THE TRAINING OF RESEARCH CHEMISTS AT THE WEIZMANN INSTITUTE OF SCIENCE

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The main problems in establishing the rules and curriculum for M.Sc. and Ph.D. students of chemistry in a graduate school are:

(a) defining the purpose of training;
(b) integrating students with B.Sc.s of uneven background;
(c) maintaining a balance between course work and independent research; and
(d) reducing the time spent in the graduate school.

The Feinberg Graduate School of the Weizmann Institute of Science has, at present, over 400 graduate students (taking both M.Sc. and Ph.D. degrees) of which 140, or about a third, are chemists. There are no undergraduates at the Weizmann Institute. The Board of Studies in Chemistry has set itself, as a primary task, the production of capable and versatile research chemists. At the same time, it hopes to broaden the horizons of its students and to encourage them to tackle new areas of research—such as geoisotopic chemistry, membrane technology, solid state chemical research, and immunochemistry—all of which are currently being investigated at the Weizmann Institute.

A salient problem in the planning of curricula at the M.Sc. and Ph.D. levels is maintenance of the optimum balance between courses and research and the type and number of courses to offer. We have decided to place the burden of coursework at the M.Sc. level, thereby enabling Ph.D. students to concentrate on their research. since the M.Sc. intake is derived from a variety of universities of Israel, from both Eastern and Western Europe, from North and South Africa, the U.S.A. and South America, the students display a wide range of knowledge and background, particularly regarding the more physical aspects of chemistry. We have, therefore, insisted on compulsory courses in mathematics, quantum chemistry, thermodynamics (for three to four semesters) for all chemists, with optional courses in the theory and practice of modern physicochemical experimental techniques (see *Table 1*). Many of these optional courses emphasize a particular aspect of a given topic, such as kinetics of rapid reactions or the physical chemistry of polymer solutions, which bring the students closer to the reality of up-to-date research. Students are also free to substitute courses from the physics or biochemistry curricula if they wish. The courses are given in English, thus enabling foreign students and new immigrants to follow the courses and at the same time enforcing a better grasp of English on all our students.

Appendix 1. Courses in chemistry given at the Feinberg Graduate School, Weizmann Institute of Science, as a two-year cycle:

Year 'A'	*Year 'B'*
Mathematics*	Mathematics*
Quantum chemistry*	Thermodynamics*
Molecular structure and spectroscopy*	Advanced quantum chemistry
Statistical mechanics	Molecular biophysics
Polymer chemistry	Kinetics
Electrochemistry	Solid state chemistry
Irreversible thermodynamics	Topics in organic chemistry—natural products or synthetic methods, etc.
Topics in inorganic chemistry	Structure and reactivity
Stereochemistry	Photochemistry
Theoretical organic chemistry	Magnetic resonance—n.m.r., e.s.r., n.q.r., etc.
X-ray crystallography	Mass spectrometry
Radioisotopes	

* Compulsory courses for all M.Sc. students.

Note: Optional courses can be replaced by lecture courses from Pure or Applied Mathematics, Computer science, Physics, the Biological Sciences and Applied Science. These courses include Hydrodynamics, Group theory, Solid state physics, Sensory biology, Topics in molecular immunology, Biophysical techniques, Photobiology, Cellular regulatory mechanisms, etc.

All M.Sc. students have two days a week free of lecture courses, an arrangement which permits them to work (for a stipend) in one of the research groups of the Weizmann Institute, and thus encourages them to form their research interests, which can be expanded into a six-month M.Sc. research project. Only very good M.Sc. students—on the basis of their work, an interview, and their M.Sc. theses—are accepted for Ph.D. work.

Ph.D. students are required to attend only a few lecture courses. We have, however, instituted a system for raising the standard of the research itself. Within six months of being admitted, each Ph.D. student must submit a detailed, written research proposal based on his reading and preliminary laboratory work. This proposal is then sent to two senior members of the staff, who interview the student and determine his overall knowledge, and his ability to undertake the proposed research. These staff members continue to see the student and his annual written reports throughout his time at the Institute. This method has ensured that only first-rate topics are suggested for graduate research and has cut down on the number of 'abandoned' students, or those bogged down with unsurmountable experimental or theoretical difficulties. It has also, incidentally, helped in the research itself by encouraging an exchange of ideas between different research groups within the Institute.

One further aspect of the training of research chemists which merits discussion is our attempt to attract the interests of students to careers in industrial research and in teaching. Only a few industries in Israel are large enough to require Ph.D. research chemists, but nonetheless an industrial clearing office within the Weizmann Institute—Yeda (meaning knowhow)—maintains contact with these organizations and promotes the establishment of new science-based industries. The presence of this organization, its slow, steady success in establishing new industries and expanding old ones, has helped many graduates (and members of the staff) to become increasingly aware of applied research and to try to tackle some of its challenges. At the

same time, a Department of Science Teaching at the Weizmann Institute, which deals mainly with the preparation and testing of textbooks and of teaching materials in physics, chemistry and mathematics at the secondary school level, has also drawn some students towards teaching as a career.

Finally, the question of the time spent in Graduate School has concerned us for some time. We hope to reduce the time needed for a M.Sc. from two years to one, as the level of B.Sc. students and curricula rises. However, the Ph.D. degree still takes from three to four years, so that Ph.D. students spend a total of five to six years at the Graduate School. This seems very long, but because of the vast and growing information and technical expertise required by a modern chemist, we have not yet found a way of reducing this span. At any rate, we hope that, after this period of training and after having been subjected to a considerable variety of courses, seminars and extra-curricular activities, the new Ph.D.s who emerge from the Graduate School will have interests and experience broad enough to equip them to undertake new challenges, and explore new areas of research in contemporary chemistry.

DISCUSSION

L. S. Bartell (*University of Michigan*)—With respect to Professor Samuel's suggestion that a rather extended period of study seems necessary for the Ph.D. in chemistry, it is of some interest to note a survey made by the American Physical Society several years ago. It was found that the shorter the time spent by a student in his studies, the more productive he turned out to be. This result casts some doubt on the advantages of a prolonged period of advanced training.

D. H. Samuel (*Weizmann Institute of Science*)—There may be a real difference between physicists and chemists in this connection. For various reasons it is true that physicists tend to carry out their best work under the age of 30; this may not be true for chemists.

J. F. Bunnett (*University of California, Santa Cruz*)—A further advantage of having a small research committee to review the thesis research proposal and the student's progress is that, in cases where a student is abandoned by a professor (owing to resignation or death), other members of the research committee can take over.