Columbia University Nevis Laboratories

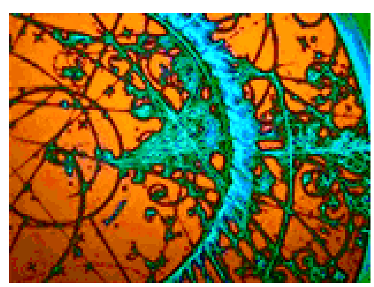
The purpose of this packet is to provide both the high school teacher coordinating a course in scientific research and the high school student interested in scientific research with a concise introduction to research opportunities in physics in general and particle physics in particular. The packet has been produced by a team at the Nevis Labs of Columbia University located in Irvington, NY. Physicists at Nevis Labs are actively involved with research in particle physics.

The goal of this packet is to stimulate interest of high school students in physics and to motivate them to attempt their own physics research projects.

Physics is often described as the study of **matter** and **energy**. It is concerned with how matter and energy relate to each other, and how they affect each other over time and through space. Physicists ask the ***fundamental*** questions — how did the universe begin? how and of what is it made? how does it change? what rules govern its behavior?

Physicists may be roughly divided into two camps: **experimental** physicists and **theoretical** physicists. Experimental physicists design and run careful investigations on a broad range of phenomena in nature, often under conditions which are atypical of our everyday lives. They may, for example, investigate what happens to the electrical properties of materials at temperatures very near absolute zero (–460 degrees Fahrenheit) or measure the characteristics of energy emitted by very hot gases. Theoretical physicists propose and develop models and theories to explain mathematically the results of experimental observations. Experiment and theory therefore have a broad overlap. Accordingly, an experimental physicist remains keenly aware of the current theoretical work in his or her field, while the theoretical physicist must know the experimenter's results and the context in which the results need be interpreted.

It is also useful to distinguish **classical** physics and **modern** physics. Classical physics has its origins approximately four hundred years ago in the studies of Galileo and Newton on mechanics, and similarly, in the work of Ampere, Faraday, Maxwell and Oersted one hundred fifty years ago in the fields of electricity and magnetism. This physics handles objects which are neither too large nor too small, which move at relatively slow speeds (at least compared to the speed of light: 186,000 miles per second!).

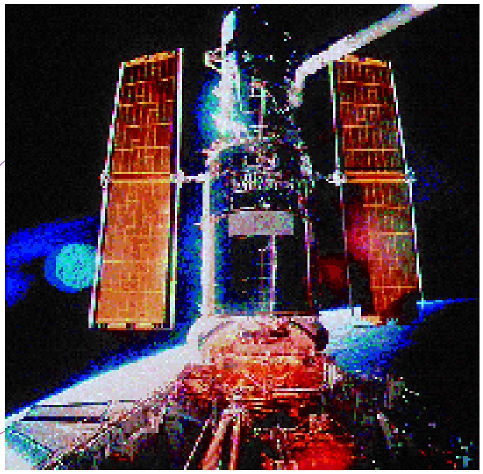


The emergence of modern physics at the beginning of the twentieth century was marked by three achievements. The first, in 1905, was Einstein's brilliant model of light as a stream of particles (photons). The second, which followed a few months later, was his revolutionary theory of relativity which described objects moving at speeds close to the speed of light. The third breakthrough came in

1910 with Rutherford's discovery of the nucleus of the atom. Rutherford's work was followed by Bohr's model of the atom, which in turn stimulated the work of de Broglie, Heisenberg, Schroedinger, Born, Pauli, Dirac and others on the quantum theory. The avalanche of exciting discoveries in modern physics continues today.

Given these distinctions within the field of physics — experimental and theoretical, classical and modern — it is useful to further subdivide physics into various disciplines, including astrophysics, atomic and molecular physics, biophysics, solid state physics, optical and laser physics, fluid and plasma physics, nuclear physics, and particle physics.

The packet contains an overview of the key topics in particle physics. Also in this packet are a brochure on opportunities for women in physics and a brochure describing the U.S. participation in the largest international Particle Physics project, the Large Hadron Collider.



High school students (and their teachers) who are interested in physics research should review the contents of this packet. Below you can find references to recent representative articles from Scientific American on major branches of physics. These articles detail specific examples of current research in each particular field. Interested students are encouraged to read some of these articles and choose one to present to their research class. The presentation should outline the entire contents of the article and highlight for the classroom audience the major point or points the author made in the piece. Besides Scientific American, other sources for general articles on current research in physics include Discover magazine and the Science Times section of each Tuesday's ***New York Times***.

The next step is for students to continue finding and reading material related to the area of physics they find interesting. The goal is to learn as much as possible from the general literature. After this the student should try to find a mentor. The student should compile a list of topics and keywords related to the field and of scientists working in the field. Using this list the student should use DIALOG™ and an internet browser to do subject and author searches. These searches should form the basis of an organized exploration of current research in the particular field the student is interested in. The student should also contact the physics, mathematics, and/or engineering departments of local colleges and universities and inquire if any faculty members are working in this area of physics. The student or the teacher should then contact physicists doing work in the field of interest, outline the goals of the high school course, and ask for help and advice. Probably the most valuable advice a prospective mentor can give is the suggestion for a research project that is at once interesting, understandable and practicable given the resources of the student researcher.

Other activities that may be helpful to a student interested in a physics research project are:

- Studying the Amateur Scientist section of Scientific American for physics related projects.
- Speaking with the physics teacher in his or her high school. Perhaps they can suggest a project and/or recommend a mentor.
- Discussing the topic with his or her parents, relatives and family friends. They may know someone who works in physics or a field related to physics and who can advise them.

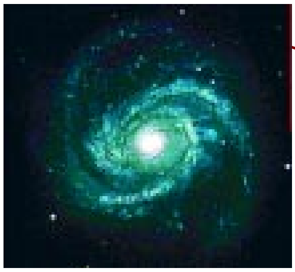
Erica Sanders, a high school student from Long Island, worked on a physics research project with a mentor from Brookhaven National Laboratory. She wrote a letter to the Lab and asked for a chance to do research. Her first project involved analyzing test beam data from the ATLAS Liquid Argon Calorimeter, destined for use at CERN's Large Hadron Collider. While involved in this work she learned a lot about computers. Erica worked on her own project which involved the use of Cathode Strip Chambers for medical imaging, specifically digital mammography. She was exposed to a wide variety of problem-solving techniques and to the way collaborative research works. Her example is evidence that high school students are capable of doing meaningful research in physics.

Not all physics research requires complex and expensive equipment. A lot of interesting research can be done with the desktop computers many students have access to at home or in school. These devices have more memory, storage, and computing power than was available to most working physicists twenty-five years ago. Also, the student should not be concerned if he or she has not yet taken physics in high school. Many scientists entering a field for the first time are self-educated.

Finally, the student should keep in mind that the world-wide physics community is incredibly active and communicative. These are the people who invented the World Wide Web. The student can and must reach out to them. As one of Dr. Robert Pavlica's students at Byram Hills High School said, "The world is just a phone call away."

Scientific American articles

Astrophysics



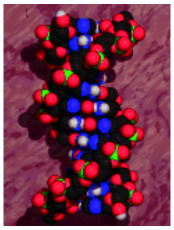
"Collapse and Formation of Stars" by A.P. Boss, January 1985
"The Great Supernova of 1987" by S. Woosley and T. Weaver, August 1989
"Black Holes in Galactic Centers" by M.J. Rees, November 1990
"The Expansion Rate and Size of the Universe" by W.L. Freedman, November 1992
"The Ghostliest Galaxies" by Gregory D. Bothun, February 1997

Atomic and Molecular Physics

"Detecting Individual Atoms and Molecules with Lasers" by V.S. Letokhov, September 1988
"The Birth of Molecules" by A.H. Zewail, December 1990
"Friction at the Atomic Scale" by Jacqueline Krim, October 1996

Biophysics and Medical Physics

"Advances in Tumor Imaging" by Maryellen L. Giger and Charles A. Pelizzari, September 1996
"The Machinery of Thought" by Tim Beardsley, August 1997



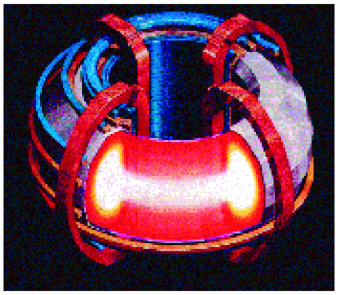
Solid State Physics

"Ion Implantation of Surfaces" by S.T. Picraux and P.S. Peercy, March 1985
"Crystals at High Pressure" by R.M. Hazen and L.W. Finger, May 1985
"Advanced Metals" by B.H. Kear, October 1986
"Quantum Dots" by M.A. Reed, January 1993
"High-Temperature Superconductors" by P.C.W. Chu, September 1995
"Electrons in Flatland" by Steven Kivelson, Dung-Hai Lee and Shou-Cheng Zhang, March 1996
"Probing High-Temperature Superconductivity" by John R. Kirtley and Chang C. Tsuei, August 1996

Optical and Laser Physics

"Laser Applications in Manufacturing" A.V.La Rocca, March 1982
"Optical Gyroscopes" by D.Z. Anderson, April 1986
"X-Ray Microscopes" by M.R. Howells, J. Kirz and D. Sayre, February 1991
"Liquid Mirrors" by Ermanno F. Borra, February 1994
"Quantum Seeing in the Dark" by P. Kwiat, H. Weinfurter and A. Zeilinger, November 1996
"Lightning Control with Lasers" by Jean-Claude Diels, Ralph Bernstein, Karl E. Stahlkopf and Xin Miao Zhao, August 1997

Fluid and Plasma Physics



"The Active Solar Corona" by R.Wolfson, February 1983
"The Structure of Comet Tails" by J.C.Brandt and M.B.Niedner, January 1986
"The Earth Magnetotail" by E.W.Hones, March 1986
"The 3He Superfluids" by O.V. Lounasmaa and G. Pickett, June 1990
"The International Thermonuclear Experimental Reactor" by R.W. Cohn, V.A. Chuyanov, N. Inoue and D.R. Sweetman, April 1992
"Tackling Turbulence with Supercomputers" by Parviz Moin and John Kim, January 1997

Nuclear Physics

"Hot Nuclear Matter" by W. Greiner and H. Stoecker, January 1985
"Radiocarbon Dating by Accelerator Mass Spectroscopy" by R.E.M. Hedges and J.A.J. Gowlett, January 1986
"Rethinking Nuclear Power" by R.L.Lester, March 1986
"Exotic Atomic Nuclei" by J.H. Hamilton and J.A. Maruhn, July 1986
"Creating Superheavy Elements" by P. Armbruster and G. Muenzenberg, May 1989
"Halo Nuclei" by Sam M. Austin and George F. Bertsch, June 1995
"Fusion" by Harold P. Furth, September 1996

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