# An English University

## Imperial College, London

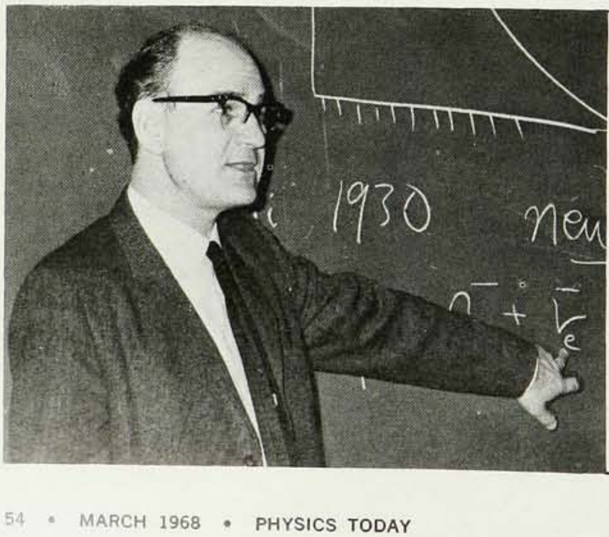
*British methods are different from those in America, but they are not so rooted in tradition as to be incapable of change. London students now have the option of completing their BSc in three or four years.*

*by Clifford C. Butler*

MOST STUDENTS IN BRITAIN who intend to become professional physicists study for a Bachelor of Science degree with honors. The undergraduate physics school at Imperial College consists almost entirely of physics majors preparing for this degree of the University of London; they devote almost all of their time to physics and the necessary required mathematics. They are unlikely to take any humanities courses although some universities expect a modest performance in one or more foreign languages. In England and Wales the physics honors courses are spread over three years, but in Scotland they usually last four years.

This physics department is one of the largest in Britain. We now have nearly 500 undergraduates taking physics honors and about 150 graduate students studying for master's and doctor's degrees. The faculty—from postdoctoral teaching assistants to full professors—numbers about 100. The undergraduate numbers have grown steadily recently and are not yet at equilibrium.

Undergraduates come from high schools widely distributed throughout England and Wales. Not many come from Scotland because the Scottish secondary-school system is different from the pattern in England and Wales. Our students come mainly from grammar schools, but a growing number come from comprehensive schools; both types of school are maintained from public funds. Grammar schools provide mainly academic, college-oriented courses; comprehensive schools are more like American high schools with a wide range of academic and vocational courses. Some students come from Public Schools, which are, of course, entirely privately financed. The educational system in England and Wales offers a general education up to the age of 15–16 when the General Certificate of Education (GCE) Ordinary Level Examination is taken in a fairly wide spread of subjects. Prospective university students remain at school for two or three more years of rather intense specialization. During these years three (or sometimes four) main subjects are studied with some general studies of a rather variable kind. Students planning to major in physics at a university will study mathematics (usually pure and applied together) and physics and a third subject of their choice (often chemistry). Some of them, however, take pure and applied mathematics as two separate courses and physics with possibly a fourth subject. At the end of their last complete year at high school they take the GCE at the Advanced Level. This is not a national examination; the tests are organized by ten examination boards set up by the universities and schools. All boards classify their successful candidates into grades A to E for each main course; these grades are a major help when choosing students for the university.




*CLIFFORD BUTLER took his degrees at Reading University, was a faculty member at the University of Manchester from 1945 to 1953, and has been at Imperial College since 1957. His research interests are in high-energy physics; with G. D. Rochester he discovered V particles in 1947.*

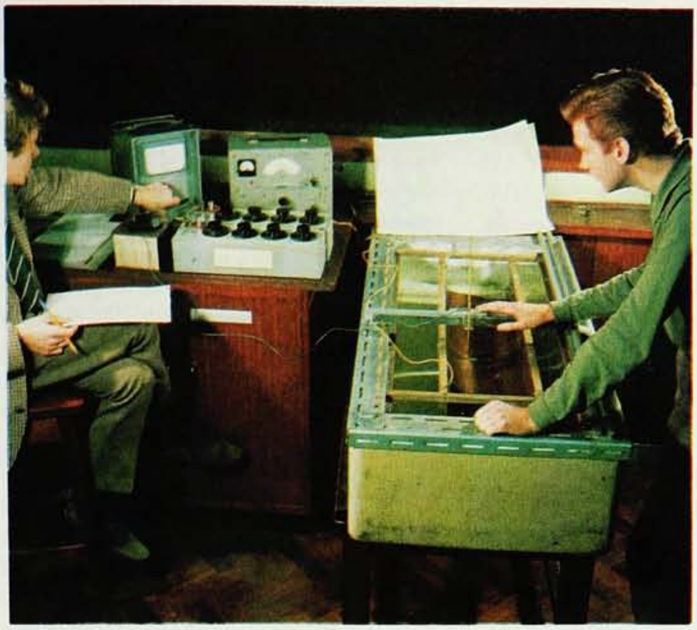
700 students applied to enter the department for the 1967–68 session. After an interview and an assessment of the results of the advanced-level examinations, 191 students were accepted. The admissions tutor and his assistants pay particular attention to the candidate's ability in mathematics; at least a B in mathematics is usually required. Our students therefore start with a working knowledge of, for example, the elements of differential and integral calculus, vectors, the binomial theorem and two-dimensional coördinate geometry. Almost all our students have at least a B in the advanced-level physics examination. All the basic aspects of physics—mechanics, acoustics, heat, optics, electricity and magnetism, and usually introductory atomic physics—are covered in the high-school course. Nevertheless the first-year university physics course begins almost from scratch. The pace, however, is fast, and we suspect that the school material is essential as a basis for rapid progress.

In October 1966 the University of London (of which Imperial is a constituent college) introduced new regulations for bachelor's degrees in science that are, I believe, unique in this country. The syllabus is now divided into roughly equal course units, and students must take a minimum of nine units to obtain a degree. Candidates for the BSc are eventually divided, if successful, into five categories: four honors groups and "pass," the lowest group. For a pass degree they must satisfy the examiner in at least eight units, but if they aspire to an honors degree our students must take additional examinations. They all start by preparing for an honors degree, and we advise them to take rather more courses than the minimum. Our standard course consists of 11 units, three in the first year and four in each of the succeeding years. Students may take all 11 units, or they may decide to take only nine or ten. In the final examination, at the end of the third year, honors candidates must take two comprehensive examinations that cover a wide range of topics in physics and are not associated with particular course units. However, provision is made for students who find the pace too demanding to sit only for a pass degree at the end of the third year, after which they may stay for a further undergraduate year and enter for honors. To do this they have to take two additional course units and the comprehensive examinations. They are assessed for honors on these fourth-year examinations as well as on their earlier examinations. A candidate may be considered only once for an honors degree as a physics major.

The course-unit structure began at Imperial College in 1966; so we now have it operating for the first and second years, but it will not operate in the third year until next October. For simplicity I will describe what we are doing in the first two years and what we currently plan to do for the third year.

Mathematics is an essential part of the physics training. Basic pure mathematics in the first and second years is taught by the mathematics department, but apart from this work and some third-year options the students spend their entire university time in the physics department. The college provides general-studies and language courses but does not make them compulsory.

The first-year course consists of



three units taken by all students. The first, and perhaps the most important, unit is mathematics, and the other two cover introductory physics, with a laboratory class included.

The mathematics unit consists of 70 lectures (50 minutes each) and 70 class-work periods in which high-school mathematics is developed to include multiple integrals, maxima and minima of functions of several variables, vector calculus, Taylor's series and elementary three-dimensional coördinate geometry. The solutions of the first- and second-order differential equations are treated, Legendre and Bessel functions are introduced, and the separation of variables for partial-differential equations is discussed. The unit includes a study of Fourier series, the elementary properties of matrices, in particular their use for orthogonal transformations, and the existence of eigenfunctions. Emphasis is on the techniques of mathematical description as a basis for the physics lectures rather than on a demonstration of mathematical principles or rigor.

The layout of the first-year physics courses is included in table 1. For details of the textbooks mentioned there see page 60.

The mechanics course provides a basis for later courses in quantum mechanics. It deals with three-dimensional motions of particles and rigid bodies, and stress is laid on the conservation laws and on the invariance of physical laws for different frames of reference. Matrix methods are used to illustrate this principle and to discuss the rotation of rigid bodies. We teach orbital motion and the collision of particles with particular reference to the motion of satellites and nuclear-scattering cross sections. Lagrangian mechanics is used to discuss small vibrations and normal modes.

The atomic and nuclear physics course includes a general discussion of the structure of the atom and an introductory discussion of the hydrogen atom with Schrödinger's equation. Nuclear disintegrations and the discovery of the neutron are described together with the main aspects of the fission and fusion processes.

The electricity and magnetism course covers many topics dealt with at high school, but vector methods are used throughout. Essentially it brings the students up to the beginning of Maxwell's theory. A full treatment of ac circuits is included.

The laboratory class is compulsory for all students and occupies about 200 hours during the first year. Students work in pairs and in the course of the session carry out approximately eight different experiments. Familiarity with basic electronic techniques is the most common experimental skill required of physicists; so all first-year students do an experiment on transistor fundamentals in which they become acquainted with the magnitudes of forward resistance, current gain, leakage current and the characteristics of a commonly used transistor. They build a common-emitter amplifier and investigate its frequency response and distortion characteristics. More traditional measurements of physical constants such as gravity and magnetic susceptibility are also made, and the students use a magnetron to measure $e/m$. There is a short lecture course on the theory of errors (text: Barford), and in the laboratory we stress the assessment of errors in physical measurements.

### *The second-year course*

Basic training in mathematics is continued in the second year to prepare for more advanced physics courses. Some topics included are functions of a complex variable, contour integration, Fourier and Laplace transforms, and a more thorough treatment of partial-differential equations and the orthogonal functions of physical importance. Matrices are treated more extensively than in the first-year course. To link with increasing computer use in the practical class a group of lectures on numerical methods, interpolation, iterative approximation, etc., is also included in this course.

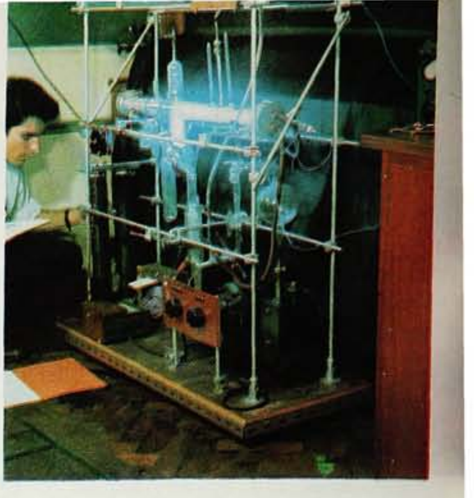
A block of lectures on theoretical physics (see table 2) includes an important classical course on thermodynamics and statistical mechanics. The treatment of quantum mechanics is based on the representation of observations by noncommuting operators. We teach the harmonic oscillator and hydrogen atom in considerable detail. There is some discussion of spin, and the exclusion principle is related to antisymmetry of the wave function of identical Fermi particles. This course forms an essential preparation for the second-year course on spectroscopy.

The electricity lectures include a treatment of Maxwell's theory and an introduction to transmission-line theory and wave guides, but the main applications of electromagnetic theory are deferred until the third year. The electronics course includes the physical background to semiconductor electronics and thus gives a detailed insight into the operation of solid-state devices. Negative-feedback amplifiers, wide-band and tuned amplifiers and some applications to control systems, digital computers, etc., are discussed.

The course in spectroscopy includes a treatment of optical spectra and a discussion of the electronic structures and properties of many-electron atoms. The solid-state course is an introduction and deals mainly with basic crystallography and the diffraction of x rays, electrons and neutrons by crystals. This course also introduces the relationship of anisotropy in physical properties to crystal symmetry and also provides an introduction to the crystallographic notation needed in third-year solid-state courses.

The nuclear-physics course deals with particle accelerators, interactions of charged particles and quanta with matter, particle detectors and nuclear reactions, and it includes an outline of modern nuclear-structure physics.

The second-year laboratory class occupies about 250 hours during the session, and again the students work in pairs. Topics include the construction and study of certain transistor circuits, audio- and radio-frequency circuit techniques to study the dielectric properties of ice and the skin effect in conductors, electrical transmission lines, the production and properties of 3-cm microwaves, spectroscopy in the visible and ultraviolet regions, the optics of the microscope, the use of Geiger counters and scalers to study beta-ray absorption, etc.



A short introductory course in computer programming is given as part of the second-year laboratory. The students learn a simple version of Fortran IV language, and computer-programming exercises are organized as part of the laboratory work.

Some students find the pace and standard of the second year rather tough. Students who want to reduce their load are advised to omit the theoretical-physics group of lectures. They will then need to take this unit during their third year and will probably spread the degree program over four years.

### *The third-year course*

Arrangements for the third year appear complicated because students are offered a flexible arrangement of optional courses. However, all students take two units that are described as the Common Course (see table 3).

The quantum-mechanics course is an essential introduction for both the solid-state and particle-physics lectures. Basically the course comprises operator theory of angular momentum, approximate methods for bound states and scattering theory. We give a careful treatment of the band spectrum of electrons in a periodic lattice to provide a theoretical basis for solid-state physics and give physical significance to the properties of a Fermi gas developed in quantum statistical mechanics. Similarly the scattering theory includes phase shifts, the Breit-Wigner formula and the golden rule (perturbation theory), which are all employed in the course on nuclear and

elementary-particle physics, later in the third year.

The solid-state physics course has three parts: a conventional treatment of quantum statistics; a course on lattice types, lattice dynamics and related properties; a section on the electronic structures of solids and magnetic properties.

The nuclear and elementary-particle physics course begins with a discussion of the deuteron; the concept of isotopic spin as applied to nucleons is introduced and p–p and p–n scattering experiments are discussed in some detail. Then we treat the pion, its properties (spin, parity, isotopic spin) and $\pi$–p elastic scattering with emphasis on the 3/2, 3/2 resonance. The properties of kaons and hyperons are outlined with the concepts of strangeness and hypercharge; the discovery of resonances and the classification of the particles into multiplets follows; finally we consider the weak interactions in outline.

Classical electrodynamics is an extension of the second-year course on electromagnetic theory, with a study of retarded potential, radiation from the Hertzian dipole and simple antennas, wave guides, and Thomson and Rayleigh scattering.

The electronics course continues the second-year course with modern solid-state devices and their application to experimental physics. We place particular emphasis on digital electronic techniques.

The remaining two units in the third year can be filled in a wide variety of ways. The particular list is naturally influenced by the range of current research programs in the department (see table 3).

Students who want to specialize in theoretical physics will take both the A and B units and no laboratory work. Some, however, take theory course A or B and practical physics. Other students may choose only one of 3, 4, or 5 and must take the laboratory class.

Theoretical course A includes further quantum mechanics and solid-state theory together with mathematics courses on matrices, tensors and group theory. Course B includes hydrodynamics, magnetohydrodynamics, differential and integral equations, complex variables and integral transforms.

The plasma and space-physics unit consists of hydrodynamics, magnetohydrodynamics, terrestrial plasma physics and space physics with emphasis on cosmic rays. The atomic physics and astrophysics unit is new and will be given in 1968–69 for the first time. Unit 4 deals with sources, propagation and detection of radiation.

Experiments in the third-year laboratory are more elaborate than those in earlier years. Many are "open ended"; the students are encouraged to take them beyond the minimum that would be considered as satisfactory. The range of experiments includes many "techniques studies" that give practice in operations needed in research. For example vacuum measurements are made on a flexible vacuum apparatus to ensure that the student could put together a system for a given performance. In another experiment the students evaporate thin films to make mirrors, antireflection coatings and interference filters. The laboratory also includes a number of advanced experiments set up under the guidance of research groups in the department. There are obviously many electronics units in the individual

**Table 1. First-Year Courses**

| | lectures |
|---|---|
| Classical mechanics (Kibble) | 30 |
| Vibrations and waves | 25 |
| Atomic and nuclear physics (Beiser) | 30 |
| Thermal physics and the states of matter (Sears) | 30 |
| Electricity and magnetism (Reitz and Milford) | 35 |
| Optics (Longhurst) | 25 |
| Total: 175 lectures; 2 units | |

**Table 2. Second-Year Courses**

| | lectures | units |
|---|---|---|
| Mathematics | 40 | 1/2 |
| Theoretical physics | | 1 |
| Thermodynamics and statistical mechanics | 28 | |
| Quantum mechanics (Mattews) | 20 | |
| Relativity and electrodynamics | 12 | |
| Electricity | | 1 |
| Electromagnetic theory (Reitz and Milford) | 20 | |
| Electronics (Harris and Robson) | 20 | |
| Atomic and Nuclear physics | | 1 |
| Atomic spectra and structure (Herzberg) | 15 | |
| Solid state physics (Dekker) | 15 | |
| Nuclear physics (Enge) | 30 | |
| Laboratory class | | 1 |

**Table 3. Third-Year Courses**

| | lectures | units |
|---|---|---|
| Common course (taken by all students) | | 2 |
| Quantum mechanics (Messiah) | 20 | |
| Solid state physics (Dekker, Kittel) | 50 | |
| Nuclear and particle physics (Segre) | 20 | |
| Classical electrodynamics | 20 | |
| Electronics: applications and computing | 20 | |
| 1. Theoretical physics A | 60 | 1 |
| 2. Theoretical physics B | 70 | 1 |
| 3. Plasma and space physics | 60 | 1 |
| 4. Atomic physics and astrophysics | | 1 |
| 5. Microwaves, masers, lasers and photoelectronics | | 1 |
| 6. Practical physics | about 200 hours | 1 |

experiments, and the students are encouraged to design and make this equipment themselves.

Another short lecture course on computer programming and numerical methods is held in the third year. Students are encouraged to reduce their own experimental data using programs of their own design with the college's IBM 7094 computer.

Some students choose two third-year units in subjects taught in other departments. At present options are available in electrical engineering, metallurgy, meteorology and geophysics.

Weekly tutorial classes for student groups of three or four from all years are given by members of the faculty and by some senior graduate students. Tutors correct the students' problem sets, grade their essays and organize general discussion.

### *Plans for a new course*

Although the unit structure for the physics honors course is relatively new, the main philosophy of the courses has evolved slowly over the last ten years or so.

Our program has a strong theoretical bias, and experience shows that it is an excellent training in basic physics for students proceeding to graduate school in theoretical physics or experimental solid-state and particle physics. It is less suitable for students who go straight into industrial research and development. We are now planning an alternative common course for the third year with a more practical flavor slanted towards the particular needs of these students.

In the future it may be necessary to make fairly radical changes to the whole program if significant changes occur in the secondary-school curriculum. There is growing opinion that the present pattern in England and Wales is too specialized, so that young people have to make vital decisions much too early, particularly between the sciences and humanities. There is now a very healthy discussion about these problems going on nationally, and I anticipate that, as an outcome, there will be significant changes in the secondary-school curriculum within a few years.

* * *

*I am very much indebted to numerous colleagues who have contributed material for this article.* □

# The Interdisciplinary Curriculum

*Some attempts to provide combined physics–chemistry–biology courses have not survived, despite enthusiastic beginnings. What is the recipe for success?*

*by John M. Fowler*

LIKE THE PROGRAMS of the United Nations, interdisciplinary courses offer obvious advantages in theory but in practice often founder on political realities. Sometimes they also work well. Following the analogy, the interdisciplinary idea appears to work most successfully when applied outside the sphere of influence of the science department, that is, in courses for the "nonscientist." But the situation is more difficult with joint introductory courses for science majors; for these courses are besieged with the possessive instincts of science departments toward their majors and with the narrow curricular views of the separate disciplines. Not surprisingly, perhaps, physics departments have, in many instances, stood out as the "hard line" department. Their rigorous view of what students should learn has left course developers with a disciplinary lump in the interdisciplinary amalgam.

I shall summarize the experience of several interdisciplinary efforts of the past 5–10 years. Also, I shall try to set down some of the logic that has led to enthusiastic beginnings and to recount problems that, in many instances, brought about their demise.

One can mark the time of high hopes with the Beloit Conference[1] of 1961. The joint conference sponsored by the chemistry and physics commissions in early 1967[2]—and the survey[3] that accompanied this conference—serve as an intermediate checkpoint. And the "Conference on Interdisciplinary Curricula in the Natural Sciences in the Liberal Arts College,"[4] held last fall at Hope College, revealed some of the serious difficulties that these courses are encountering.

### *Why interdisciplinary?*

Among the advantages of interdisciplinary approaches to science advanced in different conference preambles and proposal introductions two

*JOHN M. FOWLER is director of the Commission on College Physics and a member of the department at the University of Maryland. He obtained a BS at Earlham College in Richmond, Ind., and a doctorate from The Johns Hopkins University.*