

the physics of

ELECTRONIC and ATOMIC COLLISIONS

By Sidney Borowitz and Stephen J. Smith

The following account of the Second International Conference on the Physics of Electronic and Atomic Collisions was prepared by Sidney Borowitz, chairman of the Department of Physics at the University Heights campus of New York University, and Stephen J. Smith, chief of the Atomic Physics Section of the National Bureau of Standards.

ALMOST as soon as quantum theory was developed to explain atomic structure, it was applied to problems of the scattering of electrons by atomic systems. Early efforts were devoted largely to determining whether or not the new picture of the atom was consistent with some of the results obtained in scattering experiments. For example, Faxen and Holtzmark developed their method of describing scattering in terms of phase shifts to explain the Ramsauer effect. The crudest approximations indicated that, in a general way, the wave-mechanical picture was a satisfactory one for describing continuous, as well as discrete, spectral phenomena, and there the matter rested.

The boundaries of knowledge in physics have long since passed from the atom to the nucleus, to the quantum-theory fields, to mesons and strange particles. Atomic physics is definitely not in vogue. But a nagging set of problems in the field of continuum physics has remained. These problems are not much closer to solution today than they were thirty or forty years ago.

In recent years these neglected problems in atomic physics have acquired some technological importance in the fields of astrophysics, fusion, plasma physics, laser design, and the experimental technology associated with atomic and molecular beams. Probably for

this reason, the recent conference on the Physics of Electronic and Atomic Collisions, held at the University of Colorado, Boulder, June 12-15, 1961, attracted well over three hundred participants. The conferees represented a broad spectrum of viewpoints regarding these problems: some were interested in answering questions about some of the fundamental cross sections because the answers were important to their fields of specialization; others, because the open problems have considerable intrinsic merit, since their solution would contribute both theoretical and experimental techniques of use in a wide variety of fields.

The first such conference was held in January 1959 at New York University. Perhaps the most notable advance since the New York meeting has been the extensive work on the three-body systems of an electron and a hydrogen atom and of a positron and a hydrogen atom. It has been established that certain variational calculations provide bounds for the scattering length. This reduces the scattering problem to the equivalent of a Rayleigh-Ritz problem, and extensive calculations with the use of a 50-parameter trial function have made it possible to establish bounds, which are probably quite accurate, for the scattering length in the scattering of electrons by hydrogen atoms. The effect of having these bounds is essentially the equivalent of

having good experimental information for zero-energy scattering of electrons by hydrogen atoms. One would have expected, then, that there would be a number of model calculations capable of reproducing these accurate results for the relatively simple three-body problem and applicable to more complicated systems. These expectations were borne out, and one entire session of the Boulder conference was devoted to the results of calculations of this sort. The most surprising result of this session was one which showed that if the close coupling of the $2S$ and $2P$ states of hydrogen is considered, reasonable results are obtained in the scattering of electrons by hydrogen. One would have expected that the polarization of the atom should be treated much more carefully in order to obtain such good results.

The method of obtaining bounds has been extended to other than zero energy, and the modification of the effective range theory in the presence of long-range forces is complete. Thus, further progress on this problem is to be expected.

Model calculations were also made to test the validity of the first Born approximation for rearrangement collisions. A Hamiltonian was chosen having a spectrum with two degenerate or almost degenerate states and perturbed by the field of a charged particle whose motion was classical. These calculations indicate that the influence of nearby states may make the Born approximation invalid for these processes.

The level of sophistication of the theoretical techniques used in atomic physics seems to be rising. All sorts of methods which have been useful in other fields, especially nuclear physics, are now being applied to atomic physics. Thus, there are efforts toward calculating optical models, employing dispersion relations, using the idea of a "compound atom" during a collision, and analyzing collision processes statistically in the sense that one assumes a statistical distribution of available energy levels for rearrangement and excitation. Many-body techniques are being used for structural calculations. Attempts have also been reported to relate the scattering of electrons by atoms to experimentally known parameters, such as quantum defects; another approach reported has been to relate the calculations of the photoexcitation of atomic systems to the stopping power maximum. There have been some extensive calculations on photoionization, using the excitation in calculated Hartree-Fock fields, with a rough explanatory model in which the initial sharp drop of the photoionization cross section as a function of energy is attributed to optical electrons without nodes and a long shoulder to those with nodes.

One would hope that some of these methods will shed some light on the "more than three-body" atomic problem. The next two years of effort should bring about as much progress on this problem as has been achieved on the three-body problem in the last two years.

Just as the theorists, armed with new techniques and more powerful tools, have been busy superseding the

qualitative results of an earlier era (with quantitative and even precise calculations of low-energy collision phenomena), so have the experimentalists been building upon new electronic and vacuum technology in an effort to provide quantitative descriptions of individual collisions among electrons and atoms in various states of ionization. Indeed, the 1959 and 1961 Collisions Conferences were organized largely to emphasize the need for experimental work in support of the effort to extract from quantum mechanics useful results for low-energy scattering phenomena, and in recognition of a desperate shortage of experimental low-energy collision parameters for use in astrophysics, in ionospheric physics, and in the other fields of application of plasma physics.

THE Conference Committee for the 1961 meeting was largely successful in limiting experimental papers to those giving results of measurements of collision parameters. The program of contributed papers dealt with collision physics, and not with experimental techniques. The conference objective of encompassing the interests of both experimental and theoretical workers was successfully realized, and attendance at sessions was continuously high. Audience participation was extensive and extremely rewarding.

Although the formal program of papers was organized for maximum mutual benefit, it certainly gave a distorted view of the current effort in experimental collision physics. This field has been relatively inactive since the early days of quantum mechanics, largely because of the extreme difficulty of applying available techniques (or the complete lack of techniques) for working with low-energy charged and uncharged particles. The discovery and development of feasible techniques has thus far been the major concern of this new effort in experimental physics. This was obvious in the tone of the informal aspects of the conference: in the corridor conversations and, particularly, in the enthusiasm and interest displayed at the one informal session which was held on experimental technique. Some questions raised were: Can atoms and electrons be successfully energy-selected and used at one electron volt or lower? Can beam techniques be applied to the measurement of interactions between charged particles at low energies? Can the new ultrahigh-vacuum techniques contribute to this field? What are the current ideas on detection sensitivity limits? Can electron multipliers be used successfully in such low-energy collision problems?

Spectacular and much-needed results will be achieved with the positive solution of a few of these problems.

The experimental papers which were presented reflected an increasing level of technical sophistication resulting from these new efforts. One of the most significant results was derived from successful use of a monoenergetic electron beam to bombard nitrogen gas. Energy analysis of the forwardly scattered electron beam revealed discrete energy losses to excitations of the various vibrational states of N_2 , with probabilities

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that were several orders of magnitude larger than those ordinarily assumed for transfer of electronic to vibrational energy. The result is consistent with the formation of a temporary negative ion, a state of N_2^- , with decay to the various vibrational levels of N_2 .

Beam techniques dominated the experimental part of the program. There were beams of electrons, ions, and atoms crossing atom beams; photons crossing ion beams; and ion, atom, and electron beams traversing gas-filled chambers. The application of the beam technique is rapidly increasing in importance as a tool for observing atomic collision processes.

The most productive of these techniques, in terms of the numbers of papers presented at the conference, was the bombarding of gas samples with beams of ions and atoms, usually at relatively high energies. Cross sections for ionization and charge-exchange processes are inferred from analysis of the charged species in the transmitted beam, and of the low-energy charged particles appearing in the reaction chamber. Some of the systems studied involved gases of current interest for ionospheric or other plasma physics. Others were deliberately simple systems—involving hydrogen and the rare gases—with the objective of obtaining the least ambiguous results for comparison with various modifications of the Landau-Zener formula for charge exchange.

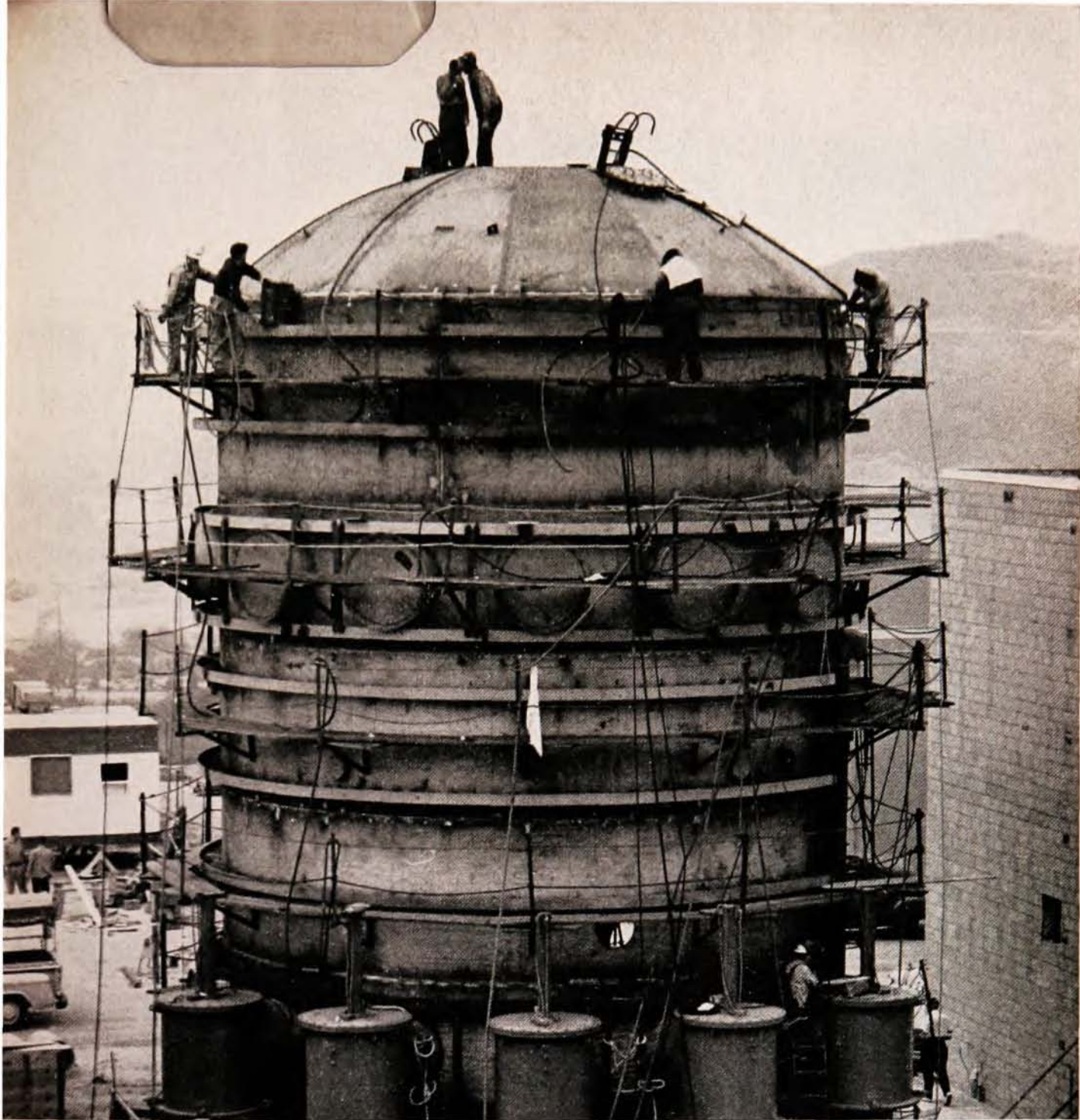
One paper provided an extensive tabulation of energy defects for ion-atom (or molecule) charge exchange to those states of the outgoing atom into which electron attachment is permitted by the optical selection rules.

Interesting comparisons were provided between cross sections for ionization by protons and by electrons of the same velocity. These tended toward the same values at high velocity, in accord with the Born approximation.

Increasing technical refinement was evident in the use of a variable-energy neutral N_2 beam, produced by exchange from an ion beam, in measurements of ionization by energetic neutral particles; in the study of charge transfer, using modulated cross-beam techniques; and in the extension of the range of measurements of charge exchange and electron-detachment cross sections to energies of only a few volts.

Always spectacular are measurements which unexpectedly reveal structure in a cross section. In this category were results showing the highly resonant character of electron capture by energetic ions of very low impact parameter (deflections of several degrees) and studies relating the appearance of structure in the energy dependence of electron-loss cross sections to the appearance of negative ions in the target gas.

The session on atom-atom collisions was the most impressive, from the point-of-view of technical sophistication of the experimental work discussed. This work included the use of high-speed rotary beam choppers for velocity selection, multipole-focusing devices and state selectors, and mechanical control of scattering geometry. One paper reported on the collision cross



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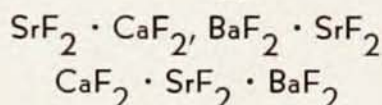
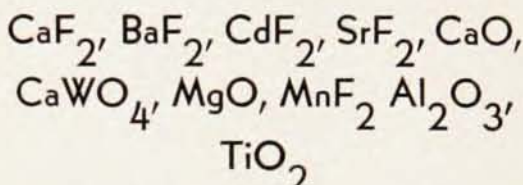
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sections of oriented TIF molecules in the $(J, M) = (1, 0)$ and $(1, 1)$ rotational states when struck by a rare-gas atom. Generally speaking, papers in this session were concerned either with fitting elastic-scattering results with physically reasonable potential functions or with the study of the products of reactive collisions.

There were several experimental papers concerned with the chemistry of free ions, such as on the formation of H_3^+ , the role of metastable ions in gaseous collisions, or negative ion formation in ozone, using mass spectrometer or other beam techniques.

Surprisingly, there were no papers concerned with either ion-ion or electron-ion interactions in spite of the importance of these processes.

There were three papers describing very elaborately instrumented cross-beam studies of electron scattering by atoms—one in which the scattering is measured through detection of the recoil atom. Other papers described production of ions by electron impact.

There were also papers dealing with optical effects: the excitation of atoms and molecules by electron and proton impact, transition probability measurements, a direct optical measurement of the C^- absorption coefficient and evidence for the existence of a metastable state of C^- , and the polarization of electron-impact radiation in helium.

A welcome breadth was added to the conference by papers on collision processes involving muonium and antimuonium, on cross sections for spin relaxation in optical pumping, and on collisional effects involved in hydrogen maser work.

Some notable contributions were made to the art of "conferencemanship" at this meeting. In order to avoid simultaneous sessions and to fit in the large number of papers (80), it was decided that many papers should be read by title only. Since a volume of detailed abstracts of papers was available to the participants before the conference, the reading by title saved considerable time without precluding interesting discussion of the papers. Finally, there were two sessions at the end of the conference, one for experimentalists and one for theoreticians, in which there were no set programs but technical discussions of detailed experimental and theoretical problems were aired. The general opinion of the participants who were polled was that these discussions were valuable.

The conference was sponsored by the Department of Defense and was organized by a large steering committee of which Benjamin Bederson was Secretary. Wesley Brittin, chairman of the Physics Department of the University of Colorado, had a smooth-running organization which allowed the meeting to proceed effortlessly. Except for being unable to guarantee perfect weather throughout the proceedings, the host institution contributed substantially to the success of the conference. These meetings seem destined to acquire a biennial character, Sir Harrie Massey having extended a tentative invitation to hold the next one in London in 1963.