THE PHYSICS OF BEAMS: PAST, PRESENT, FUTURE

Andrew M. Sessler

Last November The American Physical Society established the division of physics of beams (see PHYSICS TODAY, April, page 89). Why was this action taken? What are its implications?

The division was created in recognition of the growing importance of photon and particle beam physics. This new division does not correspond to the traditional fields of physics, such as mechanics or electricity and magnetism, or even to newer areas, such as atomic and molecular, nuclear, or particles and fields. But like these other areas, beam physics is challenging in both its practice and its intellectual content. I think the formation of the new division is indicative of how the present state of physics differs from the past. It used to be that physicists would dabble in a number of disciplines. Now, many physicists devote their entire careers to beam research.

The study of particle beams began in 1897 with J. J. Thomson's discovery of the electron. Other important early work included that of P. Lenard, who studied magnetic deflection and electrostatic properties of particle beams, then called cathode rays. One of the first applications of ion beams, and a dramatic one at that, was the α-scattering work by E. Rutherford in 1911, which established our picture of atoms.

Early interest in photon beams can reasonably be traced back to W. C. Röntgen's 1895 discovery of x rays. Also important was the discovery of the quantization of light—the photoelectric effect—which grew out of Lenard's work and was later explained by A. Einstein in 1905. Subsequently, very detailed experimental work on the photoelectric effect was done by R. Millikan.

The acceleration of beams was first achieved in the early 1930s by J. D. Cockcroft and E. T. S. Walton and by R. J. Van de Graaff, who built high-voltage dc machines. Of course, the energy of the beams was limited by the voltages that these early devices could sustain. Later, E. O. Lawrence, R. Wideroe and L. W. Alvarez developed resonant accelerators, in both circular and linear forms, which overcame the limitation inherent in dc machines. To properly build such devices, the focusing of particles, both longitudinally and transversely, had to be achieved. Many researchers in the 1940s contributed to this effort, including E. M. McMillan and V. I. Veksler, whose pioneering work on longitudinal focusing made synchrotrons possible.

In the early 1950s, Nicholas C. Christofilos and, independently, Ernest D. Courant, M. Stanley Livingston and Hartland S. Snyder invented strong focusing. From a theoretical point of view, their work was a general analysis of focusing. But from an experimental point of view, it provided the means to design, build and operate a multitude of different devices. In the 1960s researchers found that high-current beams could be stacked and stored, which enabled them to build high-energy colliding beam devices.

In the last two decades, a whole field of physics based on beams has developed. Our present ability to manipulate particles—in circular and linear colliders, in storage-ring photon factories, in neutral beam sources, in ion-traps and so on—is incredible. Today's achievements go far beyond even the dreams of early beam physicists. A century ago, who would have dreamt that particles could be held in storage rings for days (corresponding to astronomical distances of light days)? Or that currents of megamps could be transported over many meters? Or that intense beams of several microns diameter could be brought into collision?

Our ability to manipulate particles has grown out of our understanding of single-particle (linear and nonlinear) and collective phenomena. In fact, beam physicists are not just "users" of knowledge generated in other fields, but discoverers and creators in their own right. Beam systems serve as incomparable laboratories, being excellent for experimental work and exceptionally amenable to analytic and numerical study, and they have added greatly to our store of knowledge.

Among the single-particle nonlinear effects encountered in beam research are bifurcations, chaos, resonance overlap, Arnold diffusion, nonlinear modulation effects, resonance streaming and other exotic transport processes that occur in systems with more than two degrees of freedom. For example, the need to store relativistic beams was the primary motivation for the development of the theory of near-integrable Hamiltonian systems. Collective phenomena that have been encountered include instabilities, Landau damping, coupled motion, beam–beam radiation and pair production of photons, and turbulence. In fact, a number of many-body phenomena have first been observed in particle beams.

The physics of beams—that is, the sophisticated control of beams—has become the very basis for a number of physics subfields, such as particles and fields, and nuclear physics. It also contributes in a significant way to almost every other subfield of physics, from neutral beam and rf heating to plasma physics, from ion-implantation and synchrotron radiation sources to condensed matter, and from particle traps and free-electron lasers to atomic, molecular

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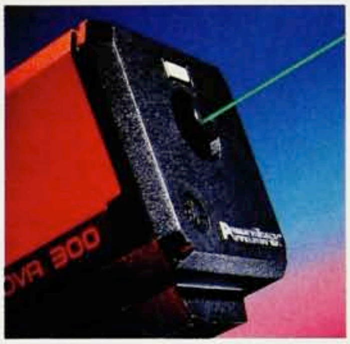

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In addition to its contributions within physics, the physics of beams has benefited many other fields of science and technology. One thinks of radiation therapy, isotope production for medical tracing, radiation processing, geoscience analysis, nanostructure fabrication, archaeology, art history, paleoanthropology, extraterrestrial minerology .... The list is endless.

But despite their many contributions, beam physicists have experienced discrimination for years, which has hampered development of the field. In establishing the new division, The American Physical Society was attempting to remedy this situation while responding to the intellectual arguments in favor of such a move. Most universities do not have beam physicists on their staffs, nor do they encourage students to obtain training in the discipline. The situation is improving, and with the creation of the new division, I hope it will improve even faster. But the need for trained personnel in particle beam physics is great, and it is not being met at the present time. Of course the US Particle Accelerator Schools, which were established almost a decade ago, are an attempt to fill this gap. But the field needs physicists with the extensive training that can only be received at a research university. I see the development of new university programs in beam physics and the strengthening of existing programs as a major goal.

A second consequence of the discrimination against beam physics is that research in the field is not officially recognized as an activity by any Federal funding agency except the High Energy Physics Division of the Department of Energy. True, other agencies do support beam physics, especially NSF and other branches of DOE, but not as a recognized program. A second major goal should be to convince Washington of the importance of beam physics research (beyond the realm of high-energy physics). This includes getting government agencies to designate such work as a research activity and obtaining funding at a level commensurate with its importance.

I believe that the physics of beams has come a very long way, but the field is only just beginning. The development and experimental use of new and ever-more sophisticated techniques in particle manipulation still lie ahead. In the future, we can continue to look forward to new understanding and further technological triumphs. ■