Rutherford Laboratory

Technical Leaflet

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P.L.A. NUCLEAR PHYSICS EXHIBITS

Four exhibits illustrate the research in Nuclear Physics carried out with the Proton Linear Accelerator of the Rutherford High Energy Laboratory. One is concerned with the study of the finer details of the interaction between pairs of protons, and the second with one aspect of the interaction of a proton with a simple nucleus (carbon). The third and fourth exhibits show two different methods for measuring to high precision the energy of particles emitted from nuclei struck by protons.

Exhibit 1 Proton-proton Scattering

The model on display illustrates how we are studying the finer details of what happens when collisions occur between free protons, the fundamental particles which form the nuclei of the lightest element, hydrogen. As well as mass and charge a proton has a spin; that is, it is rotating about an axis in space (with one half unit of angular momentum) and associated with this spinning motion is a magnetic moment. Forces between protons are interesting in their own right and also for the information they give on how more complicated nuclei are held together. At the energy of our machine there is only one process which can occur when a moving proton strikes a stationary proton. This is elastic scattering, where one proton is deflected through some angle and the target proton recoils through a corresponding angle; there is not sufficient energy to liberate the mesons, hyperons and anti particles which are produced in the larger accelerators like NIMROD. However, this elastic scattering process is capable of giving much information if studied in sufficient detail.

The most straightforward measurements are to determine the probabilities of scattering through different angles. These probabilities are related to the closeness of approach of the two protons. Deflections through very small angles can correspond to a grazing collision or to a head on collision, whereas the larger angles correspond to intermediate cases. The simplest measurements are done when the spins of the protons in the beam and in the target are orientated at random.

As in the game of billiards the motion of the protons is affected by spin; for instance when the axis of spin is vertical there can be a tendency for more protons to scatter to the left than to the right or vice versa. Measurements of this type have been made with the P.L.A. using the polarized proton source which allows us to prepare beams of protons whose spin lies predominantly in a known direction.

With more sophisticated equipment it is possible to go one stage further and determine how the direction of spin of a proton changes during a collision with a second proton and so to obtain further details of the proton-proton interaction. In fact, it is impossible to follow the spin changes which happen to individual protons; rather we look at the probabilities of finding protons spinning in a certain direction after a collision when the probability of the spin being in a certain direction before the collision is known.

The model on display shows how a spin direction for the proton beam is chosen in the polarized proton source of the P.L.A., how this direction changes as the proton is transported to the target of liquid hydrogen and how the probability of finding the spin in a given direction after the collision is measured by letting the protons make yet further collisions with nuclei of helium gas. Experimenters from Queen Mary College, London, University College, London, and the Rutherford High Energy Laboratory have contributed to this work.

Exhibit 2 The p-2p Reaction in Carbon

When a stationary proton is struck by a proton moving in a known direction with a known energy it is sufficient to determine the direction of one proton after the collision and the direction of the other proton and the energies of both of them can be simply calculated. The protons within a nucleus, however, are moving at high speeds in different directions and energy is required to release them from the forces of attraction due to the other particles in the nucleus. If the energies of two protons emerging from a nucleus and their directions are measured it is possible to calculate how the proton within the nucleus was moving before the collision, and so shed light on the structure of the nucleus. The apparatus on display shows how this is done. Counters which can identify the emerging particles or protons and measure their angle and energy are set up near the carbon target. Very precise techniques capable of measuring times as short as 2×10^{-9} of a second are required before one can be sure that the detected pairs of protons come from a single event in the nucleus due to one incident particle. This work is being done by teams from Westfield College, London, and the Queen's University of Belfast.

Exhibit 3 Magnetic Spectrometer

The angle through which light is bent on passing through a prism is determined by the wavelength of the light, and this property is used in the optical spectrometer to study the spectrum of light from any light source. Similarly charged nuclear particles passing through a region of magnetic field are bent through different angles according to their momenta and this property is the basis for the magnetic spectrometer on display. Particles leaving the target where nuclear reactions occur pass through a region of strong magnetic field between specially shaped pole pieces and emerge into a counting system at the top of the spectrometer. The instrument is capable of covering an energy range of 10% at a fixed setting of the magnetic field and has a resolution of approximately 1 part in 2 thousand in momentum. Considerable engineering ingenuity has been required so that particles emerging from the target over a wide range of angles can be studied in turn. The particles remain in vacuum between the target and the counter. The angle of setting of the magnet and the choice of any one of six targets is remotely controlled.

Exhibit 4 Solid State Counter System and Pulse Height Analysis

For some experiments it is not always necessary or practicable to use the magnetic spectrometer and simpler equipment is acceptable in spite of reduced energy resolution. In the equipment on display alpha particles from a radio-active source enter a thin specimen of specially prepared silicon where each incident alpha particle liberates over a million electrons. These electrons are collected to give an electrical pulse which is amplified and sorted according to height by the pulse height analyser. The cathode ray tube display shows the number of particles on the vertical scale while the horizontal scale displays their energy. As the distance between the alpha particle source and detector is changed the rate of registration of pulses is seen to increase or decrease and the pulse height also changes due to energy loss by the alpha particles as they move through the air gap between source and detector. In experiments using our accelerator it is not uncommon to register many millions of electrical pulses caused by nuclear particles and associated with this equipment it is most helpful to have automatic punching of paper tape which can be sent to a computer for processing and analysis of the results.