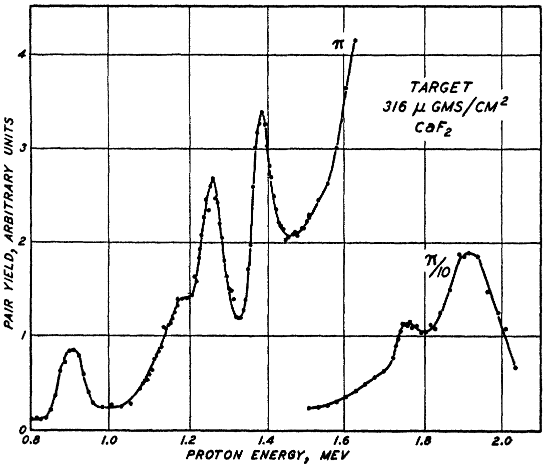

FIG. 1. Excitation curve of the $F^{19}(p; \alpha, \pi)O^{16}$ reaction taken with a CaF_2 target of thickness 316 $\mu g/cm^2$.

Ne^{20} that form the pair emitting states in O^{16}, this has been reinvestigated. The general shape of the excitation curve for pair production is shown in Fig. 1 for the energy interval 0.8 to 2.0 Mev. Five pair resonances occurring at bombarding energies below 1.4 Mev were studied in detail, using very thin targets. These data are shown in Figs. 2 and 3, where for energy calibration the gamma-ray yield as measured by a shielded Geiger counter is also shown. Small gamma-ray effects in the coincidence yield are noted in Fig. 2 for the very strong 873.5- and 935-kev gamma-ray resonances. These effects were difficult to eliminate completely and can be attributed, in this case, to the scattering of secondary electrons between detectors. The observed pair resonances occur at the following bombarding proton energies (their widths are given in parentheses): 710 kev (35 kev), 842 kev (24 kev), 1130 kev (43 kev), 1236 kev (58 kev), and 1367 kev (26 kev). An unsuccessful search was made in the energy region of 730 kev where a resonance for pair emission has been reported.[4]

To provide energy calibration, and to test the energy homogeneity of the beam the 873.5-kev gamma-ray resonance was excited using a very thin target. The observed width was 5.6 kev. Thus the states in Ne^{20} yielding the pair emitting state in O^{16} must have the widths given above and so are considerably wider than the corresponding states in Ne^{20} that excite the gamma-ray emitting states in O^{16}.

The angular correlation of the pairs was determined in the plane normal to the proton beam direction for a bombarding energy of 1.23 Mev. These data, uncorrected for the finite solid angle of the counters, can be fitted with the function $1+0.6\cos\theta$ and agree reasonably well with the only other reported observation.[5]

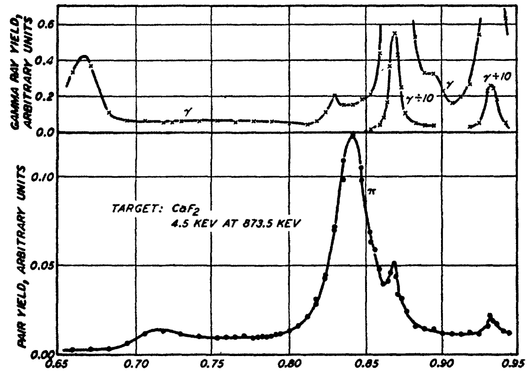

FIG. 2. Excitation curves of the $F^{19}(p; \alpha, \gamma)O^{16}$ and $F^{19}(p; \alpha, \pi)O^{16}$ reactions taken simultaneously using a thin CaF_2 target.

Since the (0 even) to (0 even) transition that is assumed to occur for the pair emission also allows a two-photon decay, a search has been made for pairs of gamma-ray quanta. A thin target was bombarded with a proton energy of 1.23 Mev. Counting rates were taken with and without sufficient aluminum absorber in front of each crystal to stop all pair electrons originating in the target. The absorber decreased the counting rate by a factor $>10^4$. If one assumes a gamma-ray counting efficiency of about 2 percent for the possible continuous spectrum of gamma-rays, it appears that there are not more than 50 percent as many gamma-ray pairs as there are electron pairs.

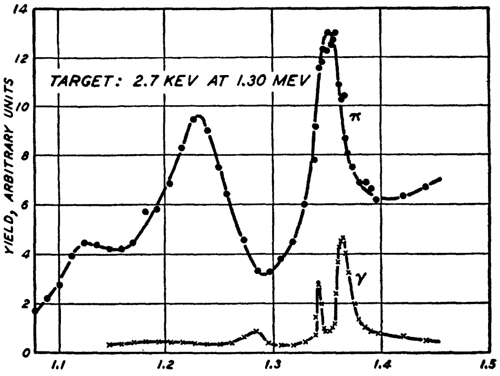

FIG. 3. Excitation curves of the $F^{19}(p; \alpha, \gamma)O^{16}$ and $F^{19}(p; \alpha, \pi)O^{16}$ reactions taken simultaneously using a thin CaF_2 target.

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Excitation Functions with an Internal Cyclotron Beam*

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THE stacked foil method for obtaining nuclear excitation functions may be used with the internal cyclotron beam if the beam is deflected by multiple coulomb scattering in a thin foil placed in the median plane. Since the "source" of particles is then well defined by the edge of the scatterer, 180° focusing may be utilized to obtain a secondary beam which is very homogeneous in energy.

In a stacked foil experiment, the energy resolution is usually limited by the spread in energy of the incident beam rather than by range straggling in the absorbers. An initial width, ΔE_0, will increase as E^{-1} as the particles penetrate the foils and absorbers. Measurements made on the proton beam of the Harvard cyclotron[1] show a width at half-maximum of 12 Mev at 110 Mev. Consequently, some method must be found to improve the energy definition for stacked foil experiments without an undue sacrifice of intensity.

The arrangement being used at Harvard is shown in Fig. 1. The scattering probe consists of 5 mils of tantalum on a polystyrene rod which passes through a hole in the cyclotron dee. The targets are placed one inch above or below the median plane, and as near the correct azimuthal angle for energy focusing,

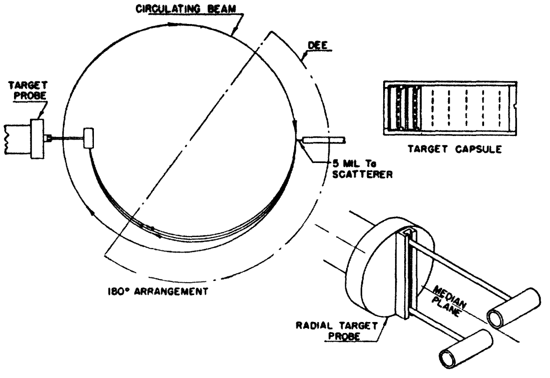

FIG. 1. Experimental geometry.

$\pi(1-n)^{-\frac{1}{2}}$, as the cyclotron geometry permits. The targets consist of foils or pellets, interspersed with brass absorbers and placed in a semi-shielded target capsule held on a radial probe. Several such capsules may be irradiated simultaneously. Using $\frac{5}{16}''$ diameter foils, about $\frac{1}{2}$ percent of the total beam is intercepted with an energy spread of 0.5 Mev at 100 Mev. If high intensity, rather than good resolution is desired, the scatterer may be placed, in the median plane, directly above or below the targets. Particles of all energy are then refocused at the target radius, after one revolution, giving an efficiency of 7.5 percent. No collimation is used in front of the targets, as this was found to spoil the energy resolution and increase the neutron background. Instead, the absorbers were made slightly larger than the foil area.

Three excitation functions for protons on aluminum are shown in Fig. 2. The activities from irradiating Al^{27} have been assigned to F^{18} (112 min), Na^{24} (15 hr), and Na^{22} (2.6 yr). A considerable amount of ~20-min activity was present, presumably owing to C^{11}; but this could not be accurately resolved from the decay curves. Identification of these nuclei rests on half-life, absorption curves, and chemical separations.

Polystyrene foils (C_nH_n) were included in the target assembly to monitor the proton current with the $C^{12}(p, pn)C^{11}$ reaction.[2] In calculating the absolute cross sections shown in Fig. 2, corrections were applied for absorption and scattering of the β-rays counted, a neutron background of a few percent, and loss of protons by nuclear absorption in the absorber stack.

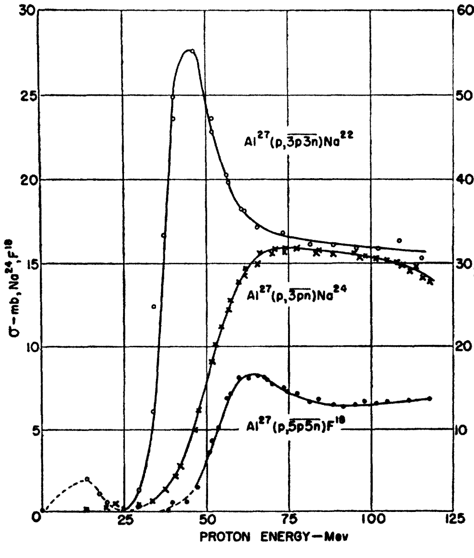

FIG. 2. Excitation functions for protons on aluminum.

A correction should also be made for loss of protons by multiple coulomb scattering. A rough experimental estimate of this effect gives 5 percent loss for protons just traversing their range. This correction has not been applied to the data shown in Fig. 2. The thresholds to be expected, including the sums of the coulomb barrier heights for all particles emitted, are shown in Table I for several modes of emission. It is evident that α-particles or heavier fragments are emitted with high probability in the formation of Na^{22} below 64 Mev and F^{18} below 110 Mev.

TABLE I. Thresholds in the laboratory system.

Reaction	$-Q$, Mev	$-Q$ +barrier, Mev
$Al^{27}(p, 3pn)Na^{24}$	32	44
(p, pHe^3)	24	36
$Al^{27}(p, 3p3n)Na^{22}$	52	64
$(p, \alpha d)$	20	32
(p, Li^6)	18.5	30
$Al^{27}(p, 5p5n)F^{18}$	91	110
$(p, 2\alpha d)$	30	49
(p, B^{10})	24	41

I wish to thank Professor Norman F. Ramsey for suggesting this problem and for helpful discussions.

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† Assisted by a Shell Development Company fellowship.

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[2] Aamodt, Peterson, and Phillips, UCRL-526 (1949).

A High Energy γ-Ray Line in the Spectrum of Mg^{24}

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IN a previous communication[1] an upper limit (5×10^{-5} photon/disintegration) was stated for the intensity of the 4.14-Mev γ-ray cross-over transition in Na^{24}. Recently, Cavanagh and Turner of AERE Harwell[2] pointed out that measurements with a β-ray spectrometer and kicksorter indicated an intensity of 1 in 2000 disintegrations for a γ-ray line with an energy of about 4.1 Mev. However, the authors state that the possibility remains that the γ-ray is some 4 to 7 percent lower in energy than the cross-over. In view of the apparent contradiction between these two results, a further investigation seemed useful.

As before, an ionization chamber[3] containing deuterium gas (5 atmos) was used with a linear amplifier, but this time the output was examined with a 25-channel kicksorter. It was found possible to resolve a high energy photoproton peak from the γ-ray background (Fig. 1).

This peak corresponds to a photoproton energy of (0.695 ± 0.025) Mev, which, combined with the binding energy of the deuteron, gives (3.62 ± 0.05) Mev for the γ-ray energy. A line of this energy would not have been observed in the previous search since it would have been swamped by the γ-ray background accepted in that measurement.

The intensity of the line was measured as 1 in (2500 ± 250) disintegrations, the results of three determinations agreeing within the statistical errors of 3 percent.

Above this line a long tail was recorded which was indistinguishable from the natural background of the counter (0.25 count/min at 30,000 ion pairs). From the statistical deviation of several background counts we can place an upper limit on the intensity of the 4.14-Mev γ-line as 2×10^{-6} photons per disintegration. This is even lower than the previously quoted upper limit.

The over-all linearity of the amplifier plus kicksorter was checked with a calibrated pulse generator throughout the runs.