Modern Physics and the Modern World

Physics 427A David Thouless Winter 2008

Introduction

This course is intended to explore developments in physics since 1930. This date is not chosen because it roughly coincides with my own lifetime, but because the revolution that began with the discovery of X-rays and radioactivity, continued with the discovery of the role of nucleus and electrons in the atom and Einstein's relativity theories, and culminated in quantum mechanics, had widespread implications for all scientific disciplines. These developments are covered by any course on Modern Physics, and are readily accessible in excellent books. The more recent scientific developments have mostly been less dramatic and less readily popularized, but some of them have been of immense practical significance, while others have led to significant improvements in technology and diagnostic medicine, or to important advances in other branches of science.

I would like it to be covered at a level that can be understood by students with only a modest level of understanding of physical science and its technological applications, but I assume some familiarity with modern atomic and quantum physics, electromagnetism, and thermal physics, at the introductory level. Where particular students are lacking in some of the background I am assuming, they should let me know, in or out of class, and I will do my best to help them. I want the course to cover topics where new physics has led to new advances in technology or in other branches of science or knowledge. It should not include advances that are primarily applications of earlier physics, such as the development of X-ray tomography, electron microscopy, or the structure of DNA, even though they were brought about by those trained as physicists, in many cases working in physics laboratories.

I want the course to cover not only the basic physics, most of which I know well, but also the technological, medical and scientific applications, which I know much less well. I am not in a position to pronounce authoritatively on these applications, and I am hoping that students will explore some of these topics and present them to the class, even when their reading is still in progress. I encourage the students to work in small groups, but each student will be required to present a properly written paper by the end of the Quarter.

Some of the topics that I have in mind are:

1. Semiconductor devices. The applications are widely varying and well known, and even the least technically minded have some idea of how much these have changed our lives.

2. Lasers. The technical applications vary from moon-ranging to grocery checkout, by way of high precision optical spectroscopy, but the physics is challenging to present.

3. Advances in magnetism. Magnetic memories are vital for modern computers, as well as for the recording industry. They depend on recent advances in magnetic materials, some of which are based on new physics, such as colossal magnetoresistance.

4. The neutron. This led to understanding of nuclear structure, to the discovery of nuclear fission with its, so far unfulfilled, promise of cheap and clean power, to the understanding of stellar interiors, and to the prediction of neutron stars.

5. Nuclear resonance. This has provided an invaluable tool for the exploration of molecular and condensed matter structure, and for many years every respectable hospital has to have its own MRI equipment.

6. Cosmic background radiation. The microwave background gives us light from the young universe, and gives us information that is remarkably independent of detailed models.

7. Neutrinos. Neutrinos were invented by Fermi as a remedy for the apparent failure of momentum conservation in nuclear β-decay. Early predictions that they would be unobservable have happily proved false, and they have provided a challenge to our understanding of the solar interior, which recent observations have finally answered.

8. Microscopy. Electron Microscopy was developed in the 1930s, and Scanning Tunneling Microscopy and Atomic Force Microscopy in the 1980s. These, and related techniques, have enabled matter to be studied at or close to the atomic scale.

9. Positrons (perhaps). Positrons were needed to complete Dirac's theory of the electron, but they are vital for understanding the origin of the

cosmic microwave background. They are also used as a tool in medicine for studying metabolic processes while they are happening (PET).

10. Advances in superconductivity. Type II superconductivity was discovered in the 1930s, but the murder of its discoverer delayed progress for fifteen years. It opened the possibility of superconducting magnets, which are far more compact and cheap to run than conventional large magnets, and are used in MRI equipment and in particle accelerators. Recent progress in high temperature superconductors has not yet lived up to its early promise, but has led to important applications.

11. Topological quantum numbers. Topological quantum numbers are a relatively new concept in physics, dating back to about 1950. Some of these, such as the quantized magnetic flux that underlies the Josephson effects in superconductors, and the quantum Hall effect discovered nearly thirty years ago, have led to great advances in the precision of fundamental constants, and to the portability of standards for calibration of instruments. This is a favorite topic of mine.

This is too long a list to cover in one quarter, so we will have to pick and choose.