Example Essay Questions

Below are examples of essay questions that have been asked as part of the *New Model Course in Applied Quantum Physics*.

Explaining devices and experiments

- The photoelectric tube we studied in class last week has some unusual properties as a circuit element, including behaving for some voltages as if it had a negative resistance". (Note: By "negative resistance" I mean that for some values of V, "R" = V/I is negative. On our IV curve for the phototube we actually had positive current at a slightly negative voltage.) What is the difference between what is happening to the conduction electrons in the photoelectric tube as compared to what happens to them in a resistor?
- Describe briefly Rutherford's experiment probing the structure of the atom and explain why the result was a surprise.
- A researcher tells you that within a 10 second window, a single electron will hit the television screen you are viewing. Sure enough, there is a flash within that time window. The researcher told you nothing else, though, and so you don't know the experimental setup being used. You only know that she has a gizmo that allows the release electrons at long time intervals. Do you know if that electron went through a two-slit interference apparatus or if it was simply shot at the screen? Explain how you arrive at your answer.
- An electron and a proton of identical energy are incident on the same potential barrier. If the probability of transmission for the electron greater than, less than, or equal to the transmission probability of the proton? Explain how you arrived at your answer.
- What is the difference between a conductor and an insulator? Give experimental evidence for the descriptions that you give, and try to account for these descriptions using a microscopic model of the material.
- Based on the model we have been describing in class, how could you account for the difference between a conductor and a resistor... Explain.

- How, if at all, can you account for the different conductivity values of different types of metals? Does copper conduct better, or does iron? How do you know? Explain how you think about the situation.
- An LED (light emitting diode) is a device like the one in your VCR remote control and many other appliances. When observed, it seems to shine in only one color. Is there a filter in the glass or is it a property of the device? Explain how you could account for the observation, based on what you know about the device. If you don't know anything about LEDs (I'm guessing that's the case for many of you), tell me, and then STILL try to figure out what might be going on. Use your everyday physics thinking on this one, if you don't know the formal response...
- We have talked about the LED and we have talked about polarization of metals. Compare and contrast the two. Compare the "current" electrons in the case of the LED and the polarized metal. What are the similarities and what are the differences? How do you know? Explain in as much detail as possible.

Interpreting representations

- Consider the n=1 and n=2 states of an electron located in an infinite square well potential. You know that the electron is in one of those two energy levels, but you don't know which. In making a measurement of the particle's location one afternoon in the lab, you find the following: it's located exactly in the middle
  of the well.
  a) how can you account for this? what do your measurements tell you about the energy of the electron?
  b) you repeat the experiment. What do you expect to find this time?
  Explain.
- Often, wave functions and potential barriers are shown on the same graph (the text does this a lot). Is it possible for a particle described by a wave function whose crest is LESS than

the height of a square potential barrier to be transmitted through a barrier? Explain.
- In class we discussed the probability of finding a particle in one or the other well, when two wells are placed close to each other. If we placed TWO particles in the two wells at the lowest possible energy and assumed that they don't interact with each other, what then? Describe the probabilities of finding the particles in well L (left well), well R (right well), or both wells. How did you arrive at your answer? (note: This calls on you to interpret the wave function pictures drawn in class, and what the various plots mean... do the best you can to describe things verbally, if at all possible.)

Discussing open-ended issues - fishing expedition questions

- Do you think a photon is more like a wave or more like a particle? Explain why you think so.
- In the infinite square well potential, there are often places (in excited states) where the probability of finding a particle is zero. Does that mean that a particle can't move through that location? Explain (i.e. explain how we can measure the location in one probable area, then later measure it in another probable area separated by a place where the probability was zero).
- You have a friend taking this class at another university, and her class is slightly ahead of this one. She calls you up one day and says, "You won't believe my crazy prof, he's so funny and always has us laughing. It's the greatest. But you know what he told me? He said that there's nothing we can do about it, quantum mechanics is the real way of thinking about the world, and all that stuff we learned in our intro classes was all wrong." What do you tell her, should she agree with the prof or not? Do you? Back up your answer with examples from your previous studies of physics.
- When did you first learn about electrons and that electrons were particles which were parts of atoms? Elementary school, high school, college? From teachers, from magazines, from TV? Do you even remember when you learned it? How do you know that it's true? This is one of those questions to help me see where you stand, so you don't have to say too much. I'm

just curious when and how you learned some of the things you're bringing to class.

- A friend of yours is taking a class like this one at another school. She calls you up one day and you get to talking about your classes. She says, "we just talked about the probability of finding particles in a potential well, and I think I figured it out. Whaddya think, the particle is always located somewhere, but we sometimes simply can't measure it. Even if we're not always paying attention to it, it's still located somewhere, right? That makes sense to me..." What do you tell her? Do you agree? disagree? Be as thorough and explicit as possible.
- A friend (not the same one who has stopped calling you, a different one...) talks to you in the hallway of the student union. You're being nerdy and talking about conduction in wires. He says the following, "When I have a wire, and it's not in an electric field or anything, it doesn't have any current, so there are no free electrons. There aren't any in the wire until an electric field, you know, a voltage or something, is on the thing. Then you get free electrons." Does his thinking agree with yours? How is it similar, how is it different? If it is similar, explain in more detail what your friend might be saying. If it is different, explain how you think about the existence of free electrons in a metal.
- A friend in your math class tells you that when doing quantum mechanics you don't have to think about classical things at all. It's either quantum or it isn't. When you do quantum, you just have to toss your intuition out the window and let the math and the weird stuff take over. Rather than simply reacting to this statement, I want you to give me TWO examples. As part (a), give me an example where your friend is CORRECT, and you had to suspend all understanding of classical mechanics in order to think about the quantum physics. In part (b), give an example where your friend is INCORRECT, and you had to use your classical reasoning to help you with the quantum mechanics.

Relating quantum physics to classical physics

- We often talk about the "probability" that something might happen. a) Give some examples from real life, and some examples from physics. For example, we could talk about the probability of events in classical physics (what's the probability that something is within 5% of its peak height?), but we often don't. Why is that? b) Why should we think about probability in the case of quantum mechanics and the physics of the very small?
- The Heisenberg uncertainty principle is a fundamental quantum principle. Would you expect there to be something similar for sound waves? analog electrical signals sent over a wire (standard telephone)? Explain why or why not.
- Suppose that the electron in the hydrogen atom obeyed classical mechanics rather than quantum mechanics. Why should this hypothetical atom emit a continuous spectrum rather than the observed line spectrum? Explain.
- The Bohr model is based on several assumptions. Discuss them and discuss their significance. Specifically, point out those that contradict classical physics, and how they do so.
- A large particle (i.e. use classical physics) is located in an infinite potential well made up of two very hard walls. In other words, the particle is bound and will be located between the two walls. The question is, what are the forces acting on the particle at any given time? Where is there an acceleration and what direction are the forces on the particle? Explain.
- When we think about a particle in a box (i.e. an infinite square well), we find that the squared-momentum (i.e. p^2) has distinct and constant values, while the momentum itself (i.e. p) does not. Explain how this can be, and draw parallels to the classical motion of a particle.

Extending and interpreting lessons from the classroom

- In the tutorial on Friday, we discussed how to localize an electron in space (somewhat) at a fixed instant of time. If we want the electron to move in the +x direction, how would we modify what we have done? What determines the speed of each of the component waves and what determines the speed of the electron?

- To describe a localized electron traveling through space, we have to think of many different values of k (meaning many different values of p). In the tutorial, we described an electron and its location at a fixed moment in time (i.e. t=0 in an equation of both x and t). How would we have to change the equations we wrote in the spreadsheet to take time into account? Would the velocity of each term of our wave be the same? Explain.
- If you made observations on a series of electrons each of which was in a state with wavefunction psi, how would you calculate the average momentum that you would measure?
- Richard Feynman, a famous physicist, once said that "electrons arrive in lumps, like particles, but the probability of arrival of these lumps is determined as the intensity of the waves would be. It is in this sense that the electron behaves sometimes like a particle and sometimes like a wave." Elaborate on this in your own words, including examples from how light behaves. I expect that you'll return to the tutorial for your response.
- An electron bound in an atom has both a kinetic energy and experiences a force so it has a potential energy. Consider the electron's kinetic, potential, and total energies. Are they positive, negative, or zero? Explain how you arrived at your answers.
- In an infinite well, a particle is bound to a fixed region in space. Imagine that it is moving back and forth with a kinetic energy, KE. Consider this particle's total energy. Is the total energy positive or negative? (hint: Does your answer depend on the value of the potential energy? how do we determine that? where is the PE zero?)
- For a quantum mechanical particle moving under the influence of a finite, localized potential, we refer to negative energy states as "bound". Why? Give as much detail as possible about such a state (i.e. about things that are always true for such a state, no matter the shape of the well). Also, describe the sign of other states of the system...
- In discussing the three-dimensional box, we end up with an equation for psi with three directions and time, also. Consider that the wave function starts in the ground state. A change is made to the system (energy is added), and the wave function

in the x direction changes. What effect, if any, does this have on the wave function in the y direction? Explain how you think about the situation.
- In this week's homework, we are using the energies of photons emitted by a system to tell us something about the character of the system. When we observe photon energies emitted by a system, what kind of energy of the system is relevant?

Listening to general commentary

- As you have studied for the exam, you have most likely encountered ideas that caused you great difficulty. Please tell me which idea or concept has been most difficult to understand and why it has caused you problems. Be as verbose as you'd like, but don't be too brief...
- In the previous question, I asked you to talk about an individual topic from the class, but in this question, I'm asking you to evaluate your overall knowledge of the material. You probably expect (or hope) to get a certain grade on this exam, and I've found that people are usually good (well, excellent) at knowing how to evaluate themselves. How do you think you will do on this exam? Explain why you think so.
- You have been doing a lot of reading on your own, doing homework on questions that I haven't even talked about in class, and so on. Could you comment on this style of learning the material? The question gets to the issue of "do you mind having this be like a literature class, where I assume you are doing the reading?"
- Many of you have covered topics like semiconductor physics and so on in other classes. Could you please tell me (using names, not numbers, since I don't know those for EE and ChemE and all) in which classes you have discussed band diagrams, charge flow, current, transistors, and so on.