COURSE GUIDE

FOR

PHYSICAL CHEMISTRY II

FCH 361
Spring 2020

State University of New York
College of Environmental Science and Forestry

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Acknowledgments

This course guide is based on the ones I developed for FCH 360, Physical Chemistry I. The inspiration for those course guides came largely from Chuck Spuches of the Instructional Development, Evaluation and Services Office here at SUNY-ESF. Some ideas are derived from Dan Apple of Pacific Crest.

Contents

Logistics

Class Meets	321 Bray Hall	MWF 11:40-12:35
Instructor	Dr. Theodore Dibble 421 Jahn	tsdibble@esf.edu 470-6596

Student Hours (aka Office Hours): Mondays 2-3 Wednesdays 9-10

Required Text: P. W. Atkins, *Physical Chemistry,* 8th or 9th edition
and Student Solutions Manual
The 8th edition and Solutions Manual are on reserve at Moon Library

Course Grade: determined by:

Homework	10%
In-class Exams (4)	60% (15% each)
Final Exam	30%

Grading Scale:

80 and up	A- to A
70 -79%	B- to B+
60 - 69%	C- to C+
50 - 59%	D

Exam Schedule

Exam	Date	Subject
I	Wed Feb. 5	Kinetics
II	Mon March 2	Concepts of Quantum Mechanics
III	Fri April 3	Applications of Quantum Mechanics
IV	Mon April 27	Further Applications of Quantum Mechanics
Final	Thur Apr 30 (tentative)	Comprehensive

For each exam you will be allowed to bring into class one 8.5" x 11" sheet of paper (the "cheat sheet") containing whatever notes you desire (3 sheets for the Final Exam). Cheat sheets must prepared by your own hand (no photocopies) and no magnification equipment is allowed. Bring your calculators.

If you have a need for a test- or note-taking accommodation, please discuss it with me.

Homework/Classwork:

Problems on the Homework will be turned in and graded. Due dates are listed in the course Schedule. Since answers will usually be available on Blackboard right after the class period they are due, I cannot give credit if you turn the *Problems* in late. The ungraded *Exercises* will also be very helpful in preparing you for the *Problem*s.

Attitude Check

Physical chemistry has a reputation as a difficult course. Some students arrive in class the first day already convinced they cannot do the work, and therefore they do not see any reason to study hard or to study smart. With this attitude, they create a self-fulfilling prophecy, like the student to the right..

DO NOT MAKE THIS MISTAKE!!!

Physical chemistry can be very rewarding. The material is deep; there is much more than just what appears on the surface or in any textbook. Yet the struggle for mastery of physical chemistry can be rewarded with a sense of accomplishment and the power of a new type of knowledge.

You **won't** have to evaluate integrals like this. The math will be much less scary!

$$e\int_{r=0}^{\infty}\left(\left(\frac{1}{2430}\right)^{1/2}\left(\frac{Z}{a}\right)^{3/2}\left(\frac{2Zr}{3a}\right)^{2}e^{-ZR/3a}\right)(r)\left(\left(\frac{1}{24}\right)^{1/2}\left(\frac{Z}{a}\right)^{3/2}\left(\frac{Zr}{a}\right)e^{-Zr/2a}\right)r^{2}dr$$

Personal Statement

I am in my 24th year at ESF, and my 14th year teaching FCH 361 (Physical Chemistry II). My appreciation for the power and profound insights found in physical chemistry led me to choose my undergraduate thermodynamics professor as a research advisor in graduate school. From graduate school on, I have been doing research in most of the topics of this course: kinetics, quantum chemistry, and spectroscopy.

My goal in this course is for students to gain an understanding of the equations and methods they will encounter in this course, rather than merely memorize a method to solve common types of problems. This goal guides the way I structure homework assignments, classroom time, and exams. Keep this goal in mind when you think about how to prepare for this course.

Some of the topics in this course and the way they are approached may be rather different from what you are used to. This may present you with a challenge; it may require extra effort on your part to meet. If you are aware of the differences, then you can figure out how to rise to the challenge.

Prerequisites - Knowledge, Skills, and Attitudes

To take this course, you must have passed one year of college physics (Mechanics, Electricity and Magnetism) and one year of calculus (Differential and Integral). There are no exceptions without my written permission, which may or may not be forthcoming.

The physics we use is primarily Electricity and Magnetism. If your algebra and calculus are rusty, then you need to brush up on those areas. You will need a good scientific calculator for homework assignments and examinations, and you will be using it in class.

There are skills and attitudes required for this course beyond the prerequisites cited in the course catalog. Here I present an incomplete list of skills you should have mastered and attitudes you should have wholeheartedly adopted:

1) Graph numerical data and interpret graphical data, by hand and using Excel.

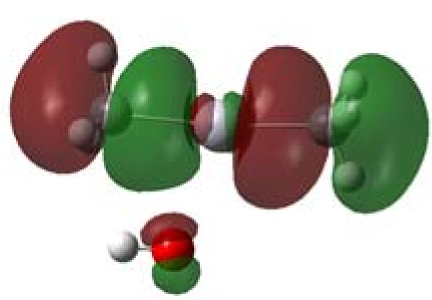
2) Extract numerical data from a statement of a problem, identify needed information, and identify the equations necessary to solve the problem.
3) Take the initiative to obtain data from reference works like the CRC or other data sources.
4) Recall and use basic principles learned in previous chemistry, math, and physics courses.
5) Make estimates, such as deciding when a quantity in an equation is negligibly small and can be ignored in calculations; estimating uncertainties.
6) Analyze the units and dimensions of quantities or equations.
7) Understand the meaning of a derivative or integral.
8) Check to see whether your answers on homework or test problems are reasonable physically, chemically, and mathematically.

If you are already skilled in all the above, great! If not, then you will want to further develop these skills this semester. Here are some ways to do that:

- We will be addressing some of these issues in class and on the Homework. So come to class, and work hard.
- See various textbooks for reviews of mathematics and units analysis.
- Your text books and notes from old classes in high school and college are still valuable sources of explanations and problems!

Background and Purpose of the Course

You may have been exposed to many of the ideas presented in this course in your first college chemistry course or even in high school. Why then, are they presented again? One obvious reason is that there is far more to these ideas than what you saw in previous courses, and many more applications. Kinetics is crucial for understanding the competing chemical processes, whether they be in a large scale reactor, the environment, or inside a cell of a living organism. As you may have been taught, thermodynamics dictates that diamond should eventually transform itself to graphite, but kinetic arguments have convinced chemists that their diamond jewelry is safe from that hazard. Quantum mechanics allows a description of the behavior of matter at the atomic level, where physical intuition based on knowledge of macroscopic objects fails. Quantum mechanics is also the basis of spectroscopy. Spectroscopy encompasses a broad range of tools used for analysis in different wavelength regions. Quantum mechanics is also the basis for understanding chemical change induced by light absorption (photochemistry). Statistical mechanics allows us to use spectroscopic data to compute the thermodynamics and kinetics of chemical reactions.



Course Goals/Objectives

Broadly speaking, there are three overarching goals for your technical learning. The first two are to help you master fundamental chemical concepts within a much more rigorous and powerful mathematical framework, and to help you develop an intuition about physical and chemical processes.

These two goals may seem contradictory, but they are not. There are very few researchers who can use the mathematical methods well without keeping a physical framework in mind.

Those who try too often make ridiculous errors without even knowing it. On the occasions when I have forgone physical thinking, I have often blundered. Most of the resulting errors were caught before doing damage, but I know at least one that made it to print. If this is the result when professionals try to do mathematics blindly, you can guess what happens when novices try.

While the physical model is crucial, much of its power lies in how it lends itself to calculation. The attitude of a physical chemist is that the physical and chemical properties of matter are subject to mathematical modeling, enabling predictions for species and systems not yet studied. If you begin to adopt this attitude, you will be making a large step towards understanding, not only this course, but any physical system you will encounter in the future.

Quantum mechanics is one of the most important scientific and intellectual developments of the 20^{th} century. It provides powerful and very useful ways of thinking about physical phenomena that cannot be understood through classical models. The third goal for your technical learning is that you begin to integrate quantum mechanical thinking into your analyses of molecular-level phenomena.

Course Learning Outcomes

After completing this course the student should be able to:

1. Use rate constants and information regarding concentrations to calculate the evolution in time of concentrations for first and second-order reactions;
2. Use the steady state, pseudo-first order, and rate-limiting step approximations to analyze reacting systems;
3. Use the principle of wave-particle duality and the de Broglie relation to relate energies to wavelengths and frequencies, as for example for the case of ejected photoelectrons;
4. Use a known (pre-determined) wavefunction to calculate expectation values for the position, momentum, and energy for model systems;
5. Calculate allowed energy levels for particles confined to one, two, and three-dimensional rectangular “boxes”, and relate the differences in energies to wavelengths of light corresponding to possible transitions;
6. Use solutions for the energy levels for the harmonic oscillator problem to relate bond stiffness constants to frequencies of oscillators and photons;
7. Use selection rules to predict which molecules can be expected to absorb/emit microwave and infrared radiation; and demonstrate the basis of selection rules via calculus.
8. Use statistical mechanics to determine the relative population of two states (or energy levels) and the fractional population of a state (or energy level), given the temperature and information sufficient to determine energy levels and their degeneracies.

Program and College Learning Outcomes

This course contributes to meeting the Chemistry Department’s objective that undergraduate students develop a “sound understanding of the fundamental chemical principles, underlying theories, and applications of physical chemistry.”

This course addresses the following College-wide learning outcomes. For detailed information about the college learning outcomes please visit www.esf.edu/acgov/iqas.htm

(1) Scientific Reasoning
(2) Quantitative Reasoning
(4) Technological and Information Literacy
(6) Critical Thinking

Course Description and Organization

The course will bounce around in the textbook. Most of the material will be from the text, but significant portions will not. Chapter numbers below refer to the 8th (9th) edition.

Chapter 22 (21) is your introduction to kinetics. While thermodynamics tells you what can and cannot occur, kinetics tells you whether something will happen before you blink or some time after your great-grandchildren are born: the world is not at equilibrium! Chapter 24 (22) presents a microscopic view of kinetics.

Chapter 8 (7) is our introduction to quantum mechanics: a field born in the 20th century. We will study the failures of 19th century physics and begin to learn a new language needed for describing matter at the atomic level. In Chapter 9 (8) we will see the bizarre predictions of quantum mechanics for selected model systems, including a model for understanding infrared.

In Chapter 10 (9) we will look at what quantum mechanics tells us about the structure of atoms and the shapes and energy levels of orbitals. In Chapter 11 (10) we will relate the descriptive and pictorial view of Molecular Orbital theory that you have seen before to their roots in quantum mechanics. In Chapter 13 (12) we will touch on the quantum mechanics of rotational motion and look more closely at molecular vibrations. Finally, we will take pieces from Chapters 16, 17, and 24 (15, 16, and 22) to look at how quantum mechanics can help us predict thermodynamic properties and rate constants in the gas-phase.

> *"Physical chemistry is TdS.'*
>
> I first heard this pun (TdS sounds like tedious) around 1990 from an organic chemistry, but it is surely older than that!

Academic Integrity

Academic dishonesty is a breach of trust between a student, one's fellow students, or the instructor. Examples of academic dishonesty includes but is not limited to plagiarism and cheating, and other forms of academic misconduct. By registering for courses at ESF you acknowledge your awareness of the ESF Code of Student Conduct. More information regarding Academic Integrity, including the process for resolving alleged violations, can be found in the Student Handbook (https://www.esf.edu/students/handbook/).

The penalties for cheating that will be administered by this instructor will include a zero on the particular assignment and, possibly, failing the course. The incident will be reported to the administration per ESF guidelines.

An older version of the academic integrity policy read:

> Examples of academic dishonesty include, but are not limited to, actions defined below.
>
> …
>
> c) Writing, or attempting to write an examination paper, computer work, or other material for another student; allowing someone else to take one's examination.

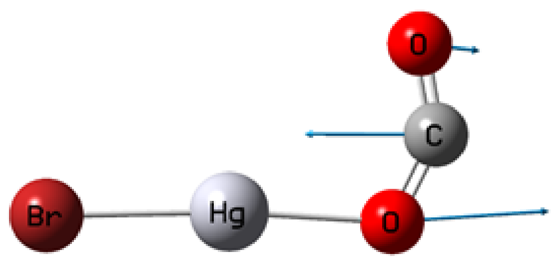
d) Possession of examinations or other test materials without permission of the instructor.

e) Using …books; looking at another's paper; or talking to someone other than the instructor or proctor during an examination, without the instructor's permission.

Cooperation on exams is not allowed.

My attitude towards cooperation on graded *Problems* is described below in the section entitled "How to Get a Good Grade in this Course". Also, read point (f) above, substituting the word "*Problems*" for "examination."

Inclusive Excellence Statement



As an institution, we embrace inclusive excellence and the strengths of a diverse and inclusive community. During classroom discussions, we may be challenged by ideas different from our lived experiences and cultures. Understanding individual differences and broader social differences will deepen our understanding of each other and the world around us. In this course, all people (including but not limited to, people of all races, ethnicities, sexual orientation, gender, gender identity and expression, students undergoing transition, religions, ages, abilities, socioeconomic backgrounds, veteran status, regions and nationalities, intellectual perspectives and political persuasion) are strongly encouraged to respectfully share their unique perspectives and experiences. This statement is intended to help cultivate a respectful environment, and it should not be used in a way that limits expression or restricts academic freedom at ESF.

Students with Learning and Physical Disabilities

SUNY-ESF works with the Office of Disability Services (ODS) at Syracuse University, who is responsible for coordinating disability-related accommodations. ODS is responsible for coordinating disability-related academic accommodations and will work with the student to develop an access plan. Since academic accommodations may require early planning and generally are not provided retroactively, please contact ODS as soon as possible to begin this process. To discuss disability-accommodations or register with ODS, please visit their website at http://disabilityservices.syr.edu. Please email disabilityservices@syr.edu or call (315) 443-4498 or for more detailed information.

When you are Struggling

As noted in the ESF **Student Handbook**, there are offices at ESF available to **provide academic support, as well as career and mental health counseling**. The Division of Student Affairs (110 Bray Hall, 470-6660) can provide help and guide you to resources. The Counseling Services Office (105 Bray Hall, 470-4716) can also assist and c**onfidentiality is assured**.

If you are absent for several days due to hospitalization, emergency, or other critical incident, the Office of Student Affairs can assist in these instances to coordinate notification to instructors.

How to Get a Good Grade in Physical Chemistry

My goal for you is not that you get a good grade in this course, although I would be delighted if you all earn high marks. Rather, my goal is to have you learn the principles of physical chemistry and how to apply them.

Why then, do you ask, do I give advice on getting a good grade?

The answer is that the graded assignments will be structured so that it is very difficult to do well without understanding the material. I will attempt to set up this course so that studying for the exams is learning physical chemistry rather than an exercise in memorization of facts, formulas, and algorithms for doing problems. Perhaps the most obvious means by which I devalue memorization is that I permit each student to bring to each exam a single 8.5" x 11" piece of paper (the "cheat sheet") with whatever notes the student wants to put there.

This class is not about memorization. If you try to get through this class by memorizing formulas and algorithms for solving certain types of problems, you are likely to fail the class. Studying for mastery does not take much more time or effort (perhaps less) than memorization, and it leads to better grades, better long-term retention, and a greater ability to apply your knowledge to real problems.

> *"You damn sadist,' said mr cummings, 'you try to make people think.'*
>
> Ezra Pound, Canto 89, 1956

So how should you study?

Come to class and PARTICIPATE

I will be presenting material that is not in the text or in a different manner than the text. I will also try to organize the material and make it more coherent; it is often difficult for students to see this organization of material in a textbook. Also, the act of writing down formulas I put on the board or things I say in class is a first step towards learning the material. This is particularly true if you can edit what I say and write, either while taking notes or in while studying outside of class. If you can do this, you will have already begun grappling with the material. In the jargon of pedagogy this grappling is called active learning, the opposite of passive learning. Active learning is the way people actually master skills or knowledge.

We will be discussing answers to *Problem*s in class. Questions based on the same logic as the *Problems* will appear on the exams. We may use class time to address problems that are not part of the homework, but do address important concepts (i.e., ones worthy of a test question). Much of your learning may take place in class discussing answers to the problems.

Ask questions in class. If you have a question, it is possible that half the class also is also wondering about the same topic. Even the best students in the class often learn something from the answer to the question you feel is too "dumb" to ask.

Finally, do not skip class to study for an exam in a later class. What you miss in my class will probably lower your final grade much more than your cramming will raise your grade in the other class.

The Textbook

Read ahead of the topics being discussed in class. This will help you to get an idea of where I am going in lecture, which will help you take better notes and get more out of the lecture. When studying outside of class, try to see how presentations in the book and in the lecture are linked. Do the example problems in the text while covering up the answer.

You may be able to get oriented to some of the material by reviewing your notes and text from General Chemistry.

Exercises

I will assign some relatively straightforward questions (*Exercises*) for you to do- these will not be graded. These are mostly intended to be fairly straightforward. You should be able to solve them by reading the book and your lecture notes. Answers to some questions are at the bottom of each set of Exercises; answers to others are in the Student Solutions Manual. You are responsible outside of class for making sure you understand the correct answers. The idea of the *Exercises* is to get you familiar with the mechanics of using, one at a time, the many equations which are a part of this course. *Exercises* will not be graded so you are allowed to give or accept help on the *Exercises* that would constitute cheating if done for graded assignments (like the *Problems*).

To do well in this class you need to not only understand the basics, but be able to apply the individual equations automatically. The analogy is, if you go to bake a cake from scratch, you want to already know a lot about baking first. (If you don't believe me, start writing instructions for your favorite recipe, starting with identifying measuring tools and baking pans, and go on through to explaining how test for doneness.) If the basics are automatic, then you will likely solve the problem (or bake the cake) efficiently and well.

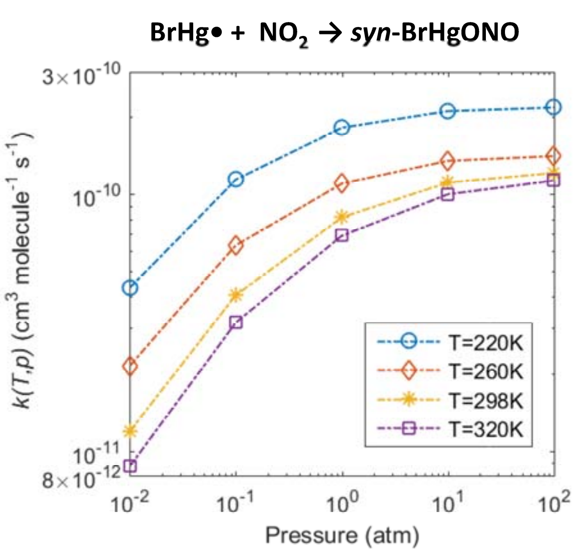
For the *Exercises* I have usually selected some of the questions that the textbook designates "Exercises." This is to enable you to check your answers in the *Solutions Manual*. When you finish the assigned *Exercises* you should ask yourself "Can I now solve the same type of problem quickly and get the correct answer?" You definitely should do the other half (a)/(b) of the Exercises from the textbook to check that you have achieved this level of competency with the material. If you have not, then you need to work harder and/or better!

Students in previous years have said that they would have done much better if they had worked through all the Exercises without looking at the answers. A few have said they spent time thinking about other ways I could ask questions on the same concepts.

Homework

I will be collecting and grading your answers to the *Problems*; answers will be posted on Blackboard. Most *Problems* are my own creations. You will not likely do well on the Homework unless you have mastered the material in the *Exercises*!

The Homework is designed to help you achieve a higher level of understanding of the material. Some problems are conceptual: these are often questions about the assumptions behind an *Exercise* or point out a pattern or oddity in its answer. Other problems are calculations, but often not ones for which the statement of the question allows you to "plug and chug." You should not expect to answer problems without thinking



for a time about the question: What is being asked? What are the knowns and unknowns? What needs to be done to get from the knowns to the unknowns?

Don't wait until the night before the due date to start doing the *Problems*!

A person can't learn to drive a car just by reading: one needs to actually get in the car and drive. By this analogy, the *Problems* might be the practice drives you take in an empty parking lot before you first get on the road: you learn in a place where no one can get seriously hurt (your performance on the *Problems* does not count a lot towards your grade). Doing problems is usually the only way to begin to learn physical chemistry (and most technical subjects).

You are allowed, nay, encouraged, to cooperate a little bit on the homework. If you are stumped about how to approach a problem, don't stay that way. Ask for a hint ("What equations do I need in order to solve this problem? What error am I making in what I have so far?"). Once you have an answer that seems right, it is appropriate to check with your classmates, and to think together about the way to understand or do a problem, or to point out and explain flaws of logic or math. Giving this type of assistance to a classmate benefits the giver, also, by forcing them to clarify their own thinking about the material. If you compare answers with a fellow student, and disagree, it is appropriate to work together to figure out what errors have been made by either student. Then, however, you should work separately to correct your answer; you may turn in the corrected work!

It is not appropriate to accept help on how to do a problem line by line or to copy someone else's answers.* This is true even when comparing answers with another student. A key concept here is to work in parallel with other students, and only come together when you are done or stuck. If two students work in parallel, they will likely express things differently, expand equations in different numbers of steps, or do some steps in slightly different order, so that their answers will not be identical.

Because *Problems* count little towards your grade, incorrect answers on the homework will not greatly hurt your grade for the course. It also follows that copying answers from somebody else will not raise your grade very much. The goal of the Homework is for you to learn the material. If you accept inappropriate help, you defeat the goal of doing homework and lower your chances of getting a good grade.

While we will discuss the answers to *Problems* in class, we will not have time to go over all the questions in detail. Answers will be posted online. **Take the time to examine the things you did right and wrong on the *Problems*.**

It is not sufficient to merely be able to do the problems. You need to think about the answers, whether they make sense physically and mathematically, and why they are what they are. **About 30% of the points on the exams** will be for conceptual (qualitative) questions that do not involve use of a calculator (part B of the in-class exams). In addition, some of the **calculation questions require a clear understanding of concepts in order to do the right calculation!** If you can do all the numerical problems in the homework, you may just be able to do well enough on the examinations to pass the course. However, if numerical problems are all you try to master, you are only aiming for a D in the course (and risking an F).

Sometimes students spend half of an hour or more trying to figure out how to start problem on the homework, without much success. This results in frustration and wastes a lot of time. Few problems should require that much time just to figure out the way to begin. Time to get help!

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* I have five surefire ways of catching and penalizing people who make a habit of accepting such "help." They are: Exam I, Exam II, Exam III, Exam IV, and the Final Exam.

If you ask me or a classmate for help, try to formulate a specific question. That way, you may get the clues that allow you to solve it yourself. You will learn the material much better this way than if you have someone else show you how to do the problem.

Students in previous years have said that they learned a lot by re-doing the *Problems* without not looking at the answers.

Office Hours and Help Sessions

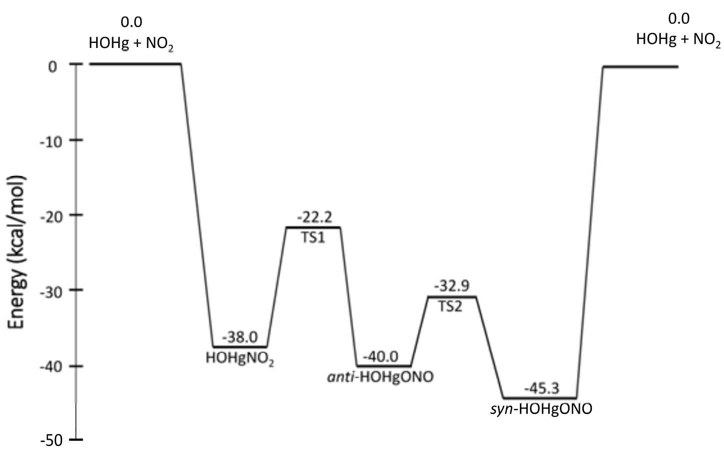
I have time set aside to help you: office hours. You can also catch me after class or email me to make an appointment to see me outside of office hours. If you drop by and I am in my office, I will probably be available to help you, although I cannot guarantee that. If you don't feel secure asking questions in class, you should be coming to office hours on a regular basis. Some questions can be handled by e-mail. If your exam score is lower than you expected, or you are confused about the homework, I expect to see you in my office from time to time.

Studying for Examinations

Do all the homework assignments again. Also re-do any additional problems that have been suggested or assigned. If you have questions, ask them in the class prior to the exam or come to my office hours. Also, you will benefit enormously by getting together with your fellow students to figure out the difficult points.

Do not wait until the day before the examination to take your first (or second) look at lecture notes, the textbook, or homework problems. That's how people get D's and F's in my courses. Rather, start several days before an exam to go over things for the *second or third time*. Review your notes and the textbook to identify ideas that are unclear; then clarify them.

As you review this material, start making a draft of your cheat sheet. Once again, the night before the exam is too late. Once you have gone over all the material, you can look back at the draft of the cheat sheet and see how best to pare it down and organize it. If you construct the cheat sheet this way, you may hardly need it during exams! If you make your cheat sheet at the last minute you will not benefit greatly from either making it or its presence during the exam.



Examinations

About 30% of the points on the exams will be for conceptual (qualitative) questions that do not involve use of a calculator. These questions may ask you to briefly explain an observation of predict the result of an experiment. They may ask you to sketch a figure representing the behavior of a system or some phenomenon, or explain phenomena presented in a graph. If you do not learn concepts, you will not be able to answer these questions. If that is the case, you will not do well in the course. In addition, some of the calculation questions may require a clear understanding of concepts in order to do the right calculation! The point is: LEARN CONCEPTS!

Standard Advice for Examinations

Look over the entire examination when you first get it. People often gain confidence by answering the easier questions before going on to harder ones, and you may benefit by skipping around (but be sure to come back to the problems you skipped!). Not all problems on the exam are worth the same number of points. If you are pressed for time, you might concentrate on the ones that are worth more.

Non-Standard Advice for Examinations

If you are simply running out of time**,** then give an outline of the way you would go about answering the question if you did have time**.** Provide some information about the answer. A numerical estimate is best**,** but information along the lines of whether the answer will be larger or smaller than the initial value, positive rather than negative, a large number or a small number.

Similarly, if you know an answer is wrong, but don't have time to figure out how you got the wrong answer, you can help yourself by writing something like: "This answer is wrong because _____; a more reasonable answer would be X." If you do this you might not lose as many points as you otherwise would for the error. The blank in the above should be something like "the answer should have been larger than the initial value (positive, a large number) rather than smaller (negative, a small number)." The "X" in the above would be a numerical estimate.

Many students get into trouble by not reading the questions carefully. If you answer the wrong question without realizing it, you will get **zero** credit.

The best use of the cheat sheet during the exam is as a way to double check formulas, results, or ways of approaching a problem. Students who are constantly scanning their cheat sheet to find a formula generally do not find the **right** formula. One needs to understand the how the material fits together and what the formulas mean. As is noted in the section on studying for examinations, the value of a cheat sheet is greatest *before* the exam, when you use it to organize the material.

Understanding the Physical Meaning of an Equation (A. P. Chatterjee and T. S. Dibble)

1) Source of Equation: is it empirical, theoretically derived (or justifiable), or, merely a simplifying assumption or hypothesis?
2) Precisely define the physical meaning of each variable.
3) Identify the limits to its use and its domain of validity.
4) Identify units and dimensions of all variables and constants.
5) Identify, if appropriate, which variables are likely to be treated as dependent, and which as independent, in its use.
6) Rearrange it to isolate each variable on the L.H.S., where possible.
7) Try to express the content of the equation for each variable purely in words, as far as possible.
8) Draw graphs, sketch lines, to illustrate key behaviors predicted by the equation; identify relevant turning points, slopes, intercepts, and asymptotes.
9) How is the equation likely to be used by a professional in science or engineering?

Checking the Reasonableness of a Calculation (T. S. Dibble and A. P. Chatterjee)

1) Identify the quantity to be determined and its units
2) Determine the sign of the quantity, or if it should be zero.
3) Estimate the magnitude of the quantity to be determined (or of the change from the initial value).
4) Compare your responses from items (1) - (3) to the answer you are checking and identify discrepancies.
5) Review the calculation to find sources of any discrepancies; your initial analysis could be in error!
6) List things done correctly and incorrectly during the calculation.
7) Identify key error(s), if any.
8) Prepare an assessment of the at least one strength, one area for improvement, and one insight, into the statement of the question or the nature/assumptions of the calculation.

On an exam, you may not have time to redo the calculation, but if you correctly identify the key error(s) and/or write down the answer to (1)-(3), you will probably have earned significant partial credit.

On an exam, step (8) will usually need to be postponed until after the exam, but don't forget to do them!