APPENDIX B

Interview Protocol (Spring 2009)

(Possible follow-up questions in parentheses)

BACKGROUND INFORMATION (name, declared major, previous physics and mathematics courses, both at CU and in high school, motivations for enrolling in the course)

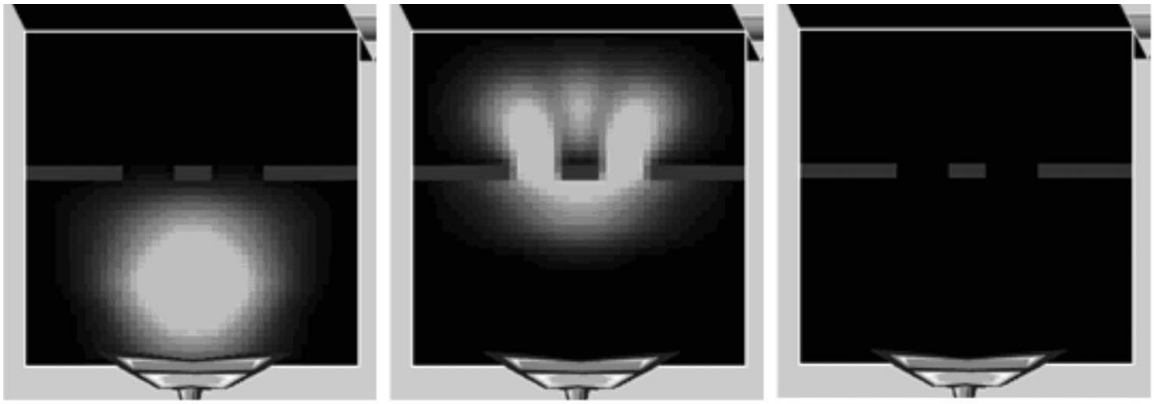
ASK STUDENTS TO DESCRIBE AN ELECTRON

DESCRIBE AN ELECTRON IN AN ATOM
(Do students use a planetary model as a first-pass description? Are students aware of the limitations of the Bohr model? Do electrons move in orbits as localized particles? Does the student describe the electron in terms of an *electron cloud*, or a *cloud of probability*? What is this cloud? Does it represent something physical, or is it a mathematical tool? If the electron is described as a wave, what is it that's waving? Is there something moving up and down in space?)

RESPOND TO THE STATEMENT:
An electron in an atom has a definite but unknown position at each moment in time.
IN AGREEMENT OR DISAGREEMENT AND EXPLAIN REASONING
(Is the student's response consistent with their earlier descriptions of atomic electrons?

DESCRIBE THE SETUP FOR THE DOUBLE-SLIT EXPERIMENT
(What is observed? Can the experiment be run with both light and electrons? What is observed when only single quanta pass through the apparatus at a time? What happens if you block one of the slits? What happens if you place a detector at one of the slits to see which slit individual quanta passed through? How do students explain the fringe pattern? If they explain the experiment in terms of localized particles, what is the source of interference? If they prefer a wave-description of quanta, how did the student explain why single quanta are detected as localized points? Is it possible for a particle to pass through two slits simultaneously? Does a wave packet description of individual particles reflect an ignorance of that particle's true position or momentum?

RESPOND TO THE ONLINE SURVEY QUESTION ON THE DOUBLE-SLIT EXPERIMENT:



(A) (B) (C)

A sequence of screen shots from the Quantum Wave Interference simulation. A bright spot (representing the probability density for a single electron) emerges from an electron gun (A), passes through both slits (B), and a single electron is detected on the far screen (C). After many electrons, a fringe pattern develops (not shown).

Three students discuss the Quantum Wave Interference simulation:

Student 1: The probability density is so large because we don't know the true position of the electron. Since only a single dot at a time appears on the detecting screen, the electron must have been a tiny particle, traveling somewhere inside that blob, so that the electron went through one slit or the other on its way to the point where it was detected.

Student 2: The blob represents the electron itself, since an electron is described by a wave packet that will spread out over time. The electron acts as a wave and will go through both slits and interfere with itself. That's why a distinct interference pattern will show up on the screen after shooting many electrons.

Student 3: Quantum mechanics is only about predicting the outcomes of measurements, so we really can't know anything about what the electron is doing between being emitted from the gun and being detected on the screen.

(Ask students to read each statement one at a time, and respond before moving on to the next statement. Are student responses to the essay question consistent with their earlier descriptions of the experiment? Are student responses consistent with their earlier descriptions of atomic electrons? If not, why not? Is the student aware of inconsistencies?)

QUESTIONS REGARDING INTERPRETATIONS OF QUANTUM MECHANICS
(Is the student aware there are multiple interpretations of quantum mechanics? Can they name any of them or describe their features? Has the student heard of the Copenhagen Interpretation, and can they describe what it entails? Does the student know what the word *determinism* means within the context of physics? Did they have an opinion as to how they think their instructor would have wanted them to respond to earlier interview questions?)

RESPOND TO THE STATEMENT:
It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.
IN AGREEMENT OR DISAGREEMENT AND EXPLAIN REASONING.

RESPOND TO THE STATEMENT:
The probabilistic nature of quantum mechanics is mostly due to the limitations of our measurement instruments.
IN AGREEMENT OR DISAGREEMENT AND EXPLAIN REASONING.