**

- Structure and function of main classes of biomolecules (**amino acids/proteins**, carbohydrates, nucleotides/nucleic acids, lipids/membranes)
- Intermolecular interactions and conventions for quantifying these interactions ( $K_d$  and binding curves)
- Enzyme catalytic mechanisms and kinetics (Catalytic mechanisms and Michaelis Menten kinetics)
- Thermodynamic parameters and equilibrium constants ( $\Delta H$ ,  $\Delta S$ ,  $\Delta G$ ,  $\Delta G^\circ$ ,  $K_{eq}$ )
- Reactions-Oxidation/reduction, isomerizations, group transfer reactions, carbon-carbon bond forming reactions, etc.

**GRADE ASSESSMENT:**

Your grade will be assigned based on your performance in the following areas:

Learning Modules/Homework	approx. 75 pts
Mid-Term Exams (3 x 100):	300 pts
Presentation Points	100 pts
Final Exam (Comprehensive ACS standardized exam)	125 pts
<b>TOTAL:</b>	<b>approx. 600 pts</b>

Grades will be assigned based on an approximate breakdown of:

% of Total Points	Letter Grade
90.0-100.0	A
85.0-89.9	A-
80-84.9	B+
75.0-79.9	B
70.0-74.9	B-
65.0-69.9	C+
60.0-64.9	C
55.0-59.9	C-
45.0-54.9	D
< 45.0	F

**PROBLEM SET POLICIES:**

Assignments will be assigned on an almost daily basis. I will ask you to hand in some of these assignments. Additional textbook problems should also be completed for your own practice!

All assignments are to be turned in at the **beginning of class** on the day that it is due. Late assignments will not be accepted for credit except under extenuating circumstances.

**EXAM POLICIES:**

Makeup exams will only be given for “serious and compelling reasons” as described in the University Catalog. Your makeup exam score will be counted no higher than the average of other exam scores. For example, if you receive an 80% on the make-up exam, but your average on all of the other exams is only 70%, then your makeup exam score will be adjusted to 70% at the end of the course; however, if you receive the same or lower than your average then the makeup exam score stands. **Only one makeup exam is allowed per semester.** The final exam will be comprehensive and **will only be given during the scheduled time so please plan ahead.**

**ACADEMIC INTEGRITY:**

Copying answers during exams, quizzes, or on assignments will not be tolerated. Instances of cheating will be reported to Student Judicial Affairs, and serious academic penalties are possible. Please refer to the university catalog for further information. The use of cell phones or headphones will not be allowed during exams.

**STUDENT LITERATURE PRESENTATION:**

During the course of the semester, we will have a series of student led presentations/discussions. Each student led presentation and discussion of a current research article from a leading biochemistry related journal. More details to follow.

**COURSEWORK EXPECTATIONS:**

I anticipate that students will need to spend 2-3 hours outside of class per class meeting to be successful. On exams, you are accountable for all assigned reading and assigned textbook problems, even though **I will not cover all the material in class.**

**CLASS SCHEDULE:**

Date(s)	Day	Chap	Topic(s)	Required Reading/Assignment	
Jan Break			CHEM 451 Review		
Jan 22	M		Course Introduction— How Enzymes Control Stereochemistry	Handout	
Jan 24	W	6	Metabolic Control-Enzyme Regulation	Ch. 6.5, <a href="#">ATCase/LM 1 Due</a>	
Jan 26	F	14/16	Role of Vitamins-Thiamine	Chapter 14.3 / Ch 16.1	
Jan 29	M	16	Citric Acid Cycle	Ch 16.2 -16.4/ <a href="#">LM 2 Due</a>	
Jan 31	W	16	Citric Acid Cycle	Ch. 10/ <a href="#">LM 3 Due</a>	
Feb 2	F	16	Citric Acid Cycle		
Feb 5	M	17	Digestion, Mobilization, and Transport of Fats	Ch 17	
Feb 7	W	17	$\beta$ -oxidation/Starvation Response-Ketogenesis	Ch 17	
Feb 9	F	18	Central Feature of Amino Acid Metabolism	Ch 18.1/ <a href="#">LM 5 Due</a>	
Feb 12	M	18	PLP Dependent Enzymes	Ch 18.1	
Feb 14	W	18	Amino Acid Metabolism Cont.		
Feb 16	F	<b>Exam 1</b>			
Feb 19	M	18	Urea Cycle and Select Pathways of Amino Acid Degradation	Ch 18.2 and 18.3	
Feb 21	W	11	General Principles of Membrane Transport Processes	Ch 10-11	
Feb 23	F	11	Examples of Membrane Transporters	Ch 11	
Feb 26	M	19	Importance of Electron Transfer Reactions	Ch 13.4; 19.1	
Feb 28	W	19	Electron Transport Chain and Oxidative Phosphorylation/ ROS	19.1-19.3	
Mar 2	F	19	Models of Proton Pumping/Molecular Motors	Ch 19.10, 19.2	
Mar 5	M	21	Lipid Biosynthesis-Fatty Acid and TAG Biosynthesis	Ch 21.1-21.2	
Mar 7	W	21	Cholesterol Biosynthesis/Terpenoid Biosynthesis	Ch 21.4	
Mar 9	F	<i>Presentation 1-<a href="#">Fatty Acid Photodecarboxylase from Algae</a></i>		Journal Article	
Mar 12	M				
Mar 14	W				
Mar 16	F	<b>Exam 2</b>			
Mar 19-23		<b>Spring Break</b>			
Mar 26	M		Natural Product Biosynthesis	TBA	
Mar 28	W		Variation on a Theme-Fatty Acid versus Polyketide Biosynthesis	TBA	
Mar 30	F	<b>Cesar Chavez Holiday</b>			
April 2	M	12	Biosignaling—Overview and G protein-Coupled receptors and second messengers	Ch 12.1-12.2 (Box 12-2)	
April 4	W	<i>Presentation 2-<a href="#">A Subfamily of Bacterial Ribokinases Utilizes a Hemithioacetal for Pyridoxal Phosphate Salvage</a></i>		Journal Article	
April 6	F	<i>Presentation 3-<a href="#">ATP Sensor that detects ATP Levels inside of cells</a></i>		Journal Article	
April 9	M	12	Biosignaling—Overview and G protein-Coupled receptors and second messengers	Ch 12.1-12.3	
April 11	W	9	DNA-Based Information Technology Basics	Ch 9	
April 13	F	<i>Presentation 4-<a href="#">Development of a Clinically Viable Heroin Vaccine</a></i>		Journal Article	
April 16	M	25	DNA Replication	Ch 25.1	
April 18	W	25	DNA Replication Fidelity/Repair	Ch 25.2	
April 20	F	<i>Presentation 5-<a href="#">Molecular basis for the thiol sensitivity of insulin-degrading enzyme</a></i>		Journal Article	
April 23	M	26	Transcription	Ch 26.1	
April 25	W	26	RNA Processing	Ch 26.2	
April 27	F	<i>Presentation 6-<a href="#">A Global Map of Lipid-Binding Proteins and Their Ligandability in Cells</a></i>		Journal Articles	
April 30	M	27	Protein Metabolism-The Genetic Code and Loading of tRNA	Ch. 27.1	
May 2	W	27	Protein Synthesis-Structure and activity of Ribosome	Ch. 27.1-27.2	
May 4	F	<b>Exam 3</b>			
May 7	M	<i>Presentation 7- <a href="#">Proteome remodeling during terminal erythroid differentiation</a></i>		Journal Article	
May 9	W	<i>Presentation 8-<a href="#">CRISPR-Mediated Tagging of Endogenous Proteins with a Luminescent Peptide</a></i>		Journal Article	

May 11	F	<a href="#">Presentation 9-Massively parallel de novo protein design for targeted therapeutics</a>	Journal Article
May 18	F	<b>Final Exam 8:00-9:50</b>	

**Additional Homework Problems (some of these problems are also found in assigned learning modules)**

<b><u>Chapter</u></b>	<b><u>Problems</u></b>
16	1-26, 28, 30,31,33,34,36
17	1-7, 9-19, 21-24, 27-29
18	1-12, 15-19
11	4,5, 7-13, 15,18-20, 22, 24
19	1-16, 22-25
21	1-7, 9, 10,13,14,16-19
12	1-11, 13, 19, 21
23	1-16, 18,19,21
9	1-6, 8, 9, 13
24	2-9, 11, 14, 15
25	1-8, 10-12
26	1, 2 ,5-7, 11, 12
27	1-5, 9-15

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# CHEM 483: INTEGRATED LABORATORY III

SPRING 2018

## COURSE INFORMATION

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Class Days: Tuesdays and Thursdays

Class Times: 11:00 am-1:50 pm

Class Location: PHSC 320

Office Hours (and by appointment)

M, W 9:00-11:00 am

Office Hours Location: PHSC 327

## COURSE OVERVIEW

---

This is the final semester in your three-semester journey through Integrated Lab. We will be focused on using instruments to interrogate complex samples.

- design a suite of experiments to probe real-life mixtures
- rationally develop GC and LC methods for complex mixtures
- make physical properties measurements
- design and execute appropriate calibration curves for the determination of several unknowns
- prepare weekly written updates which will turn into a final paper
- orally present the data effectively

## COURSE MATERIALS

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The required materials for this course are

- crazy-good lab skills ☺
- a critical eye for the chemical literature
- standard lock, goggles, lab book, etc

## COURSE ASSESSMENT AND GRADING

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Your grade in this course will be comprised of the following items:

- 10 weekly written updates
- 2 project reports
- 2 presentations

Before you do your first presentation, I will present you with my grading rubric so you know what I am looking for.

## PROJECTS

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We'll start the semester playing a little with petroleum diesel, biodiesel, and some deep eutectic solvents prepared with biodiesel-waste glycerol. This will be some analytical chemistry, some organic chemistry, some physical properties measurements, and lots of fun with instruments. Then, we'll turn to an awesome forensic chemistry lab. This will primarily be fun with separations and calibration curves.

I would guess that we need seven weeks for the fuels chemistry lab. That would put presentation on March 13<sup>th</sup>. There can be some flexibility with this as the semester goes! We will check in at the beginning of every lab period.

## ACCESSIBILITY

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If you are a student who requires or believes you will require accommodations for this class, it is your responsibility to contact the Accessibility Resource Center at (530) 898-5959 or by stopping by SSC 170. You can also learn more about the services provided by visiting the [Accessibility Resource Center](#) website. To avoid any delay in the receipt of your accommodations, you should contact the Accessibility Resource Center as soon as possible.

## WEEKLY WRITING UPDATES

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This lab meets on Tuesdays and Thursdays. Every Tuesday, please submit to Bb an update of your experimental progress for the week. Details are given in the Power Point presentation posted on your Bb site. Please note that your writing assignments will be electronically returned to you for refinement until they are polished to the level that they would be accepted in a peer-reviewed chemical journal. Thus, you may have several updates that you are working on finishing simultaneously if some of your assignments require editing. You will not receive a grade for a writing update until it has been completed and requires no further editing. If part of the experimental work that you are describing involves something like a calibration curve, you should include that curve (with appropriate title, axes, error bars, etc).

## ORAL PRESENTATIONS

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The importance of being able to orally present your research progress, mishaps, data, and results cannot be overstated. Oral presentations occur in group meetings in grad school, research team meetings in industry, and funding meetings for start-up companies. You need to be quick on your feet, well spoken, and confident. To do all these things, you need to have 100% mastery of your project-- but you also need to have prepared high quality, impactful slides. At the end of each project, you will orally present your results. Much of the work will have been done through your writing assignments and will simply need to be properly formatted for oral presentation.

## ASSIGNMENTS & GRADING

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### 11 Weekly Writing Updates @ 10 points each = 110 points

Details above.

### 2 Complete Reports @ 50 points each = 100 points

These complete reports should be a compilation of your weekly writing assignments, with a suitable introduction and conclusion. They should cite the appropriate chemical literature using proper [ACS formatting](#).

### 2 Oral Presentations @ 50 points = 100 points

Since you are all working on the same general topic, you will need to be present only your individual results. Make sure to report chemical syntheses, calibration curves, key data, and your conclusions. I would anticipate that each individual presentation should take approximately 15 minutes.

TOTAL POINTS= 410

**CHEM 270: Organic Chemistry I Lab**

## Schedule and List of Experiments

Week	Week of	Experiment
1	Aug 31	Check-in; Technique Based Experiment 1: Distillation (setup fermentation); Technique Based Experiment 2: Melting Point
2	Sept 7	Technique Based Experiment 3: Extraction
3	Sept 14	Completion of Technique Based Experiment 1
4	Sept 21	Technique Based Experiment 4: Recrystallization
5	Sept 28	Technique Based Experiment 5: Thin Layer Chromatography (TLC)
6	Oct 5	Dry Lab / Virtual Lab 1: Alkane Nomenclature
7	Oct 12	Dry Lab / Virtual Lab 2: Isomers and $^{13}\text{C}$ NMR
8	Oct 19	Dry Lab / Virtual Lab 3: Spectroscopy Workshop Part 2
9	Oct 26	Dry Lab / Virtual Lab 3: Spectroscopy Workshop Part 1
10	Nov 2	Synthesis Based Experiment 1: Competitive $\text{S}_{\text{N}}2$ and $\text{S}_{\text{N}}1$
11	Nov 9	Technique Based Experiment 6: Steam Distillation of Orange Oil
12	Nov 16	Technique Based Experiment 6: Orange Oil Cont.
13	Nov 30	Synthesis Based Experiment 2: Multi-Step Synthesis
14	Dec 7	Synthesis Based Experiment 2: Multi-Step Synthesis Cont.
15	Dec 14	<b>(Quiz???)</b> , Check-out

### **Experiment Title: Distillation (turning grape juice into wine)**

Instruments

Compounds

- Grape juice
- Dry yeast

### **Experiment Title: Melting Point**

- Instruments
  - MeltTemp

Compounds

- Phenylacetic acid
- Vanillin
- Glutaric acid
- Oxalic acid
- *o*-Toluic acid
- Fluorene
- *p*-Nitrophenol
- Acetanilide
- Trans-cinnamic acid
- Urea
- *d*-Tartaric acid
- *o*-Aminophenol
- Hydroquinone

### **Experiment Title: Extraction**

- Instruments

Compounds

- Acetic acid
- Dichloromethane
- Diethylether
- NaOH

### **Experiment Title: Recrystallization**

- Instruments

Compounds

- Acetanilide

- Trans-cinnamic acid
- Acetone
- 

#### **Experiment Title: Thin Layer Chromatography**

- Instruments
  -

#### **Compounds**

- Hexanes
- Ethyl acetate
- Catechol
- Hydroquinone
- 4-t-butylcatechol
- 2-methylresorcinol
- Phenol
- p-cresol
- 2,5-dimethylphenol
- 5 other phenols

#### **Experiment Title: Competitive S<sub>N</sub>2 and S<sub>N</sub>1 reactions**

- Instruments
  - NMR

#### **Compounds**

- Bromooctane
- KCl
- KI
- Hexadecyltributylphosphonium bromide
- 2-methyl-2-butanol
- Na<sub>2</sub>SO<sub>4</sub>
- Sulfuric acid
- NH<sub>4</sub>Cl
- NH<sub>4</sub>Br
- K<sub>2</sub>CO<sub>3</sub>

#### **Experiment Title: Orange Oil**

- Instruments
  - FTIR
  - GC-MS
  - NMR

## Compounds

- Orange peels
- Dichloromethane
- $\text{CaCl}_2$

## Experiment Title: Multi-step synthesis

- Instruments
  - NMR
  - FT-IR
- Compounds
  - $\text{NaBH}_4$
  - $\text{LiAlH}_4$
  - Pinacolone
  - methanol
  - Sulfuric acid

## CHEM 370M: Organic Chemistry II Lab

### Schedule of Experiments

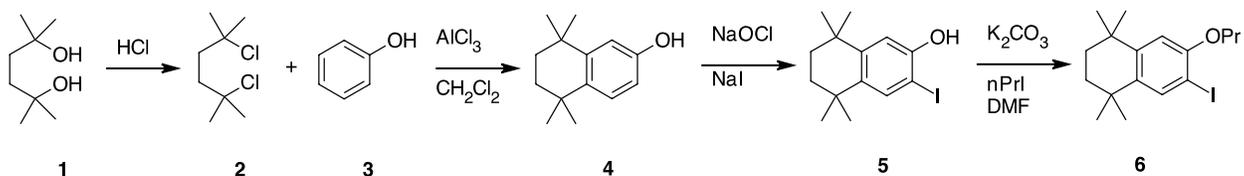
Weeks	Experiment
1-4	Transformations of Isophorone
5-8	Natural Product Derivative Synthesis: Preparation of a Precursor to a Retinoid X Receptor Modulator
9-11	4,7-dimethoxy-1 <i>H</i> -indene: A Synthesis with Multiplet Analysis
12-15	Diastereoselective Hydride Reduction to Access Syn and Anti Diols.

#### Experiment Title: Transformations of Isophorone

- Instruments
  - NMR
  - GC-MS
  - FTIR
- Compounds
  - Isophorone
  - Magnesium
  - Methyl iodide
  - Diethyl ether
  - Hydrochloric acid
  - Maleic anhydride

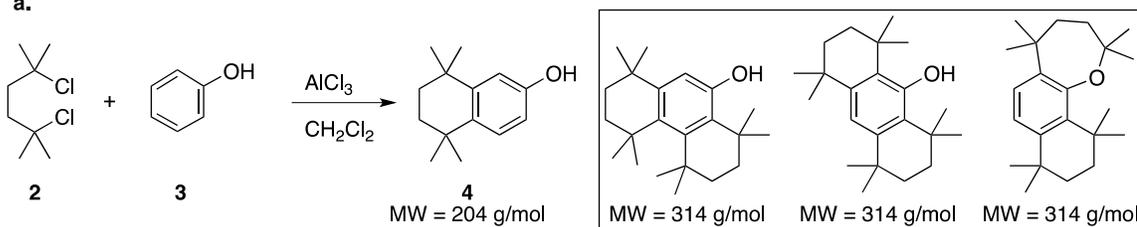
**Experiment Title:** Natural Product Derivative Synthesis: Preparation of a Precursor to a Retinoid X Receptor Modulator

- Instruments
  - NMR
  - GC-MS
  - FT-IR
  
- Compounds
  - Ethyl acetate
  - Hydrochloric acid
  - Dichloromethane
  - Sodium bicarbonate
  - Brine
  - Magnesium sulfate
  - NaOCl
  - Iodopropane
  - DMF
  -



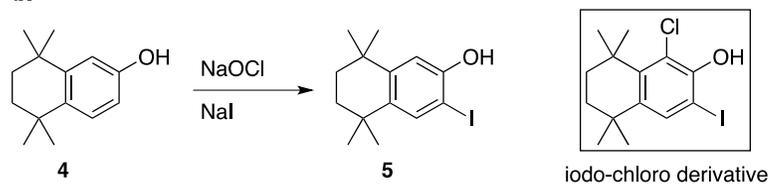
•

a.



over alkylation products

b.



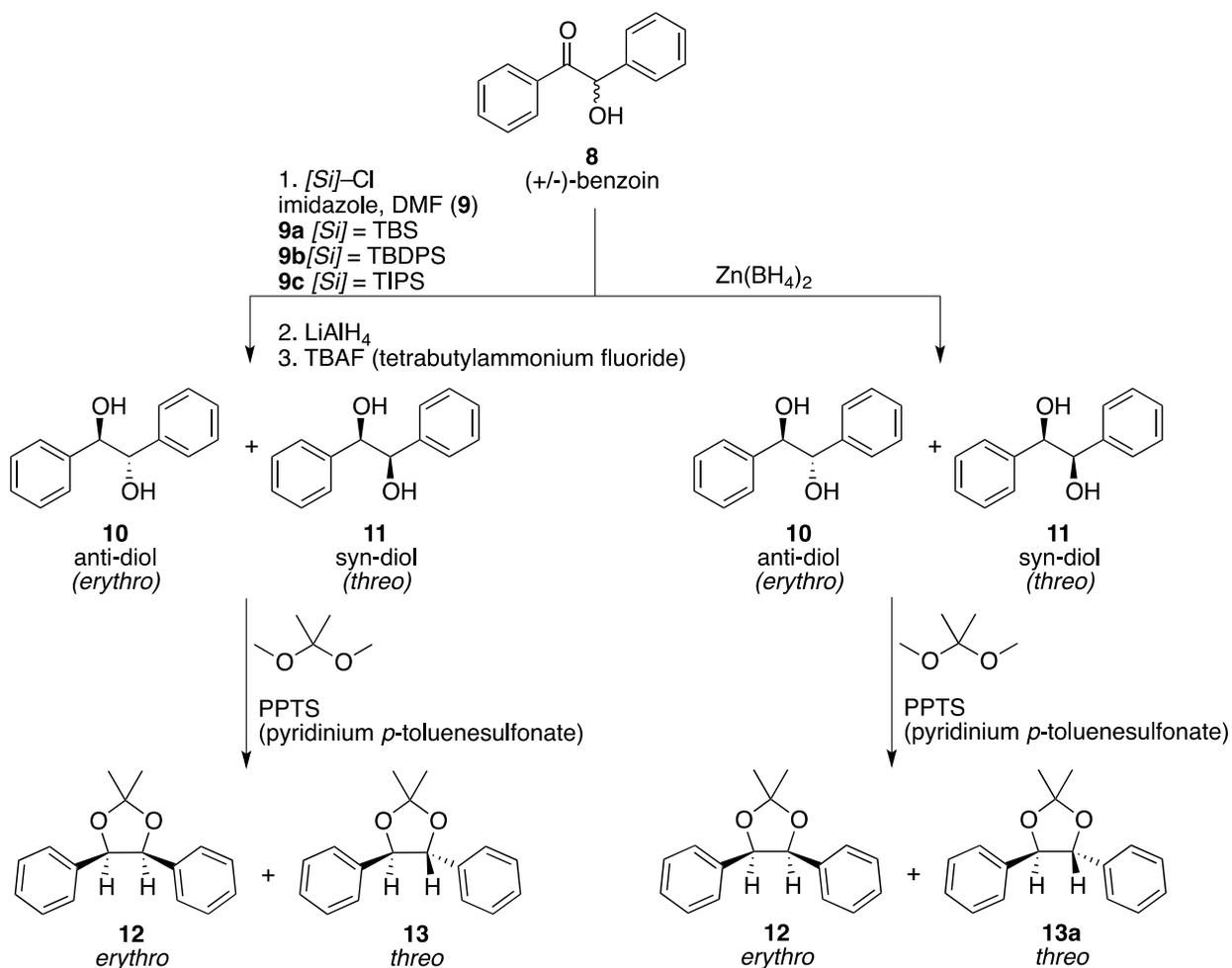
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**Experiment Title:** 4,7-dimethoxy-1*H*-indene: A Synthesis with Multiplet Analysis

- Instruments
  - NMR
  - GC-MS
  - FT-IR
  
- Compounds
  - 3-(2,5-dimethoxyphenyl)propionic acid
  - Polyphosphoric acid
  - Dichloromethane
  - Sodium bicarbonate
  - Magnesium sulfate
  - 4,7-dimethoxy-1-indanone
  - NaBH<sub>4</sub>
  - Brine
  - Ethanol
  - 4,7-dimethoxy-1-indanol
  - *p*-toulenesulfonic acid monohydrate
  - ethyl acetate
  - hexanes
  - chloroform
  -

## Experiment Title: Diastereoselective Hydride Reduction to Access Syn and Anti Diols

- Instruments
  - NMR
  - GC-MS
  - FT-IR
- Compounds
  - Acetone
  - 2,2-dimethoxypropane
  - THF
  - Zinc chloride
  - NaBH<sub>4</sub>
  - 5-hexyn-1-ol
  - butyldiphenylsilyl chloride
  - hexanes
  - dichloromethane
  -



## **CHEM 320 and 483 Analytical and Instrumental Labs**

### **Experiment Title: Gravimetric and Volumetric Techniques with Density Unknowns**

#### Instruments

- balances

#### Compounds

- salt solutions

### **Experiment Title: Titration of KHP Unknown**

#### Instruments

- balances

#### Compounds

- Potassium hydrogen phthalate
- NaOH

### **Experiment Title: Gravimetric Analysis of Chloride Unknown**

#### Instruments

- balances

#### Compounds

- Silver nitrate
- Sodium chloride
- Chloride unknowns
- Nitric acid

### **Experiment Title: Gravimetric and Volumetric Determination of Zinc in Galvanized Sheet metal and Unknown**

#### Instruments

- balances

#### Compounds

- EDTA
- Zinc metal
- HCl
- Ammonia buffer
- Calmagite indicator

### **Experiment Title: Water Hardness by Flame AA**

#### Instruments

- Balances
- Atomic absorption spectrophotometer

#### Compounds

- Calcium and magnesium ion solutions

### **Experiment Title: Analysis of Ibuprofen by UV-Vis**

#### Instruments

- Balances
- UV-Vis spectrometer

#### Compounds

- ibuprofen
- NaOH

### **Experiment Title: Redox Titration of Ferricyanide**

#### Instruments

- Balances
- UV-Vis
- Electrochemical workstation

#### Compounds

- Potassium ferricyanide
- Ascorbic acid
- Phosphate buffer

### **Experiment Title: Potentiometric Titration and %acid in Unknown**

#### Instruments

- Balances
- pH meter

#### Compounds

- KHP
- NaOH

### **Experiment Title: Iron by Standard Addition**

#### Instruments

- Balances
- UV-Vis

#### Compounds

- O-phenanthroline
- Iron ion solutions
- Vitamin tablets

### **Experiment Title: Acetaminophen by HPLC**

#### Instruments

- Balances
- HPLC

#### Compounds

- Acetaminophen
- Triethylamine
- Glacial acetic acid
- Acetonitrile

### **Experiment Title: Ion Selective Electrode Analysis for Fluoride**

#### Instruments

- Balances
- Fluoride selective electrode and potentiometer

#### Compounds

- Glacial acetic acid
- NaCl
- NaOH
- NaF solutions

**Experiment Title: Spectrophotometric and Potentiometric Determination of pK**

Instruments

- Balances
- UV-Vis
- pH meter

Compounds

- acetate buffer
- bromcresol green indicator

**Experiment Title: Determination of Caffeine in coffee by GC**

Instruments

- Balances
- GC-MS
- GC-FID

Compounds

- Coffee
- Caffeine
- Dichloromethane

**Experiment Title: Properties of a Cation exchange resin**

Instruments

- Balances

Compounds

- HCl
- Dowex-50W
- NaOH
- Iron (III) nitrate solutions

**Experiment Title: Spectrophotometric analysis of copper in brass**

Instruments

- Balances
- UV-Vis

Compounds

- Zinc and copper solutions
- Nitric acid
- Brass

**Experiment Title: Simultaneous Determination of Copper and Iron by Spectrophotometric EDTA titration**

Instruments

- Balances
- UV-Vis

Compounds

- EDTA
- Copper and Iron ion solutions

### **Experiment Title: Fuels Chemistry**

**This experiment is a multi-week group project using many instruments in a research setting**

#### Instruments

- Balances
- UV-Vis
- NMR
- FT-IR
- GC-MS
- Viscometer
- HPLC

#### Compounds

- Petroleum diesel
- NaOH
- H<sub>2</sub>SO<sub>4</sub>
- Glycerol

### **Experiment Title: Wine and Beer Analysis**

**This experiment is a multi-week group project using many instruments in a research setting**

#### Instruments

- Balances
- UV-Vis
- NMR
- FT-IR
- GC-MS
- Viscometer
- HPLC

#### Compounds

- Alpha acids
- Alpha dicarbonyls

## CHEM 381 and 382 – Integrated Physical and Inorganic Labs

Each experiment is a multi-week, group organized project

### Experiment Title: Conformational Preferences in bromocycloketone

#### Instruments

- NMR
- GC-MS
- FT-IR
- UV-Vis
- Gaussian 16

#### Compounds

- 3,3,5,5-tetramethylcyclohexanone
- glacial acetic acid
- pyridinium tribromide
- hexanes
- NaHCO<sub>3</sub> (aq)
- Na<sub>2</sub>CO<sub>4</sub>
- silica gel
- ethyl acetate
- methanol
- acetonitrile
- cyclohexane
- DMSO
- dichloromethane
- chloroform

**Experiment Title: Reversible Diels-Alder Reaction: A merger of experimental and computational chemistry**

Instruments

- NMR
- GC-MS
- Gaussian 16

Compounds

- Furan
- 2-methylfuran
- 2-methoxyfuran
- 3-bromofuran
- Maleimide
- N-methylmaleimide
- N-phenylmaleimide
- Acetonitrile

**Experiment Title: Fabrication and Characterization of Perovskite solar cells**

Instruments

- UV-Vis
- Cyclic voltammetry

Compounds

- $\text{PbI}_2$
- Methylammonium iodide
- Formamidium iodide
- Copper (I) thiocyanate
- Carbon
- Ethanol
- Titanium isopropoxide
- Dimethyl sulfide
- DMF

**Experiment Title: Synthesis and Characterization of Ruthenium (II) tetrakispyridine complexes**

Instruments

- NMR
- LC-MS
- UV-Vis
- 

Compounds

- RuCl<sub>3</sub>
- DMSO
- Ethanol
- CaCl<sub>2</sub>
- Pyridine
- 4-acetylpyridine
- Toluene
- N-hexane
- Potassium thiocyanate
- 

**Experiment Title: Preparation and Characterization of Inorganic Salen Catalysts and their use in the Oxidation of Organic Substrates**

Instruments

- NMR
- LC-MS
- UV-Vis
- FTIR
- Cyclic voltammetry

Compounds

- Cobalt (II) acetate
- Nickel (II) acetate
- Paraformaldehyde
- DABCO
- Acetonitrile
- Phenol
- 4-methoxyphenol
- 4-chlorophenol

**Experiment Title: Preparation and Characterization of Polymer Batteries**

## Instruments

- UV-Vis
- Voltmeters
- Cyclic Voltammetry

## Compounds

- Aniline
- Sulfuric acid
- Acetone
- FTO glass

## **CHEM 453M Biochemistry Labs**

### **Experiment Title: Micropipette Performance Check**

#### Instruments

- balances

#### Compounds

- water

### **Experiment Title: Buffers**

#### Instruments

- pH meters

#### Compounds

- $\text{NaH}_2\text{PO}_4$  (sodium phosphate phosphate monobasic) solid
- $\text{Na}_2\text{HPO}_4$  (sodium phosphate dibasic) solid
- Tris-HCl solid
- Tris-Base solid
- NaCl solid

### **Experiment Title: Quantification of Riboflavin by UV-Vis**

#### Instruments

- UV-Vis

#### Compounds

- Phosphate buffers
- 2-(4-Hydroxyphenylazo)benzoic acid

### **Experiment Title: Characterization of Protein-Ligand Interactions**

#### Instruments

- NMR

#### Compounds

- 3,3,5,5-tetramethylcyclohexanone
- glacial acetic acid

### **Experiment Title: Kinetic Characterization of Lactase**

#### Instruments

- UV-Vis

#### Compounds

- o-Nitrophenyl  $\beta$ -D-galactopyranoside)
- d-Galactose
- phosphate buffers

### **Experiment Title: Identification of Proteins by Mass Spectrometry**

#### Instruments

- LC-MS
- DNA thermocycler

#### Compounds

- Formic acid
- Acetonitrile
- 2,2,2-trifluoroethanol
- Ammonium bicarbonate
- Iodoacetamide
- Trypsin
- Bovine serum albumin
- Carbonic anhydrase
- Myoglobin
- hemoglobin

### **Experiment Title: Preparation of Clarified Cell Extract**

#### Instruments

- French press
- Centrifuge
- FPLC

#### Compounds

- Ion exchange buffer
- Lysozyme
- DNAase I
- Bleach
- ethanol

### **Experiment Title: Purification by Ion-Exchange and IMAC**

#### Instruments

- FPLC

#### Compounds

- Materials from previous experiment clarifying cell extract.

### **Experiment Title: Determination of Protein Concentration**

#### Instruments

- UV-Vis

#### Compounds

- BCA protein assay kit
- Previous materials from Purification by Ion exchange

### **Experiment Title: Characterization by SDS-Page**

#### Instruments

- DNA thermocycler

#### Compounds

- SDS Gels
- SDS-PAGE standards
- Buffer
- Gel Stain
- Materials from Purification by Ion Exchange

### **Experiment Title: Characterization by Fluorescence Spectroscopy**

#### Instruments

- Fluorimeter

#### Compounds

- Materials from SDS-PAGE experiment

**Experiment Title: Determination of Molecular Mass by ESI-MS**

Instruments

- LC-MS (ESI)

Compounds

- Methanol
- Glacial Acetic Acid
- Material from previous Purification by Ion Exchange

**Experiment Title: Determination of Native Molecular Mass by Gel Filtration Chromatography**

Instruments

- FPLC

Compounds

- Gel Filtration Buffer
- Molecular Weight Standards
- Material from previous Purification by Ion Exchange

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## **Final Comments continued**

Curriculum Redesign – For the past three years, many faculty have been engaged in significant redesign of courses for non-majors and majors. Faculty are now using a wide-range of active learning strategies in the classroom. One faculty member has completely flipped his classroom providing videos of himself for each topic. He uses the classroom to engage the large number of students (160) in activities that utilize and amplify the topics and approach developed in the lecture. He also used six near peers during the class time to increase the engagement by all students. Our department has also been a campus leader in the use of Supplemental Instruction (SI) based on the UMKC model. The majority of our classes now have one or two SI leaders who attend each class meeting, meet regularly with the faculty member, develop SI session learning plans and then hold three SI sessions per week. The combination of increasing active learning strategies coupled with SI has led to a significant decrease in our DFW rates. One of our faculty has been asked by our system to serve as an SI trainer for twelve of our campuses in the northern part of the state.

Chemistry Summer Research Institute (CSRI) -- Undergraduate research has always been a hallmark of our department with research being conducted during the academic year and to during the summer. In 2007, we formalized our summer research by creating the Chemistry Summer Research Institute (CSRI). We received major donations to support this institute from some industrial partners and alumni donors. Each year since 2007 we have had 10-15 students and 6-9 faculty participating in research representing each of the core areas of chemistry and biochemistry. We usually also have collaborators from other departments on campus, faculty from other universities, or industry. These student/faculty research teams work full-time for 10 weeks. Each Friday oral presentations are given by faculty (first 5 weeks) and then by the students (last five weeks). The work is also reported in written reports and also posters. As part of the CSRI experience representative faculty and students present their posters and the National Spring Meeting of the ACS.

Funding for Undergraduate Research – Much of the funding for undergraduate research comes from alumni donors, internal and external research grants and industry internships. We recently participated in National Giving Day and successfully raised over \$11,000 to support CSRI participants.

## **Studies of the Enzymatic Breakdown of Polyhydroxybutyrate**

By: Nancy Guadalupe Martinez Melgoza

Polyhydroxybutyrate (PHB) is a naturally occurring polymer that serves as a biodegradable thermoplastic that is not derived from petroleum. Traditional plastics are still degradable, but they do not return to the earth and cannot be processed by microorganisms. Thus, PHB are referred to as biodegradable material that is utilized as an exogenous carbon and energy storage compound for a wide variety of bacteria (Dawes and Ribbons 1964). The microorganisms secrete extracellular polyhydroxybutyrate depolymerases to hydrolyze the water insoluble polymer, monomer, 3-hydroxybutyrate that is then further metabolized. In order to better understand the conditions in which optimal degradation of PHB will occur, specific PHB degrading bacteria were selected based on the ability to grow on PHB as a carbon source. The objective is to better understand the conditions in which optimal degradation of PHB and how to study the system of induction leading to the PHB depolymerase.

### **Methods**

For continued growth and induction, the procedure begins with growing the test inoculum in a TSB starter culture. The objective for this is to grow up the organism in a rich media to obtain the maximal amount of cells. The M9 minimal salts provide only the exact nutrients needed for organism for growth, so it is supplemented with glucose as a carbon source. Dilute the inoculum 1:1000 into M9 media for the gram negatives, and nutrient broth for the gram positives, and proceed to grow the culture overnight. Essential media for the experiment includes 10x M9 salts (Maniatis, Molecular Cloning: A Laboratory Manual, 1982). The stock

solution is sterilized by autoclaving and proceeding to diluting it to 1X with H<sub>2</sub>O prior to use.

Separation of the supernatant and the cell pellet is achieved by utilizing a centrifuge instrument. A region of high concentration is formed containing a higher density than the surrounding medium. The result is a precipitate that sinks and collects a compact pellet at the outermost point of the tube. The cell pellet will resuspended in M9 salts in order to starve the cells. Starvation is represented as a stress that bacteria encounter during stationary phase. PHB, Poly(3-hydroxybutyrate) will be added to the induced cells and glucose will be used to monitor the un-induced cells. Induction will initiate once the resuspended cells are placed on a shaker. Samples of each induction flask should contain the induced depolymerase enzyme. In order to observe the enzyme activity, a turbidity assay will be performed.

To prepare for the turbidity assay, each sample will be micro centrifuged in order to separate the cells from its culture supernatant. The lysed cell supernatant along with a 1 mg/ml PHB stock solution will be placed into a cuvette for the 1 mL assay. PHB is an insoluble matter, therefore it is expected that you initiate the assay with opaque cuvette. Biopolymers are reserve compounds and are stored in the cytoplasm occurring as insoluble inclusions (Shimao, 2001). The assay is set to test each sample at 20 minute time points for an hour, all measured at A<sub>600</sub>. An endpoint is determined based on the highest dilution producing lysis of bacteria and clearing the broth culture.

## RESULTS

*Pseudomonas acaliphila*, C5, was the bacteria utilized to investigate if the system is constitutive or inducible. To test this question, C5 was grown and further induced with PHB and glucose was used as the control. Figure 1 represents the change in absorbance at 60 minutes versus induction time, which is measured by 24 hours. Depolymerase activity was detected in the presence of PHB. Glucose, the control, did not represent activity as it remained on the baseline. To further investigate the enzyme properties *Pseudomonas acaliphila*, different inducing agents were tested for the following experiment.

To test if glucose represses the induction of the depolymerase enzyme, a second induction was performed with the conditions of PHB and PHB with glucose. Via percent change in absorbance over time, figure 2 is able to demonstrate that with the addition of glucose, it leads to regression of the system. Figure 3 represents the testing of the monomeric unit 3-hydroxybutyrate, 3HB, and if it is readily able to induce depolymerase production. 3HB showed some brief activity at 4 hours, but there was no conclusive activity at the end of the 24 hours. Alongside PHB, the monomeric unit is unable to support depolymerase production.

## DISCUSSION

PHB degraders (i.e. bacterial strains) were selected based on the ability to grow on plates that used PHB as a carbon source. The project approximately began with Dr. Larry Hanne and Dr. Larry Kirk. In order to isolate the specific strains, they selected certain sewage and compost regions that provide a large biodiversity for

microorganisms. *Pseudomonas acaliphilia* is only one of the fourteen strains that were selected to investigate its enzyme production when introduced to Poly(3-hydroxybutyrate). The main question posed was if C5 is an inducible or constitutive system. To understand this at the cellular level, the inducer is the molecule that initiates expression of a gene that codes for an enzyme. Once the inducer is signaled, it is able to activate a repressor that will lead to the production of the secreted depolymerase enzyme.

Figure 1 concluded that C5 is an inducible system by the presence of PHB. Glucose, however, does not have much of an effect on the system, keeping its activity at the baseline. With the evident decline of glucose, figure 2 was able to elude more on its effect. PHB alone induces the system, but PHB with glucose does not have the same result, as it shows little to no activity. A plausible explanation for this is that glucose acts as a repressor. Figure 3 continues the experiment by testing PHB and 3HB. The monomeric unit is soluble whereas PHB polymer is insoluble. The monomeric unit is already present in the cell, therefore not recognized to aid in the overall enzyme activity.

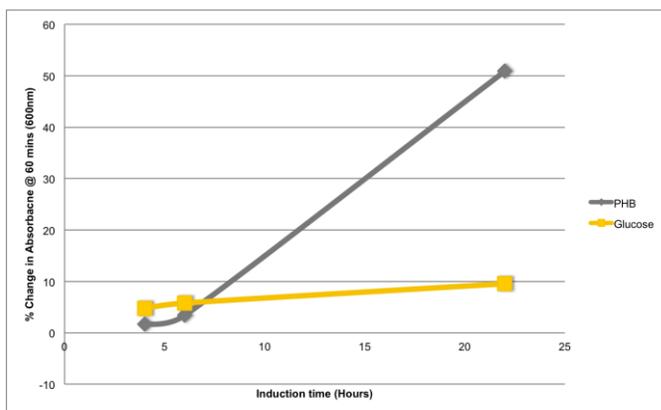


Figure 1: Percent change in absorbance at 60 minutes versus induction time. *Pseudomonas acaliphilia* was tested with PHB and glucose served as control

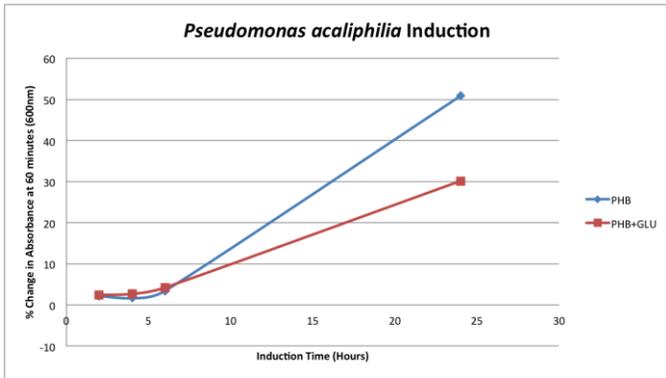


Figure 2: Percent change in absorbance at 60 minutes versus induction time. *Pseudomonas acaliphilia* was tested with PHB and PHB with glucose as the conditions

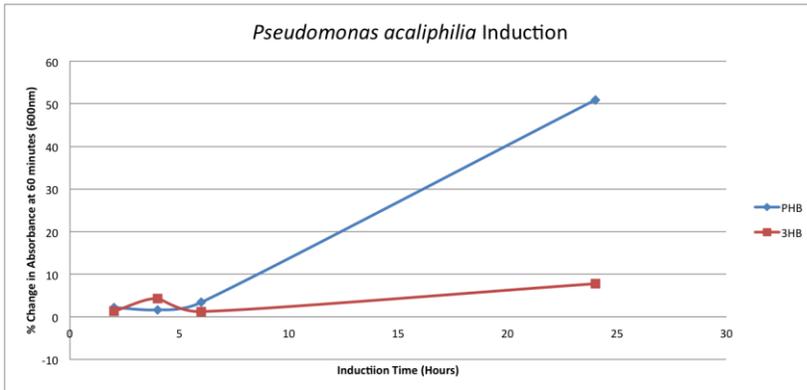


Figure 3: Figure 2: Percent change in absorbance at 60 minutes versus induction time. *Pseudomonas acaliphilia* was tested with PHB and 3HB, the monomeric unit.

## CONCLUSION

It was determined that *Pseudomonas acaliphilia* is an inducible system and only produced the enzyme in the presence of PHB. This was not evident in the beginning of the experiments due to troubleshooting with the growth conditions. By testing each individual isolate to its corresponding growth, optimal growth conditions were investigated. Whether it is a prototroph, able to grow in M9 minimal media, or an auxotroph, which requires additional nutrients to aid in

growth; each isolate was treated using the best medium that it required. The monomeric unit, 3HB, does not induce due to the possibility of already being present in the cell. Ongoing work is to be continued to look into more enzymatic protocols that can be used for future experiments.

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# Rubrene Derivative Synthesis Project

Ashley Taylor Farias

Dr. Daniel Everson

**Abstract:** The Purpose of CSRI 2017 is to perform optimization reactions of the production of 1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl and progress further into the hypothesized mechanism of the target molecule convergent synthesis. This is achieved via UV light from a photochemical reactor and constant exposure to a solution of benzene and dimethylacetelyenedicarboxylate within quartz test tubes. The procedure will be conducted on small scale as compared to the literature to minimized waste from the reaction. Starting material of the dimethylacetelyenedicarboxylate will also be collected in addition to the product molecule during separation via column chromatography. Both collected materials will be stored in labeled vials with notebook code and molecule structure. The 1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl will be stored in the freezer to prevent unwanted photoreactions while out on the bench top or decay of product. A Time Optimization reaction is preformed to get an idea of when the reaction stops yielding product in the reactor. a GC/MS is taken of test tubes removed from the reactor at 24 hour intervals to observe concentration percentiles. Distillation method of separation is tested to compare collection amounts to that of column chromatography via silica gel.

**Introduction:** Rubrene is the world record holder for charge mobility in single crystal devices. It has 18pi electrons and satisfies the  $4n+2$  rule, which refers to how easily, far, and fast these electrons can move when a voltage is applied to the crystal of Rubrene. Rubrene has a positive and negative charge in crystal in moving those charges around.

Dr. Everson's post doc advisor is an expert on Rubrene and purposed a hypothetical synthesis to access the molecule so you can vary the phenyl groups to be differing aromatic compounds. the goal is to create a specific organic semi-conducting molecule.. The hypothesis Dr. Everson has purposed is to use convergent synthesis to create a Rubrene derivative, where one end has a cation and the other an anion within the tetracene core of the molecule. This would set up greater charge mobility, surpassing that of Rubrene, while maintaining its 18 pi bonds.

### **General Experimental:**

NMR chemical shifts are reported in ppm and referenced to the residual solvent peak  $\text{CDCl}_3$  ( $\delta = 7.26$  ppm  $^1\text{H}$ ) as internal standard. NMR spectra were recorded on Bruker model \_ NMR spectrometer operating at 400 MHz and data analysis was performed using Topspin software package.

GC/MS analyses were preformed on "Franky". Used Dichloromethane to dilute concentration within vials. Total run time was 22. min.

Chromatography was performed on silica gel using standard flash techniques. Products visualized by one of the following methods: UV stain, Iodine Stain, or  $\text{KMnO}_4$  stain.

### **Synthesis Experimental:**

**1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl:** Following reference <sup>[1]</sup> To a beaker containing dimethylacetelyenedicarboxylate (3.221 g, 22.6 mmol) was added benzene (100 ml, 1,121.6 mmol) and mixed thoroughly. The solution is then distributed amongst seven quartz test tubes,

placed within the indicated slots of the rotation device for the photochemical reactor, then subjected to UV light within a photochemical reactor for approximately 72 hours. Reaction mixture then added to tarred round bottom flask and rotovaped to yield yellow oil crude (3.4 g, and purified via Flash chromatography (SiO<sub>2</sub>, 133g, 9:1 Hexanes : EtOAc, Iodine stain to visualize via TLC). Starting material visible RF =0.1, Product visible RF =0.15. 65 Fractions total, Fractions 28-36 showed retrieval of dimethylacetelyenedicarboxylate starting material, verified via <sup>1</sup>H NMR (DBA\_1018\_1) rotovaped to yield 0.378g. Fractions 40-65 showed product, rotovaped to yield 0.74g, verified product via <sup>1</sup>H NMR (DBA\_1018\_2). Compared to theoretical yield of 4.89, retrieved 15% yield.

**1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl:** Following references <sup>[4]</sup><sup>[5]</sup> To an Erlenmeyer flask containing dimethylacetelyenedicarboxylate (1.931 g, 13.58 mmol) was added benzene (100 ml, 1.1mmol)and benzophenone (50mg, 0.247 mmol) mixed thoroughly. The solution is then distributed amongst eight quartz test tubes. Solution was sparged with Nitrogen and stoppered with Neoprene Stoppers. Exposed to UV light in photochemical reactor for 72 hours. Reaction temporally stuck due to difficulty removing Neoprene stoppers. Reaction mixture produced odor and deeper yellow color than previously. Transferred to tarred round bottom to yield 1.726g of crude material after rotovap. Purified via Flash Chromatography (SiO<sub>2</sub>, 98g, 95:5 Hexanes : Acetone, Iodine stain to visualize via TLC). Starting material visible RF =0.007, Product visible RF =0.014. 60 Fractions total, Fractions 28-35 showed retrieval of dimethylacetelyenedicarboxylate starting material, verified via <sup>1</sup>H NMR (DBA\_1019\_2) rotovaped to yield 0.47g. Fractions 50-58 showed product, rotovaped to yield 0.18g, verified product via <sup>1</sup>H NMR (DBA\_1019\_1). Compared to theoretical yield of 2.99, retrieved 6% yield.

**Photochemical optimization - Reaction time of 1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl:** A 100 mL graduated cylinder was charged with dimethylacetelyenedicarboxylate (3.221g, 22.6 mmol), then filled to the 100 mL mark with anhydrous benzene (~97mL) creating a stock solution with concentration of 0.226 mmol/mL. 10 mL of stock solution was transferred to glass test tubes, thus each contained 2.26 mmol of dimethylacetelyenedicarboxylate, giving a theoretical yield of 498 mg per test tube. At each indicated time point the test tube was rotovaped into a tarred 20 mL vial and NMR taken in CDCl<sub>3</sub>. Test tubes removed at 6 hrs, 12 hrs, then 24 hrs up to 168 hours, excluding 120 hrs. No product formed, only starting material recovered at varying different colors that transitioned from yellow to orange to olive green over time progression. Starting material yields 6hrs: 2810 mg, 12hrs: 284 mg, 24hrs: 306 mg, 48hrs: 345 mg, 72hrs: 351 mg, 96hrs: 338 mg, 144hrs: 412 mg, 168hrs: 355 mg.

**1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl:** Following reference <sup>[1]</sup> To a beaker containing dimethylacetelyenedicarboxylate via vial from both ATF\_1021\_ft28-35 (DBA\_1019\_2) and DAH\_1017\_ft.30-50 was added 0.773g (0.0054398 mmol) followed by benzene (24 ml,0.307 mmol) and mixed thoroughly. The solution is then distributed by approximately 8 mL amongst three quartz test tubes, placed within the indicated slots of the rotation device for the photochemical reactor, then subjected to UV light within a photochemical reactor for approximately 24 hours. GC/MS taken of solution (DBA\_1039\_1), Reaction mixture then transferred to an Erlenmeyer flask. GC/MS revealed dimethylacetelyenedicarboxylate peak at RT 5.43 min and Product at 10.84 minutes. Late retention time impurities shown at 14.9 and

18.4) minutes. Mixed with pea sized portion of decolorizing charcoal, agitated and left to sit for 20 minutes. Filtered via gravity filtration, GC/MS then taken of solution (DBA\_1039\_3), solution is then distributed into clean quartz test tubes and resubjected to UV light. GC/MS revealed impurities have vanished, leaving product and Starting material the same. After 48 hours solution is subject to another GC/MS (DBA\_1039\_4) reveal the return of the two impurities, continued synthesis of Product. This process is repeated for 24 hr intervals for the next 2 days total days being 4, total time subject to UV light comes to 96 hours. Remaining solution transferred to a tarred vial, rotovaped and Flash Chromatography set up (SiO<sub>2</sub>, 98g, 9:1 Hexanes : EtOAC, Iodine stain to visualize via TLC). Starting material visible RF =0.8, Product visible RF =0.1. 150 Fractions total, Fractions 24-31 showed retrieval of dimethylacetelyenedicarboxylate starting material, verified via <sup>1</sup>H NMR (DBA\_1042\_7) rotovaped to very minimal yield. Fraction 60 showed product, rotovaped to yield 0.005g, verified product via <sup>1</sup>H NMR (DBA\_1042\_6). Compared to theoretical yield of 1.1978, retrieved 0.4% yield.

**1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl :** Following reference <sup>[1]</sup> To a beaker containing dimethylacetelyenedicarboxylate (3.226g, 22.6 mmol ) followed by benzene (100 ml, 1,121.6 mmol) and mixed thoroughly. The solution is then distributed amongst eight quartz test tubes, placed within the indicated slots of the rotation device for the photochemical reactor, then subjected to UV light within a photochemical reactor for approximately 24 hours. GC/MS taken of solution (DBA\_1047\_1), Reaction mixture then transferred to an Erlenmeyer flask. GC/MS revealed dimethylacetelyenedicarboxylate peak at RT 5.43 min and Product at 10.84 minutes. (97.804% : 2.196%) No late retention time impurities shown. Mixed with pea sized portion of decolorizing charcoal, agitated and left to sit for 20 minutes. Filtered via gravity filtration, GC/MS then taken of solution (DBA\_1047\_2), solution is then distributed into clean quartz test tubes and resubjected to UV light. GC/MS revealed slight change, leaving product(1.42%) and Starting material (98.58%) components. After 48 hours solution is subject to another GC/MS (DBA\_1047\_3) reveal the return of the two impurities, Starting material (94%) and product (6%). After charcoal procedure, GC/MS (DBA\_1047\_4) revealed reduction of impurities at RT 14 and 18 and ration for SM : Product (96:4) percent. This process is repeated for 24 hr intervals for the next 2 days, total days being 4, total time subject to UV light comes to 96 hours. Mechanical agitation used instead charcoal procedure via scrub brush to disturbed thin film on Test tube walls. GC/MS prior to agitation revealed Product (16%) and starting material (84%) with impurity peaks at RT 14 and RT 18 (DBA\_1058\_1). After agitation GC/MC revealed Product (16%) and starting material (84%) with no impurity peaks (DBA\_1058\_2). Resubjected to UV light for another 24 hours. More visible film upon removal from photochemical reactor. Repeated mechanical procedure. GC/MS prior to agitation revealed Product (16%) and starting material (84%) with impurity peaks at RT 14 and RT 18 (DBA\_1058\_3). After agitation GC/MC revealed Product (15%) and starting material (85%) with no impurity peaks (DBA\_1058\_4). Remaining solution then transferred to tarred vial (24.125g) and set in distillation apparatus with constant stirring, gradually being heated, and under High Vac. At 80 °c condensation amassing on walls of chamber and on the collection lip of the glassware. <sup>1</sup>H NMR taken of contents of vial whose contents were an orange solid. <sup>1</sup>H NMR (DBA\_1058\_6) of vial revealed 2:1 ratio of Starting Material to Product. Vial put back under high vac and distillation, pushed to

110°C. No collection in lip of apparatus, two visible materials in vial yellow oil clinging to top walls and solid orange product clinging to bottom. <sup>1</sup>H NMR revealed for both (DBA\_1058\_7) (DBA\_1058\_8) large amounts of product, very minimal S.M. Using <sup>1</sup>H NMR solution to dissolve the solid, transferred to tarred vial using additional Methyl chloride, rotovaped, then further subjected to high vac gave yield of 0.705g (14%) yield.

**Results:** Over the course of the summer, percent yields of 1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl have increased and held out to a steady average of approximately 15% yield. Time Optimization has proved that between 96 hrs and 144 hours of UV light exposure is optimal time for production of the product 1,8-Acetyl-1,3,5,7-cyclooctatetraen-1-yl before the product begins to revert back to starting material at 168 hrs of exposure. Distillation method of separation has produced a high product amount (0.705 grams) with that of the column chromatography via silica gel in 9:1 Hexanes: Ethyl Acetate yielding inconstant results. The two next runs of the reaction will be done via distillation to observe if it is able to provide a consistent product yield in comparison to column chromatography.

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## **Students' Laboratory skills and Techniques in General Chemistry courses**

Jessica Gonzales, Dahlia Chavez, Dr. Kendhammer

Chem 490-201

August 10, 2017

### ***Introduction***

In our Research project we are investigating students' experiences in General Chemistry Laboratory trying to comprehend what skills and techniques students actually use. Also, how difficult the equipment is in using them. We want to determine which one's are the most important and necessary in the laboratory. Some of the questions in the study, regard understanding exactly where are students' having difficulties and finding other methods to increase students' knowledge in the laboratory skills and techniques. Our major concern is why don't chemistry graduates have the skills they need to be successful in the workforce. According to some research it was brought to our attention that "high-technology industries increasingly complain that the graduates they recruit lack vital knowledge and skills they will need in the workplace.<sup>1</sup> It was question and investigated in General Chemistry I and II specifically in the laboratory setting.

Research has proven that students' proficiency in the laboratory setting are important and it takes certain skills. Some of these skills according to Reid and Shah are the connection between lab and lecture, Practical skills (hands-on experience), Scientific skills (explain and understand your results), and lastly General skills where it means to further on your skills that include teamwork and time management (Reid and Shah, 2007). However, for our research we target the practical skill Reid and Shah mention, because it is an important aspect for a student's

laboratory efficiency. The lab setting is where students are able to experience these skills. It is a perfect place for student to develop their knowledge with the equipment and chemicals. It appears in the study Bruck, Towns, and Bretz a survey was conducted for faculties across the board to investigate what were the goals in laboratory. They all had similar goals for general chemistry, organic chemistry, and upper division. The complementary goals: Laboratory skills and techniques, critical thinking aspects, experimental design skills (Bruck, Towns, and Bretz, 2010).

Although, now that we know Laboratory skills and Techniques play a major role, the crucial part is that there's very little research that focuses on this. Most research highly focuses on critical thinking aspect, such as the study of Hofstein and Lunetta's research where they aim their attention to meaningful learning. Their concerns are that students' are to preoccupied on skills and techniques (Hofstein and Lunetta, 2004). However, if we are able to strengthen these skills then we can develop more time on meaningful learning.

In order to understand how meaningful learning occurs we need to look at the Theoretical framework where our research branches from. According to Novak's Theory of Human Constructivism it implies that in order to create this meaningful learning we need three different aspects: Cognitive Aspect, Affective Aspect, and Psychomotor Aspect (Novak, 1998). Let's look into more detail what these aspects are for example, Cognitive aspect is the information you process, Affective aspect is the feelings and motivation towards learning. Lastly, is the Psychomotor aspect which is the hands on experience in the laboratory, where our skills and techniques would fall under. To construct meaningful learning we must have all these three aspects. To add on to this research we must also look at the different types of intelligence. In

Gardner's Theory of Multiple Intelligence it demonstrates the seven different types of intelligence. Based on the action or task one is doing at the moment will decide which intelligent to use. If we focus on chemistry lab skills and techniques it would be the Bodily- Kinesthetic Intelligence, contributing with movement and coordination. In spite of that, if we engrain this intelligence we would be able to concentrate on Logical Intelligence, establishing meaningful learning.

Furthermore, we were able to formulate two hypotheses. First, is how the workforce has in mind what skills and techniques they think is important, but are distinctive to the undergraduate science courses skills and techniques they think are significant, so there may be a disconnection. Second, are if student maybe overconfident in their perceived difficulty vs. the actual difficulty. In order to determine their perceived difficulty a survey was physically administered to the students for General Chemistry I / II. Then to test their actual difficulty we will interview the students where we would watch them do the skill or technique and rate them on the scale, how well they performed it. Lastly, we want to see if there is a correlation between the two, which could contribute to student being overconfident rating themselves higher than their actual difficulty.

This is important to the student's learning experience because we want them to meet the expectations for the stakeholders, and meet the expectations of growth in education. The skills and techniques could be look as the "building blocks" of the laboratory, the overall foundation. We want to increase students' proficiency in the laboratory skills and techniques. It is likely that students will use most of these skills and techniques if they continue into more advanced science or even other chemistry labs.

## ***Material and Methods***

Our primary study was focus at California State University, where if students were overconfident in their ability that include their skills and techniques in General Chemistry courses, specifically lab. To do this a survey was established to determine their perceived difficulty. We also had to determine their actual difficulty to see if there was a correlation between the two. Bringing us back to if students maybe overconfident in their skills and techniques, to approve or disapprove our hypothesis.

Therefore, the participants completed the pen and pencils survey which was administered to them. On the survey they had 30 different skills where the student were asked to rate themselves on these skills. The scale was rated from (1) very easy, (2) easy, (3) neutral, (4) difficult to (5) being very difficult, with an option of zero being non- applicable on a scale. This was based on how difficult they thought that skill or technique was for them. The laboratory skills and techniques survey was constructed from multiple different lab manuals that appear in majority of them. It was an IRB approved survey from students in the U.S suburban university, West Coast. Overall, we had 230 participants, but only looked at General Chemistry I because we had a small sample size for General Chemistry II. We converted all the data which included coding, entering demographics, entering survey responses, calculating mean, median, and mode of each individual, and each item, into Excel and then SPSS Statistical Software. We also created about a rough estimate of 113,000 histograms on excel for each person and each item, based on the survey. Base on the Lab skills and techniques survey we determine the central tendencies for General Chemistry I where we found which were the top five that the students found most easiest and hardest. Finally, we had to do a data reduction technique which was done with the factor

analysis using SPSS Statistical Software, where we had to see if our data was factorable using the Kaiser-Meyer-Olkin test.

### ***Results***

In the final analysis, we were able to conclude for General Chemistry II our results were not factorable because we had a KMO value of .448, meaning it was unacceptable in our scale. This affected our results because we could not bypass this having such a small sample of 51 participants. Despite this, we then moved on to General Chemistry I giving us a KMO value of .890. On our scale this category is known as Meritorious (Table 1). Therefore, after testing different methods the one that worked best was the Extraction method: alpha factoring and the Rotation method: Oblimin with Kaiser Normalization. This was able to give us the best output method for our factor analysis. It grouped together in specific order the skills / items on the left and formed five different factors. Factors are the underlying traits these skills/ items in each group have in common. Thus, can not be measured (Table 2). Once we had the five different factors we were able to name the five factors based on their commonalities.

Furthermore, we created a rubric based on the actual difficulty level. Now that we have all these 5 factors we want pull out a skill from each of these five factors as a representative sample instead of testing these students on all 30 skills. We were able divide it into four sections being Non-evident, marginal, proficient, exemplary because some of the skill can go beyond proficient. Once the rubric was finalized we went into the laboratory and tested each skill out to make sure we did not miss any detail.

**Table 1: Kaiser-Meyer-Olkin or the KMO test (Data factorable)**

Done by the SPSS Statistical Software to determine if our data is factorable. Based on our data we conclude for General Chemistry II our results were not factorable (value of .448), unacceptable in our scale. Despite this, we then moved on to General Chemistry I giving us a KMO value of .890 (Meritorious).

Category	Value
<b>Marvelous</b>	0.90 to 1.00
<b>Meritorious</b>	0.80 to 0.89
<b>Middling</b>	0.70 to 0.79
<b>Mediocre</b>	0.60 to 0.69
<b>Miserable</b>	0.50 to 0.59
<b>Unacceptable</b>	0.00 to 0.49

**Table 2: Five factors as a Representative sample of the 30 different skills**

This is a data reduction technique. Using a factor analysis. It is analysis done on SPSS Statistical Software which uses advanced statistics, matrixes, correlations, and puts the skills into categories which we call “Factors”. Factors are the underlying traits these skills in each group have in common. We are going to that because we want to reduce the data. These numbers you see here are how well each skill fits into the factor, the greater the number, the better it fits and correlates with the other items within the factor.

**Pattern Matrix<sup>a</sup>**

	Factor				
	1	2	3	4	5
Item10	.472				
Item25	.458	.354			
Item13	.441				
Item4	.368			.335	
Item14	.350			.330	
Item15	.330				
Item30		.840			
Item29		.781			
Item28		.581			
Item27		.459			
Item1			.892		
Item5			.806		
Item8	.310		.799		
Item3			.761		
Item7			.748		
Item2			.696		
Item6			.595		
Item9	.394		.496		
Item12				.792	
Item11				.708	
Item19					.958
Item18					.843
Item21					.680
Item20					.629
Item17					.612
Item16					.449
Item22					.426
Item26					.373

Extraction Method: Alpha Factoring.

Rotation Method: Oblimin with Kaiser Normalization.

a. Rotation converged in 17 iterations.

## *Discussion*

In conclusion, the project will continue to evaluate students in lab for General Chemistry II since we had a small sample we want to be able to determine the actual ability. We were not able to conclude our hypothesis for student being overconfident. We just know that for General Chemistry I in our Laboratory Skills and Techniques Survey the hardest central tendency can contribute to our hypothesis because on average no student rated any skills, four being difficult or five being very difficult, the mean was very low 3.03 being neutral. Once we are able to get a bigger sample that is when we can state if our hypothesis is approved or denied. More importantly, we will be able to grab one of these skills from each of these five factors.

Further work that could augment could be the results from the first hypothesis once finish. In order to distinguish if there is a gap between the expectations of industry and academia--can either be rejected or supported.

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### *Acknowledgements*

I like to give thanks to Dr. Kendhammer for giving me the opportunity of being part of her research and just being a great supervisor. Also, letting us use the laboratory, participants of the research, College of Natural Science, and lastly, Chico STEM Connections Collaborative (CSC<sup>2</sup>) for funding me. It was a great experience!

Research with Dr. Lisa Ott  
Analytical  
LETTER GRADE: A

Coconut Coir as a Sustainable Purification Method for Biodiesel Production

Meghan Riddell

CSRI 2017

Faculty Advisor: Dr. Lisa Ott

## Abstract:

The push for renewable and sustainable energy has continually increased in the recent years. Fossil fuels are being replaced with solar, wind, and other regenerative forms of energy. As such, the production of biodiesel has been increasingly popular among consumers. After being prepared by a simple chemical reaction, biodiesel must be “washed” to remove impurities such as soap and glycerol. These impurities have emulsifying properties that are destructive to the diesel engine. The conventional wash method uses approximately the same amount of water to wash, as biodiesel is being produced. This wash process creates an extremely large aqueous waste stream. In order to ensure that biodiesel is a truly sustainable fuel, it is imperative that a dry wash method be employed for the purification of biodiesel. In this paper, we will study coconut coir as a suitable dry wash material. Using Springboard Biodiesel, LLC’s SpringPro dry wash system as a model, we have produced a sustainable, inexpensive dry wash system with the equal capabilities as industry standard dry wash systems. A coconut coir filtration system is able to remove excessive amounts of soap, glycerol and methanol from biodiesel, leaving a purified product and drastically reduces the amount of aqueous waste generated by the production of biodiesel. The cost associated with a coco fiber column compared to other industry dry wash systems is fractional, making coconut coir sustainable, inexpensive and effective.

## Introduction:

According to the National Biodiesel Board’s statistics page, in 2016 biodiesel production reached an all-time production high of 2.8 billion gallons produced. (National Biodiesel Board, (Biodiesel - Production Statistics 2017) With climate change and the environmental impacts of fossil fuels at the forefront of many people’s minds, Biodiesel is a practical choice for many consumers. As such, it is imperative biodiesel is produced with as little environmental impact as possible. Biodiesel is produced by a transesterification reaction using a triglyceride feed stock source, methanol, and either an acid or base catalyst. (Figure 1) Industry often employs a base catalyzed reaction because it is much more efficient; a complete reaction can take as little as one hour. Sodium hydroxide is often utilized as the catalyst material because it is easily accessible and cost effective. The disadvantage to using a base catalyzed method is the formation of soap residues.

Glycerol is a known byproduct of biodiesel production and even after separated by density and removed, trace amounts can remain suspended in the biodiesel. Any soap or glycerol residues are

emulsifiers and cause damage to the diesel engine. As such, they must be removed. Biodiesel purification is most often achieved by washing crude biodiesel with water. Depending on the level of impurities, this washing step can be repeated 2-5 times, resulting in 20-120 liters of waste for every 100 liters of biodiesel. (Orathai Chavalparit 2009)

Because of the time and waste involved with water washing, a method for biodiesel purification which does not rely on water is desirable. Waterless purification processes are often referred to as drywash methods. According to literature, most drywash methods rely on adsorption, ion-exchange processes and membrane filtration. We based our research on SpringBoard Biodiesel, LLC's model; SpringPro, which uses a double column filtration system with natural absorbent materials as a medium. This cost associated with this particular drywash system is \$8,350. (SpringBoard Biodiesel, LLC 2014) The simplest and most absorbent mediums used in this system are based on natural materials. The most commercially available drywash material, Eco2Pure is based on wood chips and a proprietary resin bead; the medium material is approximately \$15 dollars for 1 kilogram which can treat 300-600 liters of biodiesel. (Schroeder Industries 2016) The medium used in this dry wash system is not currently reused, leading to about 15 kilograms of solid waste each time the medium's filtering capabilities are exhausted. In comparison, coconut coir is roughly \$3.00 per kilogram which will treat over 375 Liters of biodiesel.

An ideal material for drywashing biodiesel would be easily accessible, inexpensive, renewable, biodegradable and effective at removing soap, glycerol and methanol. Natural fibers are attractive to the at home biodiesel producer because they are easily sourced at any local garden center. Based on the recommendation of a cultivation expert, we chose to examine coconut coir as a drywash medium in this study. Coconut coir is a heterogeneous mixture of coconut husks, pith and coco chips. It is both inexpensive and extremely durable. Consequently, it is used for everything from brushes, to acoustic materials, to a planting medium for orchid cultivation.

Herein, we present our evaluation of coconut coir as an accessible, affordable, sustainable and effective drywash material for the purification of biodiesel. We examined coconut coir's ability to remove soap, glycerol and methanol from raw biodiesel. Because of the long shelf time of this project we were able to study both the volume of treatable biodiesel as well as long term stability of the material. Overall we find that coco coir serves as an extremely effective and sustainable drywash medium for the purification of raw biodiesel.

#### Materials and Methods:

Raw biodiesel was provided to us by Springboard Biodiesel, LLC, Chico, Ca as well as Sierra Nevada, Inc, Chico, Ca. The feedstock for both of these biodiesels is comingled, used cooking oil from local restaurants and eateries. Both companies use a base catalyzed step for the primary transesterification reaction. Both raw biodiesel samples were collected after this primary step. No purification processes were done on the raw biodiesel. Hydrochloric acid, sodium hydroxide, methanol and 2-propanol were purchased from Sigma Aldirch in 99% or greater purity. Bromophenol blue indicator was prepared as a 0.4 mass percent solution in distilled water. Phenolphthalein indicator was prepared as a 1 mass percent solution in ethanol. Hydrochloric acid was standardized with sodium carbonate in house to titrate for soap content in raw biodiesel. Sodium hydroxide was also standardized in house with potassium hydrogen phthalate and used to titrate for free fatty acid content. Both of these standardizations used a phenolphthalein indicator for endpoint.

Using Springboard Biodiesel's commercially available drywash system, SpringPro, as a model; we packed coco coir into a glass column with a glass frit to hold the material in place. Our column was approximately 1/96<sup>th</sup> the size of the commercially available system. We used 74g of coconut coir in our column, keeping mass consistent to the relative size of our model drywash system. Using an addition funnel over the top of the column, and a vacuum pump attached to the bottom of the column, the flow

rate was controlled into the column at an approximate rate of 13mL/min. This closely mimics the residence time of the SpringPro system. (SpringBoard Biodiesel, LLC 2014)

To analyze the coir's ability to remove soap, a soap titration was performed both before and after passing the biodiesel through the column. 20 drops of bromophenol blue indicator was added to 50mL 2-propanol. If the 2-propanol was initially blue, standardized 0.1 M hydrochloric acid was titrated until the yellow endpoint. Then, 10 mL of biodiesel was added to the solution with a volumetric pipet. If a detectable amount of soap was present in the biodiesel, the 2-propanol solution turned blue upon addition of biodiesel. When the solution contained soap, hydrochloric acid was titrated dropwise until the yellow endpoint was reached. This titration was then used to quantify the soap concentration.

Free fatty acid content was also studied. Using a similar method, biodiesel was titrated both before and after passing through the column. For these titrations, 10 mL of biodiesel was added to 50 mL 2-propanol. Two drops of phenolphthalein indicator was added, and the solution was titrated with standardized sodium hydroxide to the pink endpoint.

To examine glycerol content of biodiesel before and after being passed through the coco coir column we used an Agilent 5890 GC equipped with a flame ionization detector (FID). An Omegawax 250 column (30m x 0.25mm x 0.25 $\mu$ m) was utilized. Glycerol content was determined by extracting a sample of biodiesel with water to partition the glycerol into the aqueous phase. To determine the effectiveness of the extraction into the aqueous phase, a known amount of ethylene glycol was added as an extraction standard. First, 0.7020 g of ethylene glycol was weighed inside a volumetric flask. Then, 50.0 mL of 2-propanol was added and shaken vigorously. This solution was then added to 250.00 mL of raw biodiesel and stirred for 10 minutes. The 2-propanol was then removed via rotary evaporation, leaving behind a known concentration of 0.045 M ethylene glycol in raw biodiesel. A 50.0 mL aliquot of the raw biodiesel was removed and added to a 125 mL separatory funnel. 50.00 mL of deionized water was then added to the flask. The solution was mixed vigorously for three minutes to ensure thorough mixing. The

solution was then allowed to settle overnight until both layers were no longer opaque. A sample of the aqueous layer was then analyzed by GC-FID. A calibration curve was prepared with both ethylene glycol and glycerol dissolved in deionized water. (Figure 2) All samples were analyzed in triplicate.

A series of experiments were carried out with an excessive amount of free glycerol, spiked into biodiesel. Glycerol has limited solubility in biodiesel so glycerol was first dissolved into 2-propanol. Approximately 19 g of glycerol was added to 50.00 mL 2-propanol. This solution was then combined into 500.00 mL of biodiesel and stirred for 10 minutes. 2-propanol was then removed by rotary evaporation, leaving the added amount of glycerol spiked into the biodiesel. A 50.0 mL sample was removed at this point and extracted using the water extraction method above. The aqueous layer was then analyzed via GC-FID. The remaining spiked biodiesel was then passed over the column. A 50.00 mL sample was collected from the post column biodiesel, extracted with water and analyzed by GC-FID in triplicate.

Lastly, the duplication of our results was studied by purchasing new coco coir and repeating the experiments listed above.

## Results:

To be considered most effective, a dry wash material must not only be inexpensive, accessible and sustainable; more importantly it must remove soaps and methanol. The loading capacity of the material must be such that the raw fuel only need to be passed over the column once. To study the loading capacity of the coir, we first tested the column using stock samples of typical raw biodiesel supplied to us by Springboard and Sierra Nevada. We also made samples in house using Safeway vegetable oil, sodium hydroxide and methanol. Samples of Springboard's raw biodiesel contained on average 600 ppm of soap. After passing 500 mL samples at a time through the column, there was no detectable soap post column. Our inhouse biodiesel samples were made with an excessive amount of soap. On average, the soap content of our biodiesel was 3600 ppm. After 6 trials, each of the samples

post column showed no detectable levels of soap. At this point, the small scale column removed all soaps to undetectable levels for 1350 mL of raw biodiesel. Correcting for the 96-fold smaller scale, we treated the equivalent of 34.2 gal of raw biodiesel. Because of the manufacture claims of Eco<sub>2</sub>Pure's capacity to clean 200 gallons of biodiesel before its ability to remove impurities is exhausted, it is important to establish if coco coir can remove at least an equal amount of soap residues from raw biodiesel. To test this, we continued to run 500 mL batches of biodiesel through our column. (Table 1) After treating 27.8 L of raw biodiesel, the levels of detectable soap remained zero. It is imperative to note that we did not reach the exhaustive point of the coir, in the interest of time we moved on to other tests.

Methanol is generally added in excess to drive the biodiesel formation and is a significant contaminant in raw biodiesel. Examining the coco coir's ability to remove MeOH in biodiesel was also imperative. The ASTM standards for biodiesel dictate a maximum level of 0.2 mass percent MeOH in finished biodiesel. (U.S. Department of Energy 2017) Via GC-FID, we revealed that samples of our raw biodiesel contained  $3.5 \pm 0.2$  mass percent MeOH. After column filtration, the same sample contained  $0.15 \pm 0.01$  mass percent MeOH. (Table 1) This confirms that the coco coir column is effective at removing methanol to below industry standards, as well as its soap removing capabilities.

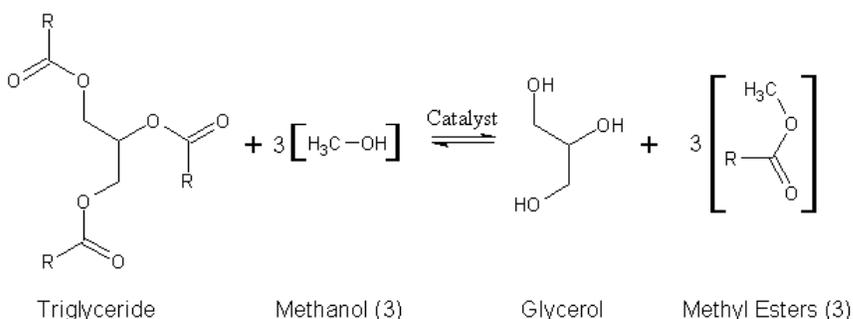
Lastly, we studied the coir's ability to remove free glycerol from biodiesel. ASTM Standards dictate a 0.240 mass percent level of free glycerin. (U.S. Department of Energy 2017) In order to quantify the amount of free glycerin in raw and drywashed biodiesel, we shook a 50 mL aliquot of pre and post column biodiesel with equal amounts of distilled water to extract any glycerol present into the aqueous layer. As described previously, we also added a known quantity of ethylene glycol to measure the efficacy of the extraction method. By GC-FID we determined the efficacy of the extraction method to be around 76%. Before passing through the column, raw biodiesel sourced from commercial producers had an initial concentration of  $0.32 \pm 0.03$  mass percent. After passing through the column, free glycerin

levels were undetectable by GC-FID. (Table 2) To ensure our findings were correct we also studied the ability of coir to remove excessive amounts of glycerol. To do this, we spiked raw biodiesel with artificially large amounts of glycerol. Our spiked biodiesel had an initial concentration of  $2.02 \pm 0.09$  mass percent. After a single run through the column, the concentration of glycerol was reduced to  $0.48 \pm 0.02$  mass percent. This demonstrates an over four-fold reduction in glycerol concentration. This is significant because the initial glycerol concentration was over 2 orders of magnitude higher than ASTM limits and well above what would ever be found in a typical sample of biodiesel. It is also important to note that these experiments were run after over 25 L of biodiesel had already passed through the column.

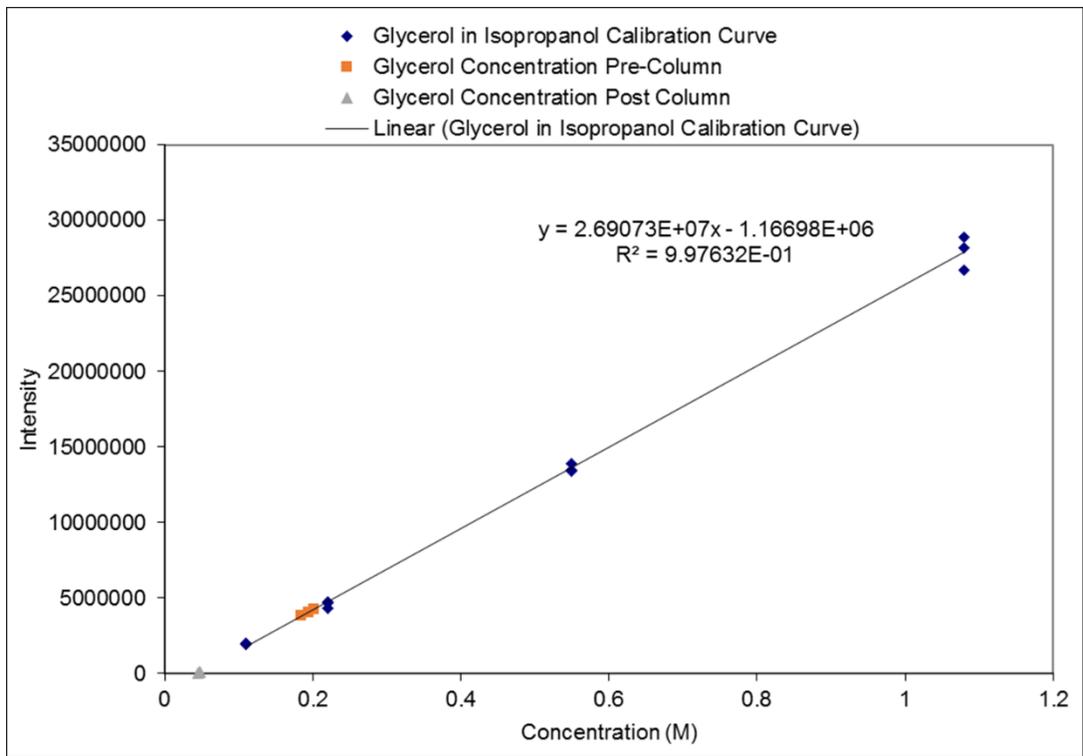
#### Conclusions:

Coco coir is a sustainable, affordable, bio-derived, and effective medium for the purification of biodiesel. Using coco coir eliminates the waste water produced in standard biodiesel purification. It is effective at removing artificially high levels of both soap and glycerol, offers a long lifetime and has the capacity to treat large amounts of biodiesel. Coco coir is a worthy consideration for both the at home biodiesel producer as well as industrial productions.

#### Figures:



**Figure 1.** General reaction for the preparation of biodiesel fuel from triglycerides.



**Figure 2.** Free glycerol calibration curve, pre and post column glycerol samples.

Tables:

	<b>before drywash</b>	<b>after drywash</b>	<b>ASTM limits</b>
soap (ppm)	> 3000	not detectable	41 for NaOH
methanol (mass %)	$3.5 \pm 0.2$	$0.15 \pm 0.01$	0.2

**Table 1.** Evaluation of soap and methanol parameters for coco coir drywash performance.

	<b>Initial [glycerol] (mass %)</b>	<b>Final [glycerol] (mass %)</b>	<b>ASTM limit</b>
Raw biodiesel	$0.32 \pm 0.03$	Not detectable	0.020 mass %
Spiked biodiesel	$2.02 \pm 0.09$	$0.48 \pm 0.02$	0.020 mass %

**Table 2.** Evaluation of coco coir as an effective material to remove free glycerol from both raw and spiked samples of biodiesel.

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# Metal Cation Selection of a Metal Organic Graphene Analogue

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In fulfillment of the requirements of CHEM 490 and CSC<sup>2</sup>

Under the mentorship of Dr. Monica C. So



## ABSTRACT:

In theory, a larger metal atom increases interactions between the metal cation and organic linker, moreover enhancing the electron transport properties of the material. Because palladium and platinum are in the same group of the periodic table, their cations should form similar MOG structures to the  $\text{Ni}_3(\text{HITP})_2$ ; furthermore, as a result of their larger atomic radius than nickel, their respective material will possess a greater conductivity than the nickel MOG. To confirm, Raman absorption spectra indicate that the palladium and platinum versions of  $\text{Ni}_3(\text{HITP})_2$  have comparable structures to the nickel MOF, and nitrogen isotherm data of the powders suggest that the material is porous, however, smaller than expected at about one fifth of the value. Electrical and thermoelectric conductivity measurements suggest that both increase with the metal cation radii; moreover,  $\text{M}_3(\text{HITP})_2$  MOGs have shown promising results in thermoelectrics.

## INTRODUCTION:

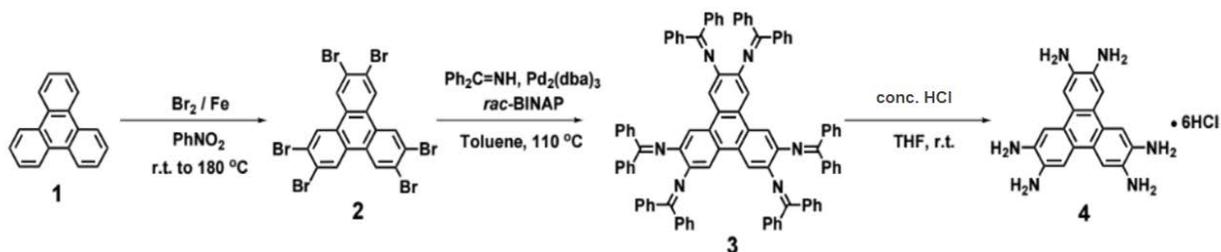
Heat is a powerful source of energy and is readily available. Vehicles, such as the common Toyota Prius to the state-of-the-art Mars Rover, take advantage of the waste heat created from braking and plutonium, respectively, by converting it to electricity to help power the vehicle. Because thermoelectric generators can convert infrared energy, or heat, into electricity and convert electricity into heat, they require no moving mechanisms to generate power for devices. Without moving parts, thermoelectric generators reduce the likelihood of malfunction and maintenance for their respective device.<sup>1</sup> Materials that act as prospects for this application must be an n-type or a p-type semiconductor and be paired with a similar material of the opposite type, and when connected by a circuit, they have the ability to convert energy.

One semiconductor, graphene, is commonly used within electronics as well as thermoelectric devices; moreover, materials that express similar properties to graphene are of interest to scientists and engineers. Several metal organic frameworks (MOFs) have been synthesized and discovered to possess the desirable graphene-like properties, earning them the label: metal organic graphene-analogues (MOGs). These materials are composed of metal ions and organic linkers that can be chemically and synthetic tuned to change their framework and conductivity, affording them greater versatility than graphene for application in electric and thermoelectric devices.<sup>2</sup> One MOG in particular,  $\text{Ni}_3(2,3,6,7,10,11\text{-hexa-aminotriphenylenesemiquinonate})_2$ , or  $\text{Ni}_3(\text{HITP})_2$ , has proven to be intriguing for the possibility of these applications due to its high conductivity and low thermal conductivity with respect to other MOGs—ideal properties for most materials used in electronic devices.<sup>1</sup>  $\text{Ni}_3(\text{HITP})_2$  has recently been identified as one of the most conductive MOFs; a pressed pellet yields 2 S/cm and its film yields 40 S/cm.<sup>3</sup> Most notable about MOGs, like  $\text{Ni}_3(\text{HITP})_3$ , are their tunability and variability. The metal cations and the organic linkers that make up the framework can be interchanged to alter the material's properties, such as thermoelectric or electrical conductivity, making them more versatile than graphene.

Recent work completed by He *et al.* at Sandia National Laboratories in Livermore, CA regarding the  $\text{Ni}_3(\text{HITP})_2$  MOG has indicated that replacing the nickel cation with a larger metal

cation, specifically palladium and platinum, will increase the conductivity of the material. The larger radius of the palladium and platinum cations should enhance the contact between the orbitals of the organic linker and the metal cation, therefore increasing the conductivity of the material. These two metals are reasonable alternatives of nickel in which they should share a similar square planar geometry with the organic linker HATP.<sup>1</sup> Because palladium and platinum are in the same group of the periodic table, their cations should form similar MOG structures to the Ni<sub>3</sub>(HITP)<sub>2</sub>; furthermore, as a result of their larger atomic radius than nickel, their respective material, Pd<sub>3</sub>(HITP)<sub>2</sub> and Pt<sub>3</sub>(HITP)<sub>2</sub>, will possess a greater conductivity than the nickel MOG. Palladium and platinum analogues of the nickel-based MOG have yet to be fully characterized and compared; however, this work aims to bridge some of the unknowns pertaining to these two MOGs and further test the theory of their conductivity in relation to the Ni<sub>3</sub>(HITP)<sub>2</sub>.

## METHODS:



**Figure 1:** Organic linker scheme <sup>4</sup>

### Hexabromotriphenylene **2** [CAS 82632-80-2]

To a flame-dried, Ar flushed 1 L RBF equipped with a stir bar, triphenylene **1** (11.940 g, 52.12 mmol, 1.0 eq), Fe<sup>0</sup> (1.08 g, 19.16 mmol, 0.37 eq), and nitrobenzene (430 mL) were added. Using an addition funnel capped with a septa, liquid Br<sub>2</sub> (23.8 mL) was added dropwise. The reactants were allowed to sit for 30 minutes. Quench trap for HBr (g) was made with 4.0 M aq. NaOH and some concentrated aq. Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> was added for any liquid that may escape. After Br<sub>2</sub> addition, the addition funnel was switched with a reflux condenser and connected to the trap using glass tubing. The reaction was placed in an oil bath and refluxed for 2 hours with a gradual temperature increase to 210 °C. After reflux, the reaction was allowed to cool, and ether was added. The mixture was vacuum filtrated and a crude pinkish-brown solid was obtained. The solid was dissolved in *ortho*-dichlorobenzene. (*Note: A lot of solvent is required.*) The solution was vacuum filtrated, and a pinkish-beige solid **2** (31.33 g, 85%) resulted.

<sup>1</sup>H NMR, 500 MHz, Cl<sub>2</sub>CDCl<sub>2</sub>, □ (ppm): 10.33 (s, 6H).

### Benzophenone protected 2,3,6,7,10,11-hexaaminotriphenylene **3**

Inside a glovebox in a vial equipped with a stir bar, Pd<sub>2</sub>(dba)<sub>3</sub> (1.29 g, 1.40 mmol, 0.25 eq.), *rac*-BINAP (1.75 g, 2.81 mmol, 0.5 eq.), and toluene was added and reactants were fermented for 30 min at 110 °C. In a RBF equipped with a stir bar, hexabromotriphenylene **2** (4.94 g, 5.62 mmol, 1.0 eq.), benzophenone imine (8.14 g, 44.9 mmol, 8.0 eq.), NaO<sup>t</sup>Bu (4.32 g, 44.9 mmol, 8.0 eq.), and toluene (120 mL) were added. After fermentation, the vial contents were added to the RBF, the vessel was capped with a septa and removed from the glovebox. The reddish-brown mixture was kept under inert gas using an argon-filled balloon and stirred for

14 hours at 110 °C. The reaction was moved to a glovebox, and dichloromethane was added and then filtered. The filtrate was subjected to column chromatography in 30% EtOAc/Hex, resulting in a yellow solution, which was recrystallized into an orange solid **3** (3.51 g, 48%).

<sup>1</sup>H NMR, 500 MHz, CDCl<sub>3</sub>,  $\delta$  (ppm): 7.71 (d,  $J$  = 7.20 Hz, 12H), 7.41 (t,  $J$  = 7.30 Hz, 6H), 7.35 (t,  $J$  = 7.48 Hz, 12H), 7.23 (t,  $J$  = 7.44 Hz, 6H), 7.20 (s, 6H), 7.16 (t,  $J$  = 7.56 Hz, 12H), 6.89 (d,  $J$  = 7.10 Hz, 12H).

### **2,3,6,7,10,11-hexaaminotriphenylene hexahydrochloride **4****

To a dry, nitrogen flushed 22 mL vial equipped with a septa, **3** (500 mg, 0.384 mmol, 1 equiv) and THF (15.0 mL) was added and sonicated to break up the solid, resulting in a transparent yellow-orange solution. Concentrated aqueous HCl (0.63 mL, 7.7 mmol, 20 equiv) was added to the solution and bubbled with nitrogen to facilitate mixing for 50 minutes. The heterogenous mixture was centrifuged and the yellow transparent liquid layer was removed. The beige solid was washed with THF (3 x 3 mL) and centrifuged; liquid layer was removed between washes and dried under vacuum for 16 hours, giving a yellow-beige solid **4** (160 mg, 77%).

<sup>1</sup>H NMR, 500 MHz, D<sub>2</sub>O,  $\delta$  (ppm): 8.12 (m, 12H), 7.62 (s, 6H).

### **Ni<sub>3</sub>(HITP)<sub>2</sub> MOF Powder**

To a 125 mL erlenmeyer flask equipped with septa, a solution of HATP  $\cdot$  6HCl **4** (141.3 mg, 0.263 mmol, 1 equiv) and DI water (20.0 mL) and a solution of NiCl<sub>2</sub>  $\cdot$  6H<sub>2</sub>O (95.7 mg, 0.404 mmol, 1.5 equiv) and DI water (30.0 mL) were combined, resulting in brownish-yellow solution. The solution was heated to 65 °C and NH<sub>4</sub>OH (1.50 mL, 21.8 mmol, 83 equiv.) was added, immediately forming a black precipitate. The black opaque mixture was bubbled with air for 45 minutes and then bubbled with nitrogen for 2 hours. The heterogeneous solution was centrifuged and liquid layer was decanted. The solid was washed with DI water (3 x 40 mL), ethanol (3 x 40 mL) and acetone (2 x 40 mL) with centrifuging and decanting after each wash. The solid was dried under nitrogen for 15 hours, resulting in a clumpy black powder **3** (75.3 mg).

PXRD, 2 $\theta$  (°): 5.2, 10.3, 13.2, 17.1, 27.8

### **Platinum MOF Powder**

To 125 mL erlenmeyer flask equipped with septa, a solution of HATP  $\cdot$  6HCl **4** (141.7 mg, 0.263 mmol, 1 equiv) and DI water (20.0 mL) and a solution of (NH<sub>4</sub>)<sub>2</sub>PtCl<sub>6</sub> (105.4 mg, 0.404 mmol, 1.5 equiv) and DI water (30.0 mL) were combined, resulting in colloidal burnt-red-brown solution. The solution was heated to 65 °C and NH<sub>4</sub>OH (1.50 mL, 21.8 mmol, 83 equiv) was injected, immediately turning the mixture a dark red-brown. The mixture was bubbled with air for 45 minutes, further darkening it to an opaque black, and then bubbled with nitrogen for 2 hours. The mixture was washed and dried using the previous procedure, resulting in a clumpy black powder (94.8 mg).

PXRD, 2 $\theta$  (°): amorphous

### **Palladium MOF Powder**

To 125 mL erlenmeyer flask equipped with septa, a solution of HATP  $\cdot$  6HCl **4** (95.0 mg, 0.177 mmol, 1 equiv) and DI water (22.0 mL) and a solution of K<sub>2</sub>PdCl<sub>6</sub> (88.1 mg, 0.269 mmol, 1.5 equiv) and DI water (12.0 mL) were combined, resulting in colloidal burnt-orange solution. The solution was heated to 65 °C and NH<sub>4</sub>OH (1.01 mL, 14.6 mmol, 83 equiv) was injected,

immediately turning the mixture reddish-brown. The mixture was bubbled with air for 45 minutes, further darkening it to an opaque black, and then bubbled with nitrogen for 2 hours. The heterogeneous solution was centrifuged and liquid layer was decanted. The solid was washed with DI water (3 x 20 mL), ethanol (3 x 20 mL) and acetone (2 x 20 mL) with centrifuging and decanting after each wash. The solid was dried under vacuum for 15 hours, resulting in a clumpy black powder (56.8 mg).

**PXRD**,  $2\theta$  ( $^\circ$ ): amorphous

NMR chemical shifts are reported in ppm and referenced to the residual solvent peak DMSO ( $\delta$  = 2.50 ppm,  $^1\text{H}$ ) and  $\text{D}_2\text{O}$  ( $\delta$  = 4.80 ppm,  $^1\text{H}$ ) as an internal standard. NMR spectra are recorded on an Agilent NMR spectrometer operating at 499.69 MHz proton NMR frequency, and the data analysis is performed using the MestReNova software package (version 11.0.4).

Powder X-ray diffraction (PXRD) experiments, referenced from Meek *et al.*, were carried out using a PANalytical Empyrean™ diffractometer equipped with a PIXcel3D detector operating in scanning line detector mode with an active length of 4 utilizing 255 channels. The diffractometer is outfitted with an Empyrean Cu LFF (long fine focus) HR DK386079 XRD tube operated at 45 kV and 40 mA and Cu K-alpha radiation ( $\lambda\alpha = 1.5418704 \text{ \AA}$ ) was used for diffraction experiments. Experiments were conducted in continuous scanning mode with the goniometer in the 2-theta orientation. Incident beam optics included the Fixed Divergences slit with Antiscatter slit PreFIX module, with a  $1/32^\circ$  divergence slit and a  $1/16^\circ$  antiscatter slit, as well as a 10 mm fixed incident beam mask and a Soller slit (0.04 rad). Divergent beam optics included a P7.5 antiscatter slit, a Soller slit (0.04 rad), and a Ni Beta filter. The samples were typically dry and ground into a fine powder, applied to a low background sample holder and mounted to a bracket flat sample stage. In a typical experiment, data was collected via a continuous scan in the range of  $3^\circ$ - $60^\circ$  ( $2\theta$ ) with a stepsize of  $0.0131^\circ$  and a scan time of 600 seconds per step.<sup>5</sup>

Raman absorptions were collected on a Renishaw inVia Raman Microscope Sox objective by taking three scans of the sample.

$\text{N}_2$  isotherms, referenced from Meek *et al.*, were collected at  $100^\circ\text{C}$  and carried out via the method of gas adsorption manometry using a ASAP 2020 automated surface area and pore size analyzer (Quantachrome Instruments, USA). The data were evaluated using the QuadraWin™ software V.5.02 (Quantachrome Instruments, USA). Prior to adsorption analysis all samples were outgassed for extended periods under dynamic turbomolecular pump vacuum and heating profiles described in the activation protocols. Outgassing was achieved using a MasterPrep™ 6 station degasser in vacuum mode with CN616 control software (Quantachrome Instruments, USA). Upon completion of the degas/heat profile, the samples were backfilled with dry  $\text{N}_2$  (UHP). Data was analyzed with Quantachrome QuadraWin software. Multipoint BET surface areas were calculated from 10 points spaced between  $P/P^\circ = 0.005$  and  $0.075$ . Ambient temperature adsorption isotherms were collected from  $P/P^\circ = 0.01 - 1.00$ .  $P^\circ$  was set to 760 mmHg.<sup>5</sup> The clearing of the pores, referenced from Wu *et al.*, was done by soaking the powders in water at  $100^\circ\text{C}$  (3 x 12 hours) and then ethanol at  $78^\circ\text{C}$  (3 x 12 hours). Activation was completed under dynamic vacuum to 50  $\mu\text{mHg}$  while ramping the temperature  $2^\circ\text{C}/\text{min}$  and holding at  $60^\circ\text{C}$  until pressure calibrated. Once the low pressure was obtained, the temperature was ramped up by  $2^\circ\text{C}/\text{min}$  and held at  $100^\circ\text{C}$  for 6 hours.<sup>2</sup>

Electrical conductivity measurements were taken by using a four point probe and calculating the sheet resistance ( $\rho/\text{thickness}$ ). Measurements were taken on the powder by pressing them into pellets with 5 tons of force using 30-70 mg of material. Two electrodes made of thin copper sheets were then attached opposite to each other on the pellets. The thickness of the powder pellets ranged from 0.3 mm to 0.7 mm.

Energy dispersive X-ray spectroscopy (EDXS) were completed on a JEOL JSM-7600F FE-SEM under 15.0 kV vacuum on sample areas of 1-5 mm<sup>2</sup> to reveal the relative elemental abundances (C, N, Cl, Ni/Pd/Pt) with  $\leq 1\%$  accuracy. Scanning electron microscopy (SEM) images were taken on the same instrument at 100-1500x magnification.

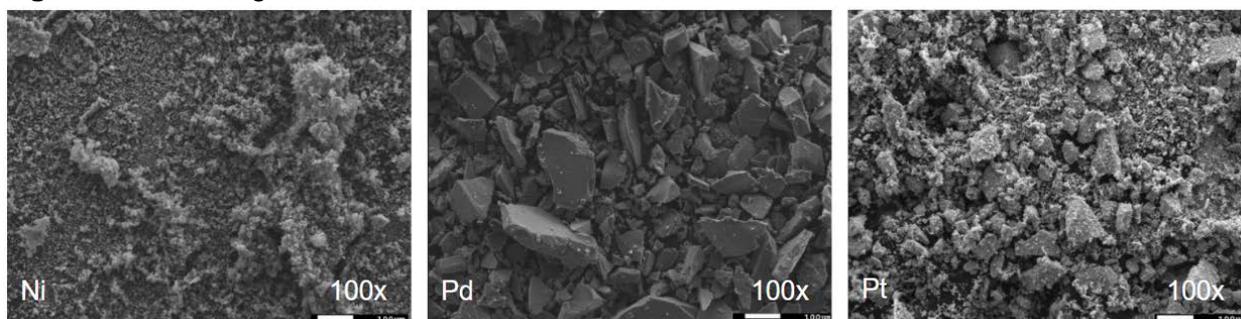
Raw data was evaluated on Microsoft Excel 2016, unless otherwise stated.

## RESULTS & DISCUSSION:

During the synthesis of these powders, air bubbling was found to be crucial for the formation of the Ni<sub>3</sub>(HITP)<sub>2</sub> MOF. When the apparatus and solution are deaerated with nitrogen, the reaction never forms a black precipitate after the addition of the base and instead forms brown clumps within the transparent yellow solution. The mechanism is uncertain; however, we speculate that either oxygen or carbon dioxide acts as a catalyst during synthesis.

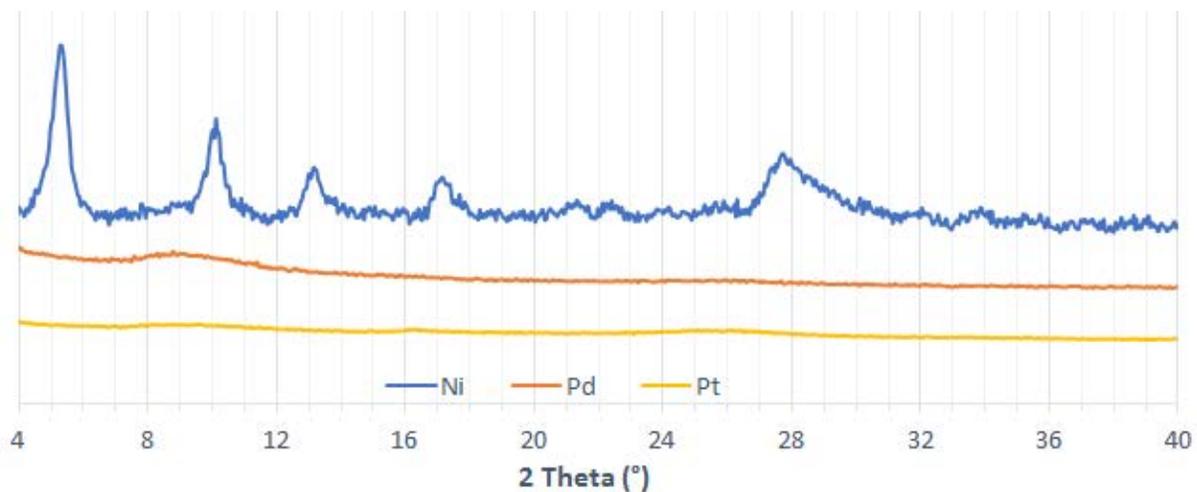
Visually, every product formed a powder of shiny black crystals with no obvious difference between the three metal versions of this MOG structure. SEM images show differences in grain size, likely due to the quality of grinding with mortar and pestle prior to the PXRD measurements.

**Figure 2:** SEM images of MOG Powders



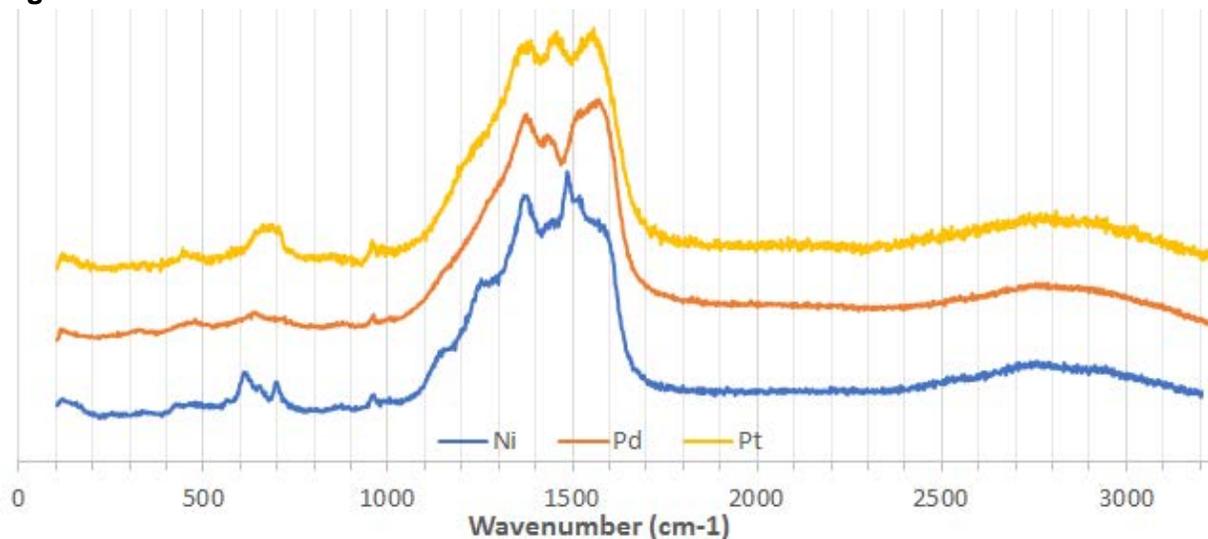
PXRD data shows that the nickel MOG synthesis was crystalline and produced a pattern accurate to the peaks displayed by Ni<sub>3</sub>(HITP)<sub>2</sub> as published in literature.<sup>2,3</sup> The PXRD of the palladium and platinum powders displayed no patterns, suggesting that their crystals lack long-range order or that they form an amorphous material with the organic linker HATP.

**Figure 3:** PXRD of MOG Powders



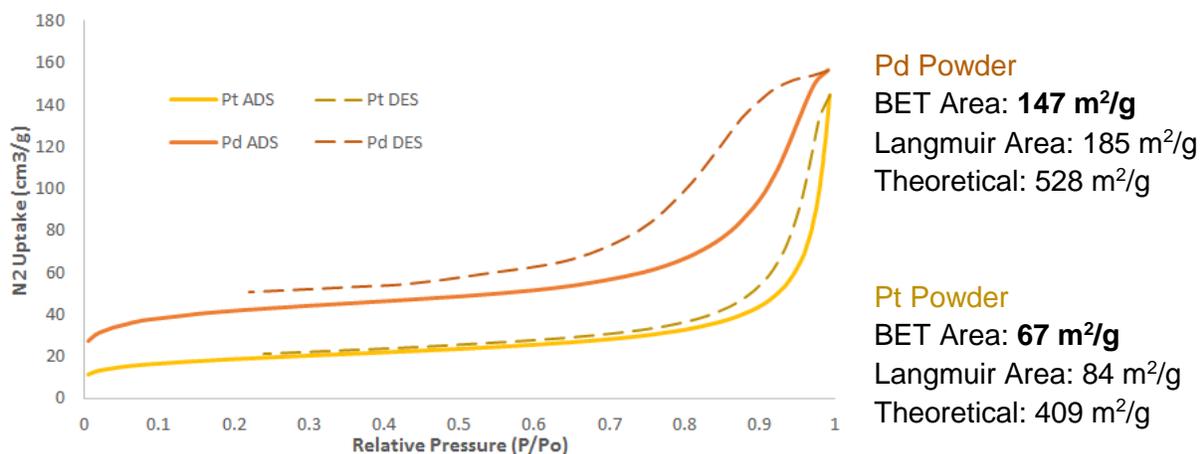
Raman spectra of the three MOGs shows similar absorption patterns, indicating that palladium and platinum form similar structure to the  $\text{Ni}_3(\text{HITP})_2$ . The broad peak within the 2500 and 3200  $\text{cm}^{-1}$  region are comparable to graphene and suggest that these materials likely have multi-layered stacking of graphene-analogous sheets. The spectra also displays small peaks within the crest of the largest peak within the 1300-1600  $\text{cm}^{-1}$  region. These small absorptions have been speculated to correspond to the presence of pores within the material.

**Figure 4:** Raman of MOG Powders



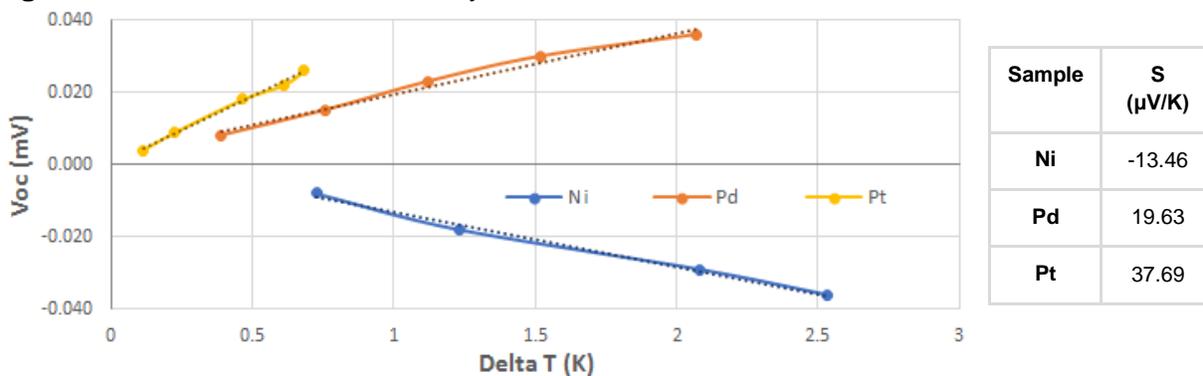
The nitrogen absorption isotherms confirm the presence of pores and reveal that palladium and platinum have BET surface areas of 147 and 67  $\text{m}^2/\text{g}$ , respectively. Although the surface areas are far lower than the expected values calculated from the  $\text{Ni}_3(\text{HITP})_2$  value of 625  $\text{m}^2/\text{g}$ ,<sup>2</sup> it indicates that both materials are porous.

**Figure 5:** Nitrogen Gas Isotherm of MOG Powder

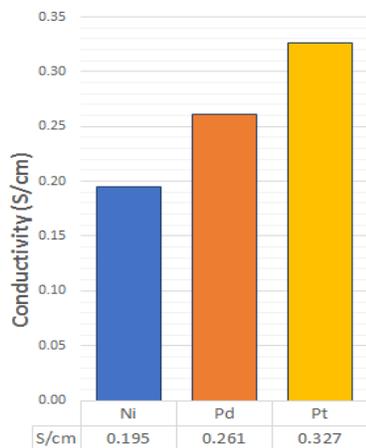


Thermal conductivity data shows that the nickel MOG has a negative Seebeck coefficient, which is indicative of an n-type semiconductor. The palladium and platinum MOGs have positive Seebeck coefficients, meaning they are both p-type semiconductors.

**Figure 6:** Thermoelectric Conductivity of MOG Pellets



Electrical conductivity ( $\square$ ) data supports the theory and displays that there is a direct correlation between conductivity and the metal cation size. Conductivity increases from nickel to palladium to platinum with the respective values of 0.195, 0.261, and 327 S/cm, indicating that the metal radii may have an effect on the MOGs formed with the organic linker HATP.



**Figure 7: Electrical Conductivity of MOG Pellets**

Sample	R ( $\Omega$ )	Rho ( $\Omega\cdot\text{cm}$ )	Conductivity $\square$ (S/cm)
Ni	48.2	5.123	0.195
Pd	43.7	3.835	0.261
Pt	40.0	3.060	0.327

Power factor (PF) is a metric for how efficient the thermoelectric material is at converting heat to electricity and electricity to heat, therefore, a greater PF is more ideal for material used for thermoelectrics. Once the Seebeck coefficient (S) and conductivity ( $\square$ ) are known, the power factor can be determined with the equation,  $\square^2 S = \text{PF}$ . Compared to the revolutionary Bismuth telluride ( $\text{Bi}_2\text{Te}_3$ ), the  $\text{M}_3(\text{HITP})_2$  have much lower power factors; however with more optimization, these MOGs has the potential to become more efficient thermoelectric materials. Similarly to the electric and thermoelectric data, the power factor of the MOG increases with the radii of the metal cation.

**Figure 8: Power Factor of MOGs**

Sample	PF ( $\text{W/mK}^2$ )
Ni	$3.54 \times 10^{-9}$
Pd	$1.01 \times 10^{-8}$
Pt	$4.64 \times 10^{-8}$

## CONCLUSION:

It can be concluded that when nickel is switched with palladium or platinum during synthesis, the metals form black powders with the organic linker HATP similarly to nickel. Both the palladium and platinum form a porous structure with the linker; however, neither material show XRD patterns, signifying that both lack long range order or are amorphous. The structure of Pd and Pt MOG is largely unknown; however, according to Raman spectra, platinum conjectured to form a similar structure to  $\text{Ni}_3(\text{HITP})_2$ . As for the effects of metal cation selection, data supports theory and hypothesis, since conductivity and efficiency appears to increase with the metal's atomic radius.

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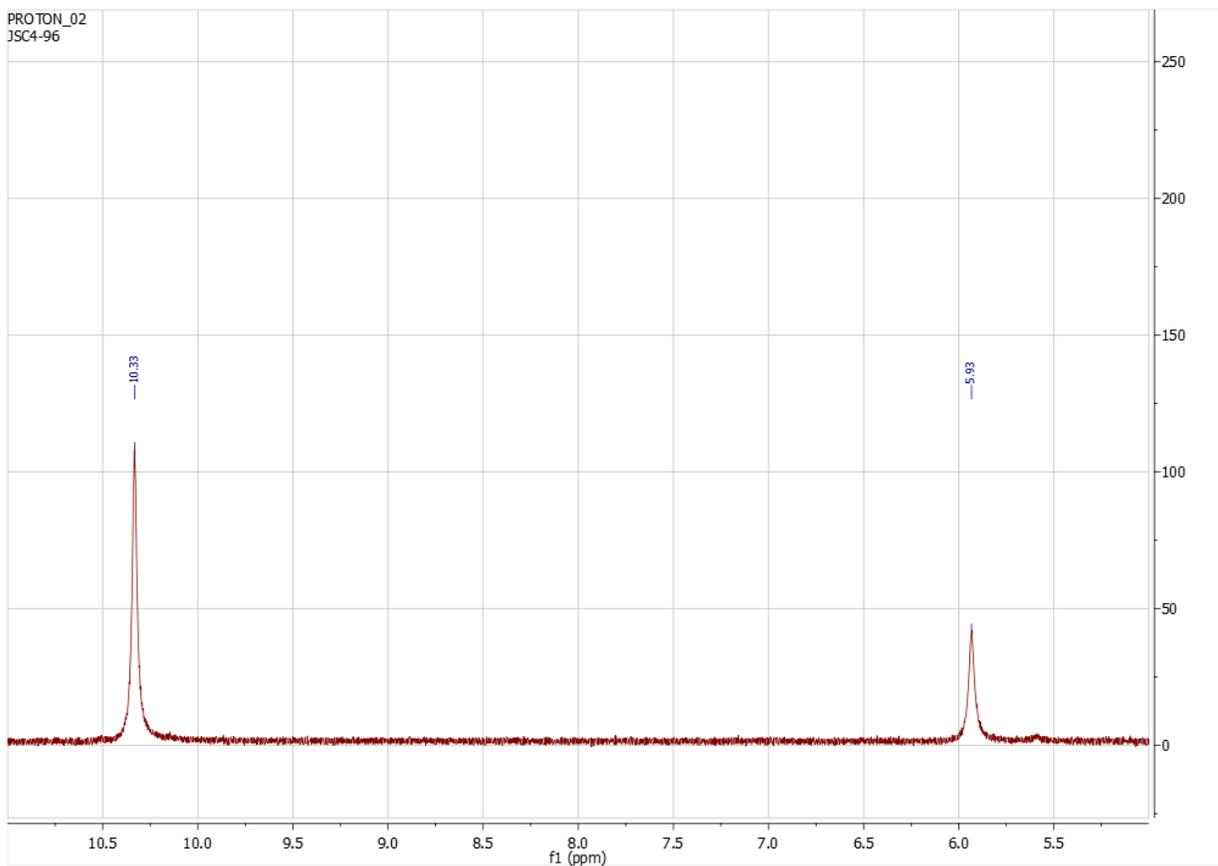
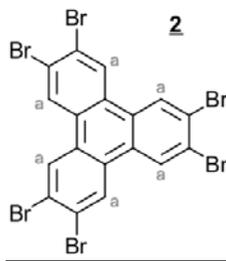
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5. Adapted in part with permission from Meek, S. T.; Teich-McGoldrick, S. L.; Perry, J. J.; Greathouse, J. A.; Allendorf, M. D. *J. Phys. Chem. C.* **2012**, *116* (37), 19765–19772. Copyright 2017 Physical Chemistry C.



## SUPPORTING INFORMATION:

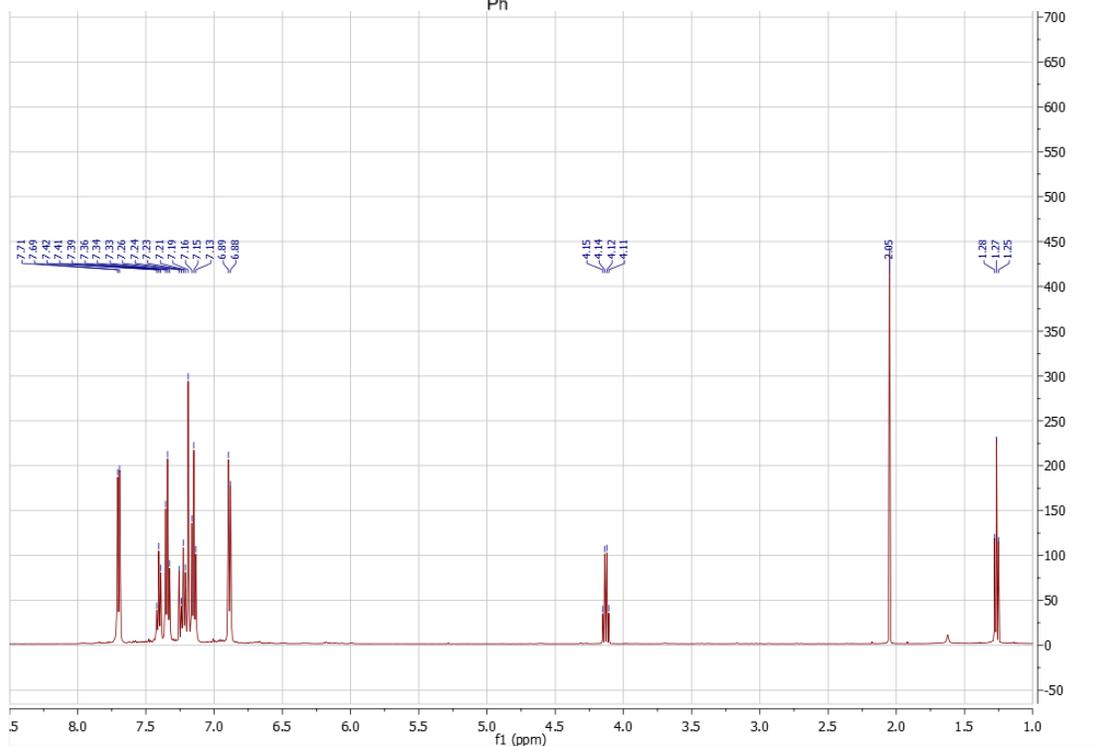
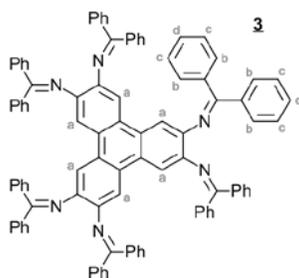
### Hexabromotriphenylene



$^1\text{H NMR}$ , 500 MHz,  $\text{Cl}_2\text{CDCDCl}_2$

Peak	ppm	Multiplicity	$J$ (Hz)	Integration	Assignment ( $\text{H}_x$ )
1	10.33	s	-	6	a

## Benzophenone protected 2,3,6,7,10,11-hexaaminotriphenylene

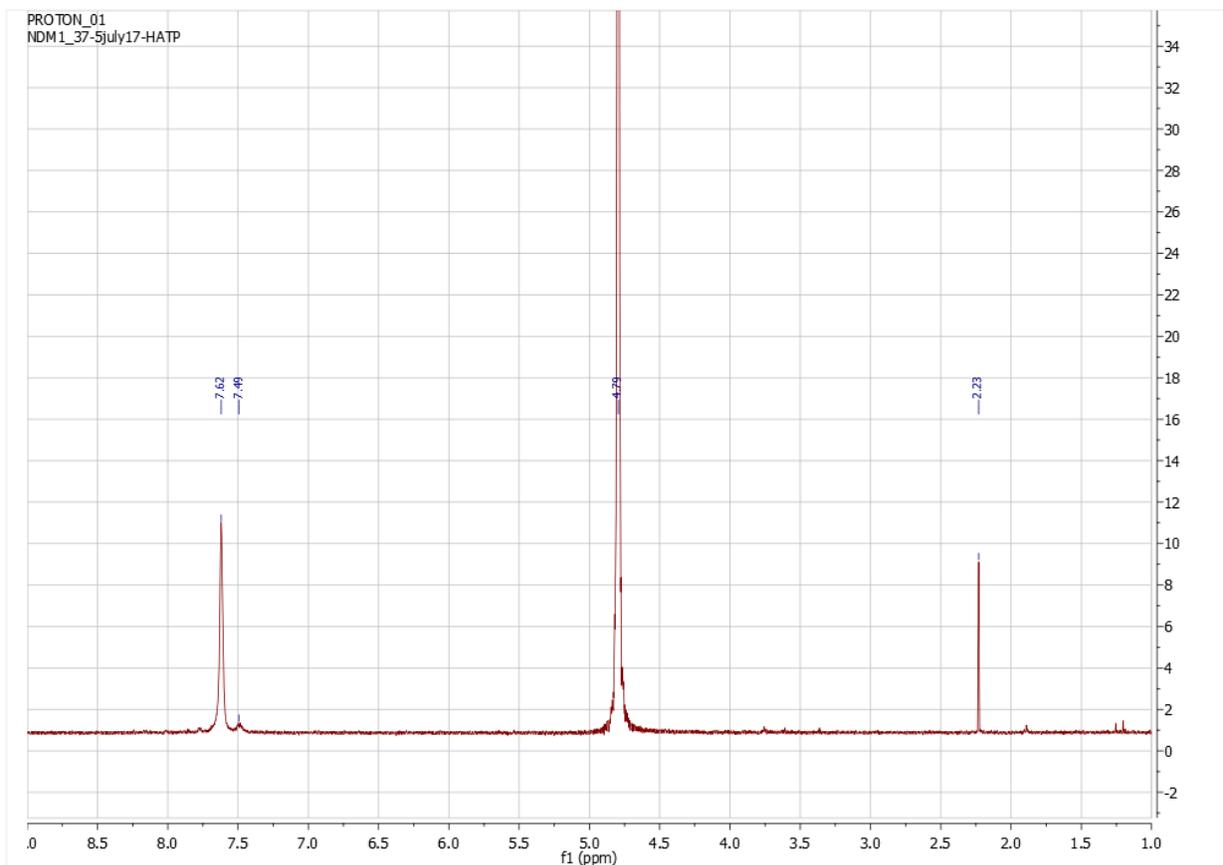
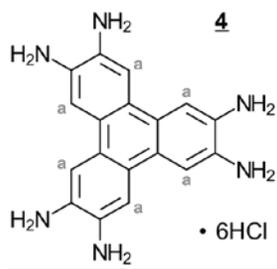


<sup>1</sup>H NMR, 500 MHz, CDCl<sub>3</sub>

Peak	ppm	Multiplicity	<i>J</i> (Hz)	Integration	Assignment (H <sub>x</sub> )
1	7.71	d	7.20	12	b
2	7.41	t	7.30	6	d
3	7.35	t	7.48	12	c
4	7.23	t	7.44	6	d
5	7.20	s	-	6	a
6	7.16	t	7.56	12	c
7	6.09	d	7.10	12	b

*Ethyl acetate impurity at 4.13, 2.05, and 1.27 ppm.*

**2,3,6,7,10,11-hexaaminotriphenylene hexahydrochloride**



<sup>1</sup>H NMR, 500 MHz, D<sub>2</sub>O

Peak	ppm	Multiplicity	J (Hz)	Integration	Assignment (H <sub>x</sub> )
1	7.62	s	-	6	a

*Acetone impurity at 2.23 ppm.*

## Response to the 2012 Suggestions and Recommendations

### Suggestions

- Sabbaticals
  - We are a relatively young faculty with most hired since 2007. During the previous periodic review cycle none of the faculty were eligible for sabbatical leave. During the current (2012-2018) review cycle three faculty took sabbatical leave.
- Research Reports
  - CHEM 300 was a course that was on the books at the beginning of the 2007-2012 review cycle, but was eliminated in favor of a different course later on.

### Recommendations

- Laboratory experience
  - We made the decision a number of years ago to modify the way we offer upper division labs to cover physical, inorganic and analytical/instrumental analysis. The resulting Integrated Lab Sequence (3 semesters long) incorporates these disciplines in multi-week, long-term projects rather than weekly experiments. In some cases a project could cover the entire semester. We necessarily cover fewer specific topics in inorganic chemistry, but those we include are covered in a very exhaustive way. We build teams of students to address various aspects of these extended projects and expect each team member to contribute to the design, implementation, acquisition and analysis of the data. Formal written and oral reports are required.
  - We recently added a faculty member whose expertise is in physical/materials science. She has contributed two major projects to the sequence. One in particular involves the preparation, characterization and evaluation of solar cells prepared from metal organic framework (MOF) using different metals and organic linkers. The MOF experiments extend the experience of our students with inorganic materials AND with characterization techniques like XRD, SEM and various electrical measurements.
  - We maintain contact with our graduates and specifically ask for input on those aspects of our degree programs they found most valuable. Almost every graduate pointed to the Integrated Lab Sequence as a major contributor to their success in graduate school or other career paths. The requirement to focus on a few areas, but in great depth with high expectations for participation and presentation provided many of the skills needed in the next step in their development as scientists.
- Certification requirements: biochemistry degree track
  - The information provided in the 2012 report only lacked clear statements about how many units of the indicated electives were REQUIRED for the certified degree. This omission has been fixed in the current report.
  - The CHEM 453M: Biochemistry Lab is a 3 unit course – 1 unit lecture and 2 units lab (6 hours per week). Although the lab is the first laboratory exposure to biochemistry, the inclusion of the 1 unit of lecture and the additional 3 hours per week of lab provide a much more in-depth experience than is typical for the laboratory of a Foundational course.