Classic Paper Presentation

The artificial production of fast particles

- ***Prof Ernest Walton***

Nobel Prize in Physics ,1951

Presented by

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The artificial production of fast particles

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The first successful experiments on the transmutation of atoms were carried out by Rutherford[1] in 1919 using swift naturally emitted α-particles. He found that when nitrogen was thus bombarded, fast protons were ejected. In the decade following, many similar experiments were made and these showed that certain other light elements could be disintegrated in like manner. Further progress was made difficult by the limited strengths of the available radioactive sources and because the energies of the α-particles emitted were too low. It became increasingly obvious that attempts should be made to produce by artificial means suitable streams of fast particles. The energy required would be small - a few microamperes of helium ions accelerated by means of a potential of a few million volts corresponds to the α-particle emission of some hundreds of grams of radium. Further, other particles which are not emitted by any radioactive substance should be accelerated and used in experiments. But the practical difficulties appeared to be immense. The potential barriers surrounding nuclei were known to be of the order of millions of volts in height and such potentials were far beyond anything which had been applied successfully to X-ray or cathode ray tubes. Their use seemed impracticable.

The recognition of these difficulties gave an impetus to the search for methods of producing fast particles without the use of correspondingly high voltages. Two main types may be noticed: *(i)* acceleration by a circular electric field in which the particles circulate many times, and *(ii)* acceleration by a series of impulses given to the particles at suitable regular intervals. These methods will now be described briefly.

(i) The betatron. This was formerly commonly called an induction accelerator because the circular electric field mentioned in *(i)* above is induced by the variation with time of a magnetic field with axial symmetry (Slepian[2], Wideröe[3]). A charged particle, if constrained to move on the circle, would be accelerated continuously as it travelled round it. If the electric field can be maintained for a sufficiently long time, a light particle could go round the circle many times and thus gain considerable energy. The method is un-

(ii) The linear accelerator. In this method a stream of charged particles is sent down the common axis of a line of cylinders, and accelerated successively by electric fields between adjacent cylinders. If a high-frequency alternating potential is applied between the odd-and-even sets of cylinders, by a suitable choice of the lengths of these cylinders it can be arranged that the field is always an accelerating one when the particle is traversing the gap between a cylinder and the next one.

The potentials on the cylinders are changed while the particles are travelling through them and thus they are shielded from any adverse fields. The method is most suitable for heavy particles because then shorter cylinders and potentials at lower frequency may be used. For the acceleration of particles to high energies, the electrical capacity of the system requires large charging currents. In practice this requires considerable high-frequency power. As the path of a particle is long, only small output currents will be obtained unless good focusing is present. The principle of the method was suggested first by Ising[8] in 1925, but some years had to elapse before tech-

In the work carried out by J. D. Cockcroft[11] and the writer, the aim was to accelerate particles by the direct application of potentials of up to 300 kilovolts, these being about the highest potentials which it had been found possible to apply to a vacuum tube for the production of X-rays and cathode rays. The conventional tubes of the time were large glass bulbs with two stems and these were used both for the rectifiers and for the accelerating tube. They may be seen in the photograph (Fig. 1). The transformer voltage

In addition to giving a steady voltage which may be any desired even multiple of the transformer voltage, the circuit has other advantages. It gives steady voltage tappings at intermediate points, these being useful when using a multi-section accelerating tube. The rectifiers are all connected in series and so may be erected as a single column and evacuated by one diffusion pump at earth potential. They, as well as the accelerating tube, were made out of straight glass cylinders, these being found to withstand high voltages much better than the largest glass bulbs obtainable.

Later development of the indirect methods. As the size of cyclotrons increases and faster particles are produced, a difficulty arises due to the relativistic increase of mass of the particle. The particle tends to get out of step with the accelerating voltage. This limits the number of times the particles can be allowed to travel round. Hence higher accelerating voltages must be applied to the dees. This means greatly increased high-frequency power and a larger gap in the magnet to give increased clearances. These difficulties can be avoided by the use of an alternating potential whose frequency changes during the course of the acceleration of a particle, but its results in the output current being reduced to a burst of fast particles at the end of each duty cycle of the high-frequency change. Appreciable current can be obtained because of the principle of phase stability (McMillan[16], Veksler[17], Oliphant[18]) which operates when relativistic speeds are reached. The effect produced is that particles, which are tending to get out of step with the accelerating voltage, have their phase automatically changed so as to bring it back to the phase stable point. Hence there is no objection to having the many accelerations necessary when quite low voltages are used on the dees, and no restrictions are placed on the exact way in which the frequency is changed. This is the largest of these machines gives particles of about 350 MeV energy. To go to higher energies will require the construction of larger magnets than have yet been built and their cost is likely to increase with at least the cube of the pole diameter. A considerable saving in the cost of the magnet can be effected if a particle can be made to move in a circle of constant radius for the whole of its acceleration. This is done in the synchrotron by increasing the magnetic field gradually during the course of the acceleration. The magnet must be laminated and, as its time constant is large, burst of fast particles are obtained only at intervals of the order of 10seconds. The method promises to be useful in the range 1,000 to 10,000 MeV. The latter figure may

A linear accelerator has the advantage that no magnet is required and that its cost should not rise much more steeply than with the energy of the particles required. Recent progress made in microwave technique has made it possible for energies of up to about 30 MeV to be obtained and the method may well prove to be useful for much higher energies.

Looking to the future, it is difficult to see how particles of energy greater than 10,000 MeV can be produced economically by existing methods. Further progress may have to await the introduction of new ideas.

Ernest Walton

MRIA

Walton in 1951

Born	6 October 1903 Dungarvan, County Waterford, Ireland
Died	25 June 1995 (aged 91) Belfast, Northern Ireland
Resting place	Dean's Grange Cemetery
Alma mater	Trinity College Dublin Trinity College, Cambridge (PhD)
Awards	MRIA (1935) Hughes Medal (1938) Nobel Prize in Physics (1951)

Scientific career

Fields	Physics
Institutions	Trinity College Dublin University of Cambridge Methodist College Belfast Dublin Institute for Advanced Studies
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18th Erasmus Smith's Professor of Natural and Experimental Philosophy

In office

1946–1974

Preceded by	Robert Ditchburn
Succeeded by	Brian Henderson

Signature

Thank you