

PROPOSED ACCELERATOR DEVELOPMENTS AT GLASGOW

§ 1. INTRODUCTION

At several meetings of the Nuclear Physics Committee during the past two years, when plans for the extension of facilities in the universities with major programmes of nuclear and high energy research were under discussion, the desire of the Glasgow Physics department to continue to concentrate upon photo-problems and to have available much greater beam intensities has been explained. We have always recognised that the provision of quanta at energies appreciably greater than the 400 MeV available from our present accelerator, most desirably perhaps in the multi-BeV region, must become a responsibility of the National Institute but we have also always foreseen a considerable and profitable programme of research with quanta at energies of 10-100 MeV if very much greater intensities could be provided.

After consideration of various types of accelerator which might meet this need we tended a few months ago to the view that a 100 MeV Linac already under construction by Messrs. Vickers Ltd. might be suitable and were encouraged by the Committee to investigate that possibility more fully.

During the past few months we have conducted at Glasgow a more systematic consideration of the potential field of research in this region and by detailed discussions of experimental techniques in relation to the actual research problems acquired a better understanding of the desirable characteristics of a suitable accelerator. These considerations are summarised in § 2 following.

It is now clear to us that the present Vickers machine is by no means the most suitable for our purpose. It should be realised that this accelerator was designed as a first stage for a multi-BeV machine and was not optimised for maximum beam intensity in the 10-100 MeV region and that without very great increase

of cost much better performance is achievable in a machine designed specifically for that purpose. Briefly, it may be stated that whereas the present Vickers 100 MeV Linac will provide $5\mu\text{A}$ mean electron current with a duty cycle of 2×10^{-4} , the proposed machine would provide $220\mu\text{A}$ at a duty cycle of 1.25×10^{-3} . This very substantial improvement would in our opinion result in a highly desirable machine for work of the type in which we wish to engage. The resolved beam intensity would be 10^4 times greater than that now employed internationally upon studies of photodisintegration of nuclei and similar topics, and would allow investigations having a new order of magnitude of precision in several fields where progress is at present impeded by inaccuracy and inadequacy of experimental data. The further possibility of producing beams of approximately homogeneous quanta by positron annihilation is also feasible with such high initial photon intensities and, if successfully achieved, would remove the formidable difficulties associated with the inhomogeneity of bremsstrahlung beams in photo-nuclear investigations.

§ 2. PROGRAMME OF EXPERIMENTS

The experimental programme envisaged spreads over an extensive area of the field of nuclear physics. A diversity of research interest and technique, highly desirable in a University research department which has a responsibility for the training of research students, is possible because of the variety of the secondary beams involved. The various projected investigations are outlined under the appropriate beam facility.

A. Electron Beams

The machine accelerates electrons and is primarily designed to deliver 500 pulses per second with mean current of $220\mu\text{A}$ at $100\text{ MeV} \pm 1.5\text{ MeV}$. This corresponds to 1.3×10^{15} electrons per second or 2.6×10^{12} electrons per pulse. At $50\text{ MeV} \pm 0.75\text{ MeV}$ these electron figures are doubled. (See Fig. 7).

The beam will be energy analysed by a magnetic system from which, into a region free from magnetic field, will emerge a current of $24 \mu A$ (1.4×10^{14} electrons/sec: 2.9×10^{11} electrons per pulse) with energy $100 \text{ MeV} \pm 170 \text{ kev}$.

(i) Elastic Electron Scattering

The elastic scattering of electrons is well established as a technique for probing the electric and magnetic structure of nuclei. Detailed and precise experiments have been performed at energies of 300 MeV and upwards where the momentum transfer is relatively large. There exist some data at 100 MeV but further studies are necessary in this energy range to determine more accurate values of form factors for low values of momentum transfer. From this information may be deduced more accurate values of the proton and nuclear radii and charge distributions near the surfaces. The number of electrons per pulse from this accelerator will be 100 times that of the Stanford machine with which the outstanding work in this field has been accomplished.

(ii) Inelastic Electron Scattering

In electron-nuclear scattering nuclei may be left in excited states which subsequently de-excite by γ -ray or particle emission. The energies of excitation can be accurately determined from a measurement of the peaks in the spectrum of the scattered electrons.

This technique which is in the earliest stages of development may prove to be as valuable as excitation by heavy particles for investigating the level structure of stable nuclei. It should also provide a useful complementary method to that of photodisintegration (discussed below) for investigating the properties of the "giant resonance".

B. Positron Beam

The electron beam falling on a high Z target produces X-rays which in

turn give rise to positron-electron pairs. The positrons from this process will be collected by a quadrupole magnet system and analysed in energy. The estimated yield is a current of 6×10^9 positrons/second in the energy range $20 \text{ MeV} \pm 100 \text{ kev}$ or 3×10^{10} positrons/second at $50 \text{ MeV} \pm 250 \text{ kev}$. This beam would have a diameter of 4 cm and an angular divergence of 3 milli-radians.

(i) Positron Scattering

It will be of interest to compare positron scattering, elastic and inelastic, with the corresponding processes for electrons. This has been studied, but not thoroughly, at lower energies and there is need for careful investigations in the energy range made available by this linear accelerator.

(ii) Positron Annihilation Radiation

The above positron beam impinging on a low Z target will give rise to "monochromatic" photons in the forward direction due to the annihilation in flight of the positrons. The peak photon energy will be 0.75 MeV beyond the peak energy of the positron bremsstrahlung spectrum. With a lithium hydride target 0.2 gm/cm^2 thick, it is estimated that 2×10^7 photons/sec at $50 \pm 0.35 \text{ MeV}$ can be obtained in a beam of 10 cm diameter 3 metres from this target. The positron bremsstrahlung background will have an intensity of 1.4×10^7 equivalent quanta/sec, giving about 2×10^5 photons in an energy band of width 0.7 MeV near 50 MeV. If a liquid hydrogen target 0.1 gm/cm^2 is used in place of the lithium hydride, an annihilation beam of the same intensity and energy width is obtained, with the intensity of the bremsstrahlung beam reduced by a factor of 2.5.

Should these estimates be borne out in practice this facility will be a paramount feature of the machine. It would revolutionise work on photo-disintegration.

C. Thin Target Bremsstrahlung Beam

(i) Nuclear Photodisintegration Cross-sections

While photodisintegration is now a well established field of nuclear

research there are many basic features of the phenomenon which are still obscure. The "breaks" in activation versus energy curves, the double giant resonances, the transition from giant resonance to quasi-deuteron absorption are all subjects for profitable future study.

The resolved electron beam at $100 \text{ MeV} \pm 170 \text{ kev}$ falling on a $0.005''$ Platinum target will produce about 10^{13} equivalent quanta/steradian/pulse in the forward direction (or in the terms in which betatron outputs are sometimes quoted, 30 r/pulse at 1 metre), the beam width at half intensity being about 30 milliradians. The energy constancy of the resulting spectrum will depend only on the constancy of the magnetic fields in the analysing magnets. It should be possible to measure and stabilise these fields to a few parts in 10^5 . The end point of the bremsstrahlung spectrum should therefore be constant to about one kev in 10 MeV .

It is, therefore, anticipated that this machine should, in respect of energy definition, be quite as suitable as the betatron machines with which the "photon difference" investigations have hitherto been conducted. The linear accelerator has however the advantage of about four orders of magnitude increase in intensity. Furthermore, the electron beam, of determined energy characteristics, is incident on a foil in a field free region, thus producing a photon spectrum more amenable to calculation. This is vitally important in "photon difference" experiments.

Experiments on photodisintegration would often be conducted with the monochromatic beam discussed in paragraph B(ii). This technique will show structure in the giant resonance region more directly than the "photon difference" method.

(ii) Energy Spectra of Photoneutrons

The facility of the shortest pulse length, $2.5 \mu \text{ sec}$, in conjunction with coincidence circuitry of $n \mu \text{ sec}$ resolving time will render possible time of flight measurements of the energies of photoneutrons. This technique has already

been exploited to a limited extent for photoneutrons. The intensity available would also permit measurements on photoprotons of energies up to 10 MeV over a flight path of 10 metres. Such counter techniques would lead to more rapid accumulation of data on the relative importance of evaporation, direct and quasi-deuteron particle emission, processes now normally studied by visual techniques.

(iii) Polarised Quanta

By using very thin targets and accepting X-rays emitted at a well defined angle to the forward direction a polarised X-ray beam can be obtained. The electron current of this linac would permit beams of useable intensity to be obtained in this way.

D. X-Ray Beam (Thick Target)

The full electron current of the accelerator, having a power of 22 KW impinging on a thick target of high Z material, will produce about 10 KW of X-ray power into a forward cone. On the usual definition of equivalent quanta this represents 6×10^{14} equivalent quanta per second.

(i) Production of Radioactive Sources

Radioactive isotopes will be produced by photo-disintegration in this intense X-ray flux. In particular, neutron deficient isotopes will be made in copious amounts. This method is thus complementary to pile irradiation.

Assuming that a sample is arranged to absorb an appreciable proportion of the flux, yields of the order of 10 m curies/second of isotopes with 1 hour half lives will result.

(ii) Other Applications

The applications of this beam to problems in biology and solid state physics are not considered here but it should be noted that the high flux will produce substantial damage in all exposed materials. Although the particle energy is far beyond the most interesting thresholds for radiation damage, the

high intensity available in short pulses would facilitate the study of very short-lived intermediate products.

E. Neutron Beams

By allowing electrons of 100 MeV to hit a high Z target a photoneutron yield of 0.02 neutrons/electron can be obtained. Thus, operating at full intensity the accelerator will produce 2.5×10^{13} neutrons/second.

(i) Neutron Time of Flight Experiment. Slow Neutrons

On an area of 100 sq. cm at the end of a 50 metre flight tube there will be about 10^7 neutrons/second.

With counting channels 2.5μ sec long, the resolution for thermal neutrons will be 0.00022 and for 50 ev neutrons will be .01. This would permit studies of nuclear level parameters by investigations of the Harwell linac type.

(ii) Neutron Time of Flight Experiment. Fast Neutrons

With the $2.5 \text{ m} \mu$ sec pulse length and with counting channels of similar width it should be possible to obtain 10^4 neutrons/second on a 100 sq. cm area at the end of a 50 metre flight tube. The resolution for 5 MeV neutrons would be 0.006.

The above experimental conditions are suitable for measuring (n, γ) reactions in the region in which this is the process energetically inverse to (γ, n) in the giant resonance. This would supplement in a valuable way the (p, γ) experiments which are now featuring largely in the programmes of Van de Graaff accelerators.

Type of Beam	Intensity	Experimental Uses
Electrons (Unresolved)	1.3×10^{15} electrons/sec $220 \mu A$ } at $100 \text{ MeV} \pm 1.5 \text{ MeV}$	
Electrons (Resolved)	1.4×10^{14} electrons/sec $24 \mu A$ } at $100 \text{ MeV} \pm 170 \text{ KeV}$	Electron elastic and inelastic scattering.
Positrons	6×10^9 positrons/second at $20 \text{ MeV} \pm 100 \text{ KeV}$ 3×10^{10} positrons/second at $50 \text{ MeV} \pm 250 \text{ KeV}$	Positron elastic and inelastic scattering.
X-Rays (Thick Target) 100 Mev electrons.	6×10^{14} equivalent quanta per second. } 10 KW.	Production of radioactive isotopes. Radiation chemistry and solid state damage experiments.
X-Rays (Thin Target) 100 Mev electrons.	5×10^{15} equivalent quanta/steradian/sec. } 5×10^{11} equivalent quanta/cm ² /sec at a } metre.	Photonuclear cross-sections. Spectra of Photonucleons. Polarisation effects.
X-Rays (Monochromatic)	2×10^7 photons/second at $50 \pm 0.35 \text{ MeV}$.	Photonuclear cross-sections.
Neutrons	2.5×10^{13} neutrons/sec. in 2.5μ sec. into 4π steradians. 2.5×10^{10} neutrons/sec. in $2.5 \text{ m } \mu \text{ sec.}$	Neutron interaction cross-sections at energies up to $\sim 20 \text{ MeV}$.