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APS DIVISION OF ELECTRON PHYSICS
the first 20 years

By L. Marton

Two decades of electron physics are discussed in the following article, based on a paper delivered at the April 1964 APS meeting. The author is chief of International Relations at the National Bureau of Standards.

A few months ago, the officers of the Division of Electron Physics decided to look into the possibility of amending its constitution by enlarging the scope of operations to include atomic phenomena, as well as electron and ionic phenomena, in the fields covered by its activities. A committee has been appointed to look into the Division activities, and this fact has given me an opportunity to look up the old records. To my pleasant surprise I found that on April 28, 1944, the Division, then called the "Division of Electron and Ion Optics", held its very first meeting. A twenty-year celebration is therefore in order, and this modest talk is offered to look back, and also, if possible, to look forward.

The title of my talk implies concentration on the history of the Division alone. This would be the wrong approach, because the activities of this Division would be hardly conceivable without considering electron-physics developments elsewhere. For this reason I shall report briefly on the early history dealing with the formation of the Division and continue with electron physics at large these last twenty years.

Let us consider first the circumstances surrounding the establishment of the Division. Until the year 1943, the American Physical Society was a kind of monolithic entity without any specialized divisions. Some areas of physics, however, were represented by other organizations, such as the Optical Society and the Acoustical Society. On January 23, 1943, the Council of the American Physical Society passed a resolution aiming "To arouse interest in special conferences and group sessions at the meetings of the American Physical Society and to suggest ways and means whereby the American Physical Society might render a greater service through appropriate recognition of such groups." Shortly thereafter, the distinguished secretary of the Physical Society, and my good friend, K. K. Darrow, called to my attention Article IX of the Constitution of the American Physical Society which in three very short paragraphs provided the means for forming a division of the Society. Two weeks after the Council meeting our correspondence started on the possibility of forming a division, and by the beginning of April, I could present to the Council of the Society a petition signed by forty fellows and members favoring the establishment of a Division of Electron and Ion Optics.

Twenty-one years ago, that is, on April 30, 1943, the Council approved the proposal of the petitioners, whose ranks included such illustrious names as Ernest O. Lawrence, Felix Bloch, C. J. Davisson, Lester H. Germer, George E. Uhlenbeck, and many others. A committee was appointed to prepare plans for the organization of the Division and report to the Council at its next meeting. Members of this committee were F. G. Brickwedde, A. J. Dempster, Otto Beeck, Darrow, Germer, and myself. This committee had essentially two tasks: one was to prepare a draft of the constitution of the Division, and the second to prepare a slate for the first Executive Committee. By July 1943, a circular was prepared and sent to all members and fellows of the Society, inviting them to enroll as members of the newly formed Division and to suggest candidates for the Executive Committee. We were fortunate enough to persuade I. I. Rabi to accept the chairmanship of the Division, although with the provision that because of his wartime duties he might delegate to the vice chairman for part of the time, or for the entire time, all of the obligations of the chairman. The first Committee consisted of Rabi as chairman, myself as vice chairman, J. R. Pierce as secretary, and two members at large: Darrow and J. A. Hipple.

I mention briefly that Professor Rabi attached some conditions to his election. This is a good place to remind you that all the organization of the Division took place in wartime with severe restrictions on many activities and on travel. For quite a while the Executive Committee of the newly formed Division didn't even know if there would be any meetings of all of the Physical Society during the next year. Finally some of the travel restrictions were sufficiently relaxed to plan on a meeting jointly with the spring meeting of the Society, which, contrary to tradition, had to take place in Pittsburgh instead of Washington. It was a two-day meeting at the Mellon Institute on April 28-29, 1944, and, just to show you the kind of uncertainties attending the wartime conditions, the inaugural program of the Division of Electron and Ion Optics listed in the *Bulletin:* "Address of welcome by the Chairman or the Vice-Chairman of the Division". As it turned out, it was the vice-chairman who had to give the address of welcome, as the chairman himself was unable to attend.

The new Division had started off very well in the sense that approximately 700 members and fellows of the Physical Society expressed at the beginning the wish to join the Division. This number represented a much higher proportion of the total membership of the Society than today. From about seven percent of the total, our membership sank to a little over three percent. It is also significant of the mood of the times that very shortly after the formation of our Division, the Division of High-Polymer Physics was formed. There was at that time clearly a need for bringing together specialized workers. It was also felt rather soon that the title of Division of Electron and Ion Optics might be somewhat too restrictive, and two years after the formation of the new Division it was proposed that the scope of the Division be enlarged. A poll conducted among members of the Division was in favor of an amendment to the by-laws and for a change of the title of the Division. I do not want to bore you with details of how the name "Division of Electron Physics" was adopted and what were the subsequent changes in our by-laws. It may be more interesting to consider the history of electron physics itself during the twenty years since the formation of the Division.

In preparing this brief survey of accomplishments in electron physics, I relied on several sources. First of all, Mr. Toots, of the National Bureau of Standards, helped prepare a statistical survey of the papers presented at meetings of the American Physical Society. A certain aspect of my collection of data consisted in looking at critical reviews presented in different places. Thus I included in this survey whatever I considered part of the definition of electron physics given in the by-laws of the Division, namely, "The physical phenomena associated with the flow of electricity across the boundaries of and through vacua, gases, and solids". For good measure I added all research on the fundamental nature of the electron. Last but not least I should mention the kind cooperation of all my friends whom I pestered for their views of what were the most significant achievements of electron physics during the twenty years. I will try to present a composite view of these different opinions and the results of surveys, and, if I miss some of the more significant points, I will ask your indulgence in advance.

One of the interesting aspects of any such survey is to show how emphasis shifted at the meetings from one particular subject to another. The early emphasis on electron and ion optics was soon replaced by a prevalence of papers on emission phenomena. Somewhat later came the enthusiasm for the collision phenomena, which led more or less naturally to optical pumping and to electron physics applied to lasers. This is a very sketchy evolutionary view, but it leads us naturally to consideration of some of the means, or technologies, which helped in the development of electron physics in those years.

First of all, we must mention the very significant progress which was made in the last twenty years in vacuum techniques, without which electron physics would have been inconceivable. It is a moot question to ask which came first—electron physics helping vacuum technology or vacuum technology helping electron physics. I am willing to concede that other branches of physics required better vacuum techniques as much as did electron physics. Nevertheless, electron physicists have been perhaps the most helpful in evolving the schemes and techniques needed for ultrahigh-vacuum work, although they greatly benefited from some of the work done by others.

One of my friends, an eminent electron physicist, feels that in listing technical advances which led to better results in electron physics I should include the progress made in modern oscillograph technology. I agree. Advanced oscillograph techniques have contributed enormously to the achievement of better results—as have all of the improved techniques of measurement and handling of very-short-time phenomena. While we electron physicists have no monopoly on pulse techniques and time-of-flight measurements, we do use them perhaps as much as anybody else in physics. One should also list the increased use of electronic data-handling equipment in experimental work.

Another important aid to electron physics research is the evolution of new detection techniques for charged and uncharged particles. Although the most significant advances have occurred in the field of high-energy physics, electron physics has benefited from some of them, such as the new scintillation counters, bubble and spark chambers, and multipliers used as square-law detectors.

So much for the help received by the experimental electron physicist. On the theoretical side, probably the greatest single aid to development has been the large-scale application of computers to theoretical problems. All modern advances in collision and similar phenomena would be hardly conceivable without the extensive calculations of wave functions with electronic computers.

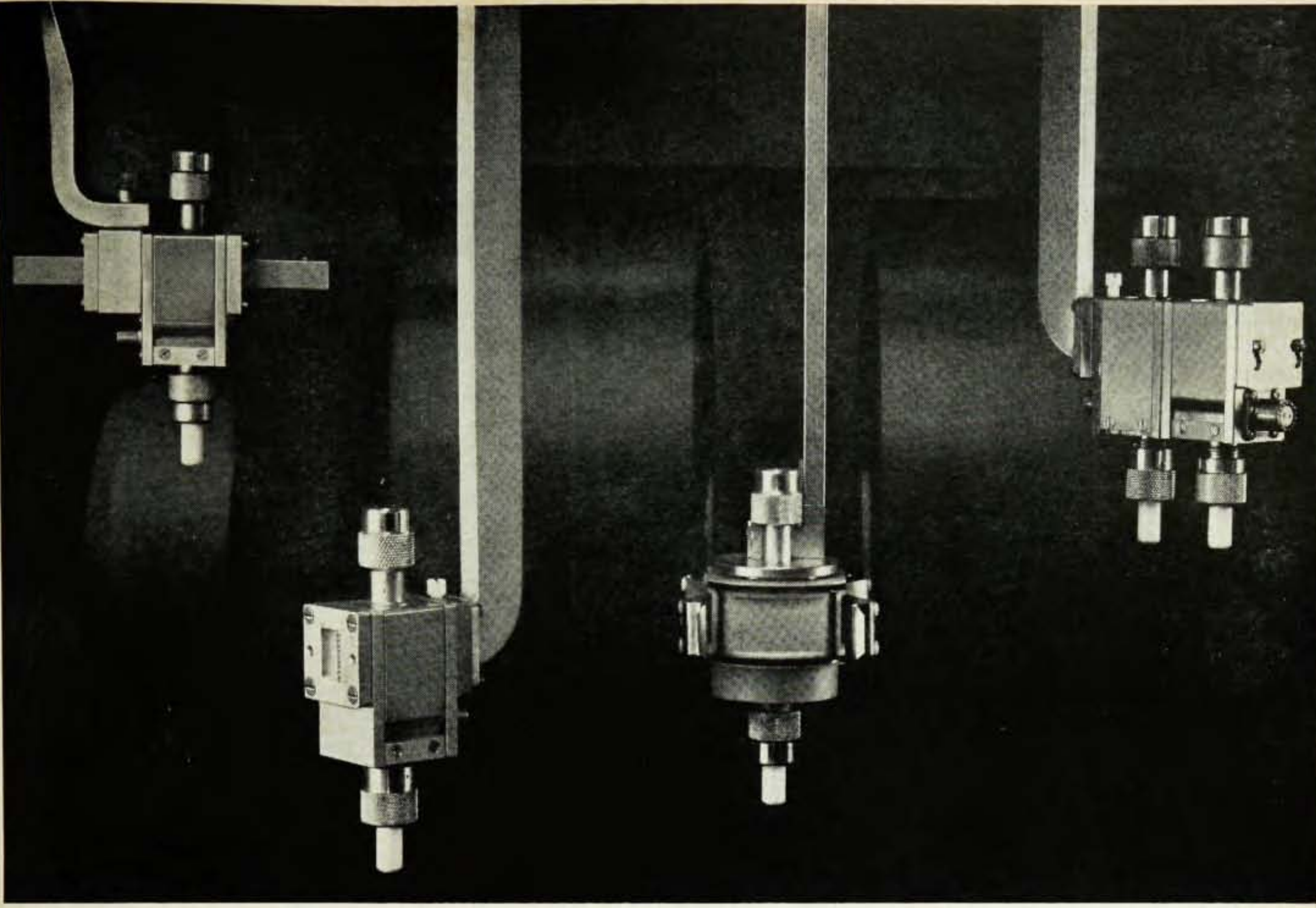
We may now look at some specific advances made in electron physics during the twenty years. There may be a number of people who feel that the really significant advances in electron physics preceded the creation of this Division. Maybe they are right if we look only at the heroic accomplishments of de Broglie, Uhlenbeck and Goudsmit, the two Thomsons, or Millikan. The last twenty years were essentially a remarkable period of consolidation, and no one can contest the importance of such work.

A few of the accomplishments, which I will list, are quite on the borderline of electron physics, and many of my friends would perhaps list them in adjacent fields. Typical examples are the Lamb shift, optical pumping, lasers, and the great number of problems linking electron physics to solid-state physics. If we look at electron physics proper, I would be inclined to list in the first place the beautiful work on the anomalous magnetic moment of the electron. The names of Kusch, Crane, and others come to mind in that respect. Another important contribution was the redetermination of the gyromagnetic ratio by Thomas, Driscoll, and Hipple. Next, I would list all of the collision phenomena. Because of the many aspects of the work in electron, atomic, and molecular collisions, it would be impossible to enumerate them all here. It may be worth while, however, to list just a few of the names of those whose work has been most prominent in the last twenty years. Leading, perhaps, is the excellent group directed by Sir Harrie Massey in London, where on the experimental aspects I would single out particularly John Hasted. Equally important is work carried out in the United States, where some of the former students of Oldenberg, such as Fite and Branscomb, have done very good work, as have Bederson and Biondi. Abroad, I would single out Dukelskii and Fedorenko in the USSR and Bates and his group in Belfast. The many applications of results to upper-atmospheric physics and to astrophysics show again the close connection between electron physics and other disciplines.

I mentioned earlier emission phenomena as being one of the fields in which there was a temporary popularity of papers within the Division. Although we still may find scattered papers on thermionic emission and on photoelectric and secondary emission, no doubt the greatest advance during the lifetime of the Division has been in field emission. Here we have to distinguish between two distinct phases of the work. One is the investigation of field emitters per se. In this type of work, Dyke and collaborators at Linfield College had the leading role. Most spectacular is the work in field-emission microscopy, which originated before the creation of our Division. Field-emission microscopy, however, has come to fruition during the past two decades, and the development of field-ion-emission microscopy has occurred entirely within the lifetime of the Division. Foremost is the name of Ervin Müller, but we should not forget Robert Gomer, J. A. Becker, and many others who have done beautiful work in this field.

Advances in gaseous electronics are the main concern of what amounts almost to a subdivision of our Division: the yearly conference on gaseous electronics. In the early years, the programs included the subject of gaseous plasma, but since the creation of the separate APS Division of Plasma Physics, the subject is avoided. It is interesting to note, however, the cross fertilization with emission work in the growing field of thermionic conversion. Many are the names one should include in this last category; arbitrarily I would pick W. B. Nottingham, because so many of his former students are engaged in conversion work, whereas in gaseous electronics at large W. P. Allis, S. C. Brown, and K. G. Emeleus come to mind.

Electron optics cannot show very spectacular advances—or if there are any, they belong in the field of high-energy physics. There have, however, been many interesting developments, and I would single out as most significant the development of quadrupole and octupole lenses, as well as some of the attempts toward corrections of the aberrations existing in electron-optical systems. Good recent work has been done in the group headed by P. Grivet as well as in the earlier theoretical approach of Scherzer. On the more applied side I would start with mentioning the electron microprobe analyzer of Castaing as being the most significant instrument developed, and then continue with such advances in microwave-tube design as the traveling-wave tube and the carcinotron (the so-called backward-wave oscillator). Electron-mi-



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croscope developments have made steady progress during this period. Whereas twenty years ago the electron microscope may have been considered by some people as an expensive plaything, the many hundred existing instruments manufactured commercially are now a standard component of almost every biological laboratory and of many chemical, metallurgical, and other laboratories. Their resolving power improved roughly by a factor of five in the intervening period.

In the applied electron-optics category I would like to include some of the significant advances in mass spectrographs. The optical elements conceived by Paul in Germany are in this category, as are Hipple's omegatron and the time-of-flight mass spectrographs which were developed following the original ideas of Goudsmit.

By defining electron optics as comprising not only geometrical electron optics but physical electron optics as well, perhaps the most significant development was that of the electron interferometer. Maybe I can without false modesty mention my name as the initiator of interferometers, together with my colleagues Simpson and Suddeth. Since that time, their development has been mostly linked with the names of Möllenstedt and Fert. The electron interferometer, although a relatively new instrument, has already contributed to the solution of some theoretically interesting problems. I would like to refer here to the theory of Bohm and Aharanov of the physical reality of the magnetic and electrostatic potential. Electron-interference experiments of Chambers and Fowler, and later those of Möllenstedt, have verified the conclusions of this theory and demonstrated, indeed, that a potential is not merely a mathematical aid to understanding phenomena.

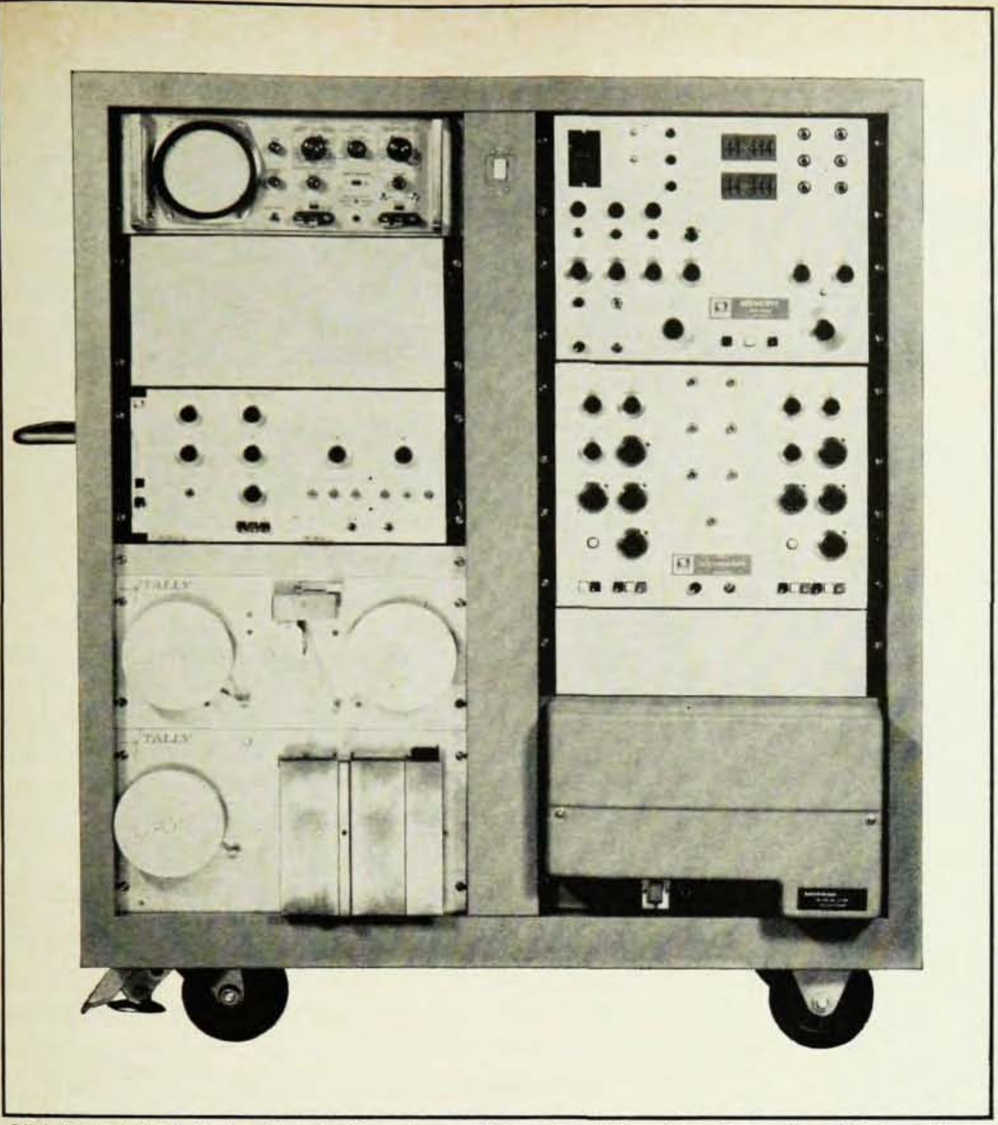
Electron scattering has been in the forefront of investigations for many years. Let us discuss electron scattering in solids first. Perhaps the most significant work deals with the so-called characteristic energy losses which have attracted considerable interest in the last ten or fifteen years and which are still actively being pursued in different laboratories. I cannot list all the names of those doing good work in this field. If I may I will list only the foremost groups by designating them with respect to the place where the work is done and the leader of the group. These are: Möllenstedt in Germany together with his students, Marton and collaborators in the United States, Watanabe in Japan, Swan and students in Australia, Boersch and students in Berlin, and Raether and students in Hamburg.

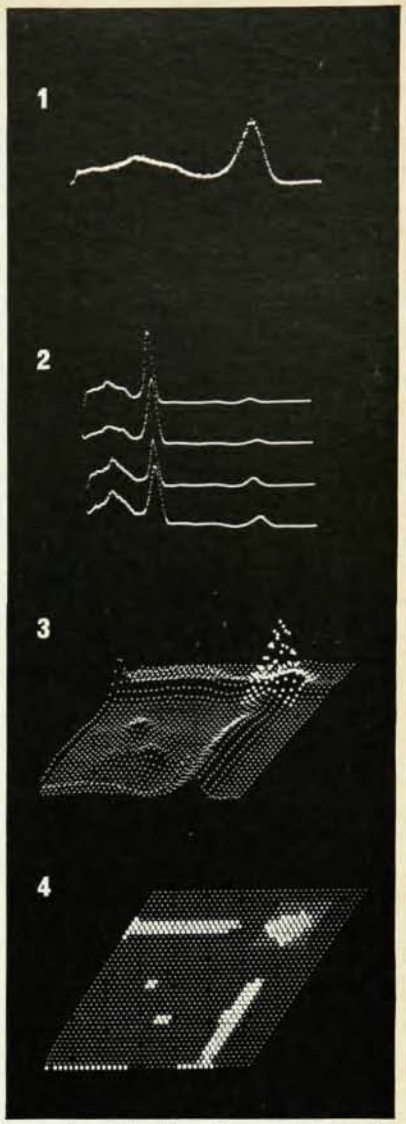
Electron-energy losses in gases come next. For recent very interesting work I would like to list the names of Lasettre and students at Ohio State University, Shultz at Westinghouse, and more recently Simpson, Kuyatt, and Mielczarek at the National Bureau of Standards.

Although many people may consider it high-energy physics, I would like to include in my review Martin Deutsch's work on positronium and Vernon Hughes' on muonium.

Until now I have concentrated mostly on experimental advances. Let us look very briefly at theoretical advances as well. The electron-energy-loss work in solids has been greatly helped by the theory of Bohm and Pines on the collective plasma oscillation in solids, whereas the electron scattering work in gases mainly bases its interpretation on the important theory of Fano and Cooper. I have referred to the contributions of Bohm and Aharanov to the quantum theory of the electron interactions, but this review would be incomplete without mentioning the very interesting and important work on minimum principles in scattering done by Spruch and collaborators at New York University.

It appears to be traditional that no review of this kind can be considered complete without the reviewer saying something about the future. He is expected to "stick his neck out" and say in what direction research is going to progress in the next few years. In trying to satisfy this requirement, I think I am safe in saying that there should be some effort in the near future in the direction of improving the values of the electronic fundamental constants. No direct observation of the elementary charge of the electron has been made since Millikan's time; the new values are all indirectly obtained values. I believe that the time has come when our technology is sufficiently good for an attempt to redetermine the directly observed value with a much greater accuracy than previously obtained. Means are also at our disposal for better e/m values, as well as h/e values. Serious further advances can be expected from the use of very monochromatic electron or ion beams for excitation purposes, both for single-particle and many-particle excitation. I would expect also great advances from a cross-fertilization of different fields such as, for instance, the use of high-energy methods in low-energy electron physics, and vice versa. In applied electron physics I would expect the greatest advances to occur as a result of work in space research and, in particular, in astrophysics. One very interesting application is just starting where our common laboratory experiment of cathode-ray sputtering is extended into its astrophysi-





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cal application of sputtering by the solar wind. Ionic propulsion is in its infancy and has not been tried out. I think it is safe to predict that serious advances should be forthcoming in that direction. The use of polarized beams has already started for a different type of experiment, and the use of polarized electron beams interacting with polarized atomic or polarized molecular beams may promise to be very interesting.

Exciting new possibilities are offered by the present and future development of superconductivity. There are already attempts to use electron physics for superconducting investigations, and the availability of very high magnetic fields offers the possibility of carrying out research in combination with charged or uncharged particles, which hasn't been possible in the past.

The resolving power of the electron microscope is getting very close to atomic dimensions. I think it would be again safe to predict that, within one or two decades, the conventional electron microscope will be able to see the atom.

At this point I would like to put in a plug for improved teaching of electron physics. I feel that teaching in this branch of physics has been somewhat neglected. Many feel that the supply of young electron physicists is far too small and that something should be done to improve it. One way may be to form a group making recommendations to the universities, and the Division can perform usefully by taking a leading role in this direction.

In conclusion, I would like to say a few words about the future of the Division. At one time, someone remarked whimsically that "old divisions never die". I think this is how it should be. If a division is vital enough and flexible enough to adapt to changing times, there is no need for it to die.

Almost 25 centuries ago Democritus laid down his famous principles, of which I would like to quote the third and the fourth:

> 3. The only existing things are the atoms and empty space; all else is mere opinion.
>
> 4. The atoms are infinite in number and infinitely various in form; they strike together and the lateral motions and whirlings which thus arise are the beginnings of worlds.

Millikan, in commenting upon them, said: "These principles with a few modifications and omissions might almost pass muster today." I think, also, that they may almost be incorporated in the by-laws of our Division. They point a way to the endless horizons open for future research and to the happy future, which, I am sure, is in store for the Division of Electron Physics.