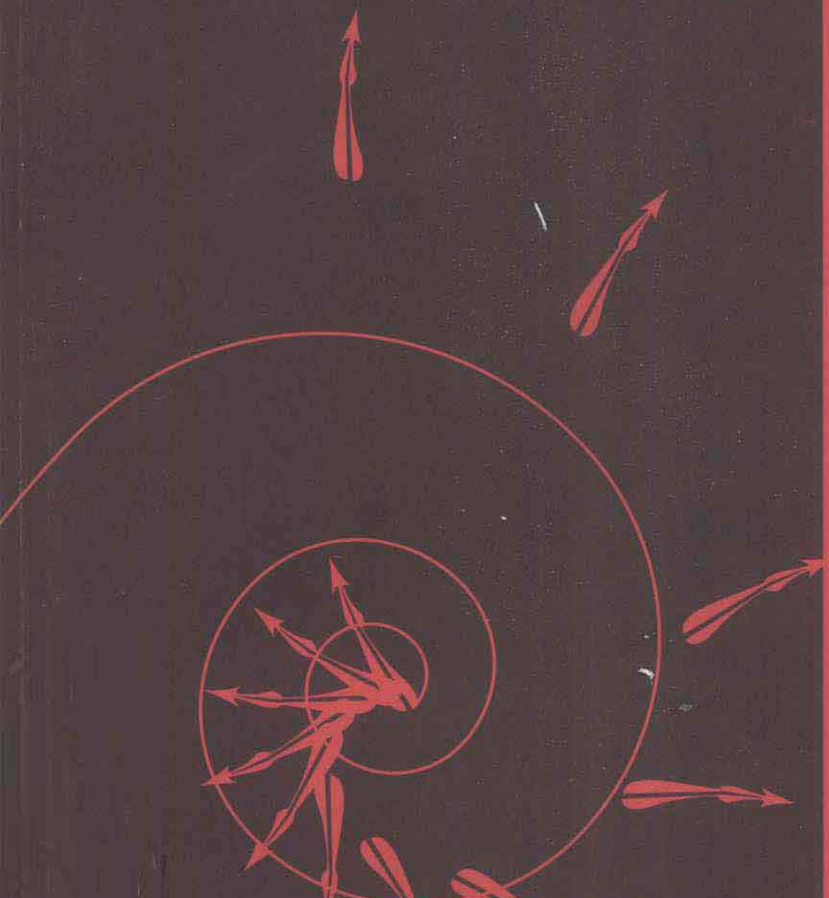
Physics 2000

E. R. Huggins
Dartmouth College



Part I
Mechanics, Waves & Particles

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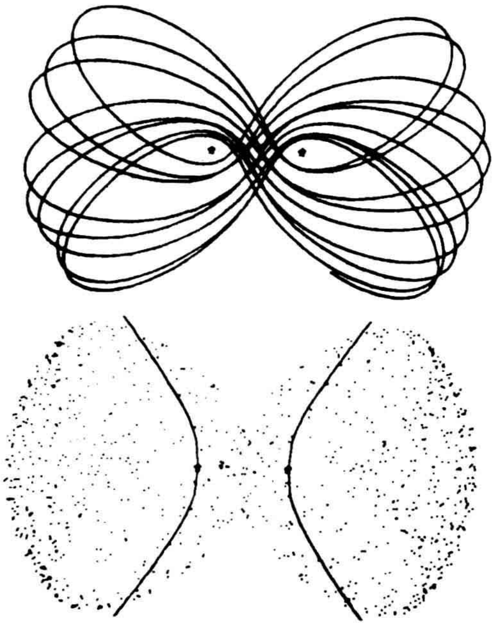

Student project by Bob Piela explaining the hydrogen molecule ion.

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ABOUT THE *PHYSICS2000* CD

The ***Physics2000*** **CD** contains the complete color version of the ***Physics2000*** text in Acrobat™ form along with a supplementary chapter covering all the calculus needed for the text. Included on the CD is the 36 minute motion picture *Time Dilation - An Experiment With Mu-Mesons*, and short movie segments of various physics demonstrations. Also a short cookbook on several basic dishes of Caribbean cooking.

The CD is available, for $10 postpaid, at the web site
www.physics2000.com
The black and white printed copy of the text, with the calculus chapter, is also available at the web site at a cost of $ 25. That includes the CD and shipping within the United States.

Use of the Text Material

Because we are trying to change the way physics is taught, Chapter 1 on special relativity, although copyrighted, may be used freely (except for the copyrighted photograph of Andromeda and frame of the muon film). All chapters may be printed and distributed to a class on a non profit basis.

ABOUT THE AUTHOR

E. R. Huggins has taught physics at Dartmouth College since 1961. He was an undergraduate at MIT and got his Ph.D. at Caltech. His Ph.D. thesis under Richard Feynman was on aspects of the quantum theory of gravity and the non uniqueness of energy momentum tensors. Since then most of his research has been on superfluid dynamics and the development of new teaching tools like the student-built electron gun and MacScope™. He wrote the non calculus introductory physics text ***Physics1*** in 1968 and the computer based text ***Graphical Mechanics*** in 1973. The ***Physics2000*** text, which summarizes over thirty years of experimenting with ways to teach physics, was written and class tested over the period from 1990 to 1998. All the work of producing the text was done by the author, and his wife, Anne Huggins. The text layout and design was by the author's daughter Cleo Huggins who designed eWorld™ for Apple Computer and the Sonata™ music font for Adobe Systems.

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Preface

ABOUT THE COURSE

Physics2000 is a calculus based, college level introductory physics course that is designed to include twentieth century physics throughout. This is made possible by introducing Einstein's special theory of relativity in the first chapter. This way, students start off with a modern picture of how space and time behave, and are prepared to approach topics such as mass and energy from a modern point of view.

The course, which was developed during 30 plus years working with premedical students at Dartmouth College, makes very gentle assumptions about the student's mathematical background. All the calculus needed for studying Physics2000 is contained in a supplementary chapter which is the first chapter of a ***Physics Based Calculus*** text. We can cover all the necessary calculus in one reasonable length chapter because the concepts are introduced in the physics text and the calculus chapter only needs to handle the formalism. (The remaining chapters of the calculus text introduce the mathematical tools and concepts used in advanced introductory courses for physics and engineering majors. These chapters will be available at ***www.physics2000.com*** in late 2000.)

In the physics text, the concepts of velocity and acceleration are introduced through the use of strobe photographs in Chapter 3. How these definitions can be used to predict motion is discussed in Chapter 4 on calculus and Chapter 5 on the use of the computer.

Students themselves have made major contributions to the organization and content of the text. Student's enthusiasm for the use of Fourier analysis to study musical instruments led to the development of the MacScope™ program. The program makes it easy to use Fourier analysis to study such topics as the normal modes of a coupled aircart system and how the energy-time form of the uncertainty principle arises from the particle-wave nature of matter.

Most students experience difficulty when they first encounter abstract concepts like vector fields and Gauss' law. To provide a familiar model for a vector field, we begin the section on electricity and magnetism with a chapter on fluid dynamics. It is easy to visualize the velocity field of a fluid, and Gauss' law is simply the statement that the fluid is incompressible. We then show that the electric field has mathematical properties similar to those of the velocity field.

The format of the standard calculus based introductory physics text is to put a chapter on special relativity following Maxwell's equations, and then put modern physics after that, usually in an extended edition. This format suggests that the mathematics required to understand special relativity may be even more difficult than the integral-differential equations encountered in Maxwell's theory. Such fears are enhanced by the strangeness of the concepts in special relativity, and are driven home by the fact that relativity appears at the end of the course where there is no time to comprehend it. This format is a disaster.

Special relativity does involve strange ideas, but the mathematics required is only the Pythagorean theorem. By placing relativity at the beginning of the course you let the students know that the mathematics is not difficult, and that there will be plenty of time to become familiar with the strange ideas. By the time students have gone through Maxwell's equations in ***Physics2000***, they are thoroughly familiar with special relativity, and are well prepared to study the particle-wave nature of matter and the foundations of quantum mechanics. This material is not in an extended edition because there is time to cover it in a comfortably paced course.

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Calculus 1 INTRODUCTION TO CALCULUS

Introduction
An Overview of Physics

With a brass tube and a few pieces of glass, you can construct either a microscope or a telescope. The difference is essentially where you place the lenses. With the microscope, you look down into the world of the small, with the telescope out into the world of the large.

In the twentieth century, physicists and astronomers have constructed ever larger machines to study matter on even smaller or even larger scales of distance. For the physicists, the new microscopes are the particle accelerators that provide views well inside atomic nuclei. For the astronomers, the machines are radio and optical telescopes whose large size allows them to record the faintest signals from space. Particularly effective is the Hubble telescope that sits above the obscuring curtain of the earth's atmosphere.

The new machines do not provide a direct image like the ones you see through brass microscopes or telescopes. Instead a good analogy is to the Magnetic Resonance Imaging (MRI) machines that first collect a huge amount of data, and then through the use of a computer program construct the amazing images showing cross sections through the human body. The telescopes and particle accelerators collect the vast amounts of data. Then through the use of the theories of quantum mechanics and relativity, the data is put together to construct meaningful images.

Some of the images have been surprising. One of the greatest surprises is the increasingly clear image of the universe starting out about fourteen billion years ago as an incredibly small, incredibly hot speck that has expanded to the universe we see today. By looking farther and farther out, astronomers have been looking farther and farther back in time, closer to that hot, dense beginning. Physicists, by looking at matter on a smaller and smaller scale with the even more powerful accelerators, have been studying matter that is even hotter and more dense. By the end of the twentieth century, physicists and astronomers have discovered that they are looking at the same image.

It is likely that telescopes will end up being the most powerful microscopes. There is a limit, both financial and physical, to how big and powerful an accelerator we can build. Because of this limit, we can use accelerators to study matter only up to a certain temperature and density. To study matter that is still hotter and more dense, which is the same as looking at still smaller scales of distance, the only "machine" we have available is the universe itself. We have found that the behavior of matter under the extreme conditions of the very early universe have left an imprint that we can study today with telescopes.

In the rest of this introduction we will show you some of the pictures that have resulted from looking at matter with the new machines. In the text itself we will begin to learn how these pictures were constructed.

SPACE AND TIME

The images of nature we see are images in both space and time, for we have learned from the work of Einstein that the two cannot be separated. They are connected by the speed of light, a quantity we designate by the letter c, which has the value of a billion (1,000,000,000) feet (30 cm) in a second. Einstein's remarkable discovery in 1905 was that the speed of light is an absolute speed limit. Nothing in the current universe can travel faster than the speed c.

Because the speed of light provides us with an absolute standard that can be measured accurately, we use the value of c to relate the definitions of time and distance. The meter is defined as the distance light travels in an interval of 1/299,792.458 of a second. The length of a second itself is provided by an atomic standard. It is the time interval occupied by 9,192,631,770 vibrations of a particular wavelength of light radiated by a cesium atom.

Using the speed of light for conversion, clocks often make good meter sticks, especially for measuring astronomical distances. It takes light 1.27 seconds to travel from the earth to the moon. We can thus say that the moon is 1.27 ***light seconds*** away. This is simpler than saying that the moon is 1,250,000,000 feet or 382,000 kilometers away. Light takes 8 minutes to reach us from the sun, thus the earth's orbit about the sun has a radius of 8 ***light minutes***. Radio signals, which also travel at the speed of light, took 2 1/2 hours to reach the earth when Voyager II passed the planet Uranus (temporarily the most distant planet). Thus Uranus is 2 1/2 light hours away and our solar system has a diameter of 5 light hours (not including the cloud of comets that lie out beyond the planets.)

The closest star, Proxima Centauri, is 4.2 ***light years*** away. Light from this star, which started out when you entered college as a freshman, will arrive at the earth shortly after you graduate (assuming all goes well). Stars in our local area are typically 2 to 4 light years apart, except for the so called ***binary stars*** which are pairs of stars orbiting each other at distances as small as light days or light hours.

On a still larger scale, we find that stars form island structures called ***galaxies***. We live in a fairly typical galaxy called the Milky Way. It is a flat disk of stars with a slight bulge at the center much like the Sombrero Galaxy seen edge on in Figure (1) and the neighboring spiral galaxy Andromeda seen in Figure (2). Our Milky Way is a spiral galaxy much like Andromeda, with the sun located about 2/3 of the way out in one of the spiral arms. If you look at the sky on a dark clear night you can see the band of stars that cross the sky called the Milky Way. Looking at these stars you are looking sideways through the disk of the Milky Way galaxy.

Figure 1
The Sombrero galaxy.

Figure 2
The Andromeda galaxy.