APPENDIX A: SUMMARY OF TEACHING ACTIVITIES

Below, I have presented my own personal reflection of my teaching activities as well as sample copies of my syllabus, course materials, exams and evaluations for each class that I taught during this period. The classes discussed here are:

Spring 2003

Physical Measurement and Instrumentation – PMI (PHYS636)

Physics Education Seminar (PHYS807)

Fall 2003

Physics of Solids (PHYS655)

General Physics-I Recitation (PHYS113)

You may access complete documentation for the courses above on K-State Online.
Please go to: http://online.ksu.edu
Login as:
User name: physfaculty@phys.ksu.edu
Password: CW119
Click on the highlighted courses below.

COURSE NUMBER	COURSE NAME
Using KSU Libraries	Basic Library Instruction - non-credit, free
PHYS101	PHYSICAL WORLD - I (Rebello, Fall 2002)
PHYS636	PHYSICAL MEASUREMENT & INSTRUMENTATION (Rebello, Spring 2003)
PHYS655	PHYSICS OF SOLIDS (Rebello, Fall 2003)
PHYS807	Physics Education Seminar (Rebello, Spring 2003)
phys 113	F03 - General Physics 1
F03 PHYS 114 Lecture	General Physics 2 Lecture, Fall 2003
phys 214 A	ENGINEERING PHYSICS 2 STUDIO A (Rebello, Fall 2002)
phys_452	Contemporary Physics (Zollman Spring 2003)

NOTE: To find documentation for my materials for my General Physics – I Recitation Section please click on "phys_113" in the list above. Then click on "Class Modules" in the left panel and then on "11:30 Recitation: Instructor – Sanjay Rebello"

Spring 2003

Physical Measurement and Instrumentation – PMI (PHYS636)

This was my second time teaching PMI at K-State. I had previously taught electronics, both analog and digital as separate courses at Clarion. However, the last time at K-State I had followed the lab manual written by Dr. Brett DePaola quite closely. Based on feedback from students the last time, as well as my own ideas, I decided to try a new approach, which was fundamentally different in some ways.

The new curriculum covered the same content as the previous one, although it differed significantly in the pedagogy. There were two significant differences. 1) The students were seldom told the circuit that they needed to build. Rather they were expected to go through a process of guided discovery to design the circuit, then simulate it, then build it, and compare the real measurements with the simulations. 2) We followed the modeling cycle pedagogy that included two phases: In the model development phase, students explored the electrical characteristics of a device by performing I-V or other measurements. Based on these I-V measurements and past knowledge they built a model of how the device works. The typical representation for this model was an equivalent circuit consisting of previously studied electrical elements (e.g. equivalent circuit of a diode based on switches, resistors and batteries). In the model deployment phase, students applied the equivalent circuit model to predict the behavior of the device when it was embedded in a circuit. They compared their predictions first with simulations and then with real measurements.

Some of the other features of the pedagogy used included collaborative learning, self-reflection, and Socratic dialog. Students were guided by a script on an activity sheet that asked them leading questions. My role and that of the teaching assistant was to walk around the class and interact with the students as they worked through the questions on the activity sheets. In keeping with the idea of Socratic dialog, seldom did we answer questions which students asked directly. Often we responded to students' questions by asking them other leading questions. Sometimes, when a problem was widely prevalent in class, I interrupted the class to go over this issue in a lecture-based format. This intervention became less likely as the course continued mainly because different students were at different stages of completion of the activities and it made more sense to address students' concerns as they arose in small groups. To be sure that the students were on the right track I began to introduce 'stopping points' in the activities. At these stopping points students were expected to talk with me and/or the TA about their approach and what they had discovered. The main purpose of these 'stopping points' was to ensure that students did not waste too much time following unproductive strategies or approaches for too long.

At the very beginning of the course, I realized that the pedagogy used in the course might be novel to most students. Therefore, this approach was made explicit to the students from the beginning and its intentions were made clear. They were told that this class would most likely be a departure from previous classes that they may have had. They were required to record all of their work in a permanent lab notebook. It was emphasized to the students that even wrong approaches could be productive learning experiences and that everything that they did – right or wrong – should be recorded in the notebook. In addition to the students, the pedagogy was also explained to the TA. I was fortunate to have a cooperative and dedicated TA (Flint Pierce) in this course who bought into the pedagogical approach and engaged in Socratic dialog with the students whenever required, rather than giving them the answers.

There was one mid-term exam and a final exam. The mid-semester exam was a take-home exam and the and the final exam was an oral exam. Both mid-terms included paper-and-pencil calculation and design problems as well as simulations to verify the paper-and-pencil design. Since I had changed the pedagogy from before I asked some of the same questions that I asked the previous year to see if students would still be able to solve these questions after using the modified pedagogy. I found that students were equally proficient at solving the exam questions. Moreover, they often used new strategies to solve problems and started from first principles in their calculations rather than following a pre-defined recipe. Students also seem to have developed superior modeling skills as was evidenced by the types of questions that they were able to solve on the final exam. One of these questions required students to look at the I-V curves of a device and work backwards to construct an equivalent circuit model for the device. All of the students who were asked this question were successfully able to solve it. The device in question was MOSFET, which we had not gotten a chance to cover in the course because of the lack of time. However, in spite of not having covered that particular device, students were able to develop an equivalent circuit model of it based on the hypothetical experimental evidence presented to them. I do not believe students in the course that I taught the previous year would have developed this skill.

My overall impressions from the new approach were positive. I also solicited feedback from students through an online mid-semester survey (using the K-State Survey System) as well as additional questions on the TEVAL at the end of the semester. Interactive engagement approaches usually result in coverage of less content. In this case, I covered about 70% of the material I had covered in the previous time I taught the course without the modified pedagogy. Through my observation of students' work and feedback from students, I believe I have identified the materials that need to be revised so that coverage can be increased while still maintaining the same pedagogical approach. Some areas where time was spent unproductively are the modeling of complicated devices such as bipolar transistors or flip-flops. In hindsight more scaffolding and some amount of direct instruction could be provided to the students in these topics so that less time is spent following unproductive leads as the students construct their models for these devices.

Other comments from the students reflected the need for a little more direct instruction to tie up loose ends. So, the next time I teach this course, I plan to spend at least one hour each week going over the main ideas that students would have learned through their activities. However, the lectures will not be a substitute for the discovery-based approach; rather they will mainly synthesize what students have already learned through this approach.

Based on my experiences in this course, I presented a poster at the 2003 Summer Meeting of the American Association of Physics Teachers. One of the students in the course, Kara Gray is a co-author for this poster. Kara is also completing her research in physics education towards an M.S. in Physics. Her research is unrelated to the course; however her knowledge of physics education research coupled with her role as a student in the course, gave her a unique perspective to provide me with formative feedback as the course progressed.

Results from student evaluations as well as handout slides from the poster are attached. I would like to thank the following individuals for their useful comments and support throughout the course:

Dr. Brett DePaola was helpful in providing me with the laboratory manual that was initial framework for the content of this course. Although, I modified the pedagogy, I was still following the content that Dr. DePaola had covered during the previous times that he taught the course.

Mr. Peter Nelson was especially useful in helping me set up the lab. He helped procure and put up the inexpensive white boards that I used in the class. He also lent me an old projection system and helped me purchase and transport the laptops that I used in the class from State Surplus in Topeka. Mr. Nelson along with Mr. Mark Newman helped reconfigure the furniture in the class.

Mr. Flint Pierce was an excellent TA. He was very cooperative with implementing the course pedagogy. He was always responsive to students' needs in the classroom and guided them along in the spirit of Socratic dialog. He also proofread and photocopied the instructional materials prepared for the course.

SYLLABUS

ROOM & TIME *Lab*: Room 312, Cardwell Hall Tuesday, Thursday 12:30 – 4:20 PM

INSTRUCTOR CONTACT INFORMATION Rm. 503 Cardwell Hall (Note: There is no elevator access above the 4th floor in Cardwell Hall. If you need to use an elevator, please call me and I can meet you in the lobby on the 4th floor of Cardwell.)

Phone: [Office] 532 1539 [Home] 537 7543 Email: srebello@phys.ksu.edu (several times daily)

OFFICE HOURS Wednesdays: 3:00 – 5:00 PM. Feel free to drop by or call me anytime.

COURSE GOALS Upon completion of this course you will be able to:

- Explain the basic physical principles underlying electronic devices and circuits that use these devices.
- Analyze and design analog and digital circuits (e.g. filters, amplifiers, multiplexers etc.).
- Simulate analog and digital circuits using industry-standard simulation tools.
- Build and test these circuits using standard electronic equipment (oscilloscopes, multimeters etc.).

COURSE PEDAGOGY This course will be based on the premise (supported by educational research) that we learn best when we are actively engaged in the learning process. In this spirit, I will minimize formal lecturing. Seldom will you be told how a device, circuit or instrument works. Rather you will discover what you learn by yourself through performing hands on experiments, computer simulations, discussing with your classmates, and above all, thinking. This process that you will engage in to actively construct your knowledge (rather than be handed down) is often called discovery-based learning.

We will provide you will handouts that will guide your discovery-based learning process. The handouts will contain information that helps you perform the activities as well as questions that you should strive to answer. Please respond to all of the questions in the lab notebook provided to you (see "Laboratory Procedures" below). Often the questions may ask you to make predictions. You will NOT be penalized for an incorrect prediction, as long as you have a logical (albeit incorrect) explanation to support it. Following this task, you will often be asked to verify your prediction through an experimental observation or a computer simulation and explain your observations. Finally, you may also be asked to apply what you have learned to the analysis or design of a different circuit. This sequence of tasks: Predict, Explore, Explain, and Apply will form the pedagogical framework in this course.

RECOMMENDED **TEXTBOOKS** There is **NO REQUIRED TEXTBOOK** for this course. However, there are four ***recommended*** textbooks. Collectively these texts will address all of the topics that we discuss in this course. The "Course Schedule" indicates the chapters in each text pertaining to each topic

I do ***NOT*** expect you to purchase any of these textbooks. Therefore, I will provide you with handouts (see "Course Handouts" below) containing explanations and questions that you will answer in class. The handouts will be as self-contained as possible so that you do not need to refer to the textbooks.

At least one copy of each textbook will be available in the lab. You can check out these textbooks from the lab for a day or so, and photocopy selected portions if you so wish.

I have listed the textbooks below (not in any particular order), along with my personal comments about each.

Principles of Electronic Instrumentation, 3rd Edition, by Diefenderfer & Holton, Brooks & Cole Publishing.	Covers both analog and digital, but covers digital in not as much depth as we would in this course. It has some chapters dedicated to instrumentation applications that are interesting, but we will not have time to cover.
Electronic Circuit Analysis and Design, 2nd Edition, by Neamen, McGraw Hill Publishing.	Covers analog almost exclusively. The last couple of chapters do address digital circuits but from the perspective of the internal hardware of digital devices and not how to use the digital devices as building blocks in circuits.
Fundamentals of Digital Logic, by Brown & Vranesic, McGraw Hill Publishing.	Covers only digital electronics and NO analog. It introduces a powerful simulation language that is used in several examples.
The Art of Electronics, 2nd Edition, by Horowitz & Hill, Cambridge University Press	This was the textbook last year (but students did not like it). It covers both analog and digital, again focusing mainly on analog. Also, it is written more as a reference book for those who may have had prior exposure to the course material.

COURSE HANDOUTS

Since there are **NO REQUIRED textbooks** for this course, I will provide you with detailed handouts that will combine material from various texts. I will make every attempt to make these handouts as self-contained as possible, so that you do not need to refer to any of the textbooks. However, the handouts will not merely contain information as in a text. Rather there will be two kinds of handouts that you will use.

- *Lab Handouts*: These handouts will serve as will also serve as guides to the discovery-based learning process that you will engage in class. They will contain information to guide your learning, and more importantly questions that you will have to answer in the lab notebook.
- *Summary Handouts*: These will be provided at the end of the week, *after* you have learned the material in class. These handouts will synthesize the information that you have discovered in class, and perhaps some additional relevant information.

WEB SITE

All of the class handouts, homework, as well as homework and exam solutions will available via *K-State Online* http://online.ksu.edu

I would also encourage you to use *K-State Online* to post any queries you have regarding the course on the Message Board so that other students can benefit from it. You may also use *K-State Online* to send me email or to check your grade.

If you were pre-enrolled in this class, *and* if you already have a *K-State Online* account (because you used it in another course previously) use your current username and password to logon, then should see PHYS636 listed as one of your options.

If you have never used *K-State Online* before, but were pre-enrolled for this class then you will need to create a K-State Online account by clicking the **Create an Account** button on the left side of the first login screen that you see.

LABORATORY PROCEDURES

The laboratory is the most important component of the course and is worth 45% of the course grade. You are expected to do the following in connection with the laboratory:

- You will be provided with a hardbound lab notebook in which you will record all of your data, analysis etc. It is important to realize that the lab notebook is a record of ALL of the events that occur in a lab, including circuit diagrams, predictions and conclusions reached with your partner. It is particularly important to record your mistakes. Please DO NOT erase or strike out these mistakes, just simply write a note in the margin later when you have figured out what you did wrong and why. Mistakes or erroneous assumptions are an important part of the learning process. A lab notebook that contains errors and mistakes can be a useful reference in the future that can alert you to what went wrong the first time.
- Before you begin using the notebook, please number all pages. Please leave the first four pages blank where you can create a table of contents indicating the page number, lab experiment, and date. Please be sure to begin the record for each date on a new page. Write the date on the top left corner of each page, and record that information, along with the lab experiment and page number in the table of contents.
- You may be asked to simulate some of the circuits that you will build in the lab prior to doing the lab. Please record your data from the simulations in the notebook. Data printed out from the simulations must be attached to the notebook appropriately. Unfortunately, we do not have access to a printer in the lab, so you would need to copy the data on a floppy and print it elsewhere.
- Complete all of the lab exercises indicated on the Worksheet. If you are unable to complete all the tasks on the handout for that week you can use the lab after hours to complete the tasks. If you need to access the lab outside of class hours. To accomplish that you will need to gain access to the laboratory after hours. If you need to do so, please contact me in advance and I can let you in.
- Please hand in your lab notebook for grading to the instructor by 5:00PM on Friday of each week there is lab. This will give you time to complete any experiments that you were not able to get done before end of lab on Thursday.
- The lab notebook will NOT be graded on neatness of your work, so please do NOT spend time trying to be unduly neat (please be legible, however!). Most of your graphs and circuits will be drawn freehand using the grid on the notebook. The lab notebook WILL be graded based on completeness of the information you provide including explanations and diagrams. The main question I will ask myself as I grade the lab notebook and which you should ask as you prepare it is: *To what extent can someone (other than the author) recreate the lab experience based on what is described in the lab notebook (as well as the handout)*?

HOMEWORK

Homework will be assigned about once every two week. A total of six homework assignments will be worth 24% of the course grade. You homework may involve questions that can involve paper and pencil tasks such as calculations, qualitative explanations, analysis and design of circuits. You may also be asked to simulate circuits as well as build and test them in the laboratory.

You are encouraged to work collaboratively on the homework, but merely copying someone's homework will be detrimental to your performance on the exams and final, where you are required to work alone.

EXAMS & FINAL

There will be two exams during the semester and a cumulative final. All of the exams and final are take-home. Like the homework, questions on the exams and final can involve paper and pencil tasks, as well as simulations. They may also require you to build and test circuits in the laboratory.

Unlike the homework, collaborative work on the exams and final is prohibited. You are however permitted to access resources such as texts, websites or any other non-human resources to answer the questions.

ASSESSMENT

Your performance in this course will be assessed by weighing various components of evaluation as follows:

Type of Assignment	Points per Assignment	Total Points
Laboratory	15 Weeks X 30 points	450
Homework	6 Homework X 30 points	180
Exams	2 Exams x 120 points	240
Final	130 points	130
	TOTAL. POINTS IN COURSE	***1000***

COURSE GRADE

Your course grade will be calculated based on the total points that you score in the course (out of a Maximum of 1000). The point range for each grade is as follows:

Points Scored in Course	Course Grade
900 or Above	A
800 – 899	B
650 – 799	C
649 or Below	D

STUDENTS WITH DISABILITIES

If you have any condition such as a physical or learning disability which will make it difficult for you to carry out the work outlined here, or which will require academic accommodations, please notify the lecturer and contact the *Student Disability Services* (Holton 202) during the first two weeks of the course.

ACADEMIC DISHONESTY WARNING

Plagiarism and cheating are serious offences and may be punished by failure on the exam, paper or project; failure in the course; and/or expulsion from the University. For more information refer to the "Academic Dishonesty" policy in the *K-State Undergraduate Catalog* and the *Undergraduate Honor System Policy* on the Provost's web page at http://www.ksu.edu/honor/

Please refer to the ***Course Schedule*** for information on the topics covered, relevant chapters in the recommended texts, as well as the dates of the Homework and Exams.

PHYS636 PHYSICAL MEASUREMENT & INSTRUMENTATION *SPRING 2003*

5 CREDITS *Instructor:* N. Sanjay Rebello *TU 12:30 - 4:20*

TENTATIVE COURSE SCHEDULE

REVISED: February 21, 2003

Subject to change with prior notice. Changes will be posted on K-State Online and announced in class

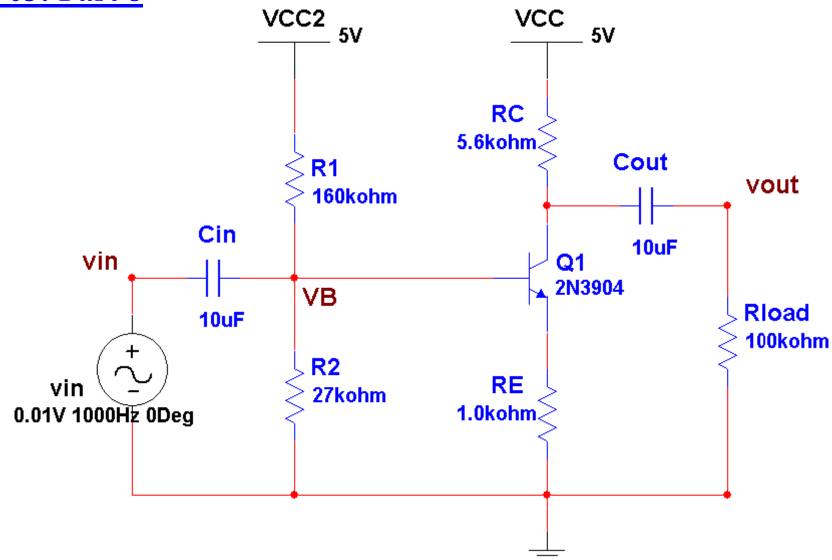
WHEN	TOPIC	Homework & Mid Term Exam (Due Date)	CHAPTERS IN RECOMMENDED TEXTS Not all sections in each chapter may be relevant. More information will be provided for each topic when we discuss it.			
			Diefenderfer & Holton	Neamen	Brown & Vranesic	Horowitz & Hill
Week 00 1/16	Getting Started	--	--	--	--	--
Week 01 1/21 –1/23	Resistive Circuits	HW 1 (1/21)	Ch 1& 2	--	--	Ch. 1
Week 02 1/28 –1/30	RC Circuits	--	Ch 5	Ch 1,2	--	Ch. 1
Week 03 2/04 – 2/06	Diodes	--	Ch 5	Ch 1,2	--	Ch. 1
Week 04 2/11 – 2/13	Diode Circuits	--	Ch 5	Ch 1,2	--	Ch. 1
Week 05 2/18 – 2/20	Transistors	--	Ch 6, 7	Ch 3, 4	--	Ch. 2
Week 06 2/25 – 2/27	Transistor Circuits	--	Ch 6, 7	Ch 3, 4	--	Ch. 2
Week 07 3/04 – 3/06	OPAMPS	HW 2 (3/04)	Ch. 9	Ch. 9	--	Ch. 4
Week 08 3/11 – 3/13	OPAMP Circuits	--	Ch. 9	Ch. 9	--	Ch. 4
3/17 – 3/21	SPRING BREAK					
Week 09 3/25 – 3/27	Digital Gates & Logic Functions	Mid Term (3/27)	Ch. 10	--	Ch. 2, 4	Ch. 8
Week 10 4/01 – 4/03	Arithmetic Circuits	--		--	Ch. 5	--
Week 11 4/08 – 4/10	Combinational Circuits	--	Ch 11	--	Ch. 6	Ch. 8
Week 12 4/15 – 4/17	Flip-Flops	HW 3 (4/15)	Ch 10	--	Ch. 7	Ch. 8
Week 13 4/22 – 4/24	Sequential Circuits	--	Ch 11	--	Ch. 8, 9	Ch. 8
Week 14 4/29 – 5/01	Sequential Ckts. - - Continued	--	Ch 11.	--	Ch. 8, 9	Ch. 8
Week 15 5/06 – 5/08	Analog – Digital Conversion	HW 4 (5/06)	Ch. 11	--	--	Ch. 9

Final Exam (take home) is due at the time designated for the final on the University's Final Exam schedule.

Transistors

Lab 03: Part 8

Designing Transistor Amplifiers



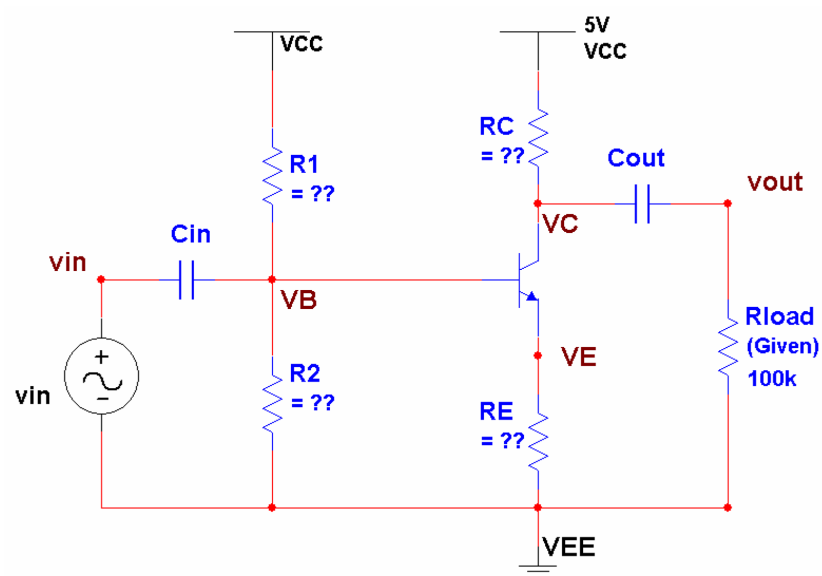
In the last activity you figured out an expression for the voltage gain of a transistor amplifier circuit shown.

$$A_v = \frac{v_{out}}{v_{in}} \approx -\frac{R_c \parallel R_{Load}}{R_E}$$

You may have noticed that the expression for Gain did not contain β or g_m or any other transistor parameter: This fact makes this circuit advantageous to use as an amplifier, because there transistor parameters are typically unreliable and therefore it is not wise to base your design such that the amplifier gain depends upon them.

In this activity you will devise a procedure that will allow you to work backward to figure out the values of various resistances in the circuit above that would give you a desired AC voltage gain, A_v (= v_{out}/v_{in}).

Q1. Suppose you were asked to design an amplifier that would provide a particular load, R_{Load} with a certain voltage gain, A_v (say 10), can you simply choose any arbitrary combination of R_E and R_C to give you the desired voltage as per the equation above (with other resistor values chosen randomly), or are there other considerations to worry about? [Hint: Go back to **Lab03 Part 6** and think about the "range of validity" in which you calculated the AC voltage gain i.e. is there a certain range of DC values of V_B (or V_{IN}) around which you should provide your AC perturbation to get your desired voltage gain?]



The act of choosing the choosing the values of various resistances (R_1, R_2, R_C, and R_E) such that the DC voltages for V_B and V_C are in a desirable range in which the circuit acts as an amplifier, is called ***biasing***. Appropriate biasing is in fact the crux of designing an amplifier circuit. The circuit topology (connections between various resistors etc.) is usually pre-determined i.e. it the one shown – what is left to the designer's ingenuity is selecting the appropriate values of R_1, R_2, R_C, and R_E that would meet at least two conditions:

1) Provide the desired AC voltage gain, A_v (= v_{out}/v_{in}). [For example, say $|A_v|$ = 25dB] *
2) Provide the appropriate DC voltage at the output (V_C), that would allow you the voltage signal at the output, v_{out} to swing in the positive and negative directions, is as large as possible without hitting the allowed extremes: V_{CC} (which is the +5V in this case) and V_{EE} (which is ground in this case.)

Since 1) above is quite straightforward, let us focus more on 2) above.

Q2. What should the DC bias voltage at the output (V_C) be in terms of V_{CC} (+5V) and V_{EE} (ground) so that the output voltage swings in both the positive and negative directions around V_C is as large as possible?

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* Gain is typically specified in decibels (dB). Later, in this activity when you use this value in your design calculations you would need to convert it to regular number.

Your answer to this question tells you unambiguously what the value the value of V_C should be. So, let us move on and see what we can say about the DC bias voltage at another terminal of the transistor: V_E.

Now V_C and V_E are two potentials that lie along the path of the main current that flows through the transistor. So, let us try and use this information, and what you know about V_C above to see if we can find out more about the value of V_E.

Q2. Finding emitter bias voltage, V_E:

(i.) How are the currents through R_C and R_E related to each other?
(ii.) How is the current through R_C related to V_C?
(iii.) How is the current through R_E related to V_E?
(iv.) How are the resistances R_C and R_E related to each other? [Hint: Think about one of the conditions that we are trying to meet when we build this circuit.]

By answering the questions (i) through (iv) above, can you find V_E, unambiguously? Explain.

Now, let us move on to find the remaining DC bias voltage at the third terminal of the transistor: V_B.

Q3. Finding base bias voltage, V_B: When the transistor is in the "ON" state, i.e. current flows through it what is the diode voltage V_{BE}? Based on this answer, and the answer to the previous question, can you find V_B, unambiguously? Explain.

At this point you have figured out what the various DC bias voltages V_C, V_B and V_E of the transistor need to be for it to meet both of your requirements 1) and 2) specified earlier. The next step is figuring out the values of R_1, R_2, R_C and R_E that would enable you to achieve the DC bias voltages that you need. As you work through this process, you may or may not be able to arrive at unique answers for each of the resistances – don't worry just go ahead and make as good a guess as possible.

Q4. Can you find an appropriate combination of values of R_1 and R_2 that would yield a value of V_B that you calculated above? Explain [Hint: You may have already done something very similar in a recent previous activity.]

Q5. Can you find an appropriate combination of values of R_C and R_E that would yield a value of the desired AC voltage gain. Keep in mind that the output voltage is supplied to a 100kΩ load resistor.

Use the values of R_1, R_2, R_C, and R_E that you calculated above and simulate the circuit. Test how well your simulated circuit meets the specifications that you set out to meet:

(i.) Perform a DC Operating Point analysis to check the values of the node voltages V_B, V_C, and V_E.
(ii.) Perform a transient analysis to find the AC Voltage gain and see if it meets the requirement: $|A_v| = 25\text{dB}$.

Q6. How well does your simulated circuit meet the specifications above. Explain any discrepancies.

Q7. Attempt to 'fix' any discrepancies by tweaking the values of R_1, R_2, R_C, and R_E that you have used. Justify why you may be adjusting these values either up or down compared to the values that you have now.

Q8. Build the real circuit and…

(i.) Measure the DC node voltages V_B, V_C, and V_E and compare them with the ones in the final simulation.
(ii.) Apply an AC signal and measure the amplitude v_{out} and v_{in}, calculate the AC Voltage Gain and compare it with the one in the final simulation above.

Additional Considerations

Q9. In the above design are the values of R_1, R_2, R_C, and R_E that you have used uniquely defined? i.e. Are there other combinations of these values that would give you the same DC Operating point as well as AC voltage results? Explain why or why not.

In the next activity you will learn about some other considerations that circuit designers typically have to worry about as they design the amplifier circuits. The considerations may narrow the number of options that you have for the various resistances and involve some 'trade offs' where you have to balance one specification with another.

Logic Gates & Combinational Circuits

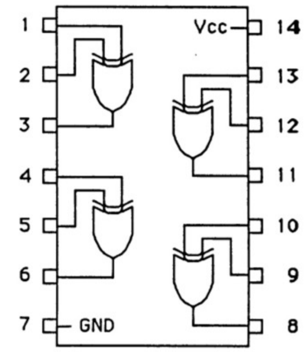
Lab 05: Part 7

Simple Arithmetic Operations

In the last couple of activities you learned about binary and other number systems and how to convert from one system to another. In this activity you will design circuits that will perform simple arithmetic operations on binary numbers.

Before we delve into the design of circuits that perform arithmetic operations, let us first explore one other gate:

Q1. Construct a Truth-Table for the **7486** Gate Shown.



7486

Q2. This gate is often called the XOR or Exclusively-OR Gate ($C = A \oplus B$)? Does that make sense? Why or why not?

Q3. What combination of NAND or NOR gates can be used to create the same Truth-Table?

Q4. Can you think of any arithmetic operation between two one-bit binary numbers that this gate can be used to perform? [Hint: Think of an operation even simpler than the four arithmetic operations – something that you would do *before* you begin to subtract two numbers, to tell what their difference may or may not be.]

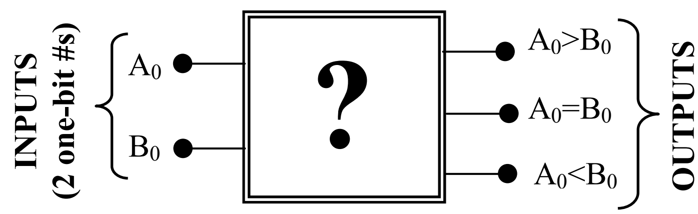
STOP for discussion OR check with instructor

Now, let us consider some simple arithmetic operations that one can perform on binary numbers and the corresponding circuits that would implement these operations.

Comparison

Oftentimes it is useful or even necessary to compare two numbers even before you proceed to perform any further mathematical operations on them. Your ultimate goal here is to design a scheme that will compare two *M-bit* binary numbers A ($=A_{M-1}\ldots A_0$) and B ($=B_{M-1}\ldots B_0$). But first let us start simple.

You will a circuit that would compare two one-bit numbers A_0 and B_0 and give a high at one of the following terminals: $A_0>B_0$, $A_0=B_0$, $A_0<B_0$ as shown.



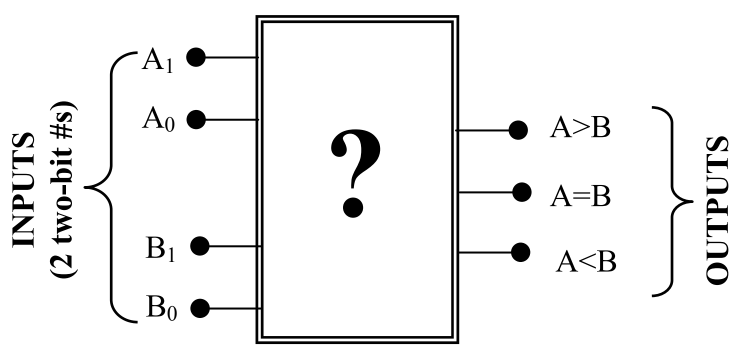
Q5. Construct a separate Truth-Table that will generate a high at each of the outputs when the corresponding condition is true: $A_0>B_0$, $A=B$, $A_0<B_0$.

Q6. From each of the Truth-Tables in the previous question, generate the most efficient logic circuits that would generate each of the outputs. [Hint: Use the techniques that you learned in previous activities; however do not neglect to consider the XOR Gate that you explored above.]

Q7. Build your circuit and test whether it gives you the desired output for various combinations of A_0 and B_0.

Q8. Compare your design with the one in file **Lab05-08** and comment on the discrepancies.

Q9. Now expand your design to a circuit that compares two two-bit numbers A ($=A_1A_0$) and B ($=B_1B_0$) and generates the output as shown. Use the circuit for a single-bit comparator (designed above) as a building block. [Hint: First compare the MSB of the two numbers. If these are equal then compare LSB to decide.]



Q10. Simulate your design and verify whether it works. Use a logic indicator for each output.

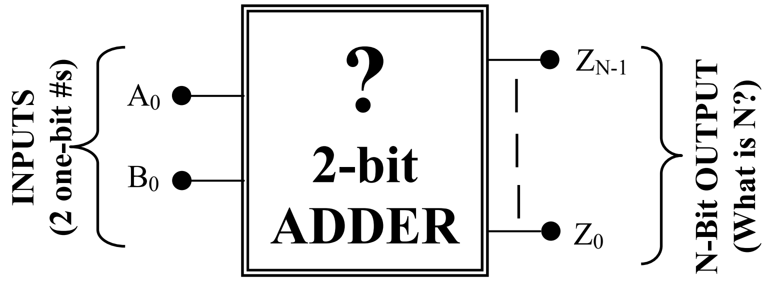
Q11. Compare your circuit design with the one in file **Lab05-09** and explain any discrepancies.

STOP for discussion OR check with instructor

Addition

Addition is one of the simplest of arithmetic operations that one can perform. You will use rules that you are familiar with in decimal digits e.g. carrying over from the units to the tens place etc.

Your ultimate goal here is to design a scheme that will add two *M-bit* binary numbers A ($=A_{M-1}\ldots A_0$) and B ($=B_{M-1}\ldots B_0$). But first we will start simple.



<u>Q12.</u> Next, let us <u>two</u> *one-bit* binary numbers: A_0, B_0, as the inputs and construct a Truth-Table would produce the binary output Z [Hint: How many possible bits (N) can Z have?]

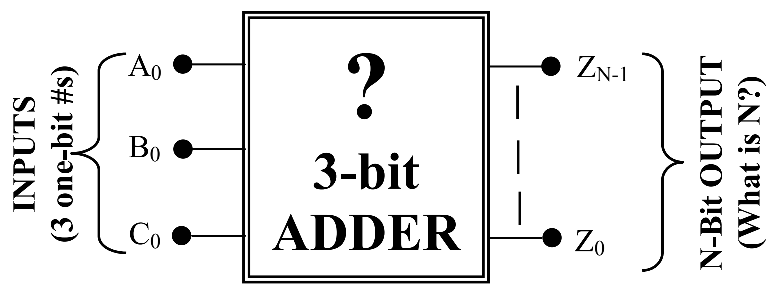
<u>Q13.</u> Based on the rules of simple addition (similar to the ones that you use for decimal numbers), construct Truth Table(s) that generates each of the bits of the output Z, from the Least Significant Bit (LSB) – Z_0 to the Most Significant Bit (MSB) – Z_{N-1}.

<u>Q14.</u> For each of the output bits Z_0 (LSB) through Z_{N-1} (MSB), design the simplest possible Boolean circuit implementation [Hint: Use the techniques that you learned in previous activities; however do not neglect to consider the XOR Gate that you explored above.]

<u>Q15.</u> Build the circuit and test whether it gives you the desired output for various combinations of A_0 and B_0.

<u>Q16</u>. Compare your design with the one in file **Lab05-10** and comment on the discrepancies.

STOP for discussion OR check with instructor



<u>Q17.</u> Now, extend your design above to add <u>three</u> *one-bit* binary numbers: A_0, B_0, C_0.

<u>Q18.</u> Build the circuit and test whether it works for different combinations of A_0, B_0 and C_0.

<u>Q19.</u> Compare your design with the one in file **Lab05-11** and comment on the discrepancies.

STOP for discussion OR check with instructor

The two-bit adder that you have developed above is often called a *Half-Adder*, and the three-bit adder is called the *Full-adder*.

<u>Q20.</u> Based on your understanding of the functioning of the Half-Adder and Full-Adder can you think of a way in which a combination of these two can be used to determine the sum of two *two-bit* binary numbers A($=A_1A_0$) and B ($=B_1B_0$) [Hint: The input C_0 in the Full-Adder is often called the *Carry-Input*. i.e. it refers to carry that is generated by adding the preceding bits of numbers.]

<u>Q21.</u> Build the circuit and test whether it gives you the desired output for various combinations of A and B.

<u>Q22</u>. Compare your design with the one in file **Lab05-12** and comment on the discrepancies.

STOP for discussion OR check with instructor

In the next activity you will encounter some more logic circuits that perform operations other than simple binary arithmetic operations.

Homework 03 [Due Tuesday, April 22]

Question 1

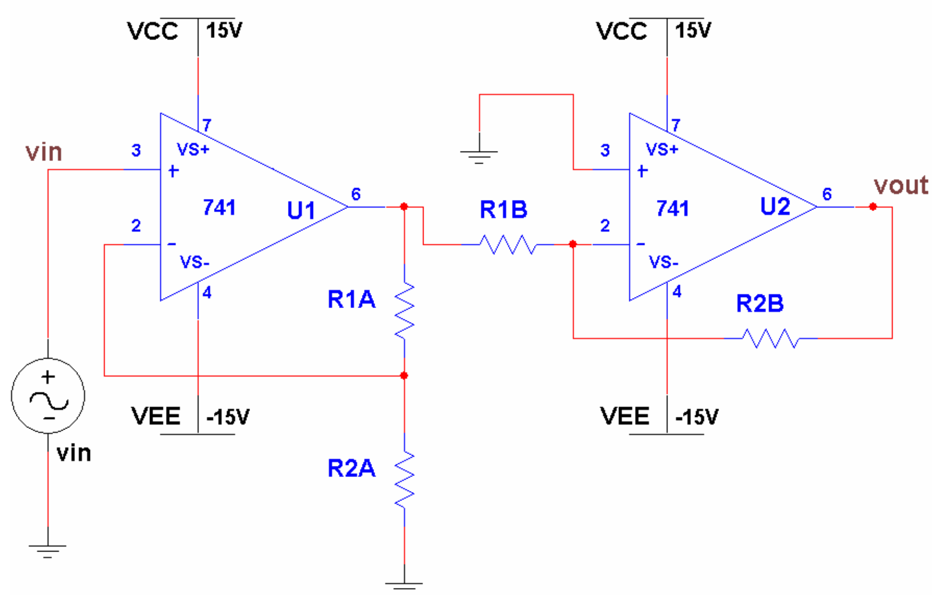
(a)

For the OPAMP circuit shown, derive an expression for the output v_{out} in terms of the input v_{in}, and the various resistances (R_{1A}, R_{2A}, R_{1B}, R_{2B}).

[Hint: First find the output of the first OPAMP. This output (say v_{out1}) of the first OPAMP is the input to the second OPAMP]

(b)

Based on the expression derived in (a), predict and sketch the waveform for v_{out} if v_{in} = 0.1V sinusoidal signal. Use R_{1A} = 1kΩ, R_{2A} = 2kΩ, R_{1B} = 2kΩ, R_{2B} = 1kΩ for the resistor values in your circuit.



(c)

Test your predictions for v_{out} in (b) with a simulation.

Question 2

(a)

Can you design a circuit that uses a *single* OPAMP to achieve the same output as the circuit in Question 1? If so, design it, and explain whether there are any advantages and/or disadvantages to the circuit that you have designed vis-à-vis the circuit in Question 1. If it is impossible to design a circuit with a single OPAMP, explain why?

(b)

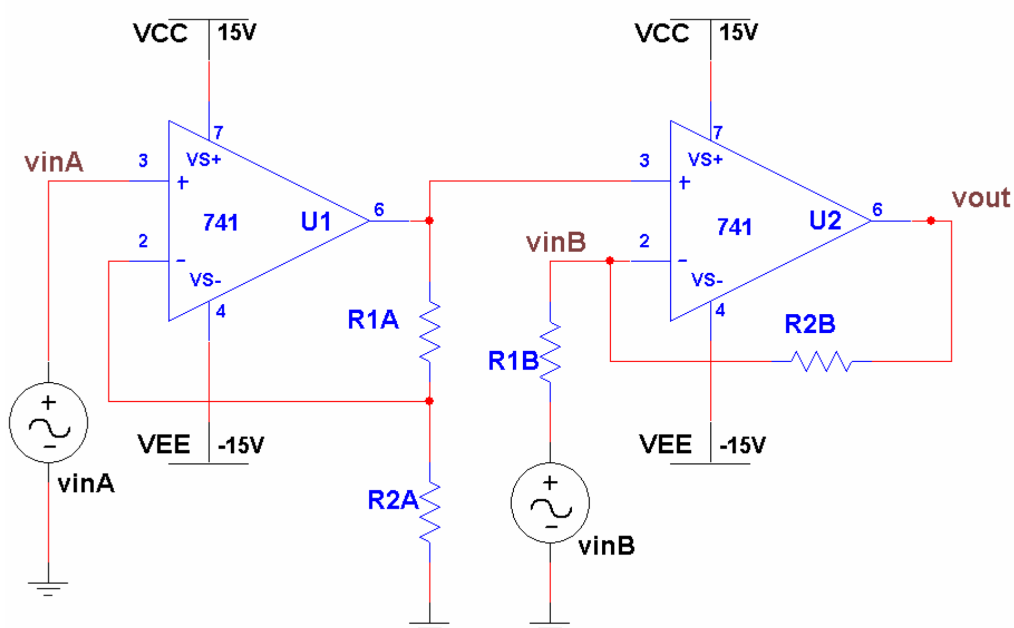
Demonstrate your results to (a) with an appropriate simulation. Assume that you are using the same values for the input voltage and resistors as in Question 1.

Question 3

(a)

For the OPAMP circuit shown, derive an expression for the output v_{out} in terms of the inputs v_{inA}, v_{inB} and the various resistances (R_{1A}, R_{2A}, R_{1B}, R_{2B}).

[Hint: First find the output of the first OPAMP. This output (say v_{out1}) of the first OPAMP is one of the inputs to the second OPAMP. To combine v_{out1} with other input v_{inB} to the second OPAMP use superposition i.e. pretend the first one is zero and find the effect of the second input. Then pretend the second is zero and find the effect of the first input.]



(b)

Based on the expression derived in (a), predict and sketch the waveform for v_{out} if v_{inA} = 0.2V, v_{inB} = 0.1V are in-phase sinusoidal signals. Use R_{1A} = 2kΩ, R_{2A} = 1kΩ, R_{1B} = 1kΩ, R_{2B} = 2kΩ for the resistor values in your circuit.

(c)

Test your predictions for v_{out} in (b) with a simulation.

Question 4

(a)

Find an expression for the current through resistor R_L. Does your expression contain R_L?

(b)

Based on your answer to (a) above explain if the circuit can be used as a constant current source that supplies a constant current through load resistor R_L.

(c)

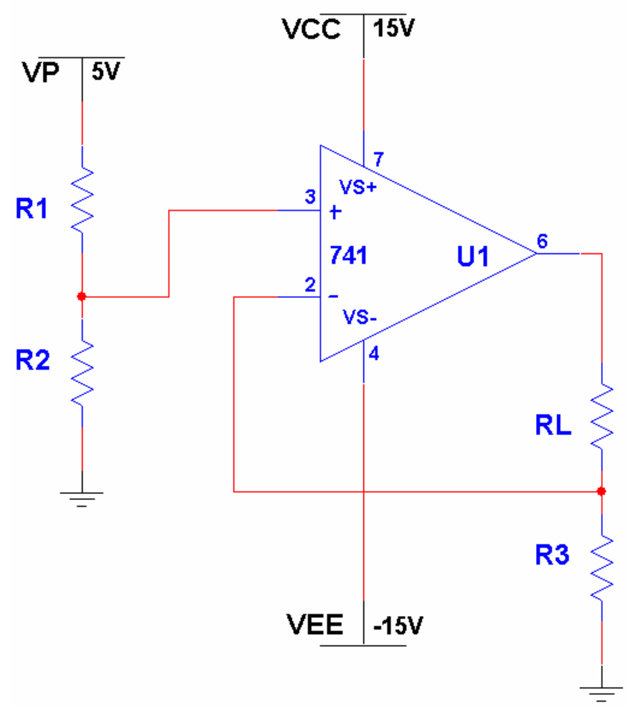
Choose appropriate values for the resistors so that a current of 2mA will flow through R_L regardless of the value of R_L. Are your values unique.

(d)

Test your choice of values in (c) using a simulation. Is there an upper and/or lower limit for R_L over which you can achieve a constant 2mA current through it? Test the limit in your simulation and explain the origin of this limit.

(e)

Based on your responses to (a) and (b) can you now modify the circuit so that you can have a *tunable* constant current source [Hint: Use a potentiometer].



Question 5

(a)

The circuit shown is a modified transistor amplifier circuit. Find the values of the resistors R_1, R_2, R_C and R_E that will satisfy the following criteria:

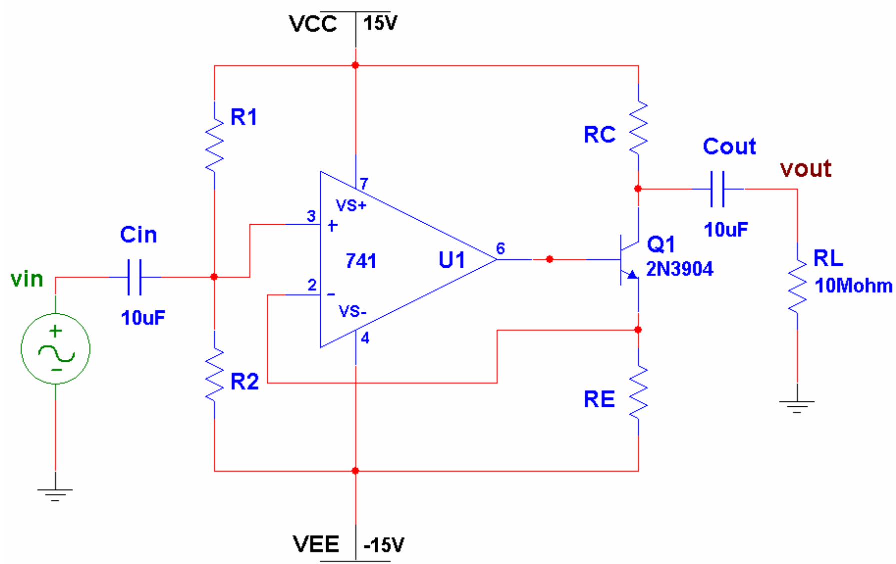
(i) A voltage gain of 30dB.

(ii) Maximum possible voltage swing at the output.

(b)

Test your design using a simulation, with a sinusoidal input voltage v_{in} = 0.1V, and measuring v_{out} to test whether your circuit meets criterion (i) above.

Also perform a DC Operating point analysis to test whether your DC voltage at the collector of the transistor meets criterion (ii) above.



(c)

Reflect on this modified transistor amplifier circuit vis-à-vis the transistor amplifier circuit that you have previously used:

(i.) When you determined the values above, can you think of any step that you did differently compared to the steps that you took to design the original transistor amplifier circuit?

(ii.) What, if any are the advantages of this circuit compared to the transistor amplifier circuit that you have used previously [Hint: Refer to (i). Did you have to make any fewer assumptions in your calculations? Also, think about the input impedance as seen by the signal source.]

(iii.) What, if any are the disadvantages of this circuit compared to the transistor amplifier circuit that you have used previously [Hint: Are there any other criteria that you did not *attempt* to meet in this circuit that you did in the previous circuit?]

Question 6

(a) Do questions **Q8** through **Q11** in **Lab04 Part 3** on the *Active Integrator*.

(b) Do questions **Q7** and **Q8** in **Lab04 Part 4** on the *Active Diode Clamp*.

Summary 03

Transistors & Transistor Circuits

Transistor – Internal Structure

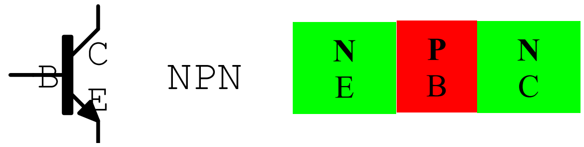
Unlike all of the devices that we have looked at so far, the transistor is an "active" device, in that it can potentially amplify a signal, rather than just respond to it.

The transistor has three terminals: Emitter (E), Base (B), Collector (C).

Transistors come in 2 flavors: N-P-N or P-N-P.

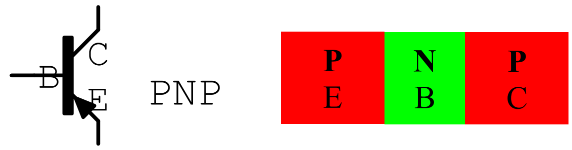
In N-P-N electrons are the primary carriers of current.

In P-N-P holes are the primary carriers of current.



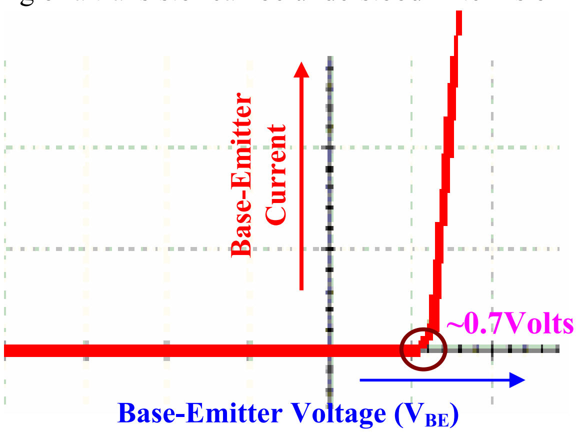
(Note: the widths of the Emitter, Base and Collector are quite unequal. Also, the Emitter is more heavily doped than the Collector.)

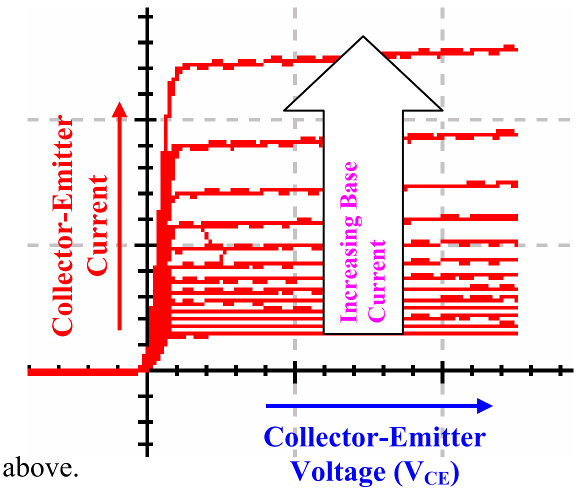
Here, we will deal only with the N-P-N transistor.



Transistor - Functioning

The working of a transistor can be understood in terms of its I-V curves shown below:





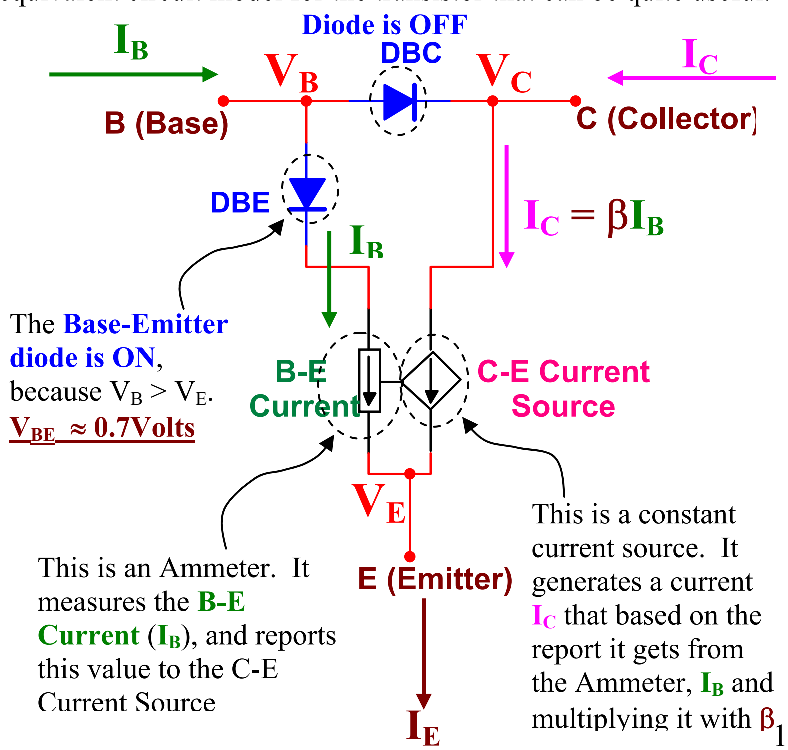
The **Base-Collector** I-V curve is similar to the Base-Emitter curve above.

Based on these I-V curves it is possible to construct an equivalent circuit model for the transistor that can be quite useful.

The two features of the I-V curves that we use are the following:

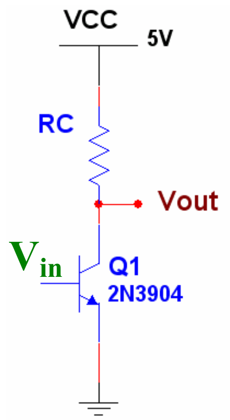
- The abrupt rise for the Base-Emitter (or Base-Collector) I-V is reminiscent of a diode. This abrupt rise occurs at a Base-Emitter (or Base-Collector) voltage of about +0.7Volts.
- The Collector-Emitter I-V curve shows an abrupt rise in Collector-Emitter Current, and then a virtually constant current. Therefore, this behavior can be characterized by a (*Constant) Current* Source.
- The value of the constant Collector-Emitter current, appears to change *linearly* with the Base Current. Therefore, this is a *Current-Controlled (Constant) Current*-Source. The constant of proportionality is the "Current Gain" of the transistor -- β.

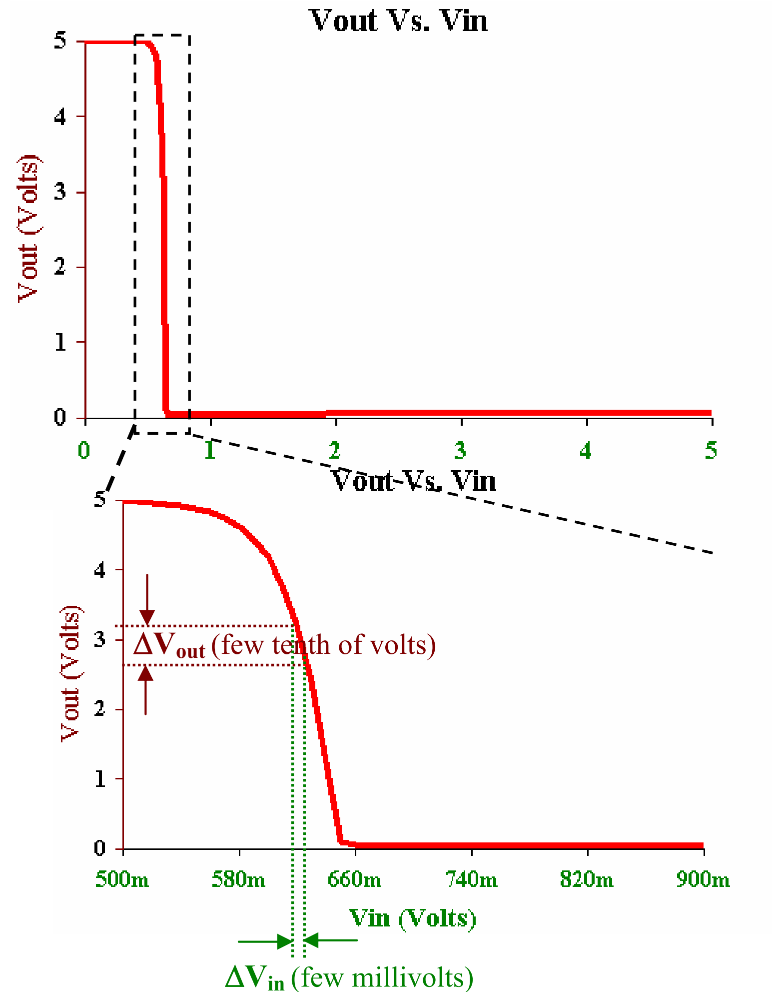
Based on these observations the equivalent circuit model shown here for a transistor emerges.



Transistor in a Circuit

When a transistor is used in a circuit as shown and a voltage, V_{in} is applied at the input the voltage V_{out} changes as shown in the adjacent graph:





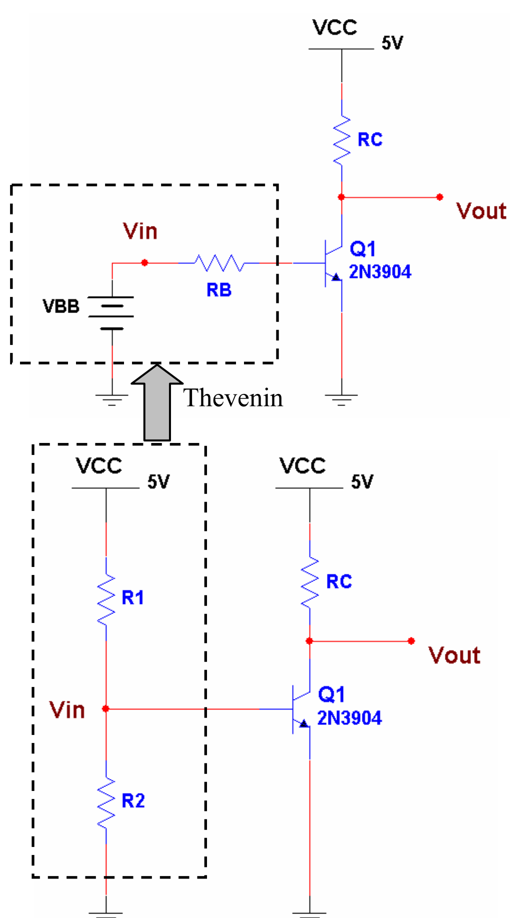
As per this graph, V_{out} changes abruptly, when V_{in} exceeds a certain value. This means the transistor can act as:

- A Variable resistor: The resistance is
  - High when $V_{in} < V_{Diode}$ (~0.7 Volts), and
  - Low, when $V_{in} > V_{Diode}$ (~0.7 Volts),
- An Inverter:
  - If V_{in} is LOW (i.e. $< V_{Diode}$), V_{out} is HIGH (i.e. close to +5V)
  - When V_{in} is HIGH (i.e. $> V_{Diode}$), V_{out} is LOW (i.e. close to 0V),
- An Amplifier: A small change in V_{in} can cause a big change in V_{out}, as shown in adjacent graph. Changes of a few millivolts in $V_{in,}$ can produce changes of a few tenths of a volt in V_{out}.

DC Biasing

For a transistor to operate as an amplifier, the small perturbation in voltage ($\mathbf{\Delta V_{in}}$, henceforth referred to in lower case as $\mathbf{v_{in}}$) must be applied around a certain value of V_{in}. For instance, as per the graph above V_{in} must be in around 0.6V for the perturbation to occur.

The process of ensuring that V_{in} is at an appropriate value so that providing a small change in it (i.e. ΔV_{in} or v_{in}) will result in a large change in V_{out} (i.e. ΔV_{out} or v_{out}), is called *DC biasing*.



DC Biasing can be provided in two ways…

1) By a combination of a DC voltage source, V_{BB} and a resistor R_B in series with it,
2) By a two resistor (R_1, R_2) potential divider connected between V_{CC} and Ground.

The relationship between 1) and 2) above is that V_{BB} and R_B are the Thevenin equivalent for the voltage divider provided by R_1 and R_2 connected between V_{CC} and Ground.

$$V_{BB} = V_{TH} = V_{CC}\, R_2/(R_1+R_2)$$
$$R_{TH} = R_1 \,||\, R_2 = R_1R_2/(R_1+R_2)$$

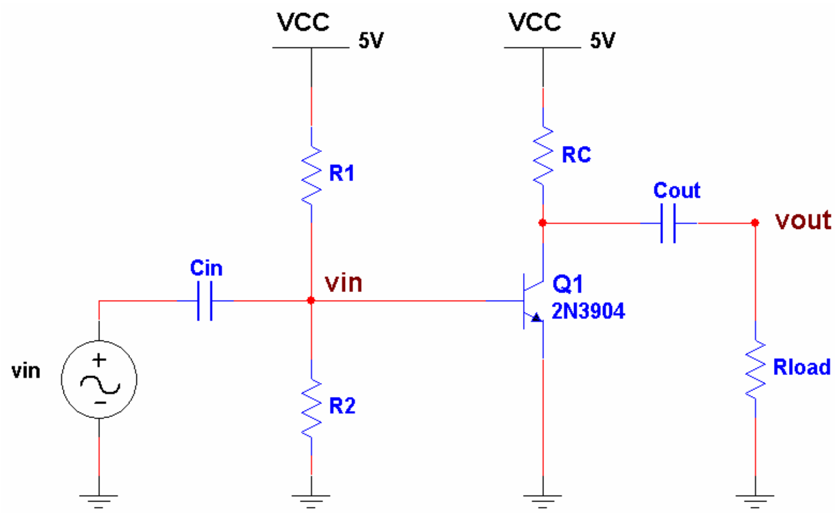
Providing the AC Signal & Measuring the AC Output

The AC signal (which is a small perturbation around the DC) is provided using an AC source.

The only way to connect an AC source (whose one end is grounded) and not affect the DC Bias that you have previously established is using an isolating capacitor, C_{in}.

The impedance of a capacitance is infinite for a DC, therefore the fact that the AC source is grounded at the other end will *not* affect the DC bias voltage of the transistor.

For the same reason, if the output is to be connected to a load resistance R_{Load} it is not connected directly, but rather through a capacitor, C_{out}.



The DC and AC Equivalent Circuit Models

To analyze the circuit above, it is convenient to replace the transistor with its equivalent circuit model.

For the <u>DC Circuit</u> (<u>Large</u> Signal) model:

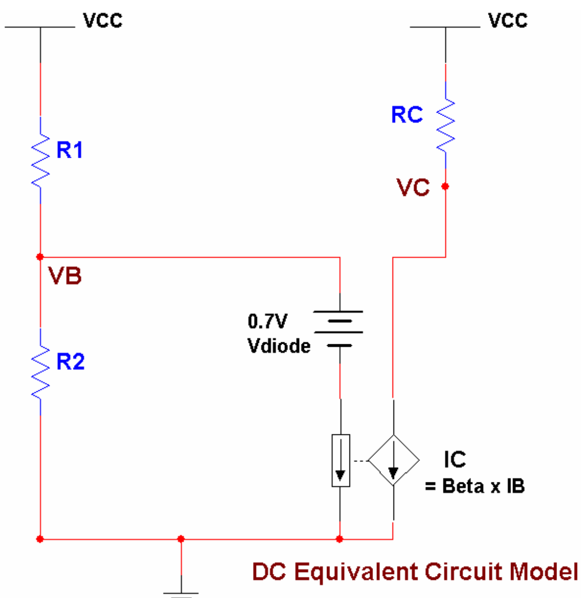
- Diode D_{BE} is forward biased i.e. it is ON (because $V_B>V_E$). It acts as a battery equal to the diode voltage ~0.7V
- Diode D_{BC} is reverse biased i.e. it is OFF (because $V_B < V_C$). It acts as an open switch or no connection at all.
- All capacitors are open switches i.e. there is no connection through them.
- AC sources are treated as ground.

When the DC model is applied, you get the values of V_B, V_C, V_E in terms of V_{CC}, V_{EE}, V_{BB} and other resistors.

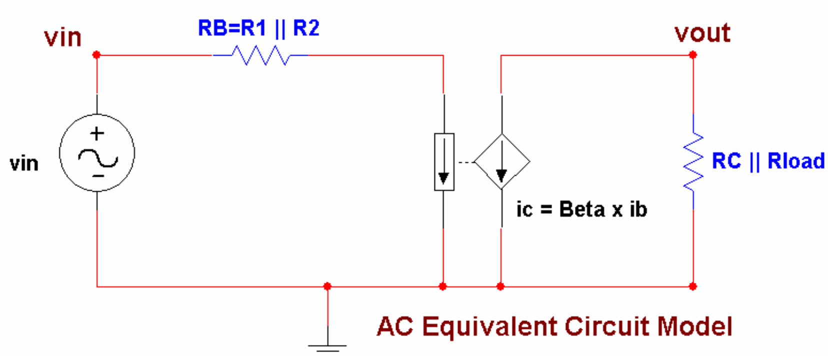
For the <u>AC Circuit</u> (<u>Small</u> Signal) model:

- Diode D_{BE} is forward biased as per the DC model above, so it acts as a wire.
- Diode D_{BC} is reverse biased as per the DC model above, so it acts as no connection at all.
- All capacitors are wires.
- DC sources are treated as ground.

When the AC model is applied, you get the values of v_{out} in terms of v_{in}, and other resistors.



DC Equivalent Circuit Model



AC Equivalent Circuit Model

Finding the AC Voltage Gain

The Small Signal equivalent model can be used to find the AC Voltage Gain, $\boxed{A_v = v_{out}/v_{in}}$ (previously called $\Delta V_{out}/\Delta V_{in}$)

Using Ohm's Law on Input side:

$i_b = v_{in}/ (R_1 \| R_2)$

Base Current

$i_b = v_{in}/(R_1 \| R_2)$

Collector Current

$i_c = -v_{out}/(R_C \| R_{Load})$

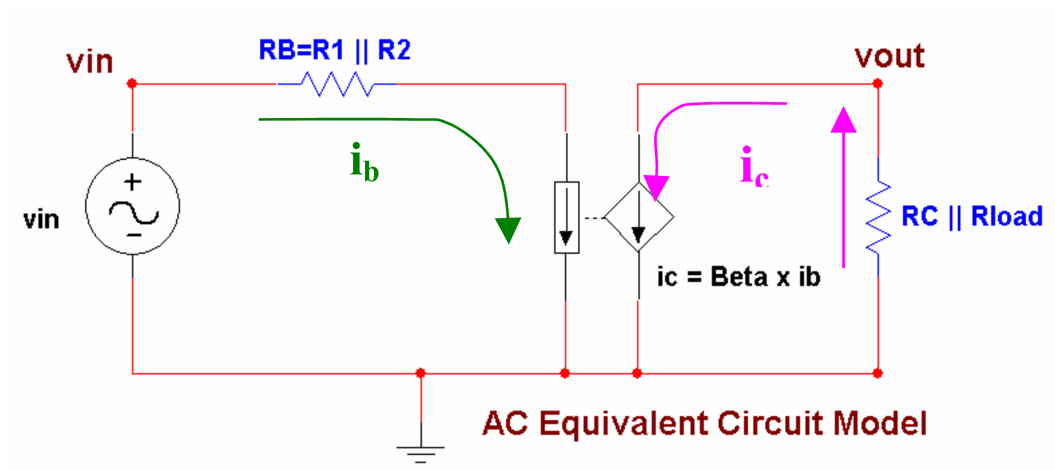
Using Ohm's Law on Output side:

$i_c = -v_{out}/ (R_C \| R_{Load})$

(Note: The negative sign reflects the direction of i_c)

Also, in the transistor:

$i_c = \beta i_b$

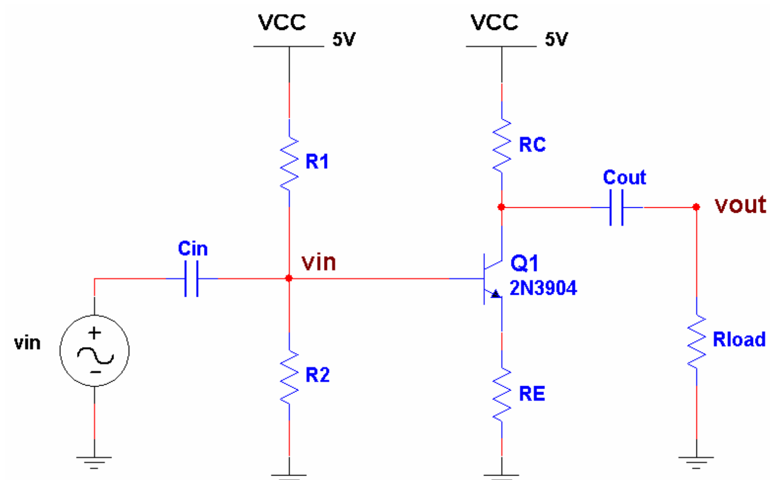


Combining the three relations above: $\Rightarrow$ $-v_{out}/ (R_C \| R_{Load}) = \beta\, v_{in}/ (R_1 \| R_2)$

$\Rightarrow$ $\boxed{A_v = v_{out}/v_{in} = \beta\, (R_C \| R_{Load}) /(R_1 \| R_2)}$

The above expression contains β, the transistor current gain. However, β is NOT a reliable parameter. It can vary from 100 to 200 with quite a bit of variation from one transistor to another. To design a transistor amplifier that is robust, the expression for AC voltage gain must NOT contain β.

The adjacent circuit accomplishes this goal. Its AC equivalent circuit is shown below.



Voltage drop across ammeter on base side of transistor is zero, so voltage at top of R_E is v_{in}

Using Ohm's Law across R_E:

$i_c + i_b = v_{in}/R_E$

But $i_b << i_c$ (because $i_b = i_c/\beta$)

So, this approximation gives:

$i_c = v_{in}/R_E$

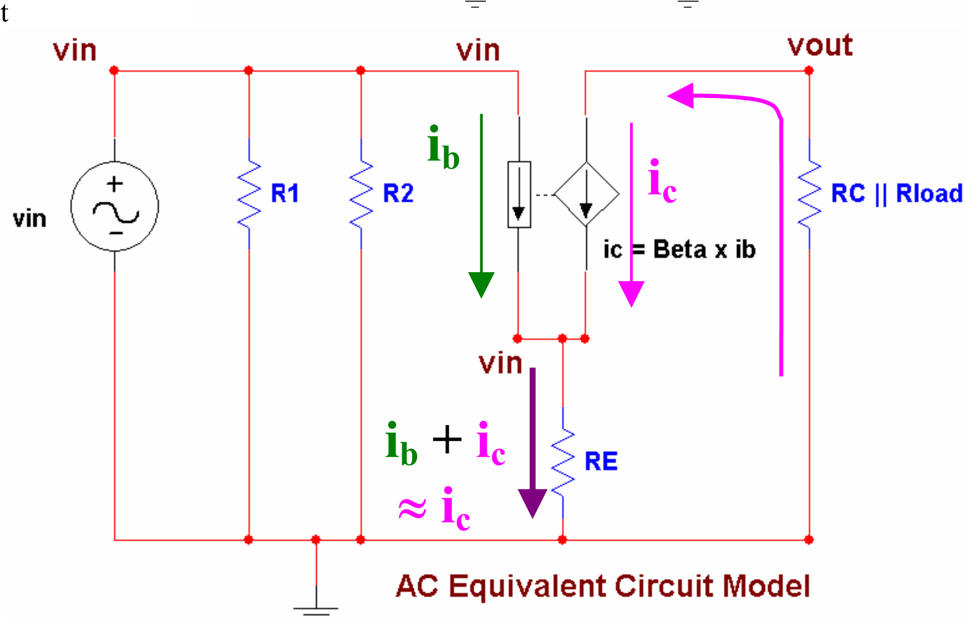
Using Ohm's Law across $R_C \| R_{Load}$

$i_c = -v_{out}/(R_C \| R_{Load})$

(Note: The negative sign reflects the direction of i_c)

Equating the two expressions for i_c above:

$\boxed{A_v = v_{out}/v_{in} = -(R_C \| R_{Load})/R_E}$



The above expression for AC Voltage Gain: $A_v = v_{out}/v_{in} = -(R_C \,||\, R_{Load})/R_E$ does not contain β.
Therefore, it is more predictable than the previous expression. Thus, the circuit above with R_E is superior to the circuit where there is no R_E (or $R_E = 0$).

Power Dissipation

Power dissipation is an important consideration in circuit design. Usually, designers try to minimize power dissipation, to prevent heating up of the circuit.
In the circuit shown below, power dissipation depends upon the currents drawn from V_{CC}

Power Dissipation: $P_{diss} = \underbrace{I_{RC}(V_{CC} - V_{EE})}_{\text{Power dissipation through } R_C\text{, transistor \& } R_E} + \underbrace{I_{R1}(V_{CC} - V_{EE})}_{\text{Power dissipation through } R_1 \text{ \& } R_2}$

Where: I_{RC} is the current through R_C and I_{R1} is the current through R_1

Designing a Transistor Amplifier

Given: DC Power supplies V_{CC}, V_{EE}.

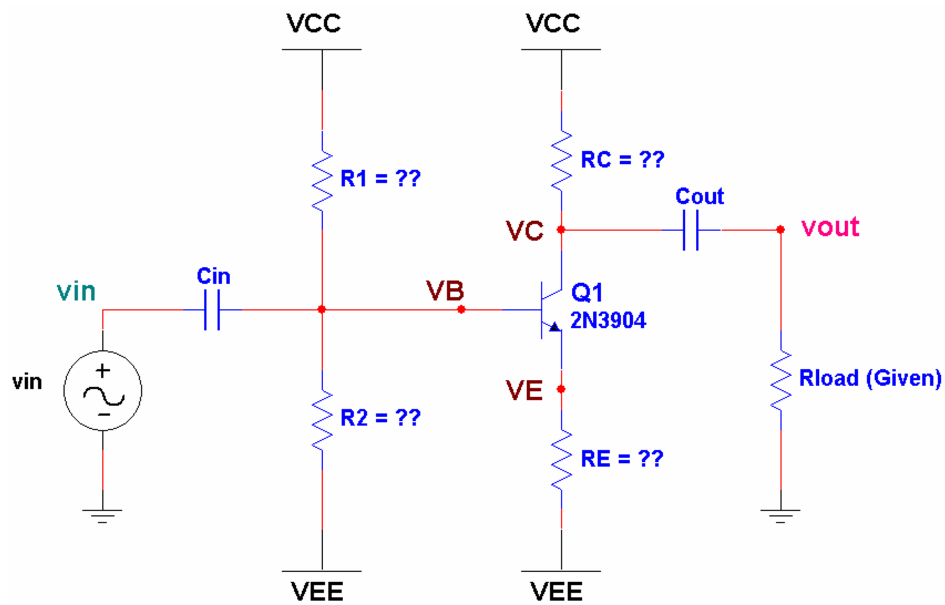
Goal: To design a transistor amplifier (i.e. find values of R_C, R_E, R_1 & R_2,) that meets the following specifications

(a) Allows for maximum voltage swing of the output signal.

(b) Provides a desired gain A_v [Note: A_v is usually specified in dB:

$A_{dB} = 20 \log (A_v) = 20 \log (v_{out}/v_{in})$

(c) Has less than certain maximum power dissipation P_{max}. OR Draws less than a certain current I_{max} from the power supplies.



You can follow the recipe described below:

Step 1: Finding R_C

(i) Calculate V_C: For maximum voltage swing [Specification (a)], V_C must be in the middle of V_{CC} and V_{EE}.
$V_C = (V_{CC} - V_{EE})/2$.

(ii) Calculate I_C: Use the for the maximum Power dissipation or Current [Specification (c)]
I_C = 80% of I_{max} [or 80% of $P_{max}/(V_{CC} - V_{EE})$]
Leave "room" for the remaining 20% of P_{diss} to occur across R_1 and R_2.

(iii) Calculate R_C: Use Ohm's Law
$R_C = (V_{CC} - V_C)/ I_C$

Step 2: Finding R_E

(i) Calculate $A_v = 10^{[20/A(dB)]}$

(ii) Calculate R_E: Use the specification for gain [Specification (b)]
$|A_v| = (R_C \,||\, R_{Load})/R_E \quad \Rightarrow R_E = (R_C \,||\, R_{Load})/ |A_v|$

Step 3: Finding R_1 & R_2

(i) Calculate V_E: Use Ohm's Law across R_E
$V_E = I_E R_E + V_{EE} \approx I_C R_E + V_{EE}$ (because $I_C \approx I_E$)

(ii) Calculate V_B: Use the fact that for the transistor to be 'ON', V_{BE} is about 0.7Volts.
$V_B = V_E + V_{BE} = V_E + 0.7$.

(iii) Calculate I_{R2}: Use fact that ~20% of P_{max} occurs across $R_1 + R_2$
I_{R2} = 20% of I_{max} [or 20% of $P_{max}/(V_{CC} - V_{EE})$]

(iv) Calculate $R_1 + R_2$: Use Ohm's Law across R_1+R_2
$R_1 + R_2 = (V_{CC} - V_{EE})/I_{R2}$

(v) Calculate R_2: Use fact that voltage division across R_1 and R_2 gives V_B
$V_B \approx V_{EE} + (V_{CC} - V_{EE}) R_2 / (R_1 + R_2) \quad \Rightarrow \quad R_2 = (V_B - V_{EE}) (R_1 + R_2) / (V_{CC} - V_{EE})$

Homework 03 [Due Tuesday, April 22]

Question 1

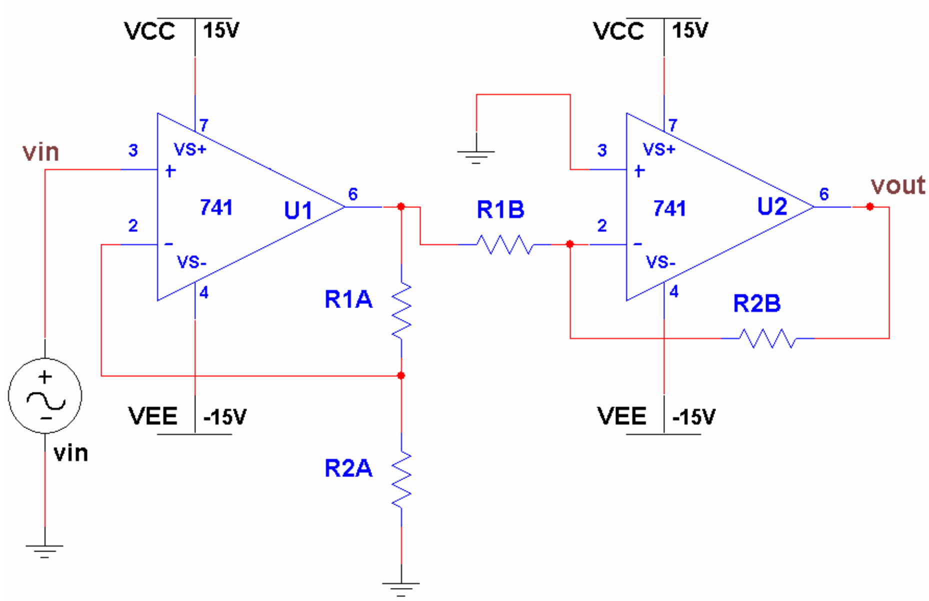
(a)

For the OPAMP circuit shown, derive an expression for the output v_{out} in terms of the input v_{in}, and the various resistances (R_{1A}, R_{2A}, R_{1B}, R_{2B}).

[Hint: First find the output of the first OPAMP. This output (say v_{out1}) of the first OPAMP is the input to the second OPAMP]

(b)

Based on the expression derived in (a), predict and sketch the waveform for v_{out} if v_{in} = 0.1V sinusoidal signal. Use R_{1A} = 1kΩ, R_{2A} = 2kΩ, R_{1B} = 2kΩ, R_{2B} = 1kΩ for the resistor values in your circuit.



(c)

Test your predictions for v_{out} in (b) with a simulation.

Question 2

(a)

Can you design a circuit that uses a *single* OPAMP to achieve the same output as the circuit in Question 1? If so, design it, and explain whether there are any advantages and/or disadvantages to the circuit that you have designed vis-à-vis the circuit in Question 1. If it is impossible to design a circuit with a single OPAMP, explain why?

(b)

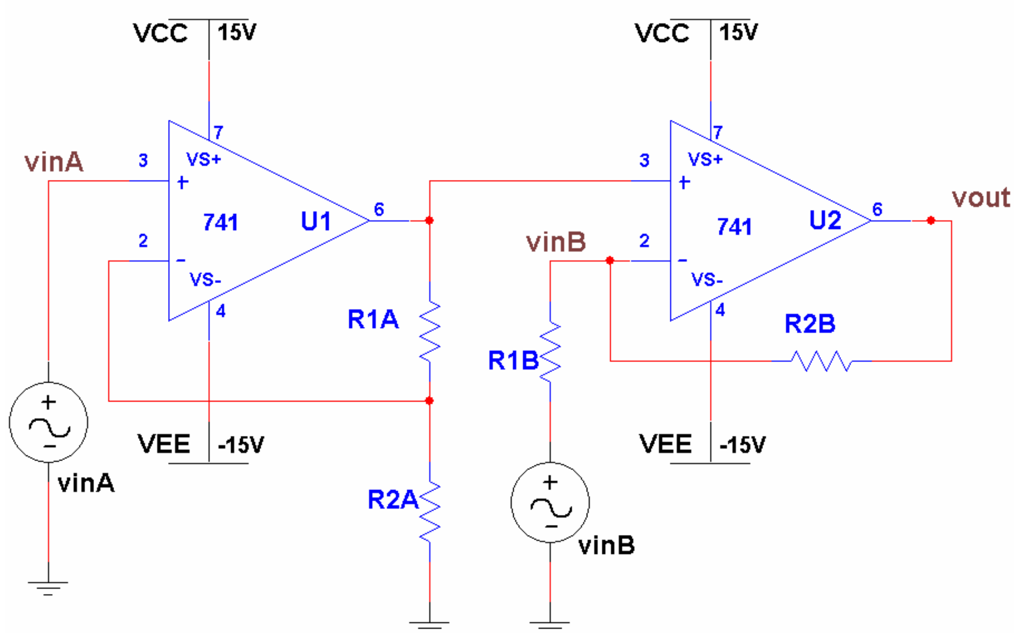
Demonstrate your results to (a) with an appropriate simulation. Assume that you are using the same values for the input voltage and resistors as in Question 1.

Question 3

(a)

For the OPAMP circuit shown, derive an expression for the output v_{out} in terms of the inputs v_{inA}, v_{inB} and the various resistances (R_{1A}, R_{2A}, R_{1B}, R_{2B}).

[Hint: First find the output of the first OPAMP. This output (say v_{out1}) of the first OPAMP is one of the inputs to the second OPAMP. To combine v_{out1} with other input v_{inB} to the second OPAMP use superposition i.e. pretend the first one is zero and find the effect of the second input. Then pretend the second is zero and find the effect of the first input.]



(b)

Based on the expression derived in (a), predict and sketch the waveform for v_{out} if v_{inA} = 0.2V, v_{inB} = 0.1V are in-phase sinusoidal signals. Use R_{1A} = 2kΩ, R_{2A} = 1kΩ, R_{1B} = 1kΩ, R_{2B} = 2kΩ for the resistor values in your circuit.

(c)

Test your predictions for v_{out} in (b) with a simulation.

Question 4

(a)

Find an expression for the current through resistor R_L. Does your expression contain R_L?

(b)

Based on your answer to (a) above explain if the circuit can be used as a constant current source that supplies a constant current through load resistor R_L.

(c)

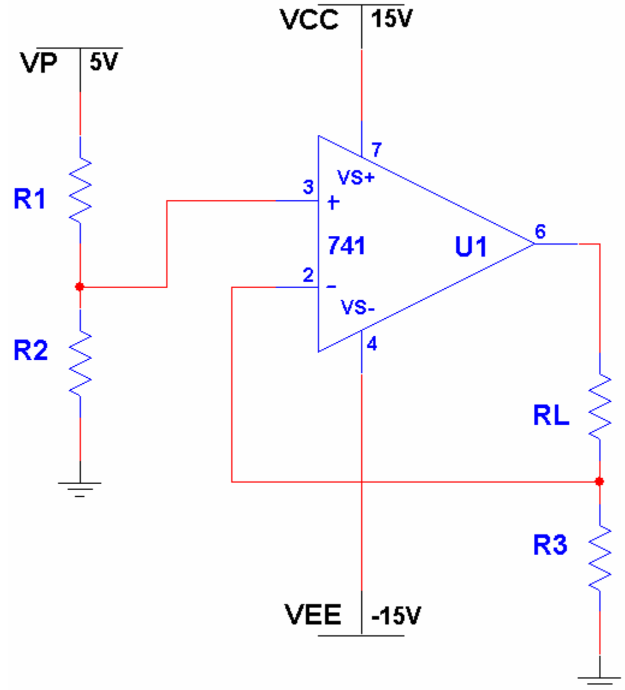
Choose appropriate values for the resistors so that a current of 2mA will flow through R_L regardless of the value of R_L. Are your values unique.

(d)

Test your choice of values in (c) using a simulation. Is there an upper and/or lower limit for R_L over which you can achieve a constant 2mA current through it? Test the limit in your simulation and explain the origin of this limit.

(e)

Based on your responses to (a) and (b) can you now modify the circuit so that you can have a *tunable* constant current source [Hint: Use a potentiometer].



Question 5

(a)

The circuit shown is a modified transistor amplifier circuit. Find the values of the resistors R_1, R_2, R_C and R_E that will satisfy the following criteria:

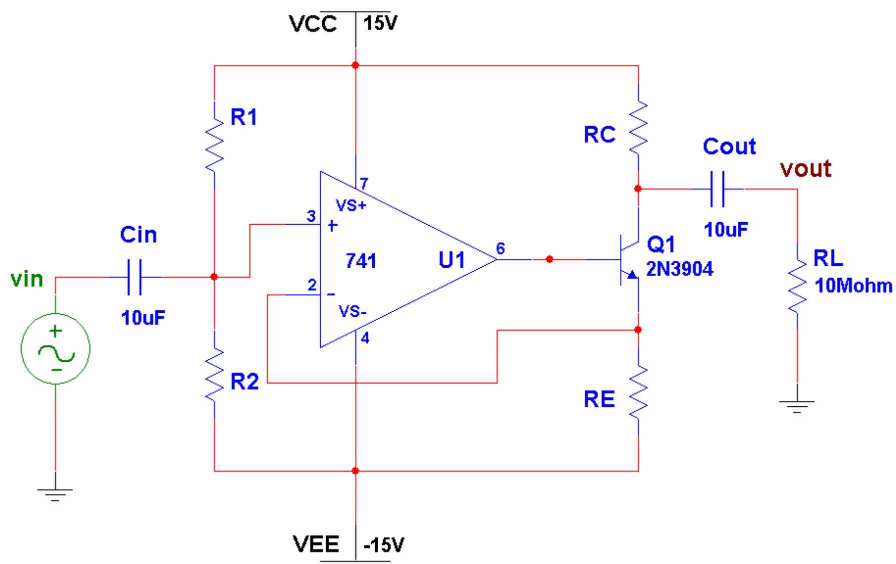
(i) A voltage gain of 30dB.

(ii) Maximum possible voltage swing at the output.

(b)

Test your design using a simulation, with a sinusoidal input voltage v_{in} = 0.1V, and measuring v_{out} to test whether your circuit meets criterion (i) above.

Also perform a DC Operating point analysis to test whether your DC voltage at the collector of the transistor meets criterion (ii) above.



(c)

Reflect on this modified transistor amplifier circuit vis-à-vis the transistor amplifier circuit that you have previously used:

(i.) When you determined the values above, can you think of any step that you did differently compared to the steps that you took to design the original transistor amplifier circuit?

(ii.) What, if any are the advantages of this circuit compared to the transistor amplifier circuit that you have used previously [Hint: Refer to (i). Did you have to make any fewer assumptions in your calculations? Also, think about the input impedance as seen by the signal source.]

(iii.) What, if any are the disadvantages of this circuit compared to the transistor amplifier circuit that you have used previously [Hint: Are there any other criteria that you did not *attempt* to meet in this circuit that you did in the previous circuit?]

Question 6

(a) Do questions **Q8** through **Q11** in **Lab04 Part 3** on the *Active Integrator*.

(b) Do questions **Q7** and **Q8** in **Lab04 Part 4** on the *Active Diode Clamp*.

Mid-Term Exam [Due Tuesday, April 01]

NOTE: Please upload all *simulation* files onto K-State Online. The file name for each file must indicated your last name, exam and question number as per the following example: "Rebello _Exam01_Q01d." You may turn in your written solutions via file upload or handwritten solutions as you did for Homework 01.

Maximum Points on Mid-Term Exam = 20 Points per Question x 8 Questions = 160 Points.

Question 1

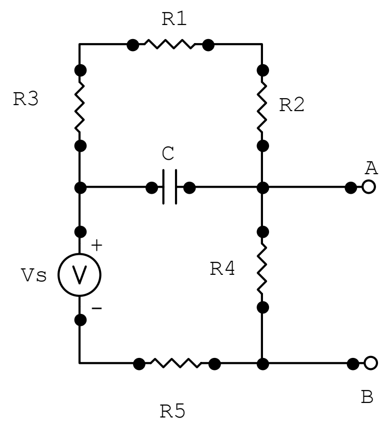
Find the Thevenin equivalent circuit for the following network between terminals A and B

(a) At very low frequencies.

(b) At very high frequencies.

(c) Repeat (a) and (b) if the capacitor is replaced with an inductor.

(d) Verify your predictions with a simulation.



Question 2

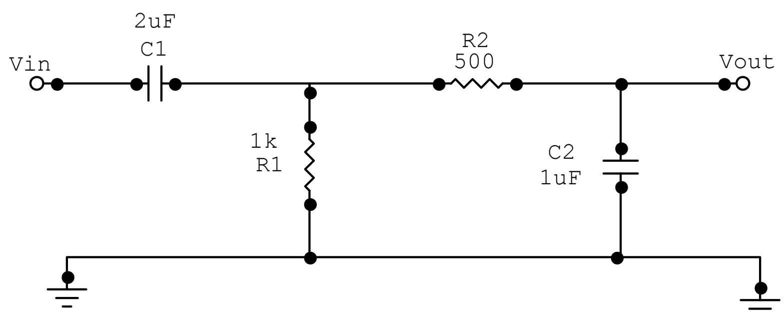
For the circuit shown…

(a) What is kind of filter is it?

(b) Determine its cut of frequencies.

(c) Sketch the Bode plot of its frequency response.

(d) Verify your predictions with a simulation.



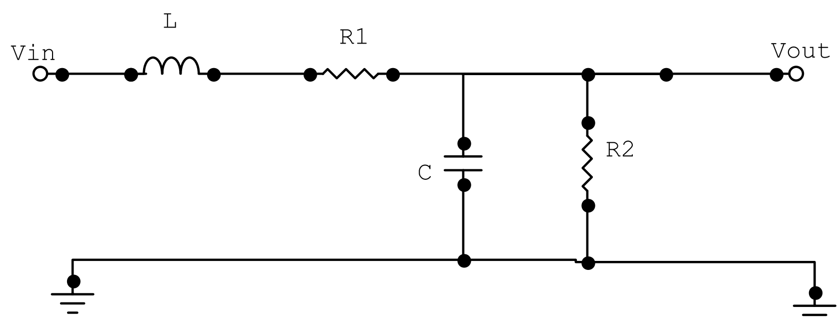
Question 3

(a) Design a circuit that has the same frequency response as the circuit shown in Question 3, but uses inductors instead of capacitors.

(b) Verify your design with a simulation.

Question 4

Calculate the magnitude and phase of the gain (v_{out}/v_{in}) as a function of frequency and the values of R_1, R_2, C and L



Question 5

Design a full wave rectifier circuit that can deliver 1mA to a 10kΩ load from using a 60Hz, 110V line supply with a 0.1% ripple factor. Find out….

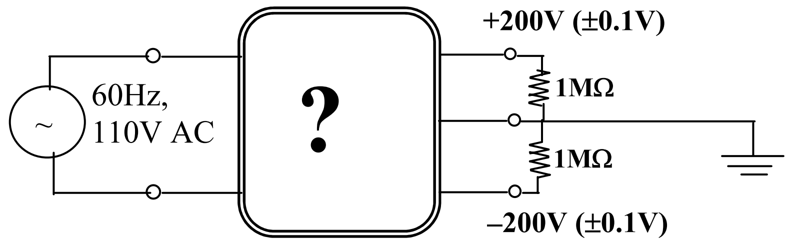
(a) The turns ratio of the transformer that you would need?

(b) The value of the capacitor(s) used?

(c) Simulate the circuit (You can use a voltage controlled voltage source as your transformer, because the other transformers may not let you change their turns-ratio). Verify your design to check whether you are indeed getting the right voltage and ripple factor that you calculated. Explain the discrepancies, if any between your design and the simulation.

Question 6

The figure shows a "black box" for a split power supply that runs off a 60 Hz, 110VAC line, and has two output terminals, at +200V and the other at –200V, each with a ripple factor ≈±0.1V when supplying a 1MΩ load.



(a) What is are the internal components of the "black box"? Draw a schematic

(b) Determine the values of each component that would meet the specifications. (Hint: You may need more than one transformer, capacitor, and diode)

(c) Simulate the circuit based on the values you determined in (b) and verify whether it meets the specifications.

(d) Explain any discrepancies between the simulation and your predictions.

Question 7

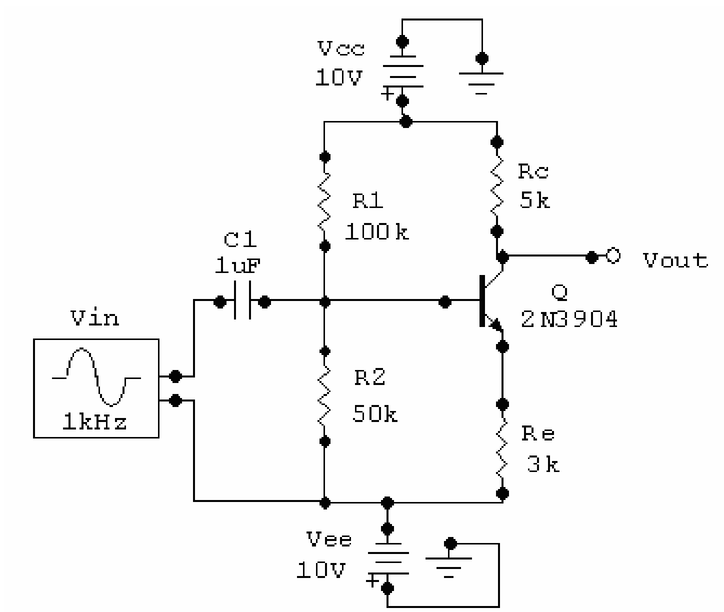
For the circuit shown…

(a) Find the DC operating point voltages and current for the transistor.

(b) Sketch the output waveform for the following circuit if v_{in} has an amplitude of 1mV.

(c) Verify your prediction using a simulation.

(d) What is the role of C_1 in the circuit? What will happen if you remove it? Verify your prediction using the simulations.



Question 8

Design a transistor amplifier that meets the following specifications:

(i) operates at a quiescent current less than 250µA,
(ii) uses a single +15V power supply (and of course, ground)
(iv) has at least a 30dB voltage gain when loaded with a 20kΩ load coupled through a 1µF capacitor,
(vi) allows for the maximum possible voltage swing, within the limits of the power supply.

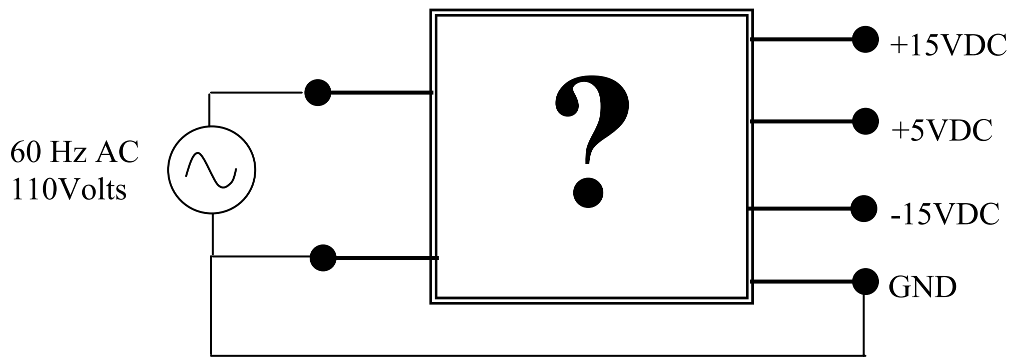
For the circuit that you have designed…

(a) What is the DC operating point of the transistor?
(b) What is the output waveform for a sinusoidal input of ±5mV?
(c) Simulate the circuit and verify whether it meets the specifications above. Attach a print out of the circuit and its output waveform.

FINAL EXAM

Question 1:

The black box shown is the power supply in our lab. Design the internal electrical circuitry of the power supply shown such that it produces the DC output voltages shown.

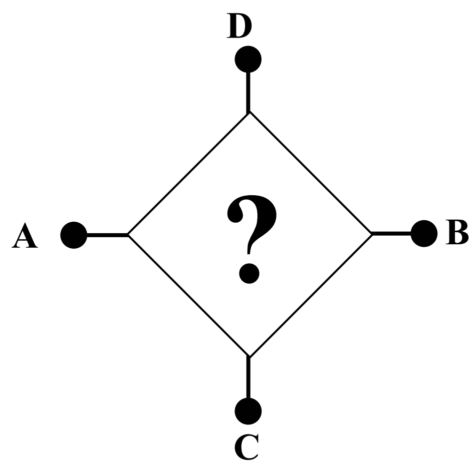


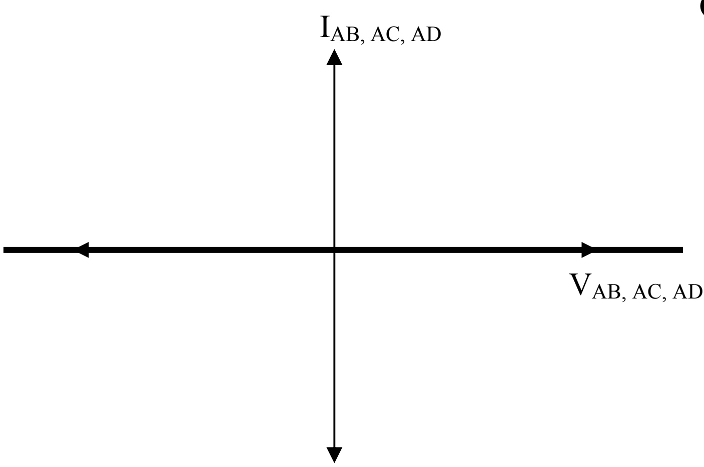
Question 2:

A four-terminal device is shown to have following set of I-V curves:

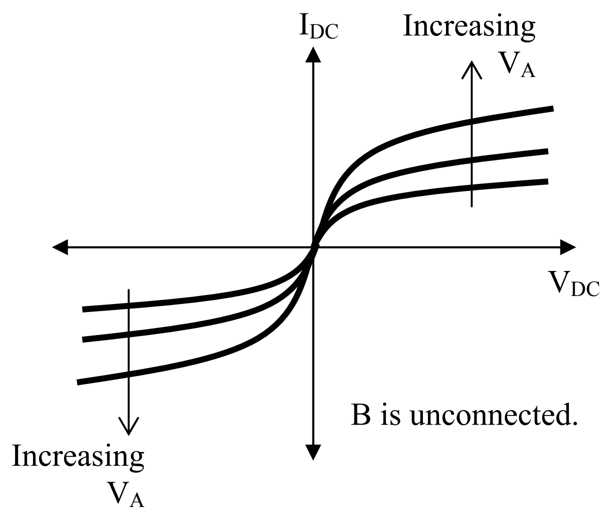
Based on the information shown what can you tell about the device?

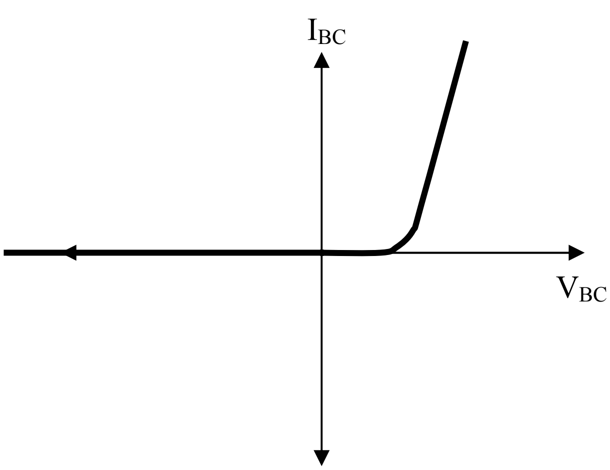
Can you construct its equivalent circuit?



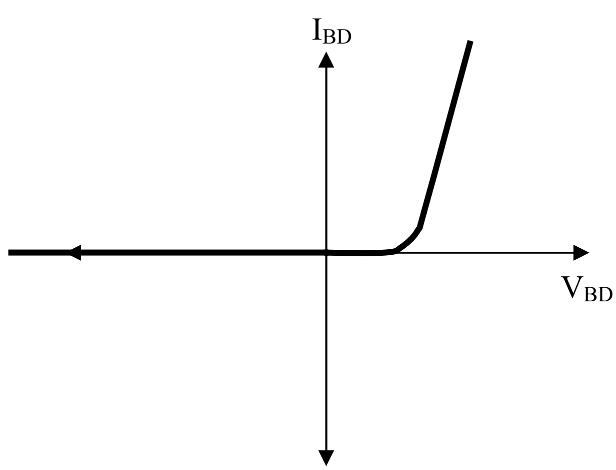


No change with voltage at the other terminal.





No change with voltage at A or D.



No change with voltage at A or C.

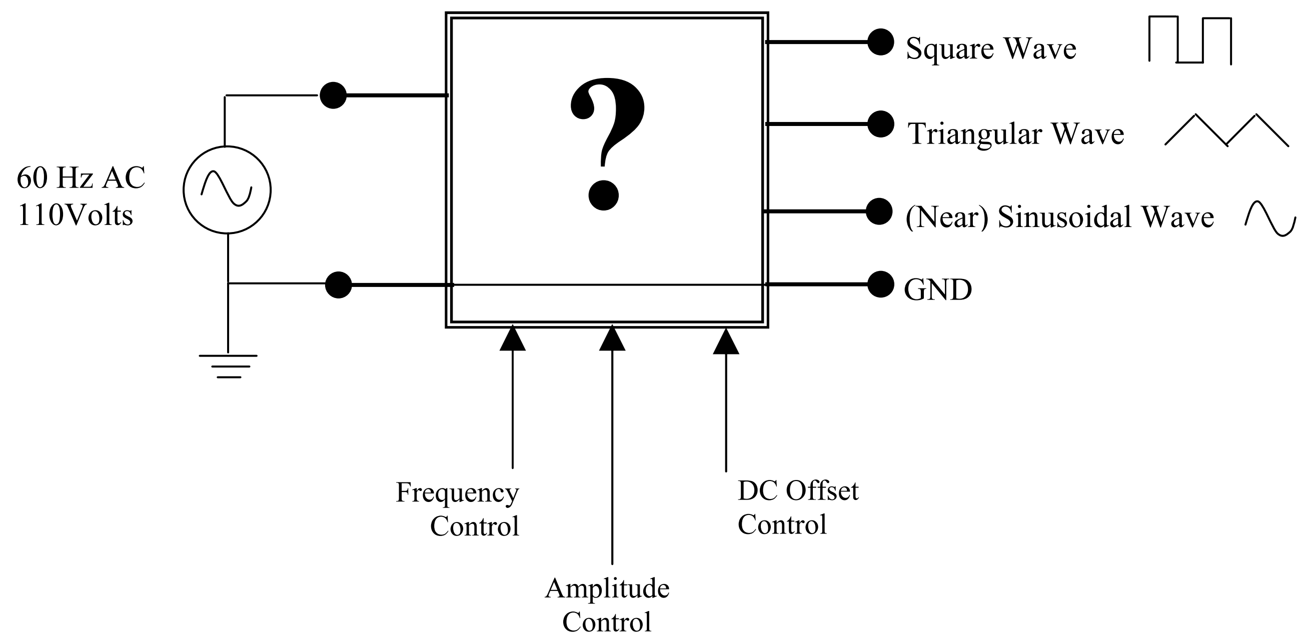
Question 3:

Design a function generator similar to one that you used in the lab in that it uses a 60Hz, 110V AC line power to produce a square wave, triangular wave or a (approximately) sinusoidal wave that allows for a…

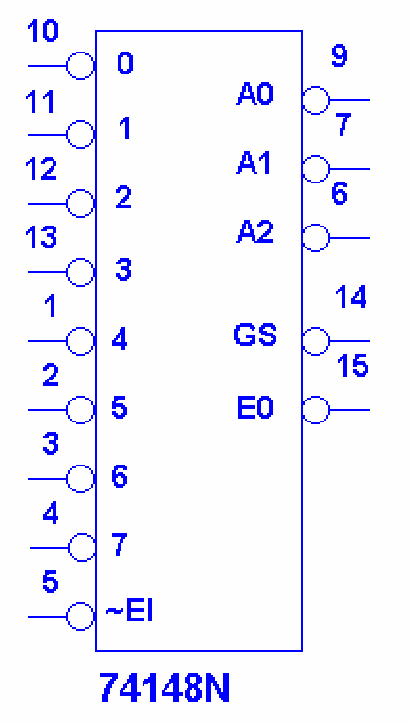
(a) Variable frequency.

(b) Variable amplitude (0 to 15V).

(c) Variable DC Offset (0 to 5V).



Question 4:



The figure shows a **74148N** chip which is an 8-input priority encoder. The chip has 8 inputs (0 through 7). Depending upon which of these inputs is active, the corresponding 3-bit binary number is displayed a the output ($A_2A_1A_0$). If more than one of the inputs is active, then the binary output corresponds to the highest input, hence the name priority encoder.

Additionally the chip has the following…

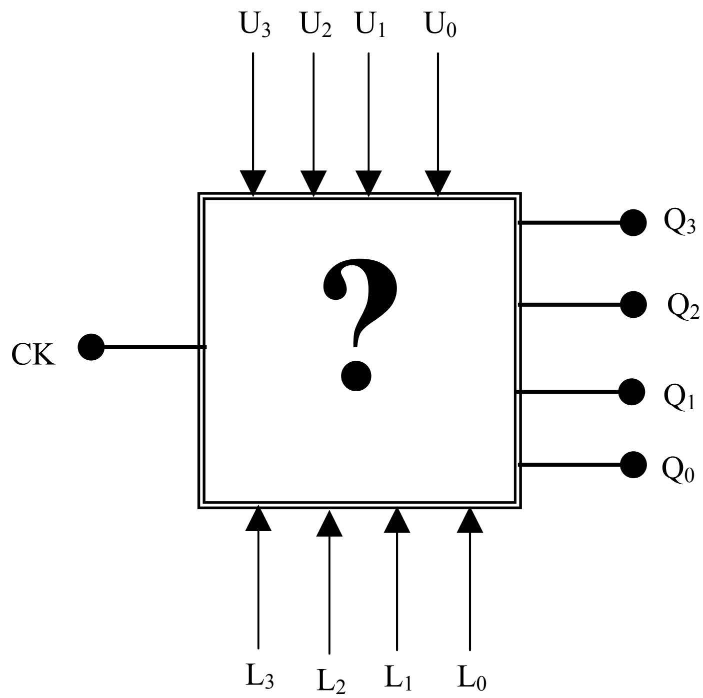
- Enable Input ~EI: The chip works only when this is active.
- Enable output EO: This is active *only* when the chip is enabled AND *all* the inputs are inactive.
- Output GS: This is active *only* when the chip is enabled and *at least one* of the inputs is active.

a) Describe the internal circuitry of the chip i.e. explain how one of the outputs (say corresponding to A_1) is calculated from the inputs and the enable input.

b) Suppose you had 16 input lines, can you think of a way in which to use this chip (perhaps more than one of these) to create a 16 to 4 priority encoder?

Question 5:

Design a counter that counts sequentially from a 4-bit binary number $L_3L_2L_1L_0$ up to a different 4-bit binary number $U_3U_2U_1U_0$. Assume you have a clock input available for use.



SURVEY REPORT

Summary

Survey Name:
PHYS636: PMI Mid-Term Survey

Offering Name:
PHYS636: PMI Mid-Term Survey

A total of **6** people participated in this survey.
75% of the people who received the survey participated.
0 of the people who received the survey opted out.

Number of people who left the survey per page number:

- Opening Page: **0**
- Page 1: **0**
- Page 2: **0**
- Page 3: **0**
- Page 4: **0**
- Page 5: **0**
- Page 6: **0**
- Page 7: **6**

Page 1

Question 1

Please rate each of the attributes for the WORKSHEETS (LAB HANDOUTS) that you use in class:

1.1 Clarity of the instructions for the simulations

Very Low	0%
Low	0%
Medium	0%
High	50%
Very High	50%
N/R	0%

1.2 Clarity of the instructions for the experiment

Very Low	0%
Low	0%
Medium	0%
High	50%
Very High	50%
N/R	0%

1.3 Clarity of the questions

Very Low	0%
Low	16.67%
Medium	0%
High	66.67%
Very High	16.67%
N/R	0%

1.4 Effectiveness in helping you to understand the concepts.

Very Low	0%
Low	0%
Medium	33.33%
High	16.67%
Very High	50%
N/R	0%

1.5 Effectiveness in helping you do the problems on the homework and exam.

Very Low	0%
Low	16.67%
Medium	16.67%
High	50%
Very High	16.67%
N/R	0%

Question 2

Do you have any other comments about the WORKSHEETS (LAB HANDOUTS)?

- They are very detailed, which is good. If something is not clear, the instructor is very good at answering our questions.
- The worksheets are usually very clear.
- Sometimes they seem to be a bit lengthy, but I do understand that it is a four hour lab and one can get quite a bit done in such a large block of time.

Question 3

If you were to design these WORKSHEETS (LAB HANDOUTS), what would you do differently?

- I would maybe not go into quite as much detail on less important aspects, or aspects of the experiment that don't need to be emphasized as much as others, for the purpose of time constraints.
- Not spend so long on the equivalent circuit for the transistor. Spend more time understanding a current controlled current source.
- Maybe have them follow along with supplimentary materials, i.e. a specific text. I know that is very difficult to do because they are in preliminary stages, and one would almost have to write the text or find one all encompassing text and go from it, and that doesn't seem to exist since we have several to reference.

Page 2

Question 4

Please rate each attribute for the SIMULATIONS that you use in class:

4.1 User-friendliness of operation

Very Low	0%
Low	0%
Medium	0%
High	50%
Very High	50%
N/R	0%

4.2 Clarity of instructions

Very Low	0%
Low	0%
Medium	0%
High	66.67%
Very High	33.33%
N/R	0%

4.3 Effectiveness in helping you to understand the concepts.

Very Low	0%
Low	0%
Medium	16.67%
High	16.67%
Very High	66.67%
N/R	0%

4.4 Effectiveness in helping you do the problems on the homework and exam.

Very Low	0%
Low	0%
Medium	33.33%
High	33.33%
Very High	33.33%
N/R	0%

Question 5

Do you have any other comments about the SIMULATIONS?

- I like the program we are using for simulations. It is very easy to use and gives useful results.
- They usually are very helpful.
- I like the simulations a lot, they really seem to work well.

Question 6

If you were to design these SIMULATIONS, what would you do differently?

- I think the simulations are designed very well.
- I can't really think of anything I'd do differently.
- Not sure, they are pretty strong as they are.

Page 3

Question 7

Please rate each attribute for the EXPERIMENTS (other than the Simulations) that you do in class:

7.1 User-friendliness of operation

Very Low	0%
Low	0%
Medium	33.33%
High	33.33%
Very High	33.33%
N/R	0%

7.2 Clarity of instructions

Very Low	0%
Low	0%
Medium	16.67%
High	33.33%
Very High	50%
N/R	0%

7.3 Effectiveness in helping you to understand the concepts.

Very Low	0%
Low	16.67%
Medium	16.67%
High	50%
Very High	16.67%
N/R	0%

7.4 Effectiveness in helping you do the problems on the homework and exam.

Very Low	0%
Low	16.67%
Medium	16.67%
High	50%
Very High	16.67%
N/R	0%

Question 8

Do you have any other comments about the EXPERIMENTS (Other than Simulations)?

- The experiments are very useful in helping us to understand what we have done in the simulations.
- Sometimes the pattern of predicting, simulating, and experimenting becomes really repetative.
- They do match well with the simulations.

Question 9

If you were to design these EXPERIMENTS (Other than Simulations), what would you do differently?

- I would maybe only have us build the final circuit. In other words, sometimes we were asked to build a circuit in "steps." We would build a smaller circuit and then build on that. Again for time constrain purposes, I think building the final circuit would suffice.
- I don't think we need to simulate AND experiment with every ciruit design. Sometimes just doing one or the other would get the point across.
- Either lighten the work as far as quantity or maybe a little less thought provoking and more cook booky, I don't know it's hard to say, they may be excellent as they stand.

Page 4

Question 10

Please rate the Overall Effectiveness of each of these components of the course:

10.1 Worksheets (Lab Handouts)

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	16.67%
Mostly Effective	83.33%
Completely Effective	0%
N/R	0%

10.2 Simulations

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	0%
Mostly Effective	33.33%
Completely Effective	66.67%
N/R	0%

10.3 Experiments (other than Simulations)

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	0%
Mostly Effective	66.67%
Completely Effective	33.33%
N/R	0%

10.4 Worksheet Questions (other than Simulations or Experiments)

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	0%
Mostly Effective	66.67%
Completely Effective	33.33%
N/R	0%

10.5 Summary Handouts

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	16.67%
Mostly Effective	50%
Completely Effective	33.33%
N/R	0%

10.6 Homework Questions

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	33.33%
Mostly Effective	50%
Completely Effective	16.67%
N/R	0%

Question 11

Please rate the appropriateness of the weight given to each of the following components in class

11.1 Simulations

Too Light	0%
Light	0%
Just Right	66.67%
Heavy	33.33%
Too Heavy	0%
N/R	0%

11.2 Experiments (other than Simulations)

Too Light	0%
Light	16.67%
Just Right	66.67%
Heavy	16.67%
Too Heavy	0%
N/R	0%

11.3 Worksheet Questions (other than Simulations or Experiments)

Too Light	0%
Light	16.67%
Just Right	33.33%
Heavy	33.33%
Too Heavy	16.67%
N/R	0%

Question 12

Please explain what you feel should be an appropriate balance between a) Simulations b)

Experiments c) "Minds-on" Questions that need thinking.

- I think the most weight should be placed on the questions that are asked. But these questions are going to be based on what we see in the simulations and experiments, so these should have sufficient weight also. Basically, the questions are what get us thinking so they should be heavily weighted, but experiments should probably be the next most heavily weighted, followed by simulations.
- There seem to be a lot of 'thinking' questions before we start tinkering with the simulation or the experiment. A few would be good, but I spend a lot of time 'thinking' my way down blind alleys.
- I think most of the focus should be on simulations and questions. While I know doing experiments is important, they never seem to contribute much to my understanding because by the time we get there we have usually already figured out what's going on.
- This is hard to tell, as the world of physics instruction is trying to lead away from the cook booky labs and more towards the discovery oriented lab. One dangerous aspect of the discovery oriented lab is that one should take care to not have the students "reinvent the wheel" so to speak. This can take away from further true discovery that has not taken place by anyone. The question of appropriate balance is a very difficult one to tackle.
- The experiments should probably be weighted as much as the simulations. If the points can be made in the experiments there probably doesn't need to be as many questions.

Page 5

Question 13

The overall pedagogy for this course may be quite different from any other course that you may have had in the past. The questions on this page ask you for feedback about this different pedagogy

Describe whether or not you feel this type of pedagogy (no formal lecture, "guided discovery") suits your learning style?

- I feel this teaching style suits my learning style in some ways and not in others. I am a very visual learner and therefore like to see what I am doing and be able to vary the experiments and see the results. I also like to figure things out for myself as opposed to someone just telling me the answer because I feel I remember things better this way. But, on the other hand, I also like to have a very structured class with very systematic daily procedures. Otherwise, sometimes I loose track of what is important in the material.
- I think that it does, but it takes a while to get used to.
- Guided discovery is a good thing but i think the formal lecture and guided discovery could be put together to make a fine balance.
- I really like the the guided discovery style.
- This set-up is very cool in it's different nature and seems to be okay with me, but sometimes I feel the need of a formal lecture, and that's probably due to the way I have been learning for my entire life, so, while it feels different, it isn't bad.
- Yes and No. The guided discovery is a great way to learn and I have learned several things that I probably wouldn't have figured out otherwise. However, I have found that sometimes down the road I figured out that I didn't understand something as well as I thought I did. Or I might have had a slightly wrong impression of something. That is where a small amount of formal lecture maybe even after the lab would re-enforce or correct the the ideas.

Question 14

Please rate the effectiveness of each of the following aspects of the PEDAGOGY of this course

14.1 Working in a pair with your partner.

Completely Ineffective	0%
Mostly Ineffective	16.67%
Neutral	33.33%
Mostly Effective	0%
Completely Effective	50%
N/R	0%

14.2 Working at your own pace.

Completely Ineffective	16.67%
Mostly Ineffective	0%
Neutral	0%
Mostly Effective	33.33%
Completely Effective	50%
N/R	0%

14.3 Making predictions.

Completely Ineffective	0%
Mostly Ineffective	16.67%
Neutral	16.67%
Mostly Effective	33.33%
Completely Effective	33.33%
N/R	0%

14.4 Testing predictions.

Completely Ineffective	0%
Mostly Ineffective	16.67%
Neutral	0%
Mostly Effective	16.67%
Completely Effective	66.67%
N/R	0%

14.5 Figuring things out for yourself rather than being told how things work

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	33.33%
Mostly Effective	33.33%
Completely Effective	33.33%
N/R	0%

14.6 Lack of a formal lecture.

Completely Ineffective	0%
Mostly Ineffective	50%
Neutral	33.33%
Mostly Effective	0%
Completely Effective	16.67%

N/R | 0%

Question 15

What aspects of the overall course PEDAGOGY would you like to change?

- I think it works very well for the most part. Perhaps a small change would be for the instructor to give a very short lecture at the beginning telling us the basic idea of what we will be doing and what we are expected to get out of each experiment.
- Answering questions with questions. Sometimes a simple answer could save hours without interfering with 'guided discovery'. (e.g. are we looking at the behaviour of the device, or an anomaly?)
- I don't think there is anything I would like to change.
- My greatest problem is the time and the credit reflection. I would like to do four two hour periods a week versus the two four hour periods a week. I personally learn much better in short, frequent bursts instead of long bursts, although lately I have had to do the long periods, because of my personal workload. As far as the credit reflection goes, it's hard for me to spend a lot of outside time on an eight hour course that is only worth five hours. A person is supposed to allot five hours a week to every hour spent in class and with work and to other difficult physics courses this is quite overwhelming.
- Each day should have an agenda and that needs to be finished each day. Obviously that would have to change some of the "learning at your own pace" and the instruction format to speed things up.

Question 16

What aspects of the overall course PEDAGOGY would you like to retain?

- I like forming our own hypothesis and predictions and then testing them. This is very effective and helps me to retain the material.
- everything else
- I like the way the class is taught. Sometimes it takes longer to get through some of the material, but I feel like I understand it better.
- Except for the time periods I like the over all make up of the course.
- I like the large amounts of lab time, and the working on labs at your own pace.

Page 6

Question 17

List the top three things that you would like to see CHANGED about this course in the coming weeks

- 1. Maybe not as much detail in the experiments so we can move a little faster and cover more material. 2. Maybe give a short overview of what is the most important thing that we should be getting out of each experiment. 3. I honestly can't think of a third thing that should be changed!
- answers to (simple) questions
- A little bit of lecture as you had begun doing in the initial part of the course.
- More information on how the circuites we're discussing fit into larger circuites. (ie when do you use this particular circuit) I can't think of anything else I would change.
- It may be too difficult to change the time periods, so I'm not sure how that challenge can be approached. Maybe a small overview preliminary type lecture or a wrap-up type lecture, although these would be difficult because of the different levels of the groups.
- Lack of lecture and reinforcing ideas. At least go over some of the concepts that we were

supposed to cover.

Question 18

List the top three things that you would like to see RETAINED about this course in the coming weeks

- 1. Making predictions as we work through the experiments. 2. Allowing us to move at our own pace. 3. Giving us feedback on our progress in the homework and in our lab notebooks.
- Being able to work at our own pace. Using the simulations. The "guided discovery" style
- Teacher (you are doing an excellent job with the overall course, I do think I am fortunate to learn from, what I consider to be the most knowledgable person in the field), the materials, and equipment.
- Summary sheets, Lab handouts

empty page

- End of Survey -

TEVAL REPORT: STUDENT RATINGS OF INSTRUCTION

Center for the Advancement of Teaching and Learning
Kansas State University

Faculty Member: REBELLO NS **Course No.** PHYS -636 **Term:** SPRING 03
Responses from 7 of 7 enrolled (100%) **Hr/Days:** 12:30 TU
COLLEGE: Arts & Sciences

PART I. INSTRUCTOR'S DESCRIPTION OF CLASS

A. Type	Laboratory
B. Size	About right
C. Physical Facilities	Satisfactory
D. Previously Taught?	1 time
E. Changed Approach?	Yes
F. Teaching Load?	Average
G. Attitude Toward Course	I was really enthusiastic
H. Control of Course	I was responsible for all decisions
I. Diversity in student prep.	A major problem
J. Student Enthusiasm	High
K. Student Effort	Satisfactory
L. Additional Comments?	I have included comments on the FIF

	Number Responding						SD*	Averages
	VL	L	M	H	VH	OMIT		VL=1 VH=5
PART II. RELEVANT STUDENT ATTRIBUTES								
(12) Strong interest in class	0	1	1	1	4	0	1.1	4.1
(13) Worked hard to learn	0	0	1	3	3	0	0.7	4.3
PART III. INSTRUCTIONAL STYLES								
A. ESTABLISHING LEARNING CLIMATE								
(2) Made objectives clear	0	0	1	1	5	0	0.7	4.6
(3) Well prepared	0	0	0	0	7	0	0.0	5.0
(5) Interested in teaching	0	0	0	0	7	0	0.0	5.0
(10) Available for help	0	0	0	0	6	1	0.0	5.0
B. FACILITATING LEARNING								
(4) Explained clearly	0	0	1	1	5	0	0.7	4.6
(6) Stimulated thinking	0	0	0	0	7	0	0.0	5.0
(7) Made helpful comments	0	0	0	3	4	0	0.5	4.6
(8) Graded equitably	0	0	0	0	6	1	0.0	5.0
(9) Sensed confusion	0	0	1	1	5	0	0.7	4.6
PART IV. OVERALL EVALUATION								
A. Obtained responses								
(1) Teacher effectiveness	0	0	0	1	6	0	0.3	4.9
(11) Incr. desire to learn	0	0	0	2	5	0	0.5	4.7
(14) Amount learned	0	0	0	2	5	0	0.5	4.7

	Averages		Comparative Status(**)	
	Raw	Adj(#)	Raw	Adj(#)
B. Averages and Comparative Status				
(1) Teacher effectiveness	4.9	4.6	H	HM
(11) Incr. desire to learn	4.7	4.5	H	H
(14) Amount learned	4.7	4.6	H	H

* Standard Deviation
** Relative to KSU classes rated by 10 or more students;
H=upper 10%; HM=next 20%; M=middle 40%; LM=next 20%; L=lowest 10%
\# Adjusted for student characteristics & class size; see TEVAL Guide

PHYS636 PHYSICAL MEASUREMENTS & INSTRUMENTATION (COMMENTS ON TEVAL)

I have never been in a class with an instructor SO completely willing to take the time and means nessary to help us understand any concept. Dr. Rebello is the best instructor I have had in my entire college career.

- FOR MYSELF, BEING EXTREMELY INTROVERTED WITH MY WORK, THE CLASS DESIGN WAS A BIT PROBLEMATIC. THERE SEEMED TO BE TO MANY DISTRACTIONS FOR ME TO REALLY ENGAGE MYSELF IN A PRODUCTIVELY ACTIVE MANNER. BUT I DO LIKE THE OVERALL SET-UP OF THE COURSE.

I really liked the guided discovery class set-up. I feel like I learned the material better and like I will remember it for a longer time than if someone had just told me the material and made me memorize things.

I do think 4 hour blocks of time are too long. It's hard to stay focused and motivated. Two hour blocks would be much better

The stopping points made me feel more confident that I was on the right track. They also allowed me to get immediate feedback instead having to wait until the lab books were graded.

Sanjay is by far one of the best instructors I have ever had. I really like the way he wants us to figure things out on our own and doesn't tell us the answer right away. He is a very patient person! I think I will have a very high retention of the material in this course because he allowed us to figure things out on our own. The only comments I have are that sometimes the labs were somewhat repetitive when we had to predict, simulate, and build for each circuit. Maybe just simulating or just building for some of the circuits would be more appropriate.

I like Sanjay's style of teaching very much. It really helps me learn by myself. If I do have to pick any gripe, it's probably the hours and hours of "reflections" ;-). But seriously, probably the only problem is that in the lab handouts sometimes almost the same question is asked again and again. It gets a bit boring writing the same thing again and again. That said, the course was real fun attending, and I think I learned a lot under Sanjay's guidance.

The course was extremely useful even for a beginner like me and the approach quite effective though it required a great deal of effort on my part. The only constraint in such a method of teaching is the time we (students) have to put into the course. I am afraid that it is a prerequisite and one should be clearly aware of that before taking the course.

Overall the course could be made more effective if the course design involves time for lectures so that our conceptual understanding will be enhanced. The flexibility on Sanjay's part to accomodate different students needs is really very considerate and reflects greatly on his dedication.

■■ ■

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Overall the course could be made more effective if the course design involves time for lectures so that our conceptual understanding will be enhanced. The flexibility on Sanjay's part to accomodate different students needs is really very considerate and reflects greatly on his dedication.

PHYS636 **TEVAL: STUDENT EVALUATION OF INSTRUCTION** **SPRING 2003**

ADDITIONAL QUESTIONS

I would appreciate if you could answer these questions in ***addition*** to those given on your TEVAL.
Your answers to these questions will provide me and the Physics Department with useful feedback about this class.
Please **DO NOT** respond to these questions on **THIS SHEET**.
Fill in the bubbles on the backside of the **TEVAL** sheet for Questions **15-34**.

Questions **15** through **21**:
Rate the **effectiveness of** the following aspects of the **laboratory activities** in helping you to **learn the concepts**.

	Completely Ineffective	Mostly Ineffective	Neutral	Mostly Effective	Completely Effective	AVG
15. *Predicting* the behavior of a circuit/device.	0	0	2	1	4	4.29
16. *Designing* the circuit.	0	0	0	1	6	4.86
17. *Simulating* the circuit/device.	0	0	0	4	3	4.43
18. *Measuring* the circuit/device.	0	0	0	2	5	4.71
19. *Comparing* your results with predictions.	0	0	2	3	2	4.00
20. *Reflecting* on your results.	0	0	1	2	4	4.43
21. *Applying* what you have learned to a new case.	0	0	0	3	4	4.57

Questions **22**through **26**:
Rate the **appropriateness of the time spent** on following aspects of the course.

	Far Less than appropriate	*Less* than appropriate	Appropriate	*More* than appropriate	*Far More* than appropriate	AVG
22. Simulations	0	0	5	2	0	3.29
23. Real Measurements	0	0	7	0	0	3.00
24. Other Questions in Activities.	0	0	3	4	0	3.57
25. Interactions with TA / instructor.	0	1	6	0	0	2.86
26. Interactions with partner. (If no partner, then leave blank.) 2	0	0	4	1	0	3.20

Questions **27**hrough **33**
Rate the **effectiveness of** the following aspects of **course pedagogy** in helping you **learn the concepts**.

	Completely Ineffective	Mostly Ineffective	Neutral	Mostly Effective	Completely Effective	AVG
27. *Hands-on*: Making observations through simulations and/or experiments.	0	0	1	0	6	4.71
28. *Minds-on*: Figuring things out by yourself.	0	0	0	2	5	4.71
29. *Guided discovery*: Sequential questions designed to help you construct your own understanding.	0	0	2	2	3	4.14
30. *Reflections*: Asking you to think about the implications of your results.	0	0	1	3	3	4.29
31. *Self-paced*: Flexible time to learn a concept.	0	0	1	0	6	4.71
32. *Socratic dialog*: The TA / instructor respond to your question with another (leading) question.	0	1	0	1	5	4.43
33. *Collaborative learning*: Working with a partner. (If no partner, then leave blank.) 2	0	0	1	0	4	4.60

Question **34**: Overall Rating

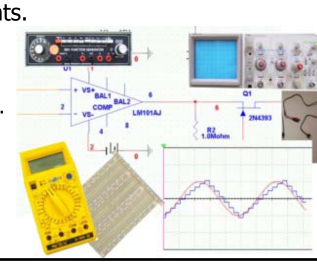
	Bottom 10%	Next to Bottom 20%	Middle 40%	Next to Top 20%	Top 10%	AVG
34. Among all classes you have taken at K-State, in which of the following categories would you rate this class.	0	0	0	1	6	4.86

Modeling Cycle Pedagogy in an Electronics Course: First Impressions

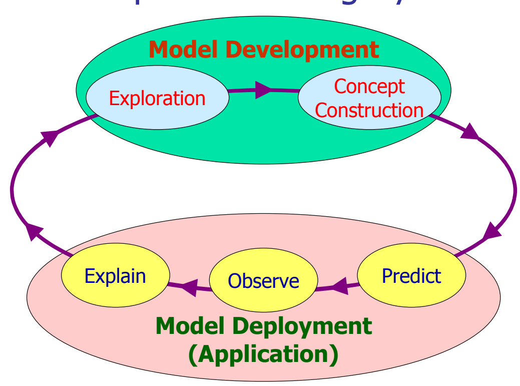
N. Sanjay Rebello
(srebello@phys.ksu.edu)
Kara E. Gray
(kgray@phys.ksu.edu)
Physics Education Research Group
Kansas State University

About the Course

- Required for Physics majors.
- Pre-requisite: 1yr. calc-based physics.
- 8 contact hrs./week – all in lab.
- Enrollment – 7 students.
- Format
  - Work in pairs.
  - Maintain lab notebook.
  - Minimal lecturing.
  - Active learning – simulations & expts.



Adapted Modeling Cycle



Model Development

- Exploration
  - Measurements (e.g. I-V Graph)
  - Simulations
- Concept Construction
  - Compare results with previous findings.
  - Reflect on comparison.
  - Synthesize experiences: Build model.

Model Deployment (Application)

Applied to Circuit Analysis & Design

- Predict
  - Apply model to predict device/circuit behavior.
- Observe
  - Test prediction: Measurement / Simulation.
- Explain
  - Understand observations in light of model.

Other Features

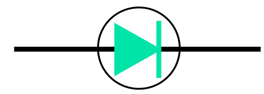
Aspects of learning used throughout cycle:

- Collaborative Learning
- Guided Discovery
- Self-Reflection
- Socratic Dialog
- Regular Stopping Points : Instructor Check

Example: Diode

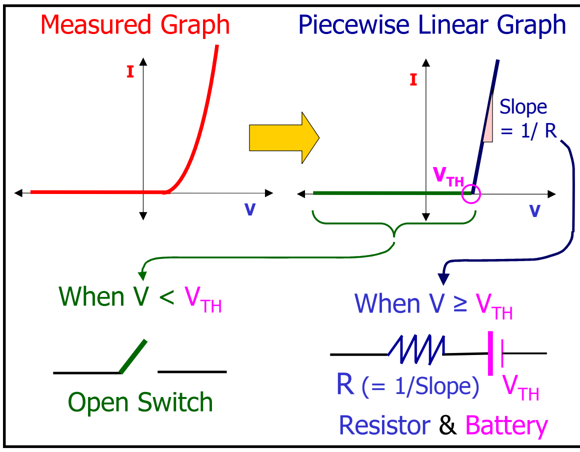
Goal:

To develop & apply an equivalent circuit model of a diode.



Model Development

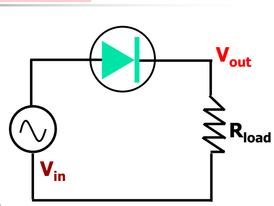
- Exploration:
  - Students **measure I-V graph**.
- Concept Construction:
  - Redraw it as **piecewise linear graph**.
  - Represent each linear piece as $I = gV = (1/R)V$
  - Determine 'g' (= 1/R) for each piece.
  - Represent each piece as a circuit element.



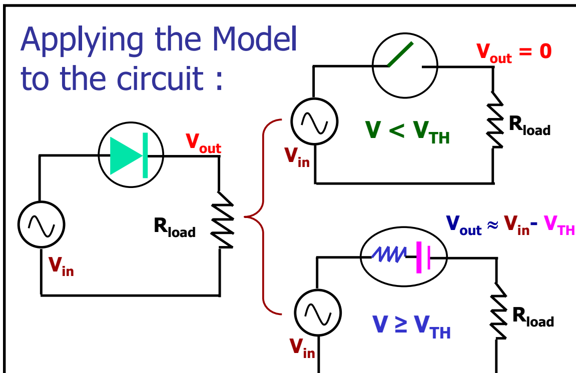
Model Deployment

For the circuit shown…

- Predict:
  - Output waveform
- Observe:
  - Simulate & Measure output.
- Explain:
  - Discrepancies b/w Prediction & Observation.

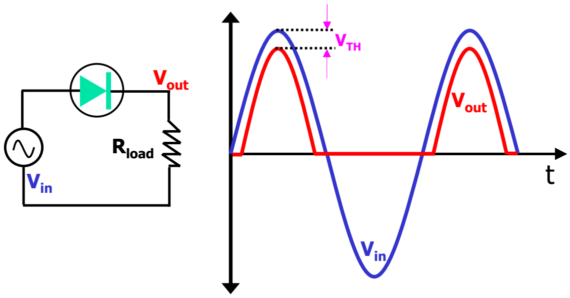


Applying the Model to the circuit :



$R_{Diode} << R_{load}$ so ignore R_{Diode}

Predicted & Observed Output Waveform



A Student's Perspective

- It felt better to discover the answers than to be told everything like in other classes.
- Using the simulations allowed us to test our designs if the problem was faulty equipment.
- Working in groups was great.
- Before we implemented stopping points it was hard to know if you were on the right track.

Instructor's Perspective

- Must explain pedagogy to students on 1st day, to get them on board. Few students remain resistant.
- Need TA who understands & buys into pedagogy.
- Scaffolding and feedback by instructor/TA essential as students build models.
- Modeling approach works well for some devices (e.g. diodes, gates) not as well for more complex ones (e.g. transistors, flip-flops).
- Students appear to develop more ingenious ways to solve problems than in traditional course, and better prepared to attempt previously unseen problems.
- Fewer (60%-70%) topics covered than in traditional course.

Future Work

- Modify instructional materials & strategies based on feedback from students & instructor's impressions.
- Conduct research on how students develop models of electronic devices using discovery-based learning.
- Develop research-based strategies to promote the modeling approach in complex devices e.g. transistors, flip-flops.
- Assess student learning of electronics based on the materials & strategies we use.

Physics Education Seminar (PHYS807)

This was my second time conducting the Seminar. This course assignment may not traditionally be considered teaching, since it overlaps quite significantly with research. However, in a sense, it could also be considered "training" or "apprenticeship" of new inductees (graduate or undergraduate) students in this field.

In this spirit, I organized the seminar a little differently from the way in which it was organized previously. The format for the seminar is described on the following page. The format was only moderately successful. The most important hurdle to the format was that most participants did not read the papers beforehand. Therefore the discussions were often uninspiring. Also, most of the first year graduate students did not participate.

Since then we have reverted back to the original format for the seminar.

PHYS807 **PHYSICS EDUCATION SEMINAR** **SPRING 2003**

F 12:30-1:20

FORMAT

The Physics Education Seminar will follow a format that is similar to last semester, but with few minor changes based on responses on the feedback survey.

Presentation: This is a talk (about 25-30 minutes) given by one of us, with questions and discussion with audience during and after the talk. The speaker will…

- submit an abstract (150 words) and title to Kim, to be displayed on the website on the Monday before the talk.
- send Kim the Power Point slides for the talk so that they can be placed on the website after making changes to the talk, if any, based on feedback from the participants.
- Following the presentation, the speaker will select no more than **one** paper in the area of her/his work not written by the speaker. **Please select papers that are reasonable in length and can be discussed in depth in the time available**. The paper will be discussed in the discussion format (below) in the week following each presentation. One copy of the paper will be available in a three-ring binder in Rm. 403 Cardwell that can be signed out for reading. If a paper is available in Adobe Acrobat format, a link to the paper will be placed on the website. I will make every attempt to have the paper up a week before we discuss it. Therefore it is necessary for speakers to have the paper ready when they give their presentation.

Discussion: In the week following a presentation, the group will discuss the paper selected by the speaker who has given their presentation the previous week. All participants are expected to have read the papers prior to the discussion. No more than **one** paper will be discussed on any day, and **it will be of reasonable length**. That should give us the opportunity to discuss the paper critically. Some questions to think about as you read the papers could be…(Note: These may not be applicable to all the papers)

- What are the primary research hypotheses and/or theoretical framework of the paper?
- What, if at all, is the research methodology of the study? What are the embedded assumptions? Can the methodology be improved?
- What are the main results and conclusions of this study? Are they convincing?
- (How) Can this study be useful to the work that we are doing in various projects? Does it bring up any new ideas that we can explore?
- Any other questions that anybody finds interesting and relevant.

The presentation speaker will serve as the discussant to lead and moderate a discussion. Unlike last semester there will **not** be a recorder and **no summaries will be posted** on the website.

Fall 2003

Physics of Solids (PHYS655)

I was both excited and apprehensive when I was assigned this course. I was excited because solid state physics was an area that I was always interested in. In fact, it is the area in which I did my doctoral research. I was apprehensive, because it would be my first time teaching this course at K-State. I had taught solid state physics once in my previous position at Clarion University, however it was offered as a summer course to be taught in an individualized instruction format to only two students over a three-week period. Therefore, I knew that this experience would be quite different from the one I had at Clarion.

Based on my positive experiences with the modified pedagogy that I implemented in PMI the previous semester (see above) and my own knowledge of, and should I say bias toward active learning, I decided to use a similar pedagogy in this course. I began by having students learn the concepts by going through 'Tutorials' – hands-on as well as computer-based activities that they would collaboratively perform in class, that would enable them to learn the concepts by themselves. My role would be that of a facilitator. As I had done in PMI, I articulated this approach to students on the first day of class. The approach appeared to work for the first two weeks of class or so. The topics covered during this period included crystal structures. I used models – both real and on the computer for students to notice patterns in crystal structures and then categorize these in terms of their similarities and differences. The approach was often very slow and time consuming. Additionally, I realized that the approach would be difficult, if not impossible to adopt when the topics (e.g. reciprocal lattice or density of states) were conceptually abstract and mathematically difficult. At the very least, I realized that it would need significant work to be able to design instructional materials that could enable students to learn these concepts by themselves. I knew I did not have the time, knowledge or experience at this time to do that. Therefore, I decided to revert to a more instructor dominated approach of direct lecturing.

I created lectures on the computer that I projected in class. Although the book by Kittel was the official text for the course, I soon discovered that some other texts did a better job at explaining some of the concepts. Therefore, in my lectures I tried to synthesize material from different books. Handouts of the lectures were also posted on K-State Online. In class, I used to interject the lectures with Tutorial exercises. Rather than be exploratory exercises, as was the case previously, these were now application exercises. Typically these were problems that I believed could be solved in a few minutes in class.

I believe that teaching from pre-prepared lectures helped me stay organized in class and also cover all of the material. Often I could focus on going over material without spending time on the detailed calculation, but rather showing students the general scheme and then focusing on the concepts. Overall, based on a mid-semester evaluation that I conducted online (using the K-State Survey System) students liked the lectures. There were some criticisms of the Tutorial though. Students felt that the Tutorials did not help them gain a deeper understanding in any way. They pointed out that many of the Tutorial exercises were long and often ended up adding to the homework. The homework too was criticized for being too out of touch with the material in the course, and more mathematically challenging than conceptually insightful.

I tried to address some of these concerns in the remaining weeks of the semester. First, I changed the Tutorial questions. I focused on questions that could be finished in a few minutes and did not involve as many detailed calculations as the homework questions did. I also put more thought into choosing the homework questions.

There were two take-home mid-semester exams and one take-home final exam. Each mid-term exam had at least one question that required numerical calculations. I believe that numerical calculation is a topic that most students do not get enough exposure to in a traditional course, but the skill to do these types of calculations often is used by computational researchers in the field. Therefore, I wanted to give students some flavor for this. In addition to the exams and homework, students were also expected to talk with one or more condensed matter research groups and present the research done by these groups in a 20 minute long talk at the end of the semester. I also had students have three lab engagements during which they visited the Semiconductor Lab and observed a researcher perform experiments related to the course. In the three visits they learned about X-ray diffraction, Hall measurements and conductivity measurements. I also organized two invited lectures from researchers in the department to talk about their work pertaining to solid-state physics.

In terms of content coverage, I was able to cover all of the topics that I had originally intended to except Superconductivity. However, I did cover some of the topics in greater depth than I had originally anticipated. For instance, I spent more time covering semiconductor devices than originally planned. This departure from the original plan was mainly because the students were more interested in this topic. Almost all of the students were graduate students who had clear ideas about what topics they were most interested in.

If I were to teach this course again, I would make the following changes 1) In terms of content, I would spend a little less time on crystal structure, which would leave more time for other topics toward the end of the course. I would change the time I spent on semiconductor devices because I believe it is an important topic and one that has vast practical applications. 2) I would not discontinue the Tutorials, but make sure that they are short exercises that are more conceptually based than calculation oriented and can be completed in a few minutes in class. 3) I would change the official text for the course. I may have one or more recommended texts, but the book by Kittel would not be designated as the foremost text in the course. 4) I would incorporate more simulations and computational work in the course, not just in the exams but also in the homework.

There are several individuals whom I would like to thank in connection with this course.

Dr. Jingyu Lin and Dr. Hongxing Jiang allowed me to avail the assistance of their research staff and to use the research facilities of the Semiconductor Group for the laboratory experiments that students observed and participated in during the course.

Dr. Jingyu Lin was also helpful in talking to me about her previous experiences with the course and sharing the syllabus, as well as the list of experiments that she had students perform in the course when she taught it previously.

Dr. Christopher Sorensen provided his graduate student (Tahereh Mokhtari) to present a lecture on their research to the class as an invited speaker.

Drs. Kai Zhu and Zhaoyang Fan helped the class with the X-Ray diffraction experiment.

Dr. Jing Li helped the class with the conductivity and Hall measurement experiment.

Dr. Ahlam Al-Rawi presented her research on molecular dynamics as an invited speaker.

Ms. Tahereh Mokhtari presented her doctoral research on soft condensed matter physics.

Mr. Peter Nelson lent me models of crystal structures during the first two weeks of the class.

PHYS655
3 CREDITS

PHYSICS OF SOLIDS

***Instructor:* N. Sanjay Rebello**

SYLLABUS

FALL 2003
MWF 10:30-11:20

ROOM & TIME

Room 146, Cardwell Hall   Monday, Wednesday, Friday 10:30-11:20

INSTRUCTOR CONTACT INFORMATION

Rm. 503 Cardwell Hall (Note: There is no elevator access above the 4th floor in Cardwell Hall. If you need to use an elevator, please call me and I can meet you in the lobby on the 4th floor of Cardwell.)
Phone: [Office] 532 1539 [Home] 537 7543   Email: srebello@phys.ksu.edu (several times daily)

OFFICE HRS

Wednesdays: 3:00 – 5:00 PM.   Feel free to drop by or call me anytime.

GENERAL COURSE GOALS

During this course you will learn about the:

- structure and properties of solids.
- underlying physics e.g. quantum principles that govern these properties.
- applications of these properties to make useful devices.

COURSE PEDAGOGY

This course will be based on the premise (supported by educational research) that we learn best when we are actively engaged in the learning process. In this spirit, although this course meets in a "lecture" format, I will typically not give a traditional lecture. Rather than passively listen to me talk about the concepts and solve problems on the board; you will think through questions that would enable you to construct many of the concepts for yourself. You will also solve problems for yourself in this class. This mode of learning requires you to interact with me as well as with others in this class in small groups.

TEXTBOOK

The official text for this course is: *Introduction to Solid State Physics,* 7th Edition, by Charles Kittel, John Wiley & Sons Inc. This text is one of the most commonly used ones in undergraduate courses in solid state physics.
A popular *graduate* level text is *Solid State Physics*, 1st Edition, by Ashcroft & Mermin, Brooks & Cole Publishing. I have both of these texts as well as a few others in my office, and am willing to lend them to anybody for a brief period of time (about a day or so).

WEB SITE

All of the class handouts, homework, as well as homework and exam solutions will available via *K-State Online* http://online.ksu.edu. *K-State Online* has changed since last semester. The website for this class will be operative by the end of this week.

CLASSWORK

As mentioned above in the Course Pedagogy section, you will not be passive observers in this class. Rather you will be expected to participate actively in your own learning. To facilitate your active participation, you will be asked to work on in class *Tutorials*. Here you will answer questions, make predictions; solve problems etc. either individually or with your neighbors. These efforts will be worth 23% of your course grade. <u>You will NOT be penalized for incorrect answers on *Tutorials* as long as you have made an honest attempt in class</u>.

HOMEWORK

Homework will be assigned about once every week. Homework assignments will be worth 28% of the course grade. Your homework may traditional (paper and pencil) questions as well s those that require you to run simulations. You will be provided information on accessing the required simulations.
You are encouraged to work collaboratively on the homework, but merely copying someone's homework will be detrimental to your performance on the exams and final, where you are required to work alone.

EXAMS & FINAL

There will be up to two exams during the semester and a cumulative final. All of the exams and final are take-home. Like the homework, the exams and final can involve paper and pencil tasks, as well as simulations.

Unlike the homework, collaborative work on the exams and final is prohibited. You are however permitted to access resources such as texts, websites or any other non-human resources to answer the questions.

OTHER ACTIVITIES

Although this is a lecture course, we will have at least two other kinds of activities:

- *Laboratories*: We will sometimes take a lecture off to visit one of the research labs in the Physics Department or College of Engineering. The laboratory visits would range from observing researchers performing experiments, to probably partaking in some of these experiments yourself.
- *Research Talks*: There is lot of exciting, cutting edge, solid state physics research going on in the Physics Department right here at KSU, and also in some other Departments. To avail of this unique opportunity of integrating this research into our educational experience we will adopt two approaches
  - *Invited Talks* by researchers (and possibly a tour of the lab): You would be expected to do some background reading on the research and ask questions to the speaker about aspects of their work that you find interesting.
  - *Summary Talks* by you and your classmates: You would be expected to familiarize yourself with the ongoing research of one of the solid state researchers in the Physics Department or elsewhere on campus and present a review of that research to other classmates. These research summary talks will be worth 10% of your course grade. If you are already working with a group doing research in solid state physics, you will be required to choose an area and researcher outside your group.

ASSESSMENT

Your performance in this course will be assessed by weighing various components of evaluation as follows:

Type of Assignment	Points per Assignment	Total Points
Class work (*Tutorials*)	15 weeks x 15 points	225
Homework	14 Homework Assignments X 20 points	280
Research Summary Talks	1 Talk x 100 points	100
Exams	2 Exams x 125 points	250
Final	1 Final x 150 points	150
	MAX POSSIBLE POINTS IN COURSE	***1005***

COURSE GRADE

Your course grade will be calculated based on the total points that you score in the course (out of a Maximum of 1000). The point range for each grade is as follows:

Points Scored in Course	Course Grade
900 or Above	A
800 – 899	B
650 – 799	C
649 or Below	D

STUDENTS WITH DISABILITIES

If you have any condition such as a physical or learning disability which will make it difficult for you to carry out the work outlined here, or which will require academic accommodations, please notify the lecturer and contact the *Student Disability Services* (Holton 202) during the first two weeks of the course.

ACADEMIC DISHONESTY WARNING

Plagiarism and cheating are serious offences and may be punished by failure on the exam, paper or project; failure in the course; and/or expulsion from the University. For more information refer to the "Academic Dishonesty" policy in the *K-State Undergraduate Catalog* and the *Undergraduate Honor System Policy* on the Provost's web page at http://www.ksu.edu/honor/

Please refer to the ***Course Schedule*** for information on the topics covered, relevant chapters, as well as the dates of the Homework and Exams.

PHYS655
3 CREDITS

FALL 2003
MWF 10:30-11:20

PHYSICS OF SOLIDS

Instructor: **N. Sanjay Rebello**

TENTATIVE COURSE SCHEDULE

Subject to change with prior notice. Changes will be posted on K-State Online and announced in class

WHEN	TOPIC[LAB]	Homework & Exam (Due Date)	CHAPTERS IN TEXTS — Not all sections in each chapter may be relevant. Please inquire with the instructor if you need more information.			
			Kittel (*Course Text*)	Hook & Hall	Omar	Ashcroft & Mermin
Week 01 08/20 –08/22	Crystal Structure	--	Ch. 1	Ch. 1	Ch. 1	Ch. 4
Week 02 08/25 –08/29	Reciprocal Lattice	HW 01 (08/29)	Ch. 2	Ch. 1, 11	Ch. 2	Ch. 5 - 7
LABOR DAY (09/01)						
Week 03 09/03 –09/05	Reciprocal [1] Lattice (contd.)	HW 02 (09/05)	Ch. 2	Ch. 1, 11	Ch. 2	Ch. 5 - 7
Week 04 09/08 –09/12	Crystal Binding	HW 03 (09/12)	Ch. 3	Ch. 1	Ch. 1	Ch. 19 - 21
Week 05 09/15 –09/19	Phonons	HW 04 (09/19)	Ch. 4	Ch. 2	Ch. 3	Ch. 22 - 26
Week 06 09/22 –09/26	Thermal Props. of Phonons	HW 05 (09/26)	Ch. 5	Ch. 2	Ch. 3	Ch. 22 - 26
Week 07 09/29 –10/03	Thermal Props. of Phon (contd.)	Exam 1 (10/03)	Ch. 5	Ch. 2	Ch. 3	Ch. 22 - 26
Week 08 10/06 –10/10	Free Electron Fermi Gas[2]	HW 06 (10/10)	Ch. 6	Ch. 3	Ch. 4	Ch. 1 - 3
FALL BREAK (10/13 – 10/14)						
Week 09 10/15–10/17	Free Electron Gas (contd.)	HW 07 (10/17)	Ch. 6	Ch. 3	Ch. 4	Ch.1 - 3
Week 10 10/20 –10/24	Energy Bands[3]	HW 08 (10/24)	Ch. 7	Ch. 4	Ch. 5	Ch. 8 - 9
Week 11 10/27 –10/31	Energy Bands (contd.)	HW 09 (10/31)	Ch. 7	Ch. 4	Ch. 5	Ch. 8 - 9
Week 12 11/03 –11/07	Semiconductors	HW 10 (11/07)	Ch. 8	Ch. 5	Ch. 6	Ch. 28 - 29
Week 13 11/10 –11/14	Semiconductors (contd.)[4,5]	HW 11 (11/14)	Ch. 8	Ch. 5 - 6	Ch. 6 - 7	Ch. 28 - 29
Week 14 11/17 –11/21	Optical Processes	Exam 2 (11/21)	Ch. 11	Ch. 9	Ch. 8	Appendix K
Week 15 11/24	Optical Proc. (contd.)[8]	HW 12 (11/24)	Ch. 11	Ch. 9	Ch. 8	Appendix K
THANSKGIVING BREAK (10/26 – 10/28)						
Week 16 12/01 –12/05	Super-Conductivity	HW 13 (12/05)	Ch. 12	Ch. 10	Ch. 10	Ch. 34
Week 17 12/08 –12/10	Super-Conductivity[9]	HW 14 (12/10)	Ch. 12	Ch. 10	Ch. 10	Ch. 34
STUDY DAY (12/12)						

Final Exam (take home) is due at the time designated for the final on the University's Final Exam schedule.

Laboratory Observations/Experiments:

[1] X-Ray Diffraction,
[2] Conductivity measurements,
[3] Hall effect measurements,
[4] Bulk semiconductor crystal growth,
[5] MOCVD epitaxial growth,
[6] Surface morphology - SEM & AFM
[7] Photolithographic patterning of LEDs,
[8] Photoluminescence measurements,
[9] Principle of SQUID,
[10] Magnetic layer fabrication

PHYS655 PHYSICS OF SOLIDS *FALL 2003*

3 CREDITS *Instructor:* N. Sanjay Rebello *MWF 10:30-11:20*

TENTATIVE COURSE SCHEDULE:

REVISED: Friday, October 17, 2003

Subject to change with prior notice. Changes will be posted on K-State Online and announced in class

WHEN	TOPIC[LAB]	Homework & Exam (Due Date)	CHAPTERS IN TEXTS — Not all sections in each chapter may be relevant. Please inquire with the instructor if you need more information. Kittel (*Text*)	Hook & Hall	Omar	Ashcroft & Mermin
FALL BREAK (10/13 – 10/14)						
Week 10 10/20 –10/24	Free Electron Gas	HW 06 (10/24)	Ch. 6	Ch. 3	Ch. 4	Ch.1 - 3
Week 11 10/27 –10/31	Energy Bands* I'm away 10/27-28 [LAB 2&3]	HW 07 (10/31)	Ch. 7	Ch. 4	Ch. 5	Ch. 8 - 9
Week 12 11/03 –11/07	Semiconductors	HW 08 (11/07)	Ch. 8	Ch. 5	Ch. 6	Ch. 28 - 29
Week 13 11/10 –11/14	Semiconductors	HW 09 (11/14)	Ch. 8	Ch. 5	Ch. 6	Ch. 28 - 29
Week 14 11/17 –11/21	Optical Processes	HW 10 (11/21)	Ch. 11	Ch. 9	Ch. 8	Appendix K
Week 15 11/24	Optical Processes	Exam 2 (11/25)	Ch. 11	Ch. 9	Ch. 8	Appendix K
THANSKGIVING BREAK (11/26 – 11/28)						
Week 16 12/01 –12/05	Superconductivity (Partly)	HW 11 (12/05)	Ch. 12	Ch. 10	Ch. 10	Ch. 34
Week 17 12/08 –12/10	TALKS	HW 12 (12/12)	---	---	---	---
STUDY DAY (12/12)						

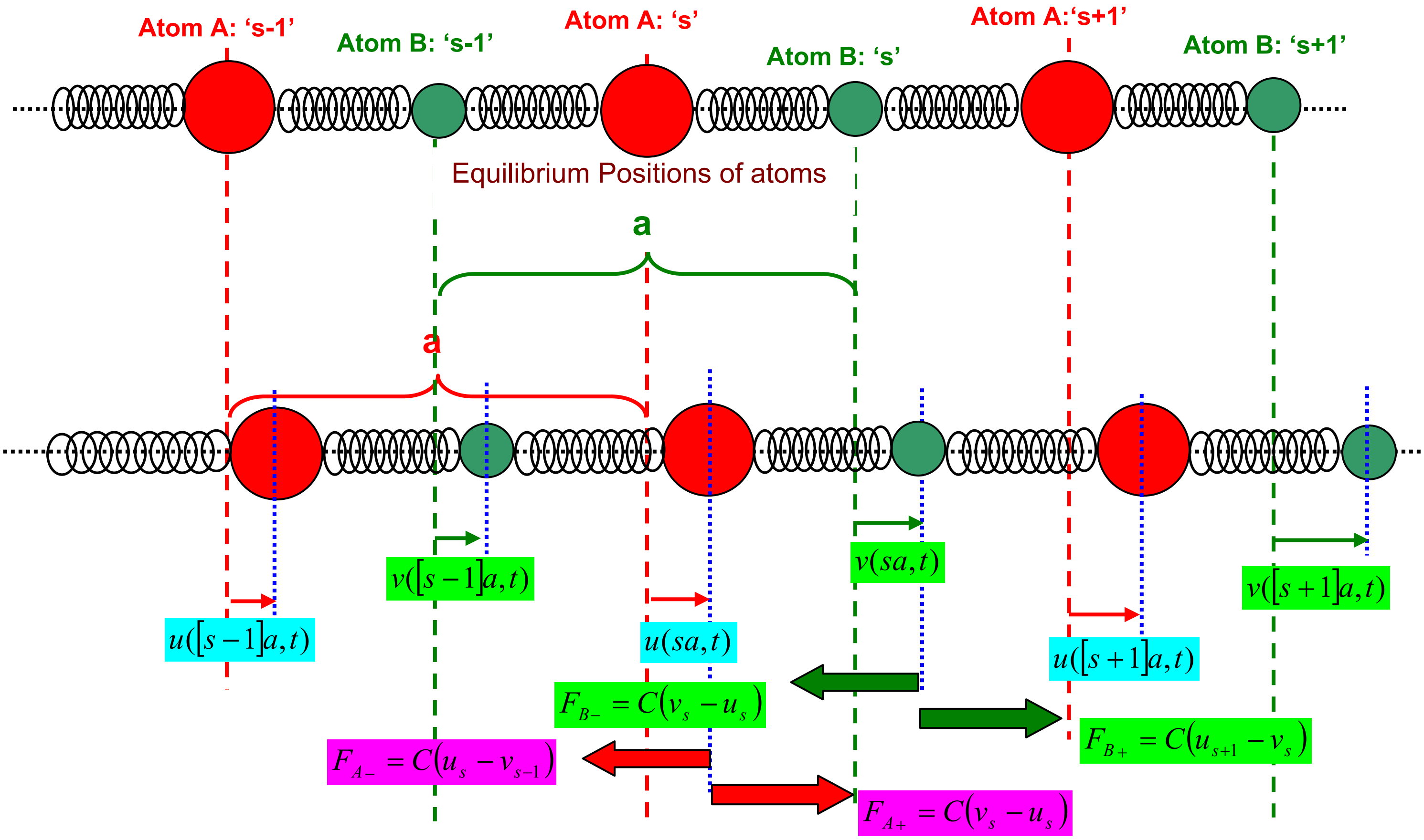
Final Exam (Take Home):
GIVEN TO YOU: MONDAY, DECEMBER 08
DUE: 5:00PM, MONDAY, DECEMBER 15

Laboratory Observations/Experiments:
[1] X-Ray Diffraction, [2] Conductivity measurements, [3] Hall effect measurements,

We will not have the time to do these labs, however you can use them as topics for your Talks
[4] Bulk semiconductor crystal growth, [5] MOCVD epitaxial growth,
[6] Surface morphology - SEM & AFM [7] Photolithographic patterning of LEDs,
[8] Photoluminescence measurements, [9] Principle of SQUID, [10] Magnetic layer fabrication

Chapter 4 – Phonons I: Crystal Vibrations (Part 2)

We have previously considered a 1D lattice of a monoatomic solid, with a lattice constant 'a' and only one atom per basis. Now we will consider a more general case, though still confined to 1D: A solid with two different basis atoms. The situation is shown below:



The amplitudes of oscillation for atom 'A' (mass M_1) and B (mass M_2) are 'u' and 'v' respectively.

The equations of motion, similar to the monoatomic basis case are below i.e. they depend on the displacement with respect to the adjacent atoms:

$$M_1 \frac{d^2 u_s}{dt^2} = F_{A+} - F_{A-} = C(v_s - u_s) - C(u_s - v_{s-1}) \quad \& \quad M_2 \frac{d^2 v_s}{dt^2} = F_{B+} - F_{B-} = C(u_{s+1} - v_s) - C(v_s - u_s) \quad (1)$$

$$\Rightarrow \quad M_1 \frac{d^2 u_s}{dt^2} = C(v_s - 2u_s + v_{s-1}) \quad \& \quad M_2 \frac{d^2 v_s}{dt^2} = C(u_{s+1} - 2v_s + u_s) \quad (2)$$

Again we use the two generic solutions:

$$\left.\begin{aligned} & u(x,t) = u\exp[i(Kx - \omega t)] \quad \text{or} \quad u_s(t) = u\exp[i(Ksa - \omega t)] \\ \& \quad & v(x,t) = v\exp[i(Kx - \omega t)] \quad \text{or} \quad v_s(t) = v\exp[i(Ksa - \omega t)] \quad \text{where } K = \frac{2\pi}{\lambda} \end{aligned}\right\} \quad (3)$$

Substituting (3) in (2) we get two equations, each containing 'u' and 'v':

$$\left.\begin{aligned}&\left(2C-\omega^2 M_1\right)u - C\left(1+\exp[-iKa]\right)v = 0\\ &C\left(1+\exp[iKa]\right)u - \left(2C-\omega^2 M_2\right)v = 0\end{aligned}\right\} \quad (4)$$

These equations can be rewritten in matrix notation:

$$\begin{pmatrix} \left(2C-\omega^2 M_1\right) & -C\left(1+\exp[-iKa]\right) \\ C\left(1+\exp[iKa]\right) & -\left(2C-\omega^2 M_2\right)\end{pmatrix}\begin{pmatrix} u \\ v\end{pmatrix} = \begin{pmatrix} 0 \\ 0\end{pmatrix} \quad (5)$$

There solution to (5) can be either:

$$\begin{pmatrix} u \\ v\end{pmatrix} = \begin{pmatrix} 0 \\ 0\end{pmatrix} \quad \Rightarrow \text{u} = 0 \ \& \ \text{v} = 0$$: The trivial solution in which no atom vibrates

OR

$$\det\begin{pmatrix} \left(2C-\omega^2 M_1\right) & -C\left(1+\exp[-iKa]\right) \\ C\left(1+\exp[iKa]\right) & -\left(2C-\omega^2 M_2\right)\end{pmatrix} = 0 \quad (6)$$

$$\Rightarrow -\left(2C-\omega^2 M_1\right)\left(2C-\omega^2 M_2\right) + C^2\left(1+\exp[-iKa]\right)\left(1-\exp[-iKa]\right) = 0$$

Using the rule that: $\exp[-iKa]+\exp[-iKa] = 2\cos Ka$ we get a quadratic in ω^2:

$$\Rightarrow -\omega^4 M_1 M_2 + 2C\left(M_1+M_2\right)\omega^2 - 2C^2\left(1-\cos Ka\right) = 0 \quad (7)$$

Solving the quadratic equation and using $\left(1-\cos Ka\right) = 2\sin^2\left(\frac{Ka}{2}\right)$ we get a quadratic solution in ω^2:

$$\omega^2 = C\left(\frac{M_1+M_2}{M_1 M_2}\right) \pm C\frac{\left\{\left(M_1+M_2\right)^2 - 4M_1 M_2 \sin^2\left(\frac{Ka}{2}\right)\right\}^{1/2}}{M_1 M_2}$$

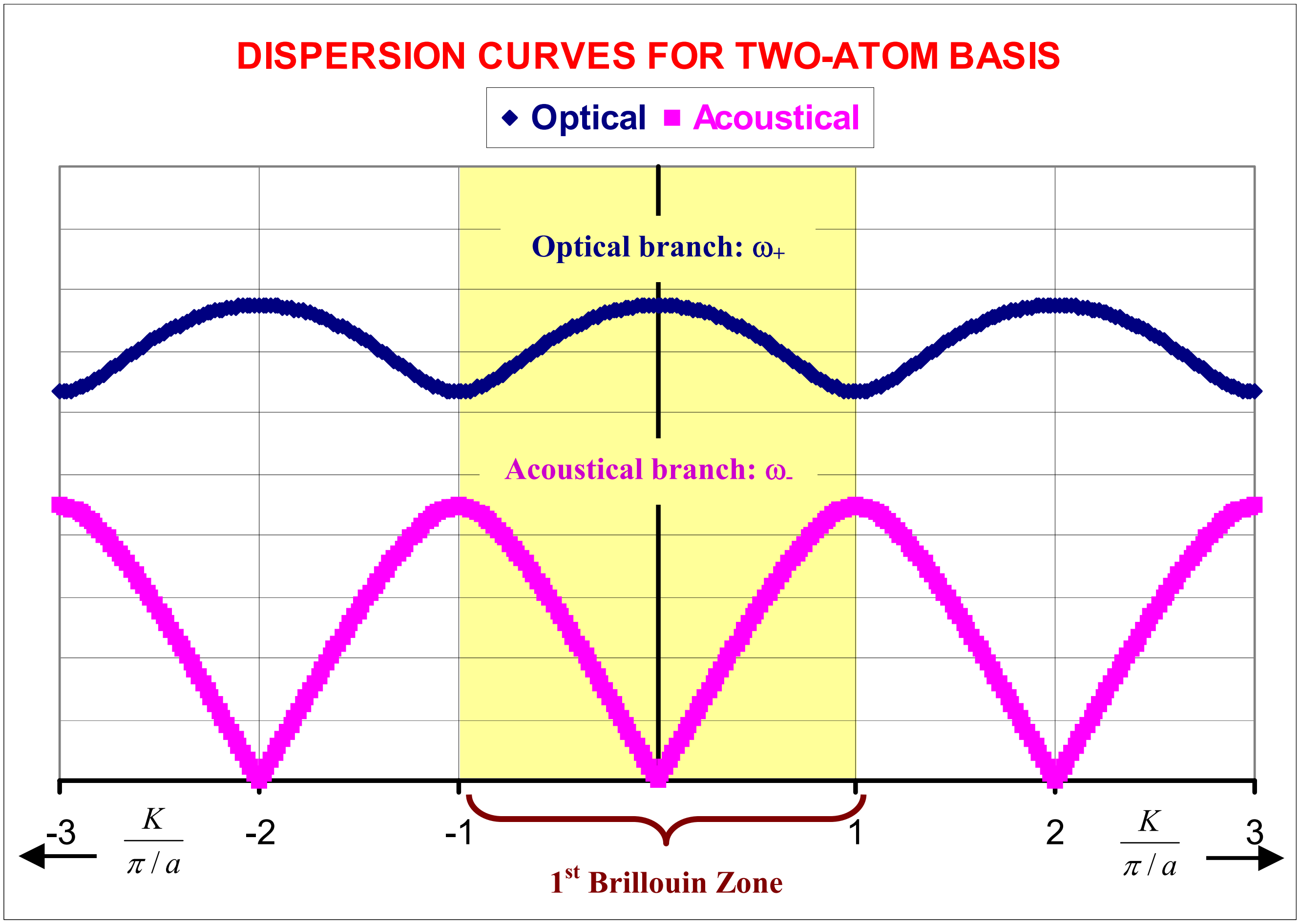
Therefore:

$$\omega_{\pm} = \sqrt{C\left(\frac{M_1+M_2}{M_1 M_2}\right) \pm C\frac{\left\{\left(M_1+M_2\right)^2 - 4M_1 M_2 \sin^2\left(\frac{Ka}{2}\right)\right\}^{1/2}}{M_1 M_2}} \quad (8)$$

There are two solutions to the quadratic equation, that yield two values for ω:

Using the + sign we get the **Optical** branch (**High** ω)

Using the – sign we get the **Acoustical** branch (**Low** ω)



Now let us consider what these two solutions mean at different wavelength limits:

Long wavelength limit

:$\lambda >> a \Rightarrow K << \pi/a$ or $K \rightarrow 0$ $\Rightarrow \sin\left(\frac{Ka}{2}\right) \rightarrow \frac{Ka}{2}$

So: $$\omega_{\pm} = \sqrt{C\left(\frac{M_1 + M_2}{M_1 M_2}\right) \pm C\frac{\left\{(M_1+M_2)^2 - 4M_1M_2\left(\frac{Ka}{2}\right)^2\right\}^{1/2}}{M_1 M_2}} \qquad (9)$$

Using the binomial approx: $$\left\{(M_1+M_2)^2 - M_1M_2(Ka)^2\right\}^{\frac{1}{2}} = (M_1+M_2)\left\{1 - \frac{M_1M_2}{2(M_1+M_2)^2}(Ka)^2\right\} \qquad (10)$$

Substituting (9) into (8) we get:

$$\omega_{\pm} = \sqrt{C\left(\frac{M_1 + M_2}{M_1 M_2}\right) \pm C\frac{(M_1+M_2)}{M_1 M_2}\left\{1 - \frac{M_1M_2}{2(M_1+M_2)^2}(Ka)^2\right\}}$$

$$\Rightarrow \quad \omega_{\pm} = \sqrt{C\left(\frac{M_1 + M_2}{M_1 M_2}\right) \pm C\left(\frac{M_1 + M_2}{M_1 M_2}\right) \mp \frac{C}{2(M_1+M_2)}(Ka)^2} \qquad (11)$$ Long Wavelength Limit

For the Optical Phonon branch, from (11) we get:

$$\omega_{OPTICAL} = \omega_+ = \sqrt{C\left(\frac{M_1+M_2}{M_1M_2}\right) + C\left(\frac{M_1+M_2}{M_1M_2}\right) - \frac{C}{2(M_1+M_2)}(Ka)^2}$$

$$\Rightarrow \quad \omega_{OPTICAL} = \omega_+ = \sqrt{2C\left(\frac{M_1+M_2}{M_1M_2}\right) - \left(\frac{C}{2(M_1+M_2)}(Ka)^2\right)}$$

Since K→0, the $(Ka)^2$ term is negligible in comparison to the other one. Therefore:

$$\Rightarrow \quad \omega_{+(OPTICAL)} = \sqrt{2C\left(\frac{1}{M_1} + \frac{1}{M_2}\right)} \qquad (12)$$

Group Velocity of ***Optical*** Phonon: $v_{g(OPTICAL)} = \frac{d\omega_{OPTICAL}}{dK} = 0$ (Standing Wave)

Phase Velocity of ***Optical*** Phonon: $v_{p(OPTICAL)} = \frac{\omega_{OPTICAL}}{K} = \frac{1}{K}\sqrt{2C\left(\frac{1}{M_1} + \frac{1}{M_2}\right)}$

Optical phonon in the Long Wavelength Limit

λ>>a ⇒ K<<π/a
OR
K→ 0

For the Acoustical Phonon branch, from (11) we get:

$$\omega_{ACOUSTICAL} = \omega_- = \sqrt{C\left(\frac{M_1+M_2}{M_1M_2}\right) - C\left(\frac{M_1+M_2}{M_1M_2}\right) + \frac{C}{2(M_1+M_2)}(Ka)^2}$$

$$\Rightarrow \quad \omega_{ACOUSTICAL} = \omega_- = \sqrt{\frac{C}{2(M_1+M_2)}(Ka)^2}$$

$$\Rightarrow \quad \omega_{ACOUSTICAL} = \omega_- = \left(a\sqrt{\frac{C}{2(M_1+M_2)}}\right)K \qquad (13)$$

Group Velocity of ***Acoustical*** Phonon: $v_{g(ACOUSTICAL)} = \frac{d\omega_{ACOUSTICAL}}{dK} = \left(a\sqrt{\frac{C}{2(M_1+M_2)}}\right)$

Phase Velocity of ***Acoustical*** Phonon: $v_{p(ACOUSTICAL)} = \frac{\omega_{ACOUSTICAL}}{K} = \left(a\sqrt{\frac{C}{2(M_1+M_2)}}\right)$

Acoustical phonon in the Long Wavelength Limit

λ>>a ⇒ K<<π/a
OR
K→ 0

Note that for the acoustical phonon, the group and phase velocity are identical. This situation is analogous to a sound wave propagating through the 1D solid: $v_{sound} = \sqrt{\frac{F}{\rho}}$ where F is the tension & ρ is the density.

But since this is a 1D chain: Density ρ = Mass per unit length $\quad \Rightarrow \rho = \frac{M_1+M_2}{a}$

Also, the tension is due to the stretching of the springs. So mean tension corresponds to the springs being stretched to about half their equilibrium length:

$F = C\frac{a}{2}$, where 'C' is the spring constant, and 'a' is the lattice constant.

Therefore: $v_{sound} = \sqrt{\frac{F}{\rho}} = \sqrt{\frac{Ca/2}{(M_1+M_2)/a}} = a\sqrt{\frac{C}{2(M_1+M_2)}}$ which is consistent with what we have above.

Short wavelength limit

When λ<<a $\Rightarrow$ K >> 2π/a or K→π/a $\Rightarrow \sin\left(\frac{Ka}{2}\right) \to \sin\left(\frac{(\pi/a)a}{2}\right) \to \sin\left(\frac{\pi}{2}\right) = 1$

So: $$\omega_{\pm} = \sqrt{C\left(\frac{M_1+M_2}{M_1M_2}\right) \pm C\frac{\left\{(M_1+M_2)^2 - 4M_1M_2\sin^2\left(\frac{\pi}{2}\right)\right\}^{1/2}}{M_1M_2}} = \sqrt{C\left(\frac{M_1+M_2}{M_1M_2}\right) \pm C\left(\frac{M_1-M_2}{M_1M_2}\right)}$$

For the Optical Phonon branch:

$$\omega_{+(OPTICAL)} = \sqrt{C\left(\frac{M_1+M_2}{M_1M_2}\right) + C\left(\frac{M_1-M_2}{M_1M_2}\right)} = \sqrt{\frac{2C}{M_2}}$$

$$\Rightarrow \quad \boxed{\omega_{+(OPTICAL)} = \sqrt{\frac{2C}{M_2}}} \qquad (14)$$

Group Velocity of ***Optical*** Phonon: $v_{g(OPTICAL)} = \frac{d\omega_{OPTICAL}}{dK} = 0$

(Standing Wave)

Phase Velocity of ***Optical*** Phonon: $v_{p(OPTICAL)} = \frac{\omega_{OPTICAL}}{K} = \frac{a}{\pi}\sqrt{\frac{2C}{M_2}}$

Optical phonon in the Short Wavelength Limit

K→ π/a
or
λ → 2a

For the Acoustical Phonon branch:

$$\omega_{-(ACOUSTICAL)} = \sqrt{C\left(\frac{M_1+M_2}{M_1M_2}\right) - C\left(\frac{M_1-M_2}{M_1M_2}\right)} = \sqrt{\frac{2C}{M_1}}$$

$$\Rightarrow \quad \boxed{\omega_{+(ACOUSTICAL)} = \sqrt{\frac{2C}{M_1}}} \qquad (15)$$

Group Velocity of ***Acoustical*** Phonon: $v_{g(ACOUSTICAL)} = \frac{d\omega_{ACOUSTICAL}}{dK} = 0$

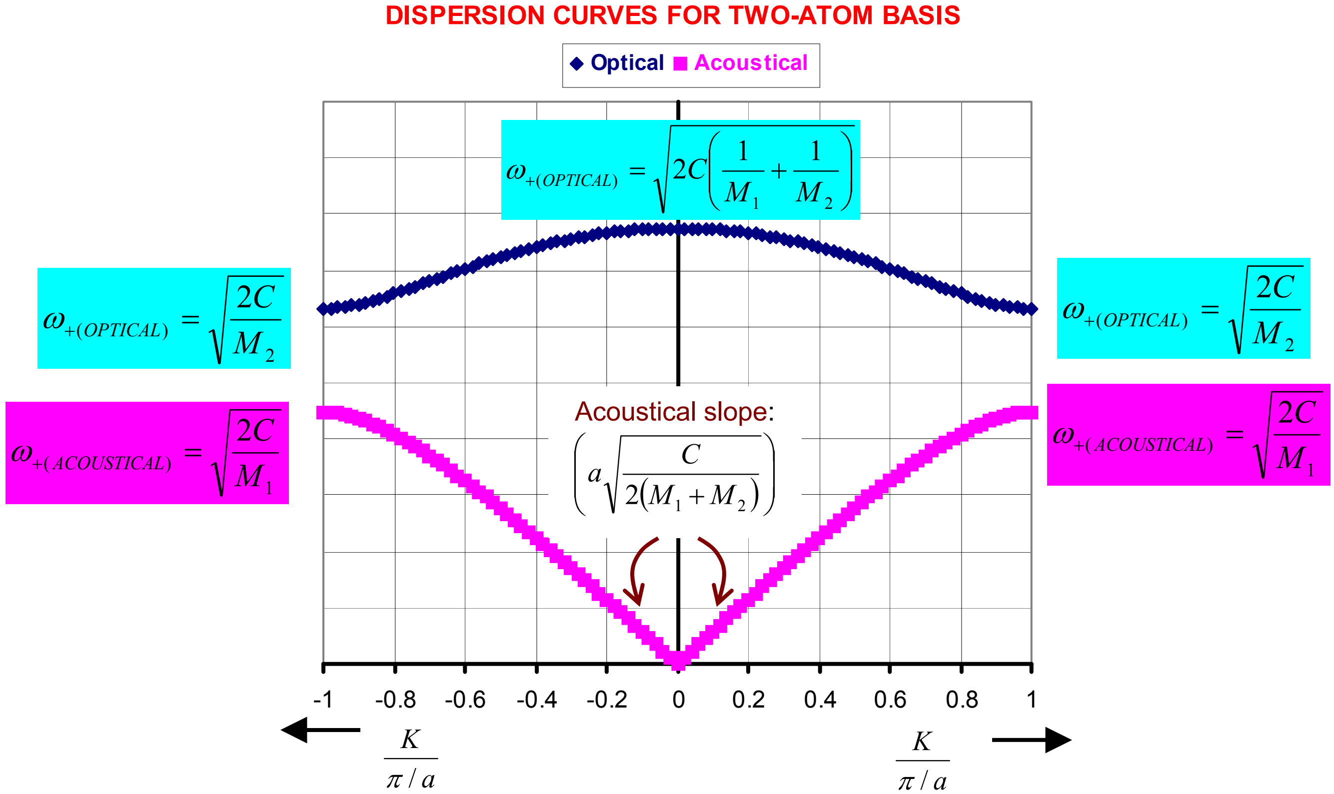
(Standing Wave)

Phase Velocity of ***Acoustical*** Phonon: $v_{p(ACOUSTICAL)} = \frac{\omega_{ACOUSTICAL}}{K} = \frac{a}{\pi}\sqrt{\frac{2C}{M_1}}$

Acoustical phonon in the Short Wavelength Limit

K→ π/a
or
λ → 2a

We can insert these values on the figure, by limiting ourselves to the 1st Brillouin Zone:



There is a physical reasoning underlying the choice of the terms "optical" and "acoustical".

To understand this reasoning let us revisit the long wavelength limit again, because it is in this limit that the physical differences between the optical and acoustical modes are most apparent.

We need to look more closely at the relationship between:

'u' : The amplitude of oscillation of atom "A", and

'v' : The amplitude of oscillation of atom "B"

Since we were focusing on the determinant that did not have these amplitudes, we would need to go back to the equations of motion (4) for masses M_1 and M_2 respectively we have:

$$\left(2C-\omega^2 M_1\right)u - C\left(1+\exp[-iKa]\right)v = 0 \qquad (4a)$$

$$C\left(1+\exp[iKa]\right)u - \left(2C-\omega^2 M_2\right)v = 0 \qquad (4b)$$

Now apply the long wavelength limit i.e. $K \to 0 \quad \Rightarrow \quad \exp[-iKa] \to \exp[0] = 1$

So we get:

$$\left(2C-\omega^2 M_1\right)u - 2Cv = 0 \qquad (15)$$

$$2Cu - \left(2C-\omega^2 M_2\right)v = 0 \qquad (16)$$

We need only one of the above to get us the relationship between 'u' and 'v', so let us use (15)

From (15) we get: $$\frac{u}{v} = \frac{2C}{2C-\omega^2 M_1} \qquad (17)$$

Optical Mode Substitute for *Optical* mode at K→0 derived in (11): $\omega_{+(OPTICAL)} = \sqrt{2C\left(\frac{1}{M_1}+\frac{1}{M_2}\right)}$

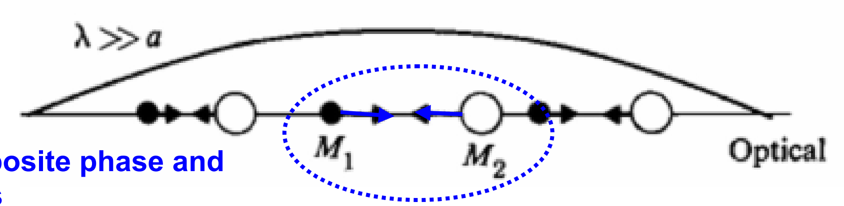
Substituting in (17) we get: $\frac{u}{v} = \frac{2C}{2C-\omega_{+(OPTICAL)}{}^2 M_1} = \frac{2C}{2C-\left(2C\left(\frac{1}{M_1}+\frac{1}{M_2}\right)\right)M_1} \Rightarrow$ $\left.\frac{u}{v}\right|_{OPTICAL} = -\frac{M_2}{M_1}$ (When $\lambda >> a$)

Physical Meaning: According to the mathematical result above, atoms "A" and "B" vibrate such that...

- Their vibrations are *out of phase* (hence the *negative* sign of the ratio u/v)
- The oscillation *amplitudes* are in *inverse ratio of their masses* i.e. the heavier atom vibrates with smaller amplitude than the lighter atom i.e. the *center of mass of the A-B molecule does not move*.

Why is this an "***optical***" mode?

If the atoms A and B are oppositely charged ions e.g. A^+ and B^-, then the type of oscillation physically described above (i.e. out of phase motion of A and B) can be established by an oscillating electric field (rather than a mechanical oscillation). An oscillating electric field is always in conjunction with an oscillating magnetic field, and together they form an E-M wave or light wave. Hence the term *optical*.



M_1 and M_2 have opposite phase and unequal amplitudes

Acoustical Mode Substitute for *Acoustical* at K→0 derived (12): $\omega_{ACOUSTICAL} = \omega_- = \left(a\sqrt{\frac{C}{2(M_1+M_2)}}\right)K$

Substituting in (17) we get:

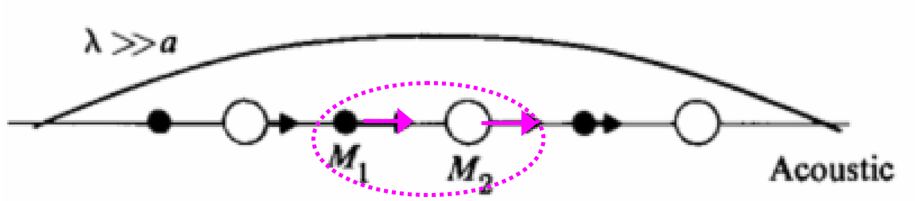
$\frac{u}{v} = \frac{2C}{2C-\omega_{-(ACOUSTIICAL)}{}^2 M_1} = \frac{2C}{2C-\left(\frac{a^2CK^2}{2(M_1+M_2)}\right)M_1}$ But K→0 $\Rightarrow$ $\left.\frac{u}{v}\right|_{ACOUSTICAL} = +1$ (When $\lambda >> a$)

Physical Meaning: According to the mathematical result above, atoms "A" and "B" vibrate such that...

- Their vibrations are *in phase* (hence the *positive* sign of the ratio u/v)
- The oscillation amplitudes are *equal* regardless of their masses i.e. the entire molecule A-B vibrates as a rigid body.

Why is this an "***acoustical***" mode?

The in phase motion of the molecule as a rigid body can be set up by a mechanical oscillation, regardless of the charges of the two atoms in the molecule. This bears a strong resemblance to sound waves (especially in the long wavelength, K→0 limit). Hence the term *acoustical*.



M_1 and M_2 have the same amplitude & phase

Going beyond 1 Dimensional Crystals

So far we have been considering phonons in a 1D crystal. If motion along only one dimension is allowed, then we can have only longitudinal oscillations. However, in more dimensions (2D or 3D) we can have oscillations that are both longitudinal and transverse.

So there can be…

Longitudinal Acoustic (LA) & *Transverse* Acoustic (TA) branches.

Longitudinal Optical (LO) & *Transverse* Optical (TO) branches.

The longitudinal modes of oscillation occur in the direction of propagation of the wave.

The transverse modes can be resolved into two mutually perpendicular directions, both perpendicular to the direction of propagation of the wave. [Analogous to the $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$ vectors of an electromagnetic wave, that are mutually perpendicular, but also perpendicular the direction of the propagation of the wave.]

In general for a solid with an atom that has 'p' basis atoms in 3 dimensions we will have a total of **3p branches** of the dispersion relation, out of which there will be…

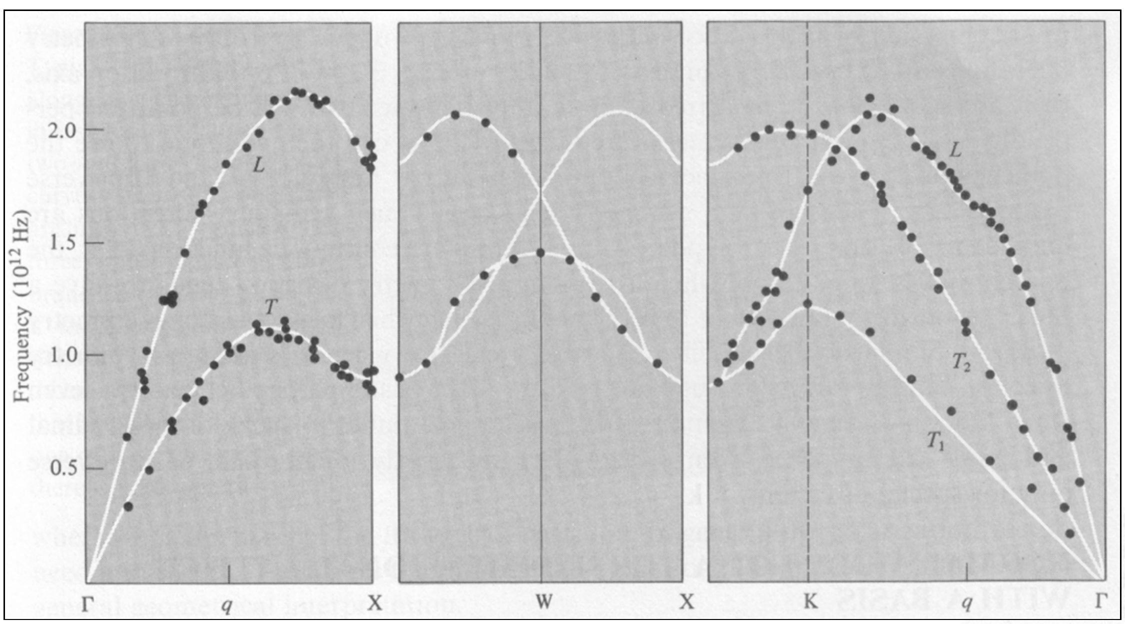
3	***Acoustical*** Branches:	1 *Longitudinal*	+	2 *Transverse*
(3p – 3)	***Optical*** Branches:	(p-1) *Longitudinal*	+	2(p-1) *Transverse*

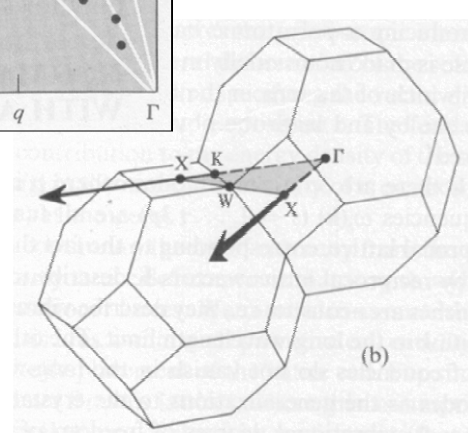
For a crystal with N atoms, each branch has N possible modes of oscillation. Thus there are…

3N	***Acoustical*** Modes	N *Longitudinal*	+	2N *Transverse*
(3p – 3)N	***Optical*** Modes	(p-1)N *Longitudinal*	+	2N(p-1) *Transverse*

It is almost impossible to visualize a graph of the dispersion relation, unless we focus on particular directions of symmetry in K-space. The dispersion relations are *not* necessarily isotropic in K-space i.e. the branches are not symmetric.

The figure below show the dispersion curves for lead (fcc), along three directions in reciprocal lattice space. The three directions are shown in the figure below as the three edges of the triangle.





Name:____

Tutorial 04, Part 2

Q1.) A diatomic 1D solid can be said to behave as a *band pass filter*. Can you explain why? What happens to a wave whose ω is at a mid-range value in this *band?*

Q2) For the 1D diatomic lattice, find the amplitude ratios u/v for the two branches at $K = K_{max} = \pi/a$. Describe the motion of the atoms physically.

PHYS655
3 CREDITS

PHYSICS OF SOLIDS
HOMEWORK 06
DUE: WEDNESDAY, OCTOBER 29

FALL 2003
MWF 10:30-11:20

Note: Change of date from the schedule.

Q1.) Chapter 6, Problem 1 in Kittel.

Q2.) Chapter 6 Problem 3 in Kittel.

Q3.) Chapter 6 Problem 7 in Kittel.

Hints for Part (b):

Use the fact that as per the Wave Equation: $\nabla^2 E = \frac{\varepsilon}{c^2}\frac{\partial^2 E}{\partial t^2}$

Use the generalized solution that : $E = E_0 \exp[i(kz - \omega t)]$ and substitute it into the wave equation above.

Then also substitute: $\boldsymbol{\varepsilon} = 1 + \frac{4\pi i}{\omega}\boldsymbol{\sigma}$ where you recall that: $\boldsymbol{\sigma} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{pmatrix}$

Substitution should give: $\left[c^2k^2 - \left(\mathbf{1} + \frac{4\pi i}{\omega}\boldsymbol{\sigma}\right)\right]\mathbf{E} = 0$

Rewriting this in matrix notation: $\left[(c^2k^2)\mathbf{1} - \left(\mathbf{1} + \frac{4\pi i}{\omega}\boldsymbol{\sigma}\right)\right]\mathbf{E} = 0$

Where $\mathbf{1}$ is the identity matrix.

This gives:

$$\begin{pmatrix} c^2k^2 - 1 - \frac{4\pi i}{\omega}\sigma_{xx} & -\frac{4\pi i}{\omega}\sigma_{xy} \\ -\frac{4\pi i}{\omega}\sigma_{yx} & c^2k^2 - 1 - \frac{4\pi i}{\omega}\sigma_{yy} \end{pmatrix}\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

For the non-trivial solution the determinant of the 4x4 matrix on the left should be zero.

Imposing this condition gives the dispersion relation.

Q4.) Chapter 6 Problem 12 in Kittel.

Some of you do not have this problem in your text, so here it is…

12. ***Density of states—nanometric wire.*** (a) Consider a nanometric wire in the form of a rectangular parallelepiped, with two sides $L_x \approx L_y \approx 1$ nm and the long axis $L_z = 1$ cm. The single particle eigenstates of the system may be written as

$$\psi = \sin(n_x \pi x/L_x) \sin(n_y \pi y/L_y) \exp[i2\pi Nz] \ .$$

The energy of the eigenstate is, with $n = n_x, n_y$:

$$E(n, N) - \epsilon(n) = (2\pi\hbar N)^2/2m = AN^2 = \tfrac{1}{2}mv^2 \ ,$$

where v is the electron velocity along the z-axis. Here $A = (2\pi\hbar)^2/2m$ and $N = \sqrt{[(E - \epsilon/A]}$. Then $\delta E = 2AN\delta N$, show that the density of states D_n at fixed n, with account of the two spin orientations and the two $\pm$ values of N, is

$$D_n(E) = 4\delta N/\delta E = 2/AN = 2/\sqrt{[(E - \epsilon_n)/A]} = 2/\pi\hbar v \ .$$

(b) Sum over the values of n for which $E \geq \epsilon_n$ to show that

$$D(E) = \Sigma D_n(E) = \Sigma(2/\pi\hbar)[1/v(E)]\Theta(E - \epsilon_n) \ ,$$

where $\Theta(x)$ is the Heaviside unit function, zero for $x < 0$ and unity for $x > 0$.

PHYS655
3 CREDITS

PHYSICS OF SOLIDS

EXAM 2

FALL 2003
MWF 10:30-11:20

DUE 5:00PM TUESDAY, NOVEMBER 25
!!FIRM DEADLINE!!

Please Observe the Following Code Regarding this Exam

- You **MAY**:
  - Refer to information in any book, notes, CD-ROM or media.
  - Refer to any material accessible over the internet.
  - Consult with your instructor for this course.
- You **MAY NOT** consult with any person other than your instructor for this course..

Each question is worth 20 points

Q1.) Consider a two dimensional hexagonal lattice of lattice constant a=3Å.

(a) The isotropic sound velocity in this lattice is 1000m/sec. Find the Debye frequency, ω_D.

(b) The crystal has one electron per unit cell. Find the Fermi Energy, ε_F.

Q2.) Atoms are arranged in a one dimensional chain with lattice spacing 'a'. Each atom is represented by the potential: $V(x) = aV_0\delta(x)$

Show that the electron energy E and the wave number k satisfy the relationship:

$$\cos(ka) = \frac{\alpha V_0}{K}\sin(Ka) + \cos(Ka)$$

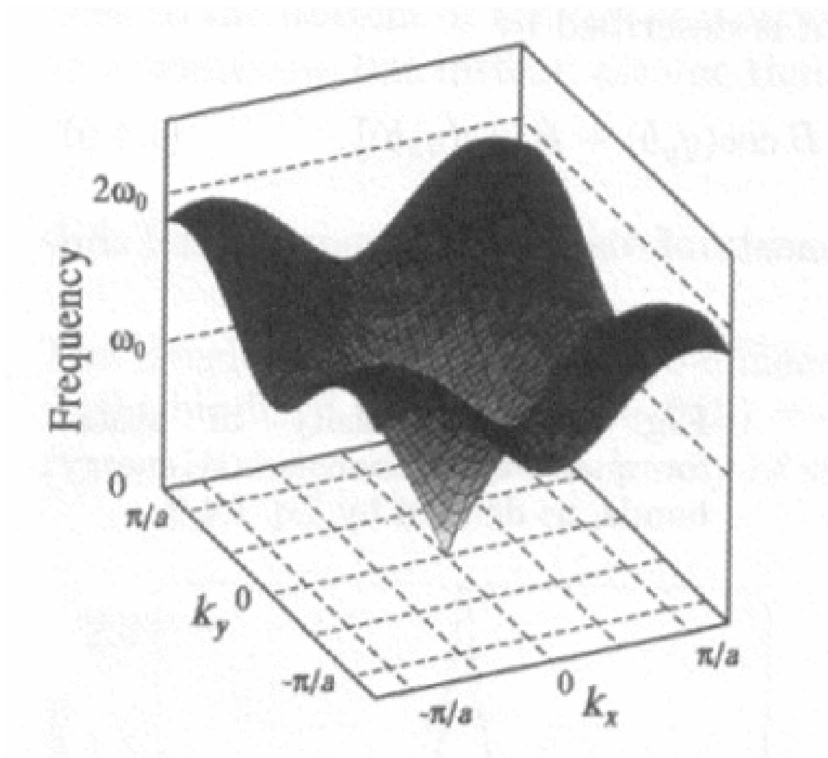
where: $K = \sqrt{\frac{2mE}{\hbar^2}}$ What is α?

Q3.) Consider a two dimensional nearly free electron system on a square lattice of lattice spacing 'a'. The Fourier transform of the weak lattice potential is V_G. We wish to investigate the band structure around the point (π/a, π/a) in the reciprocal lattice. Only **G** = (0, 2π/a) and **G** = (2π/a, 2π/a) components of V_G are important.

Find the energy gap if $V_{(0,\, 2\pi/a)} = 0$ and $V_{(2\pi/a,\, 2\pi/a)} = V_1$.

Q4.) Consider a two dimensional system with a single phonon mode with dispersion relation given by:

$$\omega^2 = \omega_0^2\left[2 - \cos(k_x a) - \cos(k_y a)\right]$$



(a) Use Excel or any other spreadsheet program to calculate the density of states in the valid range of k_x and k_y.

(b) Plot the Debye density of states function.

Q5.) Consider a system of two types of charge carriers in the Drude model. The two carriers have the same concentration (n) and opposite charges (e and −e), and their masses and relaxation times are m_1, m_2 and τ_1 and τ_2 respectively.

(a) Calculate magnetoresistance, $\Delta\rho = \rho(B) - \rho(B=0)$, where B is the applied magnetic field..

(b) Calculate the Hall coefficient.

(c) In an undoped semiconductor, the temperature dependence of the carrier concentration is given by $n = n_0 \exp(-\Delta / k_B T)$. What is the temperature dependence of the magnetoresistance and Hall coefficient.

PHYS655
3 CREDITS

PHYSICS OF SOLIDS

FALL 2003
MWF 10:30-11:20

FINAL EXAM

DUE 5:00PM THURSDAY, DECEMBER 18

!!FIRM DEADLINE!!

Please Observe the Following Code Regarding this Exam

- You **MAY**:
  - Refer to information in any book, notes, CD-ROM or media.
  - Refer to any material accessible over the internet.
  - Consult with your instructor for this course.
- You **MAY NOT** consult with any person other than your instructor for this course.

Each question is worth 25 points

Q1.) Calculate the Gruneisen constant of a linear crystal of lattice constant 'a', if the interaction potential is of the form: $U(x) = U_0 + \frac{1}{2}\kappa x^2 + \lambda x^3$

where 'x' is the difference between the lattice separation 'd' and the equilibrium lattice constant 'a'.

Q2.) Calculate the effective mass tensor in (M_{ij}) for electrons in a simple cubic tight-binding band at the center $(k_x = 0, k_y = 0, k_z = 0,)$, face center $\left(k_x = 0, k_y = 0, k_z = \frac{\pi}{a},\right)$ and corner $\left(k_x = \frac{\pi}{a}, k_y = \frac{\pi}{a}, k_z = \frac{\pi}{a},\right)$ of the 1st Brillouin Zone.

Q3.) In a certain metal the electron dispersion relation around a 'saddle' point (i.e. point of minimum energy E_0 in 3D k-space) is given by: $E(k) = E_0 + \left[a^2\left(k_x^2 + k_y^2\right) - c^2 k_z^2\right]$

Calculate the density of states around the saddle point.

Q4.) A "generic" density of states function that describes an energy gap around the Fermi energy ε_F is given by: $\mathcal{D}(\varepsilon) = \mathcal{D}_0 \frac{|\varepsilon - \varepsilon_F|}{\sqrt{(\varepsilon - \varepsilon_F)^2 - \Delta^2}}$

Where Δ is half the gap between the upper and lower energy band.

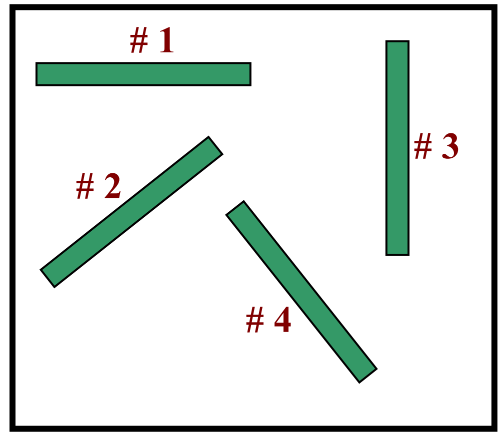
Calculate the leading term in the *change* of the total energy of the electrons as Δ is increased from zero to a finite value i.e. as the gap opens up.

Q5.) Samples are cut from a single crystal specimen in four different directions as shown. The inclined samples (#2 and #4) are both at 45°. Each cut has the same length and cross-section. The width and thickness of each is much less than its length.

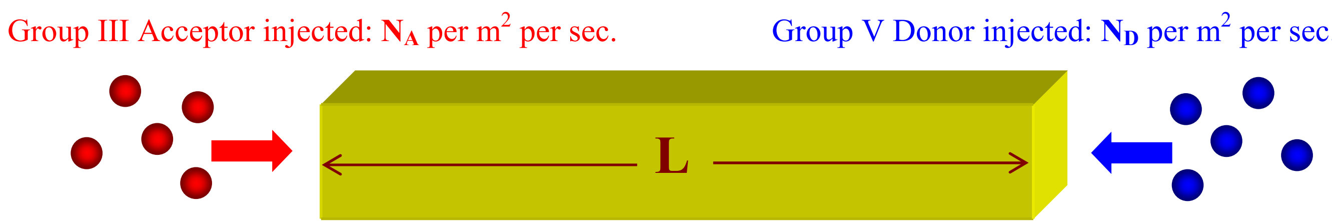
The resistance of samples #1 and #3 are measured and found to be equal $R_1 = R_3 = R$.

The resistance of sample # 2 is $R_2 = \frac{1}{2} R$

What is the resistance of sample # 4, R_4?



Q6.) Consider a sample of semiconductor material shown. It is simultaneously doped from both sides with different dopants as shown.



(a) Find the location of the p-n junction with respect to the left edge of the sample.

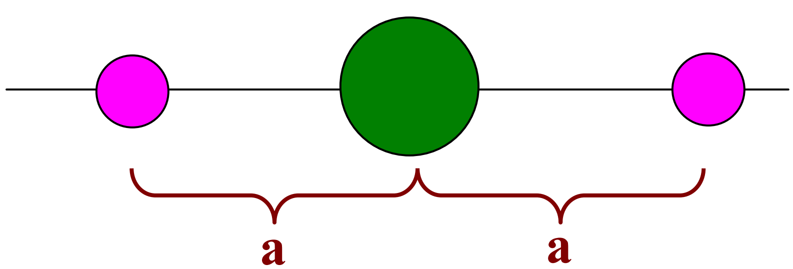
(b) Find an expression for the potential $\phi(x)$, where x=0 is at the left edge.

Q7.) (a) Where does the maximum electric field occur in the depletion region under reverse bias? What is the value of this maximum electric field under reverse bias voltage 'V'.

(b) Estimate the width 'W' of the potential barrier that the electrons must tunnel through in the Zener breakdown process.

(c) Assuming that the tunneling probability contains a factor of the form $\exp(-2\alpha W)$, where α is a constant, find the voltage dependence of the tunneling current.

Q8.) Consider a triatomic molecule shown. Use the tight binding approximation to solve for the time dependent wave functions of the electrons and their allowed energies.



SURVEY REPORT

Summary

Survey Name:
PHYS655: 'Physics of Solids' : Mid-Term Survey

Offering Name:
PHYS655 Mid Term Evaluation Course Offering

A total of **6** people participated in this survey.
100% of the people who received the survey participated.
0 of the people who received the survey opted out.

Number of people who left the survey per page number:

- Opening Page: **6**
- Page 1: **0**
- Page 2: **0**
- Page 3: **0**
- Page 4: **0**
- Page 5: **0**
- Page 6: **0**
- Page 7: **0**

Page 1

Question 1

Please rate each of the following attributes of your instructor pertaining to his INSTRUCTIONAL STYLE in ESTABLISHING A CONDUCIVE LEARNING CLIMATE

1.1 Made course and learning objectives clear at the beginning.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	16.67%
N/R	0%

1.2 Reminded us of the course and learning objectives periodically.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	83.33%
Strongly Agree	16.67%
N/R	0%

1.3 Was well prepared for each class.

Strongly Disagree		0%
Disagree		0%
Neutral		0%
Agree		50%
Strongly Agree		50%
N/R		0%

1.4 Appeared to be interested in teaching.

Strongly Disagree		0%
Disagree		0%
Neutral		0%
Agree		16.67%
Strongly Agree		83.33%
N/R		0%

1.5 Was easily available for help.

Strongly Disagree		0%
Disagree		0%
Neutral		0%
Agree		0%
Strongly Agree		100%
N/R		0%

Question 2

Please rate each of the following attributes of your instructor pertaining to his INSTRUCTIONAL STYLE in FACILTATING YOUR LEARNING

2.1 Explained concepts clearly.

Strongly Disagree		0%
Disagree		0%
Neutral		50%
Agree		33.33%
Strongly Agree		16.67%
N/R		0%

2.2 Was willing to try to explain material in more than one way.

Strongly Disagree		0%
Disagree		0%
Neutral		16.67%
Agree		50%
Strongly Agree		33.33%
N/R		0%

2.3 Stimulated us to think deeply about the material.

Strongly Disagree		0%

Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	16.67%
N/R	0%

2.4 Provided useful comments and feedback about our work.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	50%
Strongly Agree	33.33%
N/R	0%

2.5 Graded fairly and equitably.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	50%
Strongly Agree	50%
N/R	0%

2.6 Was able to sense when we did not understand something.

Strongly Disagree	0%
Disagree	16.67%
Neutral	0%
Agree	33.33%
Strongly Agree	50%
N/R	0%

Question 3

Please make any other comments or suggestions regarding the instructor's teaching style and effectiveness.

- I think the pace of the course has been too strongly emphasized. Comprehension of material should be emphasized more than the amount of material covered.
- He organizes lectures and in class notes better than any instructor that I have ever had in class. He cares deeply about the students success, and is available at any time to help the students. He works very hard, at the compromise of his own personal time and sleep.
- I like the way this class is taught. Early on, we tried to incorporate a few too many methods into classroom learning, and fell behind schedule. Since we have shifted to a more lecture based format, the class has gone more smoothly, and things are going a bit quicker. Despite restricting the format to lectures and graphic demonstrations, the material is gone over in adequate detail, questions are encoraged, and the professor is available after class if more input is needed. Good job.
- Good teaching style but pace should be slow
- It's great to have an instructing who stays around late to ask questions to.

Page 2

Question 4

Please rate each of the attributes for the LECTURES:

4.1 Are clear and easily understandable.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	33.33%
Strongly Agree	50%
N/R	0%

4.2 Help in my physics understanding.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	50%
Strongly Agree	50%
N/R	0%

4.3 Help in understanding the mathematical formalism.

Strongly Disagree	0%
Disagree	0%
Neutral	33.33%
Agree	16.67%
Strongly Agree	50%
N/R	0%

4.4 Are interesting.

Strongly Disagree	0%
Disagree	16.67%
Neutral	0%
Agree	50%
Strongly Agree	33.33%
N/R	0%

4.5 Provide opportunity for questions.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	33.33%
Strongly Agree	66.67%
N/R	0%

4.6 Help me on the homework.

Strongly Disagree	0%

Disagree	0%
Neutral	16.67%
Agree	33.33%
Strongly Agree	50%
N/R	0%

4.7 Help me on the exam.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	16.67%
Strongly Agree	66.67%
N/R	0%

4.8 Appropriately use various tools: projector and board combination is appropriate.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	33.33%
Strongly Agree	66.67%
N/R	0%

4.9 Appropriately use various representations of knowledge: diagrams, equations etc.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	50%
Strongly Agree	50%
N/R	0%

4.10 Balance both qualitative and quantitative reasoning.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	16.67%
N/R	0%

4.11 Get me thinking of things I would not have othewise thought about.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	50%
Strongly Agree	33.33%
N/R	0%

Question 5

5.1 Please rate the pace of the LECTURES

Very slow	0%
Slow	0%
Just Right	33.33%
Fast	50%
Very Fast	16.67%
N/R	0%

Question 6

Do you have any other comments or suggestions about LECTURES?

- Again, the pace of weeks past seemed adequate, but the current pace is too fast.
- I cann't say anything
- At the beginning the material was covered in a rather slow pace, but now, in order to compensate for the lost time, the new lectures are covered far too quickly. The pace at which the class is moving at currently makes it difficult to allow the material to sink in and evaluate the physical processes that are happening in solid state physics
- See Answer to Question 3.

Question 7

If you were to plan and deliver the LECTURES for this class, what would you do differently?

- I would consider leaving a chapter or parts of chapters out of the syllabus.
- yes
- Take more time for each lecture and due dates of homework. Although, he is very flexible about homework due dates which helps out quite a bit
- Possibly include example problems to foster understanding. However, at this level, EVERY problem, except trivial cases, is difficult, and I can see why this may not be a preferable method.
- nothing

Page 3

Question 8

Please rate each attribute for the TUTORIALS

8.1 Aid in my understanding of the material presented in the Lecture.

Strongly Disagree	16.67%
Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	0%
N/R	0%

8.2 Get me to think in ways that I would not have otherwise.

Strongly Disagree	16.67%

Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	0%
N/R	0%

8.3 Prepare me to solve problems that I would not have othewise solved.

Strongly Disagree	16.67%
Disagree	0%
Neutral	0%
Agree	83.33%
Strongly Agree	0%
N/R	0%

Question 9

9.1 Please rate the lenght of the in-class TUTORIALS

Too short	0%
Short	0%
Just Right	83.33%
Long	16.67%
Too Long	0%
N/R	0%

Question 10

Do you have any other comments or suggestions about the in-class TUTORIALS?

- The tutorial lengths are currently just right in length and complexity. Earlier in the semester, they were too long.
- no
- The homework, in-class discussion, lectures, exams, and lab visits provide more than enough evaluation of the course material to truly understand the physical processes of solid state physics. The tutorials cause busy work that can be covered in the homework and personal discussion.

Question 11

If you were to design these TUTORIALS, what would you do differently?

- Nothing at this point.
- May be
- Not give them out

Page 4

Question 12

Please rate each attribute for the HOMEWORK

12.1 Help me gain a deeper understanding of the material.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	16.67%
N/R	0%

12.2 Are based on the material covered in the Lectures.

Strongly Disagree	0%
Disagree	16.67%
Neutral	16.67%
Agree	33.33%
Strongly Agree	33.33%
N/R	0%

12.3 Help me learn about things I would not have othewise learned.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	66.67%
Strongly Agree	16.67%
N/R	0%

Question 13

13.1 Please rate the degree of difficulty of the HOMEWORK problems.

Too Easy	0%
Easy	0%
Just Right	0%
Hard	100%
Too Hard	0%
N/R	0%

Question 14

14.1 Please rate the length of each HOMEWORK

Too Short	0%
Short	0%
Just Right	33.33%
Long	66.67%
Too Long	0%
N/R	0%

Question 15

Do you have any other comments or suggestions about the HOMEWORK

- Sometimes the homework has been too long and too hard (thus the flexible due dates). But this flexible due date isn't a comfort when new assignments are given on a weekly basis (no time to catch up).
- nothing to say, Your help makes everything easy.
- Since the material that was covered recently is more in depth and takes more time to compute, a longer due date would be exceptional.
- Difficult, but not impossible. The starred problems, however, can be very time consuming.

Question 16

If you were to design the HOMEWORK, what would you do differently?

- for the difficult problems (as noted in the book), i would give starting hints or methods to make sure everyone is moving in the right direction.
- I can't say exactly
- Space the due dates out according to the level of difficulty of the actual problems. This is one thing that has not been effectively
- Homework OK.
- maybe not stick to book problems, assign shotrt but qualitatively thorough questions

Page 5

Question 17

Please rate each attribute for the EXAMS

17.1 Help me gain a deeper understanding of the material.

Strongly Disagree	0%
Disagree	0%
Neutral	16.67%
Agree	33.33%
Strongly Agree	50%
N/R	0%

17.2 Was based on the material covered in the Lectures.

Strongly Disagree	0%
Disagree	16.67%
Neutral	33.33%
Agree	16.67%
Strongly Agree	33.33%
N/R	0%

17.3 Helped me learn about things that I would not have otherwise learned about.

Strongly Disagree	0%
Disagree	0%
Neutral	0%
Agree	50%
Strongly Agree	50%

N/R	0%

Question 18

18.1 Please rate the degree of difficulty of the EXAM problems.

Too Easy	0%
Easy	0%
Just Right	16.67%
Hard	66.67%
Too Hard	16.67%
N/R	0%

18.2 Degree if difficulty of EXAM problems compared to the HOMEWORK problems.

Too Easy	0%
Easy	16.67%
Just Right	0%
Hard	16.67%
Too Hard	66.67%
N/R	0%

Question 19

19.1 Please rate the length of the EXAM.

Too Short	0%
Short	0%
Just Right	16.67%
Long	16.67%
Too Long	66.67%
N/R	0%

Question 20

Do you have any other comments or suggestions about the EXAM

- This was way too long to assign in combination with a homework immediately before and after its due date.
- my instructor is very helping so it doesn't create much trouble
- Adjust the exam problems to the level of working alone, the level of the homework, and length of the due date.
- I'm very glad it was a takehome exam.
- Did most of my learning during the exam

Question 21

If you were to design the EXAM, what would you do differently?

- make the problems less complex. either that, or to some extent make it a group quiz.
- I don't know exactly
- make it slightly easier and less time consuming

- Perhaps one question shorter, for the amount of detail inherent in the questions. To finish the problems does not take much time. To finish and UNDERSTAND the problems takes substantial time.
- nothing

Page 6

Question 22

Please rate the Overall Effectiveness of each of these components of the course:

22.1 Lectures

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	0%
Mostly Effective	66.67%
Completely Effective	33.33%
N/R	0%

22.2 Tutorials

Completely Ineffective	16.67%
Mostly Ineffective	0%
Neutral	50%
Mostly Effective	33.33%
Completely Effective	0%
N/R	0%

22.3 Homework

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	16.67%
Mostly Effective	83.33%
Completely Effective	0%
N/R	0%

22.4 Exams

Completely Ineffective	0%
Mostly Ineffective	0%
Neutral	0%
Mostly Effective	66.67%
Completely Effective	33.33%
N/R	0%

22.5 Labs

Completely Ineffective	0%
Mostly Ineffective	16.67%
Neutral	16.67%
Mostly Effective	50%

Completely Effective		16.67%
N/R		0%

22.6 Invited Lectures

Completely Ineffective		0%
Mostly Ineffective		33.33%
Neutral		16.67%
Mostly Effective		33.33%
Completely Effective		16.67%
N/R		0%

Question 23

Please rate the OVERALL EVALUATION of the course for each of the attributes below:

23.1 Overall Teacher Effectiveness

Very Low		0%
Low		0%
Medium		0%
High		33.33%
Very High		66.67%
N/R		0%

23.2 Increasing my desire to learn the material

Very Low		0%
Low		0%
Medium		16.67%
High		50%
Very High		33.33%
N/R		0%

23.3 Amount of material learned.

Very Low		0%
Low		0%
Medium		16.67%
High		33.33%
Very High		50%
N/R		0%

Question 24

24.1 If another physics major is interested in solid state physics and asks you about taking this course, you would...

Strongly Against		0%
Against		0%
Neutral		0%
In Favor of		66.67%

Strongly in Favor of		33.33%
N/R		0%

Question 25

List the top three things that you would like to see CHANGED about this course in the coming weeks

- -less overall work (just reduce it a little bit!) -not assigning lectures to read over the weekend -giving more hints on homework
- Nothing is there
- pace at which the material is covered, lenght of the take home exams shortened, or proportional to the class level, and due date for homework extended. Plus more lab visits. They were awesome
- Perhaps a brief discussion of the homework problems/exam problems on the due date/handback date to clear up any problems students have encountered.

Question 26

List the top three things that you would like to see RETAINED about this course in the coming weeks

- -presentation of lectures (they're great, really) -talking about connections between homework and lectures in class -tutorials are good too
- Everything is going fine
- in class lectures, Sanjay's great work ethich and willingness to help, and overall class environment. It is very relaxed and conducive to learning
- The lectures are amazing. Keep them. Tutorials are good, as well, so long as the time spent on them is minimized.
- I don't think I have much right to suggest changes with the amount of classes I've missed.

- End of Survey -

TEVAL REPORT: STUDENT RATINGS OF INSTRUCTION
Center for the Advancement of Teaching and Learning
Kansas State University

Faculty Member: REBELLO NS **Course No.** PHYS -655 **Term:** FALL 03
Responses from 5 of 6 enrolled (83%) **Hr/Days:** 10:30 MWF
COLLEGE: Arts & Sciences

PART 1. INSTRUCTOR'S DESCRIPTION OF CLASS

A. Type	Lecture
B. Size	About right
C. Physical Facilities	Exceptionally good
D. Previously Taught?	None
E. Changed Approach?	No
F. Teaching Load?	Average
G. Attitude Toward Course	I was really enthusiastic
H. Control of Course	I was responsible for all decisions
I. Diversity in student prep.	A minor problem
J. Student Enthusiasm	Very high
K. Student Effort	Excellent
L. Additional Comments?	No additional comments

	Number Responding: VL	L	M	H	VH	OMIT	SD*	Averages VL=1 VH=5
PART II. RELEVANT STUDENT ATTRIBUTES								
(12) Strong interest in class	0	0	1	3	1	0	0.6	4.0
(13) Worked hard to learn	0	0	0	2	3	0	0.5	4.6
PART III. INSTRUCTIONAL STYLES								
A. ESTABLISHING LEARNING CLIMATE								
(2) Made objectives clear	0	0	1	3	1	0	0.6	4.0
(3) Well prepared	0	0	0	1	4	0	0.4	4.8
(5) Interested in teaching	0	0	0	1	4	0	0.4	4.8
(10) Available for help	0	0	0	0	5	0	0.0	5.0
B. FACILITATING LEARNING								
(4) Explained clearly	0	0	0	4	1	0	0.4	4.2
(6) Stimulated thinking	0	0	0	4	1	0	0.4	4.2
(7) Made helpful comments	0	0	1	3	1	0	0.6	4.0
(8) Graded equitably	0	0	0	1	4	0	0.4	4.8
(9) Sensed confusion	0	0	0	3	2	0	0.5	4.4
PART IV. OVERALL EVALUATION								
A. Obtained responses								
(1) Teacher effectiveness	0	0	0	3	2	0	0.5	4.4
(11) Incr. desire to learn	0	0	0	3	2	0	0.5	4.4
(14) Amount learned	0	0	0	3	2	0	0.5	4.4

B. Averages and Comparative Status	Averages: Raw	Adj(#)	Comparative Status(**): Raw	Adj(#)
(1) Teacher effectiveness	4.4	4.6	HM	HM
(11) Incr. desire to learn	4.4	4.5	HM	H
(14) Amount learned	4.4	4.1	HM	M

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* Standard Deviation
** Relative to KSU classes rated by 10 or more students;
H=upper 10%; HM=next 20%; M=middle 40%; LM=next 20%; L=lowest 10%
# Adjusted for student characteristics & class size; see TEVAL Guide

PHYS655 PHYSICS OF SOLIDS (COMMENTS ON TEVAL)

Sanjay - Great class. I feel I really learned a lot. The teaching method was nonconventional, but I felt it was a success (with a few minor changes during the semester). One problem was the amount of material trying to be covered - 9 chapters in Kittel is still a lot (I think the original plan was 12?). The tests were a little bit too long (A shorter test per 2 chapters might have worked out better), but I still learned a lot from them. The tutorials were occasionally helpful, but sometimes just seemed like busy work.

Sanjay is really very helpful. He is always ready to tell us what we don't know.

Great Lectures and Lecture Notes. Good Qualitative explanations of Quantitative Results. Very Helpful, very knowledgeable in subject matter. Course pace was good although sometimes rushed. Textbook was good but sometimes difficult to understand. Next time, more labs and guest ~~[illegible]~~ lectures.

GOOD CLASS OVERALL, BUT TWO THINGS COULD IMPROVE THIS CLASS FURTHER:

1: A DIFFERENT TEXT.

2: MORE EXAMPLES TO GAIN MATHEMATICAL UNDERSTANDING. EXAMPLE PROBLEMS OFTEN AID MORE THAN OTHER METHODS.

PHYS655 **TEVAL: STUDENT EVALUATION OF INSTRUCTION** **FALL 2003**

ADDITIONAL QUESTIONS

I would appreciate if you could answer these questions in ***addition*** to those given on your TEVAL.
Your answers to these questions will provide me and the Physics Department with useful feedback about this class.
Please **DO NOT** respond to these questions on **THIS SHEET**.
Fill in the bubbles on the backside of the **TEVAL** sheet for Questions **15**-**34**.

Questions **15** through **21**:
Rate the following attributes of the **LECTURES**.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	AVG
15. Are clear and easily understandable.	0	0	0	2	3	4.60
16. Help in my physics conceptual understanding.	0	0	0	2	3	4.60
17. Help in understanding mathematical formalism.	0	0	0	3	2	4.40
18. Are interesting.	0	0	0	4	1	4.20
19. Provide opportunity to ask questions.	0	0	0	2	3	4.60
20. Help me do the homework.	0	0	0	2	3	4.60
21. Help me on the exam.	0	0	0	2	3	4.60
22. Appropriately use projector, board etc.	0	0	0	1	4	4.80
23. Appropriately diagrams, equations, etc.	0	0	0	0	5	5.00
24. Balance qualitative and quantitative reasoning	0	0	0	3	2	4.40
25. Get me thinking about things I would not have otherwise thought of.	0	0	0	2	3	4.60

Questions **26**through **28**:
Rate the following attributes of the **TUTORIALS**.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	AVG
26. Aid my understanding of lecture material.	0	1	1	2	1	3.60
27. Help me solve problems I would otherwise not have solved.	0	1	2	1	1	3.40
28. Get me to think in ways I would not have otherwise thought.	0	1	0	3	1	3.80

Questions **29**through **31**:
Rate the following attributes of the **HOMEWORK**.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	AVG
29. Help me gain a deeper understanding.	0	0	0	4	1	4.20
30. Are based on materials covered in lecture.	0	0	0	4	1	4.20
31. Help me learn about things I would otherwise not have learned.	0	0	0	2	3	4.60

Questions **32**through **34**:
Rate the following attributes of the **EXAMS**.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	AVG
32. Help me gain a deeper understanding.	0	0	0	3	2	4.40
33. Are based on materials covered in lecture.	0	0	1	4	0	3.80
34. Help me learn about things I would otherwise not have learned.	0	0	0	1	4	4.80

THANK YOU FOR YOUR TIME

General Physics-I Recitation (PHYS113)

I was assigned to teach one recitation section in General Physics-I. I had taught recitation in General Physics-II previously, when I was here as a post-doc. Therefore, I was quite comfortable with the format for this course and what the students expected in the recitation.

There were some aspects that were different from my previous experience. The most notable of which was the use of online homework using WebAssign. Students were expected to turn in their homework the day before the recitation section. This meant that students often completed their homework before they came into the recitation section. Several of these students were not interested in the recitation section, because they used to go over the homework in class that had already been completed. Although, I used to focus on the problem solving procedure that could be applied to problems other than the homework problem, they did not find the recitation helpful.

I realized that this was the case, both through anecdotal feedback as well as from the mid-term survey. Therefore, I changed my strategy for the course. Rather than solve homework problems, I solved problems that were different from the homework, but similar enough to be helpful on the exams. As before, I tried to present a strategy that could be broadly applied to several problems and was not specific to the problem at hand. I created Problem Solving Strategy handouts that laid out the strategy as well as an example of how the strategy was applied. Then I displayed the strategy in class using a projector while I solved the problem at hand on the board. This practice was meant to demonstrate how the strategy could be applied to specific problems.

There were some complaints from the students in connection with the differences between the problem strategies that I demonstrated and those that they had learned in the lecture. These differences sometimes resulted in students getting points taken off exams for not following the strategy learned in the lecture and following my strategy instead. In the future, I will make it my responsibility to communicate with the lecture instructor and try to come up with a consistent strategy so that students are not confused by being presented with two methods.

I would like to thank the following individuals for this course:

Dr. Ruma De' for substituting for my class once when I was out of town on official business.

Mr. Zdeslav Hrepic for substituting for my class when I was out of town on two occasions on official business.

Mr. Peter Nelson for setting up the viewing screen for projection in my class, often at short notice.

PHYS113	**GENERAL PHYSICS I -- RECITATION**	*FALL 2003*
21310	***Instructor:*** **N. Sanjay Rebello**	*T 11:30-12:20*

INFORMATION

ROOM & TIME	Room 145, Cardwell Hall Tuesday 11:30 – 12:20
CONTACT INFORMATION	Rm. 503 Cardwell Hall (Note: There is no elevator access above the 4th floor in Cardwell Hall. If you need to use an elevator, please call me and I can meet you in the lobby on the 4th floor of Cardwell.) Phone: [Office] (785) 532 1539 [Home] (785) 537 7543 Email: srebello@phys.ksu.edu (I check my email several times daily)
OFFICE HRS	Mondays: 3:30 – 4:30 PM. Tuesdays: 2:30 – 3:30 PM Feel free to drop by or call me anytime.
REVIEW SESSIONS	I will conduct a review session for this Recitation Section on the **Monday before each exam** from **7:30 to 8:30pm**. (*Except for Exam 3 when it will be on the Thursday, Oct. 23 before the exam, because I will be out of town on Oct. 27-28*) **The room will be announced. Please check K-State Online (See below) for the room announcement prior to each Review Session.**
INFORMATION ON K-STATE ONLINE	I will be posting various materials e.g. **Problem Solving Strategies** for each chapter on **K-State Online**. After logging on to the PHYS113 General Physics I Course website, please click on "**Modules**" and then on "**11:30 Recitation: Instructor – Sanjay Rebello**" to access the materials that I post.

Below is a copy of the information regarding Recitations and Homework which appears your syllabus for this course provided by your course instructor Dr. David Van Domelen.

RECITATIONS

Recitations meet once a week on Tuesdays at various times and in various rooms. Be sure you attend the recitation you enrolled for!

Homework for this course will be submitted electronically via WebAssign.com. You will need to purchase an individual license for this at the copy center when you buy your lab manual. I will be assigning passwords for all of you to begin with, be sure to change your password as soon as possible so that no mischievous sorts try to take over your account. Your ID will be the same as your Kansas State eID (which is also your K-State Online ID).

Homework will be due at 12:01 in the morning the day of Recitation for that homework set. You will have five tries on every problem before the system locks you out and marks the problem wrong. The recitation instructor will go over each problem using the numbers from the textbook, but your own assignment will have randomized numbers unique to you.

Each homework set will be graded out of 6 points, usually one point per problem. Sometimes, however, a problem will be rated at 2 points (these cases are noted in the Syllabus Schedule Excel file). The total score on homework will be scaled up to 200 total points (roughly doubling your points), click on "progress report" in K-State Online to see the scaled-up score. Your recitation instructor will be responsible for transferring scores from WebAssign to K-State Online.

Given that I may be basing some exam problems on homework problems, it would be a good idea to attend recitations and ask questions about anything that you didn't understand (even if you got the right answer!).

PROBLEM SOLVING STRATEGIES:
EQUILIBRIUM PROBLEMS – CHAPTERS 8 & 9

Definition of New Terms

Equilibrium: An object is in equilibrium if
- It does *not move* at all. (*Static* Equilibrium)
- It is *moving at a constant velocity*. (*Dynamic* Equilibrium)

For an object to be in equilibrium, it is not sufficient that all the forces on it are balanced, because even if the forces balance out, they could still make the body rotate. So, we also need to make sure that the body does not rotate i.e. we need to worry about where the forces act,

So, we need to define a new term that takes into account three things:
- What the magnitude force is?
- What point on the body does it act?
- What direction does the force point?

This new term is Torque:

Torque: Torque (τ) describes the "turning effect" of a force.
The magnitude of a torque (τ) due to a force, F acting at a point distant 'r' from the point of rotation is given by:

$$\tau = |rF\sin\theta|$$

Where: r = Distance between point about which body can rotate and point where force acts (in meters)
F = Magnitude of Force (in Newtons)
θ = Angle between a line joining the point of rotation and the line of action of the force (i.e. the force vector.

Torque can be either:
- *Clockwise* : CW (or *Negative*): If it makes the object rotate clockwise.
- *Counter Clockwise*: CCW (or *Positive*) If it makes the object rotate counter clockwise.

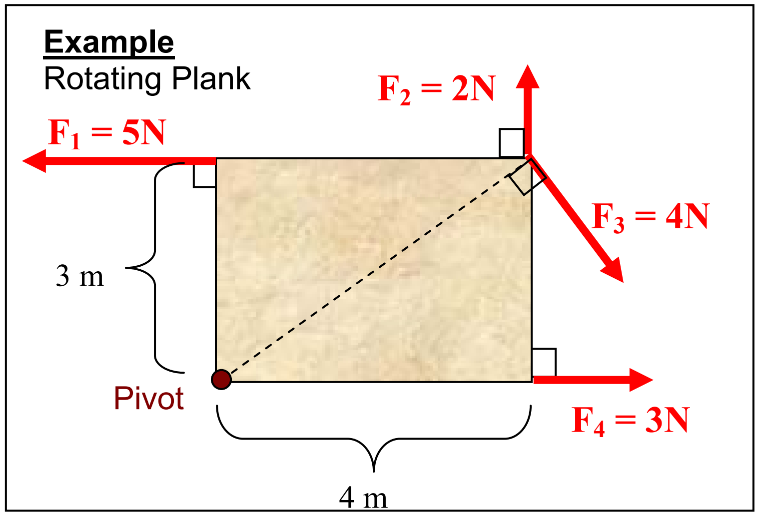
Problem Type: Finding the Net Torque (about a point) acting on an object.

Given:
- Point of rotation of object [NOTE: Torque is *always* calculated about a point. It makes no sense to say, "The torque is ….." You've got to state: "The torque about this point is …."]
- Magnitude of forces F_1, F_2… etc. acting on an object.
- Points of application of these forces.
- Directions in which these forces act.

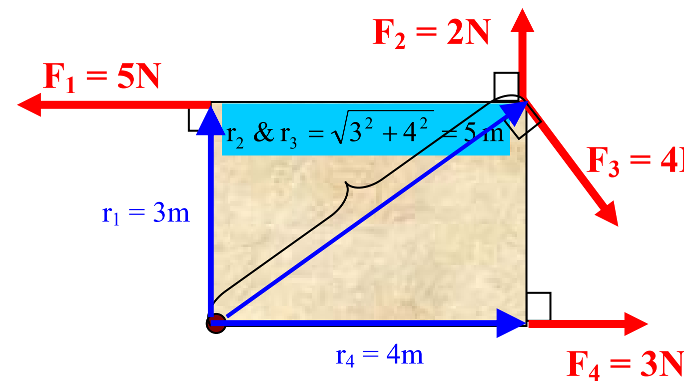
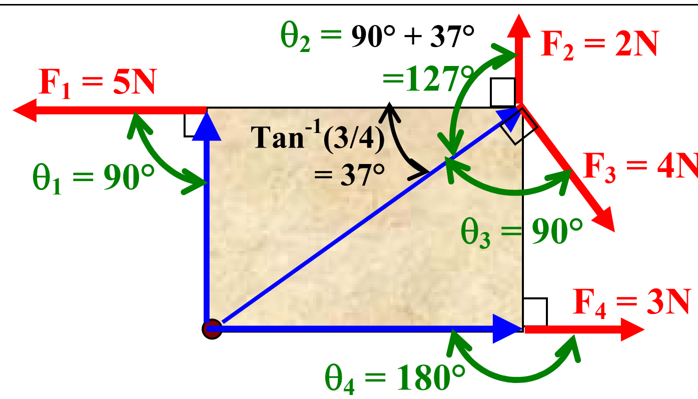
Find:
- Net Torque ($\sum\tau$) acting on the object about the given point of rotation.

Below, we will…
- Describe the step-by-step strategy
- Apply it to a the "Plank Example"

Example: Rotating Plank (See figure):
A rectangular plank of wood (3m x 4m) is pivoted about the bottom left corner. Various forces (see figure) act on the plank. Find the net torque about the pivot point?



Problem Solving Strategy:

Step#: Description of Strategy	***How it applies to the above example***
Step 1: For each force given, find the distance between the point of application of the force and the pivot point. In the example: $r_1 = 3$ meters $r_2 = \sqrt{3^2+4^2} = 5$ meters $r_3 = \sqrt{3^2+4^2} = 5$ meters $r_4 = 4$ meters	
Step 2: Find the angles between the line of action of each force (F) and the line (r) joining each force with the point of application. In this example: $\theta_1 = 90°$ $\theta_2 = 90° + \text{Tan}^{-1}(3/4) = 127°$ $\theta_3 = 90°$ $\theta_4 = 180°$	
Step 3: Calculate the magnitude of torque due to each force, using the formula $\lvert\tau\rvert = \lvert rF\sin\theta\rvert$	$\lvert\tau_1\rvert = \lvert r_1 F_1 \sin\theta_1\rvert$ = (3m) (5 Newt.) (sin 90°) = 15 m Newt. $\lvert\tau_2\rvert = \lvert r_2 F_2 \sin\theta_2\rvert$ = (5m) (2 Newt.) (sin 127°) = 8 m Newt. $\lvert\tau_3\rvert = \lvert r_3 F_3 \sin\theta_3\rvert$ = (5m) (4 Newt.) (sin 90°) = 20 m Newt. $\lvert\tau_4\rvert = \lvert r_4 F_4 \sin\theta_4\rvert$ = (4m) (3 Newt.) (sin 180°) = 0 m Newt.
Step 4: Find the sign (*positive* or *negative*) for each τ, depending upon whether it will tend to rotate the object CCW or CW.	Sign of τ_1 is *CCW*, so *positive*: ⇒ $\tau_1 = +15$ m Newt. Sign of τ_2 is *CCW*, so *positive*: ⇒ $\tau_2 = +8$ m Newt. Sign of τ_3 is *CW*, so *negative*: ⇒ $\tau_3 = -20$ m Newt. Sign of τ_4 is irrelevant because $\tau_4 = 0$.
Step 5: Add the individual torques *with* their appropriate signs to find the net torque and its appropriate sign: + (CCW) or – (CW)	$\Sigma\tau = +15 + 8 - 20$ ⇒ **$\Sigma\tau = +3$ m Newt.** (**CCW**)

Problem Type: **Equilibrium Problems**

Given: A body in *equilibrium*

- Several known forces acting on it (except one or two unknown forces.)
- The location where each of the forces act on the body (except perhaps one of the forces).
- The directions in which the forces act.

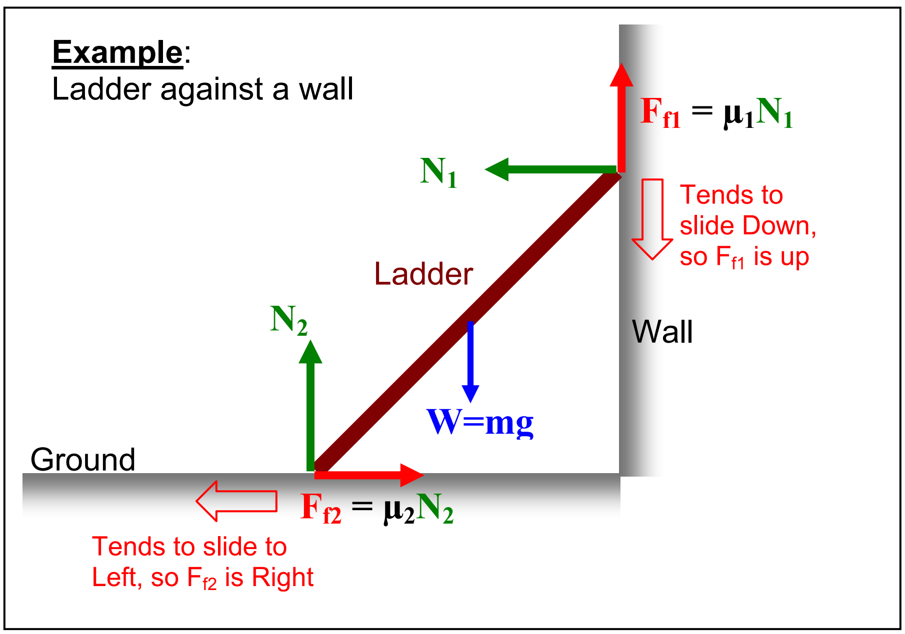
Find: The following…

- The unknown force(s) that are not given above.
- The location where a particular force or forces have to act.

Things to take care about:

Some things that are NOT explicitly given, *but you will be expected to know*:

- Anytime an object rests on a surface it experiences an upward Normal force (N). Two things are important to remember about Normal forces:
  - The Normal Force (N) is *not necessarily* equal to the weight (W = mg) of the object.
  - If there are two or more points of contact where the object rests on a surface (e.g. two legs of a table resting on the ground), then they could experience *different* Normal forces N_1 and N_2.
- The weight (W=mg) of an object ….
  - Always acts vertically downward.
  - Acts from the geometrical center of the body (e.g. at a point L/2 from the left end of rod of length L)
- Whenever there is friction, the force of friction acts at each point of contact.
  - The magnitude of each force of friction is $F_f = \mu N$ (where N is the normal reaction at that point of contact and μ is the coefficient of static or kinetic friction).
  - The direction of force of friction is opposite to the direction in which the object moves or tends to move (For instance, if a ladder resting against a wall is sliding down, then the friction at the point of contact with the ground will be toward the wall, and the friction at the point of contact with the wall will be upward. See Figure).



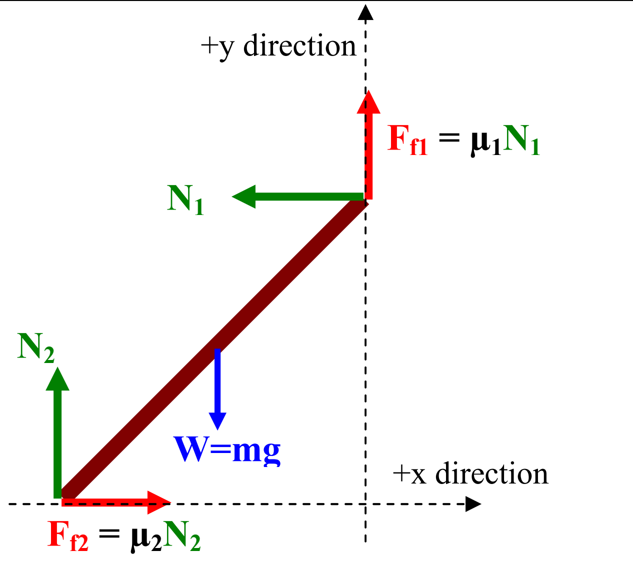
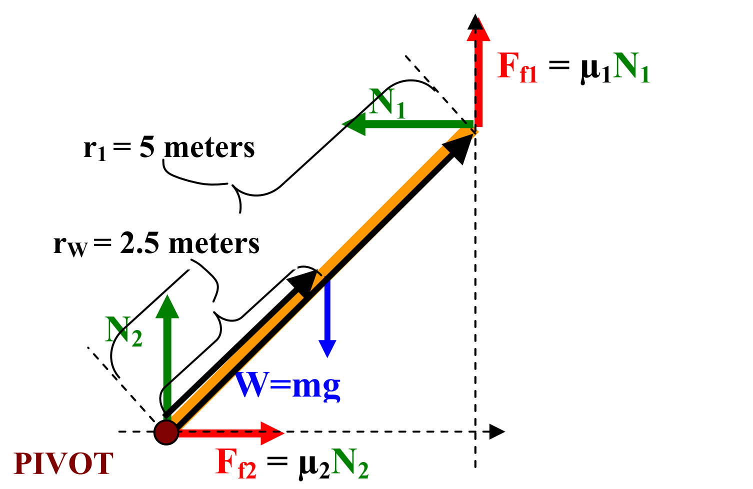
We adopt a step-by-step strategy to solve these types of problems, as described below.

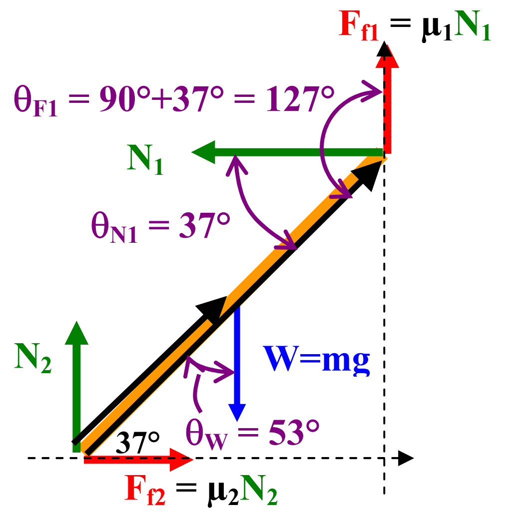
Below, we will…

- Describe the step-by-step strategy
- Apply it to a the "ladder example"

Example: Ladder against a wall (See figure):

A 5 meter long ladder of mass 50kg rests against a wall making an angle of 53° with the ground. The coefficient of static friction between the wall and the ladder is 0.6. What must be the coefficient of static friction between the ground and the ladder, so that the ladder does not slip?

Step#: Description of Strategy	*How it applies to the above example*
Step 1: Draw the free-body diagram. This includes: ➢ The reference +x and +y directions. ➢ All forces labeled with vectors. [At this stage it is okay to label the frictional forces as F_f -= μN]	
Step 2: Write down the force equations in each direction: $\sum F_x = ma_x = 0$ $\sum F_y = ma_y = 0$	$\sum F_x = ma_x = 0$ $\Rightarrow \mu_2 N_2 - N_1 = 0$ equation (1) $\sum F_y = ma_y = 0$ $\Rightarrow \mu_1 N_1 + N_2 - mg = 0$ $\Rightarrow (0.6)N_1 + N_2 - (50kg)(9.8) = 0$ $\Rightarrow (0.6)N_1 + N_2 = 490$ equation (2)
Step 3: Choose a pivot point (about which you will write the $\sum \tau = 0$ equation). [NOTE: It is most convenient to choose point through which most number of *unknown* forces act.]	In this problem foot and the top of the ladder are the two candidates for the pivot point, since • N_2 and F_{f2} act through the foot, and • N_1 and F_{f1} act through the top. Let us choose the **foot** as the pivot point, since we also do not know μ_1 there.
Step 4: Find the distances (r) between the pivot point and each of the points where the various forces act. In this example: r_1 (distance to top edge) = 5 meters. r_W (distance to center of ladder where its weight acts) = 2.5 meters. r_2 (distance to foot of ladder) = 0 m **Because the pivot point IS at the foot of the ladder**.	

Step#: Description of Strategy (Continued)	*How it applies to the above example* (Continued)
Step 5: Find the angles (θ) between line joining the pivot point to the point where the force acts. [NOTE: You do not need to do this for all of the forces. You can ignore the forces that pass through the pivot point, because the 'r' for these forces is zero, and they will not contributed to the torque anyway.] In this example: θ_{F1} (angle between r_1 and F_{f1}) = 127° θ_{N1} (angle between r_1 and N_1) = 37° θ_W (angle between r_W and W) = 90°-37° = 53°	
Step 6: Calculate the magnitude of torque due to each force, using the formula. $$\lvert\tau\rvert = \lvert rF\sin\theta\rvert$$ [NOTE: The torque due to forces that pass through the pivot point will automatically be zero, because 'r' for these forces is zero.]	$\lvert\tau_{F1}\rvert = \lvert r_1 F_{f1} \sin\theta_{F1}\rvert = (5m)(\mu_1 N_1)(\sin 127)$ $\Rightarrow \lvert\tau_{F1}\rvert = (5m)(\mu_1 N_1)(\sin 127) = (5m)(0.6)N_1 (\sin 127)$ $\Rightarrow \lvert\tau_{F1}\rvert = \underline{2.4N_1}$ $\lvert\tau_{N1}\rvert = \lvert r_1 F_{N1} \sin\theta_{N1}\rvert = (5m)(N_1)(\sin 37°)$ $\Rightarrow \lvert\tau_{N1}\rvert = \underline{3N_1}$ $\lvert\tau_W\rvert = \lvert r_2 W \sin\theta_W\rvert = (2.5m)(W)(\sin 53°)$ $\Rightarrow \lvert\tau_{N1}\rvert = (2.5m)(mg)(\sin 53°)$ $\Rightarrow \lvert\tau_{N1}\rvert = (2.5m)(50)(9.8)(\sin 53°)$ $\Rightarrow \lvert\tau_{N1}\rvert = \underline{978.3}$ $\lvert\tau_{N2}\rvert = \underline{0}$ Reason: N_2 passes through the pivot point. $\lvert\tau_{F2}\rvert = \underline{0}$ Reason: F_{f2} passes through the pivot point.
Step 7: Find the sign (*positive* or *negative*) for each τ, depending upon whether it will tend to rotate the object CCW or CW.	Sign of τ_{F1} is *CCW*, so *positive*: $\Rightarrow \underline{\tau_{F1} = +2.4N_1}$ Sign of τ_{N1} is *CCW*, so *positive*: $\Rightarrow \underline{\tau_{N1} = 3N_1}$. Sign of τ_W is *CW*, so *negative*: $\Rightarrow \underline{\tau_W = -978.3}$. Sign of τ_{N2}, τ_{F2} is irrelevant because they are zero.
Step 8: Set up the equation for net torque under equilibrium conditions: $$\sum \tau = 0$$	$\Rightarrow \tau_{F1} + \tau_{N1} + \tau_W + \tau_{N2} + \tau_{F2} = 0$ $\Rightarrow 2.4N_1 + 3N_1 - 978.3 = 0$ $\Rightarrow 5.4N_1 - 978.3 = 0$ $\Rightarrow N_1 = 181.2$ Newt. Equation (3)
Step 9: Solve the two force equations and the torque equation to find the unknown quantities. $$\sum F_x = ma_x = 0 \quad \sum F_y = ma_y = 0$$ $$\sum \tau = 0$$	Equation (1): $\Rightarrow \mu_2 N_2 - N_1 = 0$ Equation (2): $\Rightarrow (0.6)N_1 + N_2 = 490$ Substitute (3) into (2) $\Rightarrow (0.6)(181.2) + N_2 = 490$ $\Rightarrow N_2 = 381.3$ Newt. (4) Substitute (4) into (1): $\mu_2 (381.3) - 181.2 = 0$ $\Rightarrow \mu_2 = 0.475$

TEVAL REPORT: STUDENT RATINGS OF INSTRUCTION

Center for the Advancement of Teaching and Learning
Kansas State University

Faculty Member: REBELLO NS **Course No.** PHYS -113 **Term:** FALL 03
Responses from 24 of 42 enrolled (57%) **Hr/Days:** 11:30 T
COLLEGE: Arts & Sciences

PART 1. INSTRUCTOR'S DESCRIPTION OF CLASS

A. Type	Lecture
B. Size	About right
C. Physical Facilities	Satisfactory
D. Previously Taught?	None
E. Changed Approach?	No
F. Teaching Load?	Average
G. Attitude Toward Course	I was really enthusiastic
H. Control of Course	Some decisions made by dept. committee
I. Diversity in student prep.	A minor problem
J. Student Enthusiasm	Mixed; both high and low
K. Student Effort	Satisfactory
L. Additional Comments?	

	Number Responding						SD*	Averages
	VL	L	M	H	VH	OMIT		VL=1 VH=5
PART II. RELEVANT STUDENT ATTRIBUTES								
(12) Strong interest in class	1	7	12	2	2	0	0.9	2.9
(13) Worked hard to learn	2	1	4	11	6	0	1.1	3.8
PART III. INSTRUCTIONAL STYLES								
A. ESTABLISHING LEARNING CLIMATE								
(2) Made objectives clear	1	0	3	6	14	0	1.0	4.3
(3) Well prepared	0	1	1	3	19	0	0.7	4.7
(5) Interested in teaching	1	0	1	4	18	0	0.9	4.6
(10) Available for help	1	0	1	4	18	0	0.9	4.6
B. FACILITATING LEARNING								
(4) Explained clearly	1	0	1	4	18	0	0.9	4.6
(6) Stimulated thinking	0	2	1	11	10	0	0.9	4.2
(7) Made helpful comments	0	1	3	10	8	2	0.8	4.1
(8) Graded equitably	0	0	4	6	13	1	0.8	4.4
(9) Sensed confusion	0	0	5	9	10	0	0.8	4.2
PART IV. OVERALL EVALUATION								
A. Obtained responses								
(1) Teacher effectiveness	0	1	1	6	16	0	0.8	4.5
(11) Incr. desire to learn	0	2	7	11	4	0	0.8	3.7
(14) Amount learned	0	1	9	12	2	0	0.7	3.6

	Averages		Comparative Status(**)	
	Raw	Adj(#)	Raw	Adj(#)
B. Averages and Comparative Status				
(1) Teacher effectiveness	4.5	4.8	HM	H
(11) Incr. desire to learn	3.7	4.1	M	HM
(14) Amount learned	3.6	4.0	LM	M

* Standard Deviation
** Relative to KSU classes rated by 10 or more students;
H=upper 10%; HM=next 20%; M=middle 40%; LM=next 20%; L=lowest 10%
# Adjusted for student characteristics & class size; see TEVAL Guide

PHYS113 GENERAL PHYSICS – 1 RECITATION (COMMENTS ON TEVAL)

Sanjay is a very good recitation instructor. He takes time to write out things on the board that other instructors usually just verbalize, which makes it easier to follow along. I love the colored chalk that he uses - it makes problems that are complicated more visually conceivable. The problem solving strategies he uses are a good idea.

This is definatly the best recissation I have ever been in! Sanjay is an AWESOME teacher! He was always very kind & understanding & more than willing to help out whenever needed! His use of color on the board & his steps were very useful. If it hadn't been for him I would have never passed physics. He is very good & organized about sending out useful emails. It is obvious he cares about the sucess of his students & how well they do in class! I would definatly recommend him to anybody! Thank you Sanjay! -Andi Holste

Rebello was an excellent instructor, however I'm not even in his recitation. I come to his instead of the other one b/c the other recitation teacher is too hard to understand and she doesn't care about her students. Rebello is committed to helping his students learn and do well.

Thank you for taking the time and effort to help your students. I only succeeded in this class because of your help. Everything you did was very helpful. The review sessions helped us out a lot. You make a great teacher.

Sanjay saved me in physics. Without him explaining things so I understand, I would be lost or no longer in this class. He went above + beyond the requirements for a recetation instructor and I thank him for that. I know he is so appreciated by everyone - not just his recetation class. Sanjay was my teacher this semester.

SANJAY DID A TERRIFIC JOB. IT HELPED ME WHEN HE WROTE OUT EVERY STEP AND EXPLAINED WHY HE DID CERTAIN STEPS. THE PROBLEMS AND ANSWERS POSTED ONLINE WAS A VERY GOOD STUDY GUIDE, AS WELL AS THE REVIEW SESSIONS. WE HAD SUBSTITUTES TWICE, AND THEY HELPED ME TO REALIZE HOW GOOD SANJAY DID. IF HE WOULD HAVE TAUGHT THE LECTURE, I COULD HAVE UNDERSTOOD SO MUCH MORE.

Wonderful teacher, so helpful & thoughtful! One of my top 3 teachers ever.

The reviews & the online help pages helped me much more than anything in the lecture.

I think that you have done a very good job of teaching the material and explaining the things we didn't understand. you made an extra effort to make more material available to us by posting things on-line and solving extra problems. I really appreciate that because it helped me alot. I definitely think I learned more from you than I did my lecture teacher and I wish you could be the lecture teacher as well as the recitation teacher. Thank you.

- Recitation needs to happen before homeworks are due. Maybe homework due on Thursday - that is a major point in going to recitation.
- One constructive remark for Sanjay, sometimes he dwells on the steps and doesn't get to the point quickly -- however I would rather have it this way as opposed to having huge gaps in problem solving procedure.
- I like Sanjay very much. He does not make you feel stupid, he is genuinely interested in seeing students succeed.
- Sanjay needs to teach more recitation sections so that more people have access to him!
- The reviews are essential and the lecture hall is the best place for them.

[redacted] - Sanjay is Excellent!

I think there should be more communication between the rec. instructor & the lecture instructor. There were times when it was confusing or even contradictory! Example: I lost pts. on an exam b/c I worked a problem like the rec. inst. & not like the lecture inst. Also, at times I did not feel prepared for exams b/c the rec. inst. stressed pts. that were not even discussed in lecture or visa versa.

As a student, I am very grateful for Sanjay's willingness to help me out personally outside of class. I have learned the most about physics through his way of teaching.
He is by far, the best recitation instructor that I have ever had. I believe it is his enthusiasm & willingness to help others that counts the most.

Overall, I think Mr. Rebello is an outstanding teacher. He realizes where students are in their understanding and uses different methods (detailed) to get students mentally prepared for present & future material.

I felt like I learned much more in this course by going to recitation as compared to going to lecture. Sometimes I was confused on the tests because the test problems always seemed to be different than anything gone over in lecture and recitation. Going over problems in recitation that are more similar to test problems would help a lot. I felt like the underlying concepts were not explained thouroughly in recitation, but that was also the case in lecture.

Without this recitation, physics would have gone very badly for me. The only thing that could have been better is having it twice a week! Thank you for your effort, you helped a lot of people.

Sanjay was an amazing teacher. He was always very clear about what we were covering and was very clear when explaining strategies to solve problems. He was always willing to give extra help. The review sessions he had helped out tremendously. Without Sanjay as my instructor, I would probably have dropped Physics. I feel Sanjay willingly went beyond his duty in helping students understand Physics. He is a great teacher!

Sanjay is an excellent instructor who really puts a lot of time into making sure the students get plenty of review and have many resources to help them learn. I really enjoyed him as a teacher.

This recitation helped me greatly to understand the material. I think you could cover more problems in recitation if you didn't take the time to be so thourough. The use of colored chalk on the initial diagrams was helpful, but a little too time consuming afterward. I did think the extra problems were extremely helpful in increasing my understanding

PHYS113-RECITATION SECTION 3 (T 11:30) **FALL 2003**

TEVAL: STUDENT EVALUATION OF INSTRUCTION

ADDITIONAL QUESTIONS

I would appreciate if you answer these questions in *addition* to those given on your TEVAL.
Your answers to these questions will provide me with some useful feedback about my teaching.
Please DO NOT respond to these questions on **THIS** SHEET.
Fill in the bubbles on the backside of the TEVAL sheet for Questions 15-34.
Please use the scale shown below to fill in the bubbles, except for Questions 33 & 34.

①	②	③	④	⑤
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Thank you for your time

15. I was able to clearly understand the instructor's accent, and what he said in recitation.
16. I was able to clearly read and understand what the instructor wrote on the black board.
17. I was able to clearly read and understand what the instructor projected from the computer screen.
18. The instructor enabled me to learn the material through the use examples and illustrations.
19. I had adequate opportunity to *ask* questions or clarifications of the instructor *in* recitation.
20. I had adequate opportunity to *think* and *answer* questions that were posed in the recitation.
21. I did not hesitate to interact with the instructor *outside* of recitation (via email, office hours etc.)
22. The use of K-State Online made it easier for me to access the material in this recitation.
23. I found the *homework problems solutions* posted online to be helpful in enabling me prepare for the quizzes.
24. I found the *problems solving strategies* & *reviews* posted online to be helpful in enabling me prepare for the quizzes.
25. I found the *instructor's solving the problems on the board* in recitation helpful in enabling me to *understand the underlying concepts*.
26. I found the *instructor's solving the problems on the board* in recitation helpful in enabling me to develop my *problem solving skills*.
27. I found the instructor's *going over variations* to the assigned problem to be helpful in understanding the *underlying concepts*.
28. I found the instructor's *going over the variations* to the assigned problem to be helpful in developing my *problem solving skills*.
29. I found the *review sessions* before the exams to be helpful in enabling me to do well on the exams.
30. I found the solving of recitation problems *other than* the homework problems to be useful to my learning.
31. The instructor chose problems (other than the homework) that were at the *appropriate level of difficulty*.
32. The instructor successfully integrated the homework problems and the concepts.

For Questions 33 & 34 questions below, please use the scale shown

①	②	③	④	⑤
Bottom 10%	Next to Bottom 25%	Middle 30%	Next to Top 25%	Top 10%

33. Overall, among *all* of the classes that I have taken in college (K-State or elsewhere), I would you rate this recitation among the _______. [Use the scale above to fill in the bubbles]
34. Overall, among *all of the science classes* that I have taken in college (K-State or elsewhere), I would rate this recitation among the _______. [Use the scale above to fill in the bubbles]

PHYS113-RECITATION SECTION 3 (T 11:30) **FALL 2003**

TEVAL: STUDENT EVALUATION OF INSTRUCTION

STUDENT RESPONSES TO ADDITIONAL TEVAL QUESTIONS

PART E. ADDITIONAL QUESTIONS

	Number Responding						Averages
	VL	L	M	H	VH	OMIT	(VL=1; VH=5)
(15)	0	0	0	11	13	0	4.54
(16)	0	0	0	5	19	0	4.79
(17)	0	0	0	8	16	0	4.67
(18)	0	0	2	4	18	0	4.67
(19)	0	0	0	8	16	0	4.67
(20)	0	0	3	11	10	0	4.29
(21)	0	0	4	9	11	0	4.29
(22)	0	0	1	7	16	0	4.63
(23)	0	1	6	5	12	0	4.17
(24)	0	0	5	6	13	0	4.33
(25)	0	0	1	5	18	0	4.71
(26)	0	0	1	12	11	0	4.42
(27)	0	0	1	7	16	0	4.63
(28)	0	0	3	9	12	0	4.38
(29)	0	0	3	6	15	0	4.50
(30)	0	0	3	7	13	1	4.43
(31)	0	0	2	9	13	0	4.46
(32)	0	0	1	6	17	0	4.67
(33)	0	1	2	4	17	0	4.54
(34)	1	0	2	6	13	2	4.36