Editorial

Pierre GRIVET, 1911-1992
His contribution to electron optics

On June 1st 1992, Pierre GRIVET died at the age of 80. Until 1982, he directed the Institut d'Electronique Fondamentale at Orsay, which he had created many years before and which was one of the first major Laboratories to be associated with the CNRS. In 1972, he was elected a member of the Académie des Sciences.

With J.J. TRILLAT and G. DUPOUY, he was one of the pioneers of electron microscopy in France. When he graduated from the ENS (Ecole Normale Supérieure) in 1935, he attempted to improve a method of measuring the velocity of light. This work, interrupted by the outbreak of war, formed the basis for his doctoral thesis, presented in 1941. Throughout this period, however, he also followed closely the theoretical and experimental work on electron optics, concentrated for the most part in Germany, which led to the development of the earliest high-resolution transmission microscopes.

It was in 1941 that P. GRIVET joined the research laboratory of the Compagnie Générale de Télégraphie sans Fil (CSF), where he worked on the optics of electron beams in high-frequency vacuum tubes and television tubes; he became director of the newly created Laboratory of Television and Electron Optics, and was soon leading a young and dynamic group. In 1941-42, he wrote a Précis d'Optique Electronique, devoted to lenses and microscopes. He was then interested with the task of designing a simple electron microscope, operating at 50 or 60 kV, that could be used by non-specialists.

The earlier microscopes that had been built in various countries were almost all fitted with magnetic lenses. Only a few attempts to use electrostatic lenses in electron optics had been made, even though these were in routine use in oscilloscope and television tubes. In France G. DUPOUY was beginning on the construction of a magnetic microscope in Toulouse. At that time, microscope designers had no accurate information concerning the relative aberrations of magnetic and electrostatic lenses and a resolution of the order of 10 nm, - routinely available with the commercial SIEMENS models in 1940 - was amply sufficient for the needs of the users. Although such a resolution was distinctly better than of an optical microscope, it was still far from the limit determined by the familiar effects : diffraction, spherical and chromatic aberrations coupled with the properties of the source. External factors essentially determined the practical limit : mechanical defects, inadequate stability of the voltage and current supplies, vibrations, parasitic magnetic fields....

After a careful study of all the informations available in occupied France, GRIVET audaciously chose to pursue the electrostatic design. Electrostatic lenses possess two fundamental advantages over their magnetic rivals : they are lighter and, to a first approximation, insensitive to fluctuations in the voltage source when all the elements of a complex system are fed from the HT generator of the electron gun. Conversely, the construction of strong and hence small lenses raises the problem (poorly understood in 1941) of sparking between the electrodes; this in turn causes sharp variations in the supply voltage and can at worst lead to irreversible damage to the lenses.

GRIVET therefore launched a program of systematic studies of all the problems that arose in the construction of a prototype two- lens microscope with no condenser, giving a direct magnification of 6-7000 (or 25000 when the fluorescent screen was magnified optically), with a theoretical resolving power of a few nanometers.

Symmetric unipotential (einzel) lenses, with three plane electrodes, were studied in depth by GRIVET himself and H. BRUCK. The potential distributions were accurately established using scaled-up models and an electrolytic tank : an analogue device for solving Laplace's equation in an elegant way. The optical properties were then determined by trajectory tracing. The foci of the objective lens had to be outside the field, so that the object would not disturb the potential distribution, and the focal distance was hence of the order of 5 mm; the spherical aberration was to be as small as possible. The projector lens could have foci within the field and hence a shorter focal distance.

The difficult problem of designing the lens to avoid sparking between the stainless steel electrodes and along the insulator on which the central electrode was mounted had to be overcome. Many other technological problems had to be solved : magnetic screening of the lenses, within which the electrons were slowed down to energies of a few keV and hence sensitive to stray magnetic fields; direct recording of the images on photographic plates in the vacuum; focusing of the image by mechanical microdisplacement of the specimen.....

The first prototype was in operation in 1942, the excitation being provided by an unstabilized HT generator for X-ray tubes. Two improved models were built in 1943 and put at the disposal of a biological laboratory (Institut Pasteur) and a laboratory for the physical chemistry of materials (Michelin).

The final version of the CSF electron microscope was put on the market in 1946 and some 60 instruments were sold during the following five years. This microscope had been improved in many ways : the 60 kV HT generator had a stability of about 10^{-4}; a high-brightness gun designed by H. BRUCK enabled the image to be observed comfortably at a direct magnification of 14 000; the magnification could be varied from 2000 to 14000 by altering the projector voltage and the image was focused by making small changes to the objective voltage. The best resolution was a few nanometers.

During these years, GRIVET and his colleagues did not confine their activities to developing the CSF microscope. GRIVET himself examined ways of calculating the optical properties of lenses by using models of the axial potential simple enough to give analytical solutions of the trajectory equations. After finding that a weak residual astigmatism, due to imperfect rotational symmetry of the central electrodes, was sufficiently serious to limit the resolution of the instruments, he studied this "ellipticity aberration" in greater detail and suggested that it could be corrected by placing an appropriate system of electrodes below the objective. The latter, which created a multipole potentiel, was studied both theoretically and experimentally by F. BERTEIN, whose work led to the introduction of the device that was later called the "stigmator". Another student of GRIVET, E. REGENSTREIF, established formulae for all the properties of electrostatic lenses in terms of the minimum value of the axial potential and worked out the full theory of lenses with elliptical openings, with correction of the spherical aberration as a distant objective.

In 1945, GRIVET and his team designed a new microscope with a shorter colûmn and three lenses, with which diffraction patterns could be easily observed. The magnification was continuously variable from 2000 to 40 000. A prototype was built in 1948 but in the face of the mounting competition from high- resolution magnetic microscopes, the CSF decided not to market it.

In 1948, GRIVET was appointed Professor of Electronics and Radio Science at the Sorbonne. At the ENS, he formed a research laboratory named Laboratoire de Radioélectricité, in which many new lines of research were developed by the young research staff newly recruted, as well as the work on electron microscopy. A thermoionic emission microscope, for observing phase transitions and recrystallization in refractory metals at high temperature was developped by A. SEPTIER, who made a detailed theoretical and experimental study of a wholly electrostatic immersion objective with plane electrodes. The resolution was 0.1 mm. The instrument was later converted by L. HUGUENIN into a photoemission microscope, giving images of conducting objects at room temperature.

A lithium ion microscope, using a heated solid source, was built by M. GAUZIT, based on a two-lens CSF microscope. Grid lenses which had been proposed before the war by L. CARTAN for focusing the ions in a mass spectrometer, were studied at length by M-Y. BERNARD, with a view using them in a linear ion accelerator.

In 1950, GRIVET organized the first International Conference on Electron Microscopy.

In the years between 1955 and 1962, GRIVET's interests turned towards accelerator optics as, in close collaboration with A. SEPTIER, to the study of strong focusing lenses with quadrupole symmetry, both electrostatic and magnetic.

After some years at Fontenay-aux-Roses, the Laboratoire de Radioélectricité moved in 1962 to the new campus at Orsay, where it was renamed the Institut d'Electronique Fondamentale. It was now a large laboratory and was one of the first to be associated administratively with the CNRS. The work on charged-particle optics, which always received the enthusiastic support of P. GRIVET, was now concerned with the creation and focusing of intense ion beams (G. GAUTHERIN and C. LEJEUNE) and the possible application of quadrupoles in high-voltage microscopes and microprobe instruments. Such lenses are much stronger than round lenses and can be grouped into systems that are stigmatic and free of spherical aberration (D. DHUICQ, P.H. MÖLLER). Finally, round magnetic lenses with very high fields were studied by P. BONJOUR, using rare-earth polepieces cooled to very low temperature, and superconducting windings.

This broad study of scientific research and in particular, the work on electron microscopy, was remarked in 1972 by GRIVET's election to the Académie des Sciences. In his own account of his research contributions at that time, he modestly mentioned only his own work on the invention of the stigmator despite his participation in many of the successful projects at the CSF and in his own laboratory.

His career continued at Orsay for many years, during which he left his personal mark on many generations of young research students, many of whom left to join other universities or to work in industry. For more than 45 years, he explored the avant-garde regions of physics and electronics, always alert to possible applications in university or industrial laboratories. He pioneered the first linear accelerators for electrons in France, subsequently built by the CSF, and nuclear magnetic resonance as a technique for chemical analysis and later, for medical imaging. He made a fundamental contribution to the study of noise in electronic devices. He was one of the principal participants in the introduction and development of quantum electronics in France, and contributed to the study of masers and atomic clocks, the applications of Josephson junctions in electronics, the use of superconductors to build ultra- stable oscillators at very high frequency and particle accelerators.

The numerous publications and more general works by GRIVET all have the stamp of authority. In particular, he produced a major text book on electron optics, which was first published in French and later translated with major revision into English, where it went through two editions. This book (Electron optics), familary known among electron microscopists as "GRIVET", remains a standard text for anyone involved in using or designing particle- beam devices.

Lastly, we recall that GRIVET created the first post-graduate courses at the University of Orsay, in close collaboration with the French Atomic Energy Commission (CEA), in which electron optics played an important part.

His many former colleagues, his numerous students and the members of his laboratory have all been saddened by the news of the death of Pierre GRIVET, who will be remembered as an inspiring leader and a scientific personality of the highest level.

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