BEAM HANDLING SYSTEM OF THE UNIVERSITY OF MARYLAND CYCLOTRON

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Abstract

The University of Maryland cyclotron now produces the following beams on a regular basis: $E(^1H^+)\leq 100$ MeV, $E(^2H^+)\leq 82$ MeV, $E(^3He^{+2})\leq 200$ MeV, $E(^4He^{+2})\leq 165$ MeV. Uses of these beams and properties of the beam transport system for the various experimental areas are surveyed, and results of beam studies presented. Problems now under consideration are briefly discussed.

Since attaining the first internal beam in the summer of 1969, the University of Maryland cyclotron now produces sustained operation at energies up to 82 MeV for deuterons, 165 MeV for alphas and 100 MeV for protons. Studies are now underway to improve the general quality of the cyclotron beam and the particular quality of the beam in the upper experimental area, as well as to push the maximum proton energy up to above 120 MeV.

Figures 1, 2 and 3 show the general layout of the University of Maryland Cyclotron Laboratory. The cyclotron and the lower experimental area (Figure 1) are on the same floor, and the upper experimental area (Figure 3) is on a floor 25 feet higher. Figure 2 shows a vertical section of the entire laboratory, including the magnet shaft, in which the analyzing magnets are located.

The beam in the lower experimental area is either transmitted achromatically to the scattering target or, using the lower switching magnet, one can obtain up to 0.06% $\frac{\Delta E}{E}$ for 1 mm slits. Two 60" radius of curvature, 90° bending angle, double-focusing analyzing magnets are operated asymetrically to provide energy analysis of up to 0.012% $\frac{\Delta E}{E}$ per mm as well as the 25 foot vertical translation. An identical switching magnet then directs the beam down the proper line with effectively zero additional dispersion.

Most nuclear physics experiments in the lower experimental area are carried out on line E, where the maximum energy resolution of 0.06% $\frac{\Delta E}{E}$ is obtained with slits at S5E. This line has a five foot scattering chamber with provisions for two independently moveable arms on which detector telescopes may be mounted. The best overall resolution in an experiment on the line has been approximately 100 kilovolts, for a 140 MeV alpha particles elastic scattering experiment using Si(Li) detectors.

Line D has a smaller scattering chamber used solely by the nuclear chemistry group for their scattering experiments, at a minimum resolution of roughly twice that of line E.

Line B was originally set up to study neutral pion production by scattering of He^3 and He^4 particles off various heavy nuclei. In addition to this, however, several interesting irradiation experiments have been performed, primarily dealing with radiation damage to biological materials, and to a lesser extent damage to the crystal structure of certain metals. Studies are now underway to attain a uniform beam over large spot sizes for use in the irradiation of biological materials.

In addition to the facility on line B, line A will provide for the intense irradiations required by the radio-chemistry group at the University of Maryland. This line provides the desirable properties of large phase space acceptance (radial 30 milliradian, vertical 15 milliradian) and a large spot size (almost 1 cm square).

All upper experimental area work to this date has taken place on line G. In addition to the greater energy resolution this line can provide, it has been shown to possess less neutron and gamma ray background.

One of the big problems in obtaining fine energy resolution for such high energy particles is slit scattering at the energy analysis slits. For example, the range of 120 MeV protons in tantalum is approximately 14 mm, that of 80 MeV deuterons, approximately 4 mm and that of 160 MeV alphas approximately 2 mm. One obvious advantage of having a very large dispersion of the analyzing system is that one can use large slit widths to obtain reasonably good energy resolution but at the same time minimize slit scattering. The best minimum energy resolution thus far obtained in an upper experimental area scattering experiment is about the same as that obtained in the lower experimental area; considerable work must be done on detectors and detector electronics before the maximum energy resolution of the analysis system can be realized in an actual scattering experiment. Studies are now underway in an attempt to minimize the slit scattering effect in the overall experimental resolution by using various combinations of slits at F9, F14 and F15G.

One of the problems in determining how well the analyzing magnet system is performing is lack of a definitive measurement tool possessing adequately fine resolution. Despite these severe limitations, several important results have been obtained regarding properties of the beam and the magnet system.

Good focusing spots and optical characteristics have been observed, with excellent transmission through the system. For all beams collimated to 10 milliradians divergence in both directions, the only loss in beam current is at the energy resolution slit F9 or F14.

Typical running parameters are:

E(proton)	65 MeV	100 MeV
ΔE/E(cyc) FWHM	≈0.25%	≈0.25%
Raw beam current*	600 nA	250 nA
Spot size	2 mm x 2 mm	2 mm x 2 mm
Solid angle	10^{-4} sr	2.5×10^{-5} sr
ΔE/E(analyzed) FWHM	15 keV	30 keV
Current on target	50 nA	25 nA

*Current limited by experimental requirements.

The analysis system is of course extremely sensitive to instabilities of the cyclotron--it seems particularly important to have a well-centered beam. Small coherent vertical oscillations in the cyclotron and changes in the precessional pattern of the beam in the extraction region become particularly disastrous with the analyzing magnets.

An indirect measurement of the energy spread of the raw beam has been implied from the width of the beam spot at the dispersive focus F14. The beam intensity vs. energy profile is a relatively flat shape with a width of approximately 0.15% (less than 12 mm wide at the dispersive focus.) This small width, less than originally expected, is approximately what one would obtain by assuming that all extracted beam comes from the same turn number in the precessional cycle after the $\nu_r = 1$ resonance. This interpretation is also consistent with the relatively high transmission obtained (almost 10%) at the nearly ultimate energy resolution of the analyzing system.

Typically, somewhat over half the internal beam is extracted from the cyclotron, and approximately one half dropped at the exit of the cyclotron (slit 1, at the entrance to the beam transport system) with the remainder being focused at slit S2a; approximately half of that is passed through the divergence slits S2b for 10 mr x 10 mr divergence, and about 10% of what is left passes through energy defining slits S14 of 1 mm width with $\frac{\Delta E}{E}$ approximately equal to 0.012%. Thus, for the conditions under which the beam transport system now operates, with the cyclotron in stable operation somewhat over 1% of the cyclotron internal beam reaches the target with nearly the ultimate energy resolution obtainable with the system.

It should be noted that this efficiency requires proper care in setting up the cyclotron, in particular, proper centering of the cyclotron beam. If the beam is uncentered, multiple turns in the precession cycle following the $\nu_r = 1$ resonance will be extracted, resulting in a doubling or even tripling of the energy resolution of the extracted beam and the concommitant loss of efficiency of the entire transport system.

One additional problem seems to be that the vertical divergence of the beam is considerably larger than that normally expected from a sectored-focused cyclotron. The phase space can be shaped somewhat using the quadrapole doublet and singlet at the exit of the cyclotron, but large scale magnification of the beam vertically is ruled out due to the concommitant increase in the radial divergence, as well as the desire for a small spot vertically so that one can obtain high quality energy resolution.

Nuclear physics work done so far on line G includes primarily elastic and inelastic scattering of high energy protons and alpha particles off various nuclei.

An unusual beam handling set-up has been used for in-beam detector tests for NASA flight instruments. This group is studying the spectrum of nuclear particles in outer space using detector telescopes placed in rocket satellites, which are calibrated using particles from the cyclotron. A continuum of energies from 0 through the maximum energy available for each particle is obtained using a variable energy rotating beam degrader placed just behind slit 2a. The beam degrader consists of a variable thickness curled-up aluminum wedge which is rotated into the beam, thus providing a variable thickness of 0 to approximately 17 mm of aluminum. The degraded beam is then energy analyzed by the analyzing magnets, and the detector telescopes are put directly in its path. After collimation, a particle intensity of approximately 1,000 per sec is then delivered to a few square centimeters area at the detector. Using two settings of the cyclotron and a large number of settings of the aluminum wedge degrader, an effective continuum in particle energy is obtained for these low intensity beams.

In-beam gamma ray experiments are now being planned with a target behind the scattering chamber on line G. Use of a large shielded beam dump, and a quadrapole behind the scattering chamber to refocus the beam into the scattering chamber minimizes the background obtained from the beam dump. Preliminary runs show extremely small neutron and gamma ray background, essentially zero with blank targets in place.

As mentioned previously, studies are now underway concerning use of the cyclotron beam for irradiation of biological matter. It is envisioned that line H will be set up in the forseeable future for experimental medical applications of the cyclotron beam. A magnetic spectrometer is now being installed in the spectrometer pit in the upper experimental area, and it is hoped that within the next year the beam line to the spectrometer will be completed.

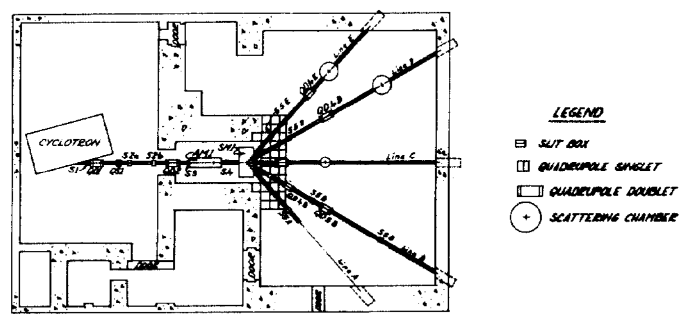

Figure 1.

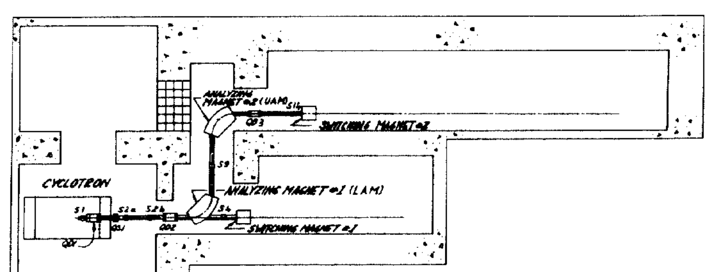

Figure 2.

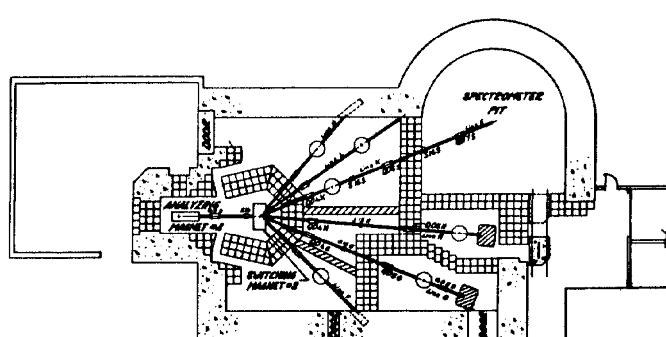

Figure 3.