The Quantum World Around Us: Teaching Quantum and Solid-State Physics to Non-Science Majors

James K. Freericks and Amy Y. Liu
Department of Physics, Georgetown University, Washington, DC 20057

We are developing a physics course for non-science majors at Georgetown University entitled "The Quantum World Around Us." This course is intended to introduce liberal-arts students to the fascinating ideas and applications of quantum mechanics and solid-state physics. Without using advanced mathematics, we present the fundamentals of quantum mechanics, develop the quantum theory of solids, and apply quantum theory to describe materials and devices encountered in our daily lives. Our goals in offering this course are: (i) to raise the level of scientific literacy of students to a point where they can follow popular-press accounts of scientific discoveries, particularly in the areas of chemistry, physics, and materials science, and (ii) to increase the awareness of students of the impact of the seemingly academic notions of quantum physics on their everyday lives.

The fundamental ideas of quantum mechanics are introduced using the model based on path integrals presented by Feynman in his book *QED* (1). We choose this approach, which is also used by Taylor (2), over the more traditional wave-mechanics approach because we feel that it is more accessible to students who do not have a background in high-level math. Students are given a set of rules, taken as postulates, for computing probability amplitudes for events. This allows them to analyze semi-quantitatively the behavior of quantum particles. The more advanced concept of wavefunctions is introduced later in the course, after the students have gained an understanding of the behavior of quantum particles. We employ both pictures in the development of the quantum theory of solids and in discussions of a number of applications of solid-state physics to modern technology. Even though we do not utilize sophisticated mathematics, we do require careful scientific reasoning on the part of the students.

The course can be divided into four parts. We begin with a treatment of the quantum-mechanical problem of a spin one-half particle, as developed by Styer (3). The Stern-Gerlach experiment and a two-slit experiment based on that apparatus are used to introduce conceptual features of quantum mechanics, including probability theory and quantum interference. We then treat the behavior of light, following Feynman's *QED*. In this model, probability amplitudes are represented by arrows, and event probabilities are computed using simple rules for combining arrows. These rules are applied to examples involving mirrors, lenses, and diffraction gratings, leading up to a detailed analysis of the two-slit experiment. The third phase of the course focuses on the first six chapters of *The Quantum Universe*, by Hey and

Walters (4). We discuss the Heisenberg uncertainty principle, and then describe kinetic and potential energies, and quantum-mechanical energy levels. The particle in a box is introduced as a simplified model for an atom, and is used to illustrate the connection between Feynman's probability arrows and the wavefunction of a quantum particle. The Pauli exclusion principle is discussed, and the periodic table of the elements is built. In the final phase of the course, which is based primarily on *Scientific American* articles, we describe the band theory of solids, illustrating differences between metals and insulators, and describe the optical properties of solids, making contact back to atomic energy levels. We end the course with discussions on magnets, lasers, superconductors, and their applications.

Assignments are tailored to fit the strengths of the non-scientist by focusing on writing. The students write several short essays and two longer papers. In the essays, students are asked to explain physical phenomena that are not explicitly discussed in class, but that can be understood using the models developed in class. Many essays are based on *Scientific American* readings or on world-wide-web sites describing quantum applications such as scanning tunneling microscopy. For one of the long papers, each student chooses an article related to quantum mechanics and solid-state physics from *Scientific American* and writes on an aspect of the article that relies on quantum notions. This assignment requires students to synthesize the information in the article with what they have learned in other parts of the course to demonstrate a true understanding of quantum phenomena. The other long writing assignment is based on Tom Stoppard's *Hapgood* (5), a cold-war spy play in which the world of espionage is used as a metaphor for the world of subatomic particles. Students write on various aspects of quantum mechanics depicted in the play, analyzing the metaphors and explaining the various quantum concepts that are involved.

For further information about this course, see the web site at http://www.physics.georgetown.edu/~jkf/quant_mech/quant_mech.html.

REFERENCES

1. Feynman, R. P., *QED: The Strange Theory of Light and Matter*, Princeton, Princeton University Press, 1985.
2. Taylor, E. F., "Demystifying Quantum Physics: Feynman's Simple QED," in Proceedings of the International Conference on Undergraduate Physics Education, New York, AIP Press, 1996 (this volume); Smith, R. C. and E. F. Taylor, *Am. J. Phys.*, **63**, 1090-1096, 1995.
3. Styer, D. F., private communication; see also his world-wide-web site at "www.physics.oberlin.edu/courses/StrangeQ.html."
4. Hey, T. and P. Walters, *The Quantum Universe*, Cambridge, Cambridge University Press, 1987.
5. Stoppard, T., *Hapgood*, Boston, Faber and Faber, 1994.