



postdoctoral personnel, exchange of ideas by research correspondence and participation by the faculty in professional meetings and research conferences. Frequent colloquia are shared by Pomona and the other associated colleges of the Claremont group.

Nearly every Pomona physics major functions as a laboratory assistant during his junior or senior year. Two are assigned to each general physics section under the close supervision of a professor who also works full time in that section. Inasmuch as printed instructional material is largely avoided, the three instructors must carry on a continuing dialog with their students about the experiment in progress. Student instructors profit enormously, both through a deepened understanding of their subject and through real involvement in the education of others. Moreover younger undergraduates readily identify with and respect them.

Having proved to our own satisfaction that serious research can be carried on in an undergraduate department with great benefits for participating students and faculty, we have resisted pressures to expand into some type of graduate program. It seems clear to our faculty that any such step would drastically reduce the opportunities now enjoyed by our undergraduates, since research equipment, space and faculty time would be pre-empted by graduate students. At a time when competition for good graduate physics students is almost desperate and with several eminent graduate schools located in Southern California, it would appear that we would be sacrificing distinction in undergraduate physics for mediocrity in the graduate field.

An appraisal

Pomona's average annual enrollment since 1950 has been less than 1200, of whom fewer than 300 are men majoring in science. In this period 170 students have been graduated in physics, an average of ten per year. Of these, 142 have continued with graduate study and 120 of them received first-year graduate fellowships and assistantships, including 18 NSF and five Woodrow Wilson fellowships. The graduate schools to which the students have gone include UC Berkeley (26 students), Cal Tech (17), Stan-

ford (12), UCLA (10), Harvard (9), MIT (5), and 29 others with fewer numbers. Of those who entered graduate school between 1950 and 1963 with a PhD as the stated goal, 65% have achieved the doctorate and a few others are still candidates. For those of the last group who participated in research at Pomona, the PhD attainment was 80%.

In the same period the Pomona physics faculty has published 52 research papers, contributed frequently at American Physical Society meetings and special research conferences, and has delivered eight invited research reviews and digest articles. They have received seven fellowships for postdoctoral study and research.

In two areas only the Pomona physics department appears to have failed. Since 1950 it has graduated just six women and produced five high-school physics teachers.

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Reed College

Emphasis on an extensive senior-year special project forms part of a program designed both as preparation for graduate school and as training for immediate employment in industry.

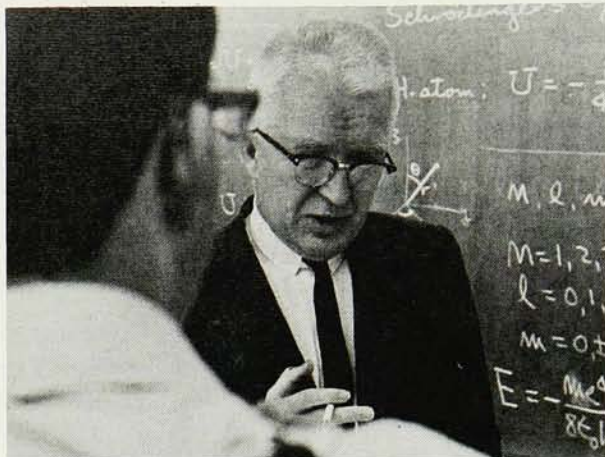
by William L. Parker

IN TERMS OF A PHYSICAL ANALOGY our curriculum is certainly an example of dynamic equilibrium—at times almost unstable equilibrium. It is in such a state largely as the result of tensions: tensions between theorists and experimentalists, tensions between classical ideas and modern ideas both as to subject matter and methods of approach, and tensions between an abstract, conceptual treatment and a phenomeno-

logical treatment. All of these tensions exist within the department itself; in addition there are tensions with our mathematics department as to who shall teach the applied mathematics, and that tension common to all liberal-arts colleges between the need for a broad general education and the desirability of thorough specialized training in the major field.

The primary aim of Reed College (Portland, Oregon) is to graduate well trained physicists who are broadly

educated. We do not think of ourselves as primarily a preparatory school for graduate work, although our graduates must be able to go on to graduate school, and most of them do. We like to feel, however, that the curriculum, although not being a terminal program, is sufficiently complete to allow a graduate to go out as a physicist into an industrial position without further formal education. Some do take industrial jobs, and they are successful. Before launching into the program for



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physics majors, let me give you a brief description of our activities that are a service to the rest of the college. The beginning mathematicians, chemists, biologists, and pre-meds take a regular technical course, which will be described later.

Program for nonmajors

For those other students in the humanities and social sciences who wish to learn something about science (and also to satisfy a distribution requirement) but do not have sufficient mathematical background to handle the standard courses, we offer a one-year course called "The Physical Sciences." It has been offered now by the department for some fifteen years. During a portion of its existence it was shared with the chemistry department, but recently it has been the sole responsibility of the physics department, with the contents of the course depending in large measure on the individual teaching it. For several years it was a rather unusual combination of Newtonian mechanics from the *Principia* for the first semester, and in the second semester from the point of view of differential equations that are solved by computer. For several years we have also tried a plan in which much of the second semester has been elementary astrophysics preceded by the necessary classical and modern physics required to make the astrophysics intelligible. Both schemes have worked reasonably well, and in future years the course may well be one or the other or some combination. Experience with the computer, which is part of the laboratory, appears to appeal strongly to the students and will be continued. Some members of the

department would like to see the course abandoned and one of the more traditional general courses revised to accommodate these students, but there are difficulties that, at the moment, we cannot overcome.

Combined disciplines

The freshman course taken by most of our physics or chemistry majors, many mathematicians, and some biologists is a combined course in general physics and chemistry. It was introduced about eight years ago in an attempt to solve a problem that is probably peculiar to Reed. Because of the heavy humanities requirement it was impossible for a student to take mathematics, physics and chemistry all in his freshman year. As a result a student interested in both physics and chemistry had to decide on his major before having any college-level work in the subject. Then he had the problem of picking up the remaining course, usually as a junior, when the standard freshman course was something less than appealing. The combination is a "course and one half", meaning that it occupies a little over one third of a student's time and would normally be classified as a six-hour course. The first semester is given entirely by the physics department and the second by the chemistry department. Resnick and Halliday is used as a text, or perhaps "reference" might be slightly more accurate (see textbook table on page 60). We cover mechanics through wave motion and electric and magnetic fields up to Maxwell's equations in integral form, spend about a week on special relativity, take a brief look at physical optics and do a final week leading to a justification of

Schrödinger's equation and its application to the particle in a box. Thermodynamics is thoroughly covered by the chemists; calorimetry, electric circuits, and geometrical optics are treated briefly in the laboratory. A student must have studied both physics and chemistry in high school, and admission is restricted to those who, from their records, appear competent to handle the course.

We still give a standard one-year course in general physics, which is taken by those students who are not qualified for the combined course and by some mathematicians and biologists who do not wish to undertake the more rugged experience. Here again we use Resnick and Halliday. The character of freshman mathematics is such that students do not get sufficient work in simple applied calculus in time for our purposes in first-year physics. As a result, in both courses we spend some time on simple calculus, including the differentiation and integration of x^n , and the trigonometric and logarithmic functions.

Second-year problems

The sophomore course, "Advanced General Physics," is essentially a second trip around much the same material, but with considerably higher powered mathematics and more physical sophistication. Double and triple integration, differential equations and vector calculus are introduced as needed and used extensively. For mechanics we use Stephenson, and Purcell for electricity and magnetism. We spend considerable time on special relativity, and selected portions of thermodynamics are covered at roughly the level of Zemansky. The final month is a phenomenological treatment of modern physics at the usual junior level. In the sophomore laboratory the students spend five weeks with the computer in the first semester, during which they write a program for the damped harmonic oscillator. The second semester is almost entirely devoted to basic vacuum-tube electronics.

The staff is more dissatisfied with the program of the first two years than with that of the upper-class years. The presentation of three general courses at the freshman level is a bit of a hardship on what is a rather small department (seven men this year) particularly because a large amount of

individual work with students is required in the upper-class years. We are not happy with the combined course—the pace is too fast and furious—and there is repetition in the sophomore year of material that was covered in the freshman courses. We would like to try a three- or four-semester “in line” course; we probably will do so if we can find another solution for the chemistry problem.

In the first two years of the program, tradition, phenomenology, and experiment have won over their opponents. Almost the reverse is true for the upper-class program with the exception of three semesters of advanced laboratory. The standard courses taken by all majors in the junior year are classical mechanics, electricity and magnetism and a mathematics course entitled “Applied Mathematical Analysis,” which is given especially for physics majors. In the senior year the required courses are principles of modern physics and the senior thesis. In none of the courses is a textbook used, and for each one the content is at least partially a function of the individual teaching it.

Physics in depth

The course in classical mechanics at one time was based on Goldstein, but has developed beyond that. It begins with a rather thorough mathematical preparation including linear algebras, the theory of linear operators and operator algebras, tensor analysis and group theory. The object is to prepare the student for a fairly advanced

discussion of covariance. Based on this mathematical background, the classical formulations of Newton, Lagrange, and Hamilton and Jacobi are developed in considerable detail. In connection with the Lagrangian formulation considerable time is given to Noether's theorem and the connection between symmetries and conservation theorems that it provides. We then apply the various formulations to specific systems with small oscillations and central forces among the problems discussed in detail.

The electricity and magnetism course is unusual in that the subject is developed from quite a different basis than is typical. After an introductory mathematical period, about a month is spent on special relativity from a four-vector approach. Then, based on Coulomb's law, special relativity and a generalization of Newton's third law, we derive Maxwell's equations. The rest of the course is more standard, dealing first with the solution of electrostatic and magnetostatic problems. This section includes a short course on ordinary- and partial-differential equations. It then goes on to the treatment of radiation, but from the basic principles rather than from Maxwell's equations. All of the standard problems are treated. The course concludes with a brief phenomenological treatment of electric and magnetic materials.

The senior course in modern physics was originally given from Leighton's book, but has deviated from this in recent years. It begins with a thorough-going treatment of quantum mechanics proceeding this year (experimentally) from the Feynman sum-over-paths formalism. The formalisms of Heisenberg, Dirac, Schrödinger and Schwinger are developed later. Traditional applications—such as to atomic spectra—are made, and we discuss perturbation methods in detail. The primary motivation of the course is to give the student an introduction to several different formalisms so he will be better able to choose the appropriate method to solve a particular problem.

Laboratories taken during the last two years cover solid-state electronics, microwave and light optics, and a selection of experiments in atomic and nuclear physics. They tend to be run on a project basis, and some members of the department feel that we should

condense them into two rather than three semesters.

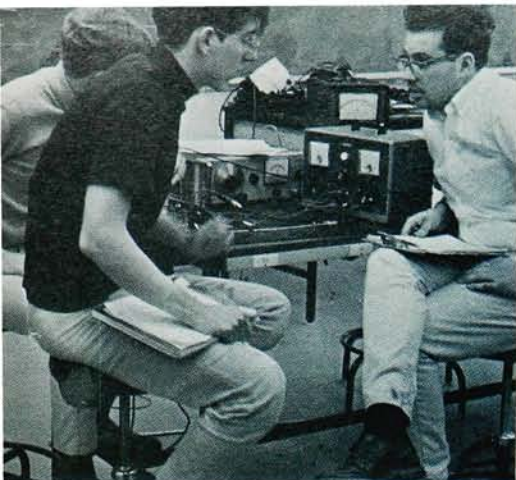
Thesis and selected topics

The senior thesis, which is required of all students, is in a sense the culmination of the entire program. The senior must spend one fourth of his time for the entire year on the project. Topics may range all the way from the development of a new experiment for the advanced laboratories to a sophisticated theoretical problem. They have included such things in recent years as the design and construction of a radio telescope and the preparation of holograms as well as “The ‘Already Unified’ Field Theory of Rainich, Misner and Wheeler” and “Thermodynamics and Riemannian Geometry.” Although a sizeable portion of the students work on problems of their own choosing, many of the theses are closely related to the research interests of the faculty, and it is not uncommon to have a group of theses dealing with various aspects of the same general problem extend over several years. In recent years we have had one or two biophysical investigations per year, and even some psychophysical ones, which have required the cooperation of other departments.

The courses described above constitute the minimum program for practically all our students. A major will, of course, also have had at least three years of mathematics, and will have studied humanities, social sciences and a foreign language. We also offer three optional upper-class courses, one or more of which are taken by about half of our majors. They are thermodynamics, solid-state physics and classical field theory. The last is an outgrowth of the classical-mechanics course. In it the mathematical techniques and formulations worked out in the junior course are applied to systems with many degrees of freedom and a mathematical formulation similar to that used in quantum mechanics is developed. The thermodynamics course is definitely physically oriented—Callen's text has been used—while the solid-state course is largely phenomenological and at the level of Dekker or Kittel. Both are open to either juniors or seniors.

We have described the courses in some detail both because they are somewhat different from the standard ones, and, more importantly, because





they are the bulk of the curriculum.

Perspective

It is safe to say that, with the exception of the advanced laboratories, we

now cover in the first two years most of the material that ten years ago was covered in three years. The last two years deal with the "backbone" of physics—classical mechanics, electromagnetic theory, relativity and quantum mechanics—at a level and with a mathematical sophistication that the older ones of us associate with graduate school. It seems to work! The best students can often save valuable time in graduate school and proceed to independent work that much faster. The average students may have to repeat some of the material in graduate school, but they are more than adequately prepared for it. The poor students did not try it in the first place or dropped by the wayside.

Life can never be a complete bed of roses and our program is no exception. There are definite losses; a student taking the minimum program can graduate knowing little about optics, thermodynamics and statistical mechanics, and practically nothing about the latest developments in solid-state physics, nuclear physics or particle theory. We hope they will browse in the library and learn some of these things, and many of them do so.

We end as we began with a system in dynamic equilibrium. Five years from now it will almost certainly be different; we hope it will still be producing broadly educated graduates who are well prepared for industry, education courses and graduate work. □

Swarthmore College

Highly motivated upper-class students can take part in an honors program wherein independent study leads to the presentation of seminars and eventual grading by invited outside examiners.

by William C. Elmore

THE SWARTHMORE HONORS PROGRAM, initiated in 1922 by President Frank Ayedelotte, has come to distinguish Swarthmore's educational processes and results from those of most other colleges and universities. In recent years about 90% of those majoring in physics have either obtained doctoral degrees or are currently pursuing graduate work in physics at schools such as Cornell, Yale, Harvard and

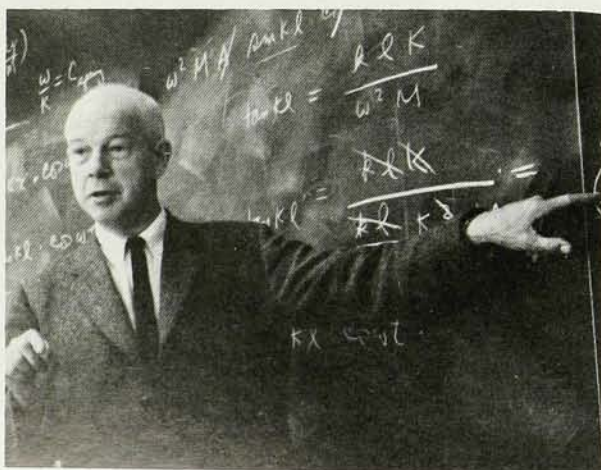
Princeton; the complete list includes at least 20 different universities. Swarthmore graduates are on the physics faculties of more than 25 colleges and universities, as well as on the staffs of most of the national laboratories.

Beginning at the beginning

The department currently offers a single one-year introductory general physics course that is fairly conventional. It serves the needs of prospec-

tive majors in physics as well as majors in the other sciences and engineering. The course is based on three weekly lectures, one weekly conference section and an afternoon laboratory session. To accommodate the current enrollment of 83 students, there are five conference sections and five laboratory sections. In the laboratory, students work in teams of two; all teams do the same experiment in a given week. Much of the laboratory equipment has been constructed in the physics shop, which is staffed by a full-time mechanic. Considerable thought and effort have gone into making the experiments interesting and instructive and into writing an effective set of laboratory notes. Each student keeps a "research" notebook that is initialed by the instructor for completeness and correctness before the student departs from the laboratory. Each week students are given problems that are evaluated by upper-class student assistants. A group of the most capable students is assigned to a "hotshot" conference section in which topics too advanced for the average student are discussed.

We have not been able to justify a



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