

THE NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

Introduction

The main spearhead in experimental physics during the last 50 years has been towards probing more and more deeply the ultimate structure of matter. In this activity, the part played by particle accelerators has been an increasing one.

After the structure of the electron cloud forming the outer part of the atom had been elucidated some 30 years ago, the charged nucleus became the focus of attention. It gradually became clear that in order to understand the forces holding the nucleus together, the structure and interactions of the neutrons and protons themselves must be further explored. Such exploration is in the forefront of physics today, and has revealed phenomena quite unsuspected when the theory of the nucleus as a whole began to take shape.

In microscopy, closer and closer examination of small 'objects' requires shorter and shorter wavelengths, and good illumination. In a somewhat similar way the finer details of nucleon behaviour has required the provision of intense beams of particles with ever increasing energy.

This trend to more energetic beams has made the provision of increasingly large accelerators necessary. Thus, to relieve Universities of the increasing burden of having to build and operate such machines, the Government in March 1957 set up the National Institute for Research in Nuclear Science to provide facilities for nuclear physics research which would be available for common use by universities and similar institutions.

The Institute is an independent body having received a Royal Charter in 1958. The Governing Board comprises representatives from the universities and the Atomic Energy Authority. The first Laboratory of the Institute is the Rutherford High Energy Laboratory situated near the Atomic Energy Research Establishment at Harwell and occupying a site of some 65 acres. The Laboratory is being equipped to carry out research into the physics of the nucleus, and the structure and interactions of elementary particles. The main equipment of the Laboratory will consist of two proton accelerators: a 50 MeV proton linear accelerator already in operation and a 7 GeV proton synchrotron (NIMROD) at present under construction. The Laboratory will also contain supporting facilities for conducting experimental work.

In order to use these machines profitably, to make the complicated and difficult measurements which are required to help elucidate some of the baffling problems associated with ultimate nature of nuclear matter, a considerable amount of auxiliary apparatus of varying degrees of complexity and sophistication is required. While the design of the accelerators is the task of the Institute alone, the design and provision of this apparatus and its application to the problems of measuring nuclear properties is shared between the Institute and the Universities. Much of this instrumental work requires the applications of wider technologies, such as cryogenics, optics, and data handling to the special problems of nuclear measurement.

The Proton Linear Accelerator

The 50 MeV proton linear accelerator was designed by the Atomic Energy Authority and handed over to the Institute in 1959. The machine consists of three cylindrical resonant cavities, placed end to end, into which pulses of protons are injected at 500 KeV from a Cockcroft-Walton generator and accelerated successively to energies of 10, 30 and 50 MeV. Each resonant cavity is contained in an evacuated tank, the total length of three tanks being some 100 ft. Each cavity, excited into resonance at 200 Mc/s from pulsed RF power supplies, contains a series of hollow cylindrical electrodes known as drift tubes spaced at intervals down its axis, and it is in the gaps between successive drift tubes that the acceleration occurs. Each pulse lasts 200 microseconds and the repetition rate is 50 pulses per second.

Emergent pulses of protons pass through a concrete shielding wall into the experimental area where the nuclear physics experimental apparatus is set up. In order to make the most efficient use of the machine, a bending magnet has been installed which deflects the proton beams in any five or more directions, thus enabling several sets of apparatus to be set up and left undisturbed. In addition to performing experiments with 50 MeV protons, the machine has been designed so that it is possible to obtain protons at energies of 30 and 10 MeV. It is also possible to accelerate protons with their axes of spin substantially aligned in one direction; such 'polarised' beams enable those features of the complicated proton-proton interaction which are connected with its spin to be explored in more detail.

There are three broad fields of nuclear research which will be carried out using the accelerator ~~in~~ experiments aimed at studying the interaction between nucleons, experiments designed to extend the so called "optical" model interpretation on the scattering of neutrons and protons by nuclei and, finally, experiments aimed at studying details of nuclear structure. Experiments in these broad fields are at present being carried out by teams of physicists from the universities of Oxford, Birmingham, Manchester and Glasgow, and King's College and University College, London, and the Atomic Energy Authority, together with the resident Nuclear Physics Group of the Institute.

The maximum proton current which has so far been achieved is 4.5 micro-amperes (2.7×10^{13} protons/sec.) This is many times greater than has been achieved with other accelerators of this kind. Furthermore, the beam has a well defined energy, giving the high resolution required in precise measurements. The machine may be extended at a later date by the addition of further sections to give a higher energy beam.

NIMROD (7 GeV Proton Synchrotron)

The main physical feature of the 7 GeV proton Synchrotron at present under construction, is a large ring-shaped electromagnet, 150 ft. in diameter and weighing 7,000 tons. A toroidal-shaped evacuated chamber made from a glass-fibre reinforced epoxy resin is situated between the poles of this magnet. A pulse of protons given an initial acceleration of 15 MeV in a linear accelerator is injected into this chamber and the protons are forced by the magnetic field into a circular orbit in which they receive an acceleration from a radio-frequency electric field once in each revolution. When after approximately 1 million revolutions the protons have reached their maximum energy, they are either extracted from the vacuum chamber or allowed to bombard internal targets and the resulting secondary particles channelled into an adjoining building where they will be used for experiments. During the acceleration period, lasting 0.72 secs., the magnetic field strength and the frequency of the electric accelerating field have both to be increased steadily to confine the proton orbits to the magnet ring, and in such a manner as to maintain the delicately balanced stability in the motion of the protons. The whole machine is housed in a semi-underground circular building of reinforced concrete 200 ft. in diameter with 6 ft. concrete roof on which a 20 ft. layer of earth is placed as additional radiation shielding.

Heavy currents up to 9,000 amperes with an applied voltage up to 15 kV are needed to energise the electromagnet during the short acceleration time. The power requirements are intermittent since the magnetising current is only required for the duration of the pulse while the protons are being accelerated; so some form of energy storage is required. This is provided by heavy flywheels incorporated in a motor alternator set, connected to the magnet through a bank of rectifiers. This equipment supplies direct current of gradually increasing strength during the pulse followed by a period decay. Energy is thus stored in the inductive windings of the magnet coils (made from 250 tons of extruded copper bar) during the current-rise period and is subsequently returned to the flywheels in the intervals when power is no longer required. The amount of energy being shuttled to and fro amounts to some 40 megajoules. In this way, the flywheels act as a buffer between the load (the magnet windings) and the electrical supply.

The machine is designed to produce at least 10^{12} protons per pulse at a repetition rate of 28 pulses a minute; this is equivalent to about 1/16th of a microampere which although small in absolute terms represents a very high current compared with those obtained from similar machines elsewhere. When completed Nimrod will be used for fundamental research into the physics of elementary particles, in particular the recently discovered unstable strange particles (hyperons and heavy mesons) and antiparticles. The study of the modes of creation, the detailed properties of these new particles and the way in which they interact with other particles form the main subject of present-day high energy research and will be the principal field of investigation in which Nimrod will be used.

Experimental Apparatus

As described above, Nimrod will produce some 10^{12} protons circulating round the magnet, about every two seconds. In order to make good use of these protons, much remains to be done. In general, the beam has to be extracted, or else particles produced by the beam striking an internal target have to be extracted. This leads to many challenging experimental and theoretical problems in charged particle optics; beams have to be formed and 'cleaned' so that they contain only the required type of particle, and a limited energy range. The design of

deflecting, focussing, and particle separating systems is made more difficult by the large physical size and power consumption of the units involved. Economy as well as precision, in design is therefore essential.

Having produced a beam interactions with some 'target' must be observed. Such interactions are generally complicated in the sense that collisions may occur in which one of several things can happen, and more than one particle is produced. The advantage of "visual techniques" in which these collisions can be "seen", in sorting out the statistics of such events is obvious. At these high energies the pioneer visual detector, the cloud chamber, has been largely replaced by the 'bubble chamber' in which the roles of gas and liquid are reversed. A further visual device, the 'spark chamber' where the particle betrays its path by triggering a series of sparks is now gaining in importance.

The bubble chamber is a complex and expensive piece of apparatus, requiring the merging of several branches of technology, viz. magnet engineering, cryogenics, optics and photography. A table showing bubble chambers being prepared for use on Nimrod is given below.

Chamber	Length of Active Material	Universities Involved	Remarks
"National Hydrogen"	150 cm.	Imperial College, Birmingham and Liverpool.	Nearing completion at the Rutherford Lab; to be used at CERN before returning for Nimrod operation.
16" Hydrogen	40 cm.	Imperial College	Completed, and presently at Saclay
Heavy Liquid	150 cm	University College, and National Institute	Under construction
Helium	80 100 cm. approx.	Oxford	Design study underway

Although these chambers have been initiated by University groups, a considerable contribution to their design and operation is being made by the Institute.

Although visual techniques are especially important at high energies, considerable use is made of counter techniques also. Scintillation counters may be used, as at lower energies, for particle detection, and much use will be

made of Chevenkov counters; since the direction of the Chevenkov radiation from a moving charge is a function of its velocity and at the medium through which it travels, optical systems can be devised which effectively measure the velocity of the particle.

Having obtained a large number of photographs of the tracks in the bubble chamber for example, considerable effort is needed to sort them out and elucidate the information which they contain. To do this such topics as 'picture recognition' and large scale 'data handling' by computers become very important, and much development is needed. These problems have much in common with those in other branches of applied physics and engineering, and involve extensive use of computers. At present the Institute's computing programme is carried out using the Mercury and IBM computers of the U.K.A.E.A. but a Ferranti Orion is now on order for delivery ^{by} in September 1962. The Orion is a fast, modern transistorised computer having a very comprehensive instruction code and built-in time-sharing facilities. The version on order will have a 16,000-word core store, two 16,000-word drum stores and six magnetic tape decks.

Radiochemical Laboratory

A radiochemical laboratory consisting of four "hot" laboratories is being set up for use by chemists from Universities and the Atomic Energy Authority who wish to do chemistry on high energy machines.

The Work of the Rutherford Laboratory

The previous section has described sufficient of the Institute's work to show that exploration of the nucleon, like the exploration of space, is an enterprise which requires the co-ordination of very many specialised skills and interests. Although very few physicists are able to understand fully the intricacies of nuclear theory, or even to assess the precise significance of the experiments they are doing, most will be able to get a feel for the general nature of the limitation to our understanding, and the progress which is being made, by attending some of the frequent lectures by specialists held at the Laboratory.

Below, to illustrate further the diversity of work covered, are brief reports of the various sections at the time of going to press. Attempts are made to prevent the division into definite groups from being too rigid, and changes of staff between them are encouraged.