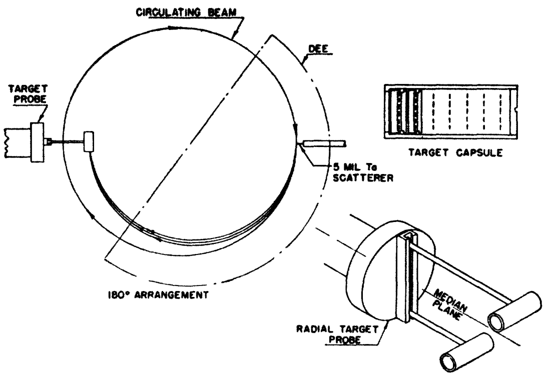

FIG. 1. Experimental geometry.

$\pi(1-n)^{-\frac{1}{2}}$, 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 $\sim$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.

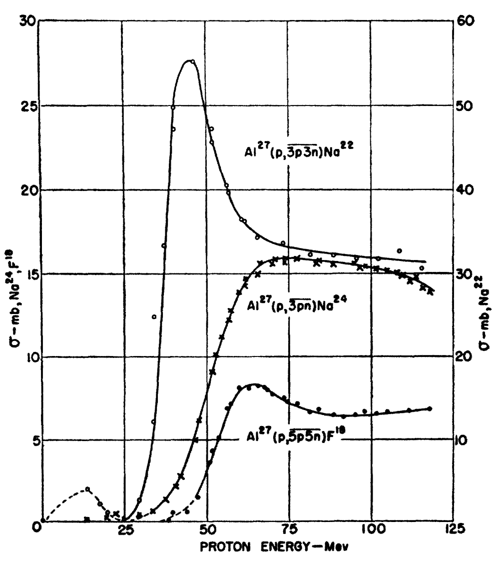

FIG. 2. Excitation functions for protons on aluminum.

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

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

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.

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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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.

The relation between proton pulse height and channel number was found to be correct within 2 percent by ascertaining the positions of the photoproton peaks produced by the 2.618-Mev γ-line of RdTh and the 2.758-Mev γ-line of Na^{24}.

Three measurements were made in consecutive weeks with sources of Na_2CO_3 and NaF irradiated to about 100 mC in the pile at AERE Harwell. First, with the source far away from the counter the 2.76-Mev line was recorded; then the source was brought close to measure the high energy γ-line. Known attenuation was introduced to bring the pulse height into the kicksorter range. Bringing the source close to the counter increases the average ionization current due to γ-rays, and it was necessary to

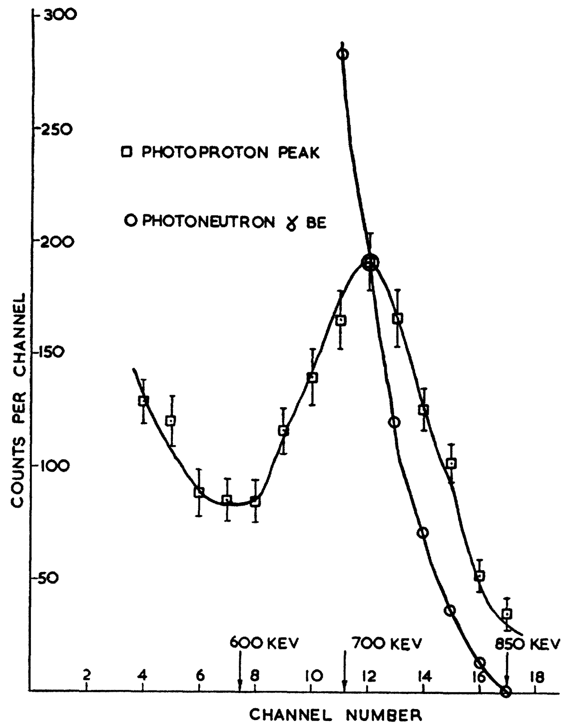

FIG. 1. Photoproton distribution from Na^{24} γ-rays disintegrating deuterium in ion chamber; and deuterium recoils from RdTh-γ-Be neutrons.

check the validity of extrapolating the energy calibration from the low energy region to the expected photoproton energy. This was done by examination of the deuteron recoil spectrum produced by a RdTh-γ-Be source with successive increases of the γ-ray background. No significant shift with γ-ray intensity was observed, and the position of the end point of the recoil spectrum agreed with the expected maximum energy (848 kev) to within 3 percent.

It is difficult to reconcile the correct position of the recoil spectrum end point with an instrumental shift of the photoproton peak. The possibility of positive ion effects in the chamber has been considered carefully, and calculation showed that the worst possible case of reduction of pulse height would produce a loss of 10 percent. Taking the extreme case of 10 percent and adding the calibration errors, etc., the photoproton energy might be as high as 790 kev and the energy of the γ-ray accordingly 3.81 Mev.

It is unlikely that the line is due to impurities in the irradiated material, since the same results were obtained with Na_2CO_3 and NaF, and the counting at the peak decreased with the period of Na^{24}.

It is interesting to compare the upper limit for the 4.14-Mev cross-over line (2×10^{-6}) with the theoretical predictions by Blatt and Weisskopf.[4] Assuming the well-known 4^+, 2^+, 0^+ assignment for the 4.14-Mev, 1.37-Mev, and ground-state level of Mg^{24}, the probability of the 4.14-Mev $(2)^4$-pole relative to the 2.76-Mev $(2)^2$-pole becomes 10^{-6}.

As to the new line (the energy of which as stated, lies between 3.6 and 3.8 Mev) it has to be decided whether it is due to a transition from the 4.14 Mev level to a new level at (400 ± 100) kev or to a transition from a new (3.7 ± 0.1)-Mev level to the ground state. The first alternative can be excluded by considering the various transition probabilities concerned in such a scheme (again using the calculations of Blatt and Weisskopf). The only possible transition probability would need an assignment of 7^+ to the (400 ± 100)-kev level. Similarly, for the second alternative we can exclude all spin and parity assignments for the 3.7-Mev level other than 2^+ or 2^-, or values above 7 for the spin.

We are indebted to Lord Cherwell for his interest in this work and for extending to us the facilities of this laboratory.

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[3] Wilson, Beghian, Collie, Halban, and Bishop, Rev. Sci. Instr. **21**, 699 (1950).
[4] J. M. Blatt and V. F. Weisskopf, privately circulated notes to appear as part of a book on nuclear physics. The authors believe the formula to be correct to a factor of $10^{\pm2}$.

Continuous γ-Radiation of β-Emitters*

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It has long been known that a weak continuous γ-radiation is emitted in the β-decay of nuclei.[1] The theory of the effect was first given by Knipp and Uhlenbeck[2] and Bloch,[3] and later extended to include forbidden β-transitions and different kinds of β-interactions by Chang and Falkoff.[4]

The increased efficiency of detection of γ-radiation allowed by the use of scintillation counters suggested a new and more quantitative investigation of the phenomenon. Sources of P^{32} and RaE of the order of 0.1 millicurie were used. The γ-radiation was measured by means of NaI(Tl) crystals (about $1\times1\times0.5$ cm), a 5819 phototube, a linear amplifier, and a one-channel discriminator. The γ-continuum to be investigated and γ-ray lines for energy calibration were also observed and photographed on an oscilloscope screen. Both the total intensity and the spectral distribution of the continuum were studied.

To avoid admixture of ordinary bremsstrahlung produced in the stopping of the β-rays, the following arrangement was used. The sources were deposited on relatively thin supports (3 mg/cm^2 Cellophane for P^{32} and 3 mg/cm^2 Ni for RaE) and placed at about 15 cm from the lead-shielded detector. A beam from the source was allowed through a $\frac{1}{2}$-inch hole placed at half the distance between source and detector. This diaphragm was covered with a $\frac{1}{2}$-inch Lucite plate to absorb the β-rays completely. Various tests have satisfied us that with this geometry ordinary bremsstrahlung produced in the support and other materials near the source did not exceed a few percent of the total measured γ-intensity.

Energy calibration of the pulse size was obtained by measuring the position of the peaks due to the 87-kev line of Cd^{109}, the 47-kev line of RaD, and the annihilation radiation. In the low energy region investigated (30–300 kev) it was assumed that the pulse represented the energy dissipated in the crystal by photoelectric absorption, as the photoelectric cross section in NaI at these energies is much larger than the scattering cross section. Corrections were applied to the measured pulse-size distribution to allow for the following factors: (1) absorption in the Lucite plate, (2) efficiency of the crystal (this was calculated by means of the known absorption coefficients in I and Na); and (3) lack of resolution of the detecting system. For the last purpose, the shape of the peaks due to monochromatic lines was measured and found to be approximately represented by gaussian curves with a width at half-