Laser-Driven Accelerators

With the latest series of high energy projects (ISABELLE 400 GeV proton-proton storage rings, UNK 5 TeV fixed target proton synchrotron and LEP 50—130 GeV electron-positron storage ring), many people believe that we are seeing the final generation of conventional machines. This is not because the acceleration or beam storage mechanisms involved have reached some technical limit (on the contrary they seem capable of extension to cope with still increasing energies) but because we are running into the limits of what Burt Richter calls 'fiscal feasibility' due to the size of the machines. Construction and operating costs would become extremely difficult to confront.

This realization has provoked concern about appropriate research and development on novel acceleration techniques. A HEPAP sub-committee in the USA, chaired by Maury Tigner, issued a 'call to arms' in 1980 to ensure sufficient attention for such long-range accelerator research even in hard financial times. In Europe, ECFA is taking up the same theme in organizing a Conference in Oxford in September of this year (see page 151).

From the physics side a similar plea has come from Abdus Salam (see 'A message from gauge theories', October issue 1981, page 347) since he was worried that the energy regime for interesting physics is moving beyond what can be experimentally investigated. Salam in particular mentioned the extremely high voltage gradients available in laser beams as one of the possible routes to a new high energy regime. The power densities and strong electric fields in laser beams have led to speculation over many years as to their application in accelerating particles to high energies.

In order to give more direction to this area of research in the USA, a Workshop on 'Laser Acceleration of Particles' was held at Los Alamos from 18—23 February bringing together some sixty physicists and engineers with expertise in the fields of accelerators and of lasers.

Several devices for using laser fields have been proposed and they can be classified in three broad categories — 'far-field' accelerators (such as the principle of inverse free electron lasers), 'media' accelerators (which, for example, use the inverse Cherenkov effect or laser-controlled plasma waves), and 'near-field' accelerators (using a loaded guiding structure such as cavities or gratings). These different approaches come from the fact that a particle cannot be accelerated by the absorption of single photons (because of momentum conservation) and thus some other element has to intervene.

In the 'far-field' type a particle moves in the same direction as a light wave and slightly slower. It experiences a transverse field which is almost cancelled by the magnetic field in the opposite direction. If, however, the particle orbit can be modulated, for example, by static undulator magnets, the magnetic field transforms transverse into longitudinal energy and the particle will be continuously accelerated (or decelerated if in the opposite phase). This is the inverse of the free electron laser mechanism.

This type (and related 'two-wave' accelerators) were discussed at the Workshop and it seemed clear that they are not appropriate for very high energies. They involve substantial deviations from straight-line motion which becomes increasingly difficult at high energies and the rate of acceleration falls. They could, however, cope with energies of a few GeV and handle very high (kiloamp) currents.

The above limitation does not apply in the 'media' type of laser accelerator where accelerating fields are created by polarizing media. An example is the inverse Cherenkov effect where experiments have already been carried out at Stanford (reported by R. Pantell). They operate by having laser light cross a beam of electrons in a gas cell at the Cherenkov angle. Electrical breakdown in the gas is believed to limit the peak accelerating field to several hundred MV/m and accelerators of up to 50 GeV were discussed. Multiple scattering and radiation in the gas may be a problem when aiming for high energies.

Another accelerating mechanism relies on the 'ponderomotive' force produced by laser beams in a plasma (the type of force associated with radiation pressure) producing moving bunches of electrons. The collective electrostatic field of the electrons is then used to accelerate particles. In the 'ponderomotive snowplow' proposed by W. Willis, high energy protons are injected into the electron bunch which is known to travel in a short wave packet of laser light traversing a plasma. T. Tajima and A. Dawson emphasize the acceleration of electrons picked up from the high energy side of the thermal tail in the plasma, and accelerated across the bunch. Computer simulations of these effects were presented by Tajima and D. Sullivan and an experiment using a powerful CO_2 laser was described by C. Joshi, in which acceleration of more than 1 MV was observed in good agreement with the simulations.

A good variation on this scheme was described by Tajima in which the beat waves created by two nearby laser wavelengths are used instead of the short wave packet. The snowplough effect is most efficient when the wavelength of the beats is matched to the wavelength of the plasma waves. Joshi showed results of an experiment in which a carbon dioxide laser was run at two frequencies to create the beat wave and the presence of the plasma wave was verified by Thompson scattering of laser light. Sullivan showed a movie of a simulation of that mechanism in which accelerating gradients of 50 GV/m were developed. The physics of these processes is interesting but it obviously remains to be demonstrated that plasmas can be sufficiently well controlled.

The 'near-field' type of laser accelerator can be typified by acceleration using the longitudinal field associated with evanescent waves near a grating. A simple wave would have accelerating gradients falling towards zero as the velocity approaches that of light but a substantial accelerating field could be retained between two gratings a fraction of a wavelength apart or by a single grating illuminated by composite laser waves. R. Palmer put forward this latter possibility which might result in accelerating gradients of 1 GeV/m. However the accelerated currents are likely to be small (perhaps only 10^4 particles per bunch) compared to the conventional linac.

The similarity between a grating and a linac was explored. This led to consideration of an optimum wavelength — longer wavelengths allow higher currents but the breakdown fields associated with longer pulselengths is lower. M. Tigner worked out that the optimum may lie in the 1 to 10 mm region. Suitable high power lasers have not been developed in this region but this could change with the advent of, for example, the free electron laser.

The working groups urged that the limits on acceleration in gas in grating structures be measured as a function of wavelength and that further experiments on accelerating gradients in plasmas be carried out. The Workshop summary was presented by J. Lawson and the proceedings will appear in about six months.

There are some topics of basic physics concerning the interactions of laser fields with particles, plasmas and materials which clearly need further study and the road to realizing the great potential of laser accelerators is sure to be a hard one. Nevertheless emerging from the Workshop was a recognition of the great potential which exists and the identification of laser-driven accelerators as a specific field for investigation and systematic development. These matters, among others, will be reviewed in the ECFA Conference on novel particle acceleration techniques at Oxford in September.

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50 years of positrons

This year marks the 50th anniversary of one of the major landmarks of modern physics — the discovery of the positron, the antimatter counterpart of the electron. This provided the first evidence for antimatter, and it was also unprecedented for the existence of a new particle to have been predicted by theory. The positron and the concepts behind it were to radically change our picture of Nature. It led to the rapid advancement of our understanding, culminating some fifteen years later with the formulation of quantum electrodynamics as we now know it.

In addition, the past half century has seen positrons develop from a curiosity into one of the major tools — in electron-positron colliders — for today's particle physics research. If the list of proposed new high energy projects is anything to go by, they will continue to be exploited for a long time to come.

(Oddly enough, this year is also the fiftieth anniversary of another major milestone in particle physics — the discovery of the neutron. This we shall be returning to later this year. But it is clear that in view of these two major advances, 1932 could

Sketch of the first positron event, seen by Carl Anderson in 1932 in his cloud chamber exposed to a magnetic field of 15 kilogauss. A 63 MeV cosmic ray positron entered the chamber from below, lost energy in the central lead plate, and emerged again in the top half of the chamber. The difference in track curvature between the two halves of the chamber showed that the particle was definitely moving upwards.