$C^{12}(\gamma,n)$ Yield Curve Near Threshold*

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The $C^{12}(\gamma,n)$ yield curve has been studied near the threshold for the reaction with a 22-Mev betatron. A discontinuity in slope, or "break," is observed to occur 370 kev above the threshold. This is in disagreement with previously published results. The discrepancy is important since it indicates a disagreement in the measurement of the $C^{12}(\gamma,n)C^{11}$ threshold, and this threshold is used to establish the energy calibration of the betatron.

INTRODUCTION

THE energy calibration of betatrons operating in the 20-Mev region is customarily made by measuring thresholds. Photonuclear reactions whose threshold energies are accurately known are used for this purpose. For example, the (γ,n) reactions in Be^9, Cu^{63}, O^{16}, and C^{12} are often used.

This paper reports on a study of the $C^{12}(\gamma,n)C^{11}$ yield curve in the vicinity of the threshold. The work was done with the 22-Mev betatron at the University of Illinois. The reaction is particularly important because it has the highest threshold (18.73 Mev) of the commonly used calibrating reactions.

EXPERIMENTAL TECHNIQUE

Because of the high threshold value, some difficulty is experienced in obtaining samples which are satisfactorily free of background activities. In this respect it is somewhat better to detect the reaction by counting radioactivity than by measuring the neutron yield, since the counting period may be arranged to discriminate against short-lived background.

In the present experiment the 20.5-minute β^+ activity of C^{11} was counted. The experimental arrangement was very similar to that used in a recent study of the $O^{16}(\gamma,n)O^{15}$ reaction.[1]

Cylinders of polystyrene were irradiated, four at a time, for periods of 10 minutes. Counting was begun about a minute after irradiation and was continued for 10 minutes. The samples were placed about 26 cm from the x-ray target.

RESULTS

The results of the measurements are shown in Fig. 1, where the observed activity is plotted against the integrator setting (setting of the energy controlling device). Each point which is shown is an average of from two to six irradiations. In all, some 70 irradiations were made in about eighteen hours of running time.

The apparent threshold is at an integrator setting of 7–241±4 and this then corresponds to 18.73±0.03 Mev.[2] In addition, a sudden change of slope, or "break," is observed to occur at an integrator setting of 7–290±5, corresponding to 19.10±0.04 Mev.

The energy increment per integrator unit is 7.5 kev.

The presence of breaks in the $C^{12}(\gamma,n)C^{11}$ yield curve has been previously reported by Katz *et al.*[3]

The background activity is energy-independent to within experimental accuracy and was determined to be mostly due to nitrogen and oxygen. This was deduced from half-life measurements. The background activity was about three times cosmic ray background.

To check on the quoted threshold, half-life measurements were made at integrator settings of 7–240 and 7–250. For these measurements the samples were irradiated for 40 minutes to enhance the carbon activity as much as possible. The decay curves were followed for 50 minutes. The irradiation at 7–250 showed an appreciable activity of 20-minute half-life. The irradiation at 7–240 showed none.

Figure 2 shows the $C^{12}(\gamma,n)C^{11}$ yield curve for a distance of about 1 Mev above threshold. The data which are plotted in Fig. 1 are shown by the solid dots and the statistical error is about as big as the dots. The

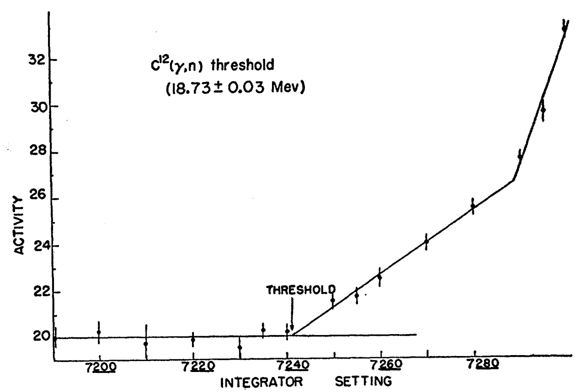

FIG. 1. $C^{12}(\gamma,n)C^{11}$ yield curve near threshold. The observed activity is plotted against the integrator setting. Each point represents the average result of from two to six irradiations.

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[1] A. S. Penfold and B. M. Spicer, following paper [Phys. Rev. **100**, 1377 (1955)].

[2] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).

[3] Katz, Haslam, Horsley, Cameron, and Montalbetti, Phys. Rev. **95**, 464 (1954).

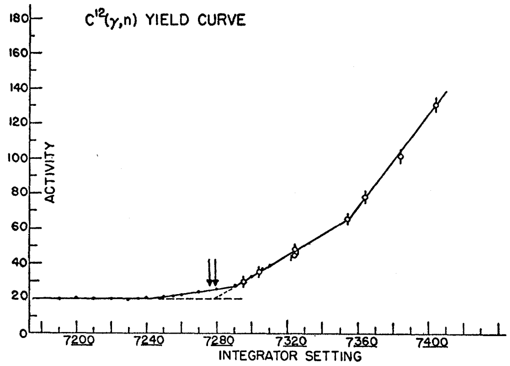

FIG. 2. $C^{12}(\gamma,n)C^{11}$ yield curve near threshold. The data from Fig. 1 are shown by solid dots. The open circles represent the results of an earlier determination. The two arrows indicate the position of the threshold as erroneously quoted on two occasions.

data shown by the open circles were obtained at an earlier date. The curve is thus a composite one showing data taken at two different times. The two sets of data could be put together with confidence because of the excellent long-time stability of the betatron and because of an energy checking procedure described elsewhere.[4]

Each of the open circles in Fig. 2 represents the result of irradiating a single polystyrene cylinder at 40 cm from the x-ray target.

Two breaks are evident in Fig. 2; one at an integrator setting of 7–290 and the other at a setting of 7–354. These correspond to energies of 19.10±0.04 Mev and 19.55±0.05 Mev.

Because the yield curve points are taken relatively far apart it is impossible to determine the detailed nature of the yield curve in between the breaks.

DISCUSSION

The results demonstrate a basic difficulty of using threshold measurements in light elements to fix the energy scale of an accelerator. The difficulty arises from the fact that the yield curves have fine structure in the form of discontinuities in slope, or breaks. These breaks have been interpreted as manifestations of narrow resonances in the gamma-ray absorption cross section.[1,3]

The difficulty may be illustrated with the aid of Fig. 2. The apparent threshold of 7–241 corresponds to the point at which the C^{11} activity becomes too small to be detected. However the setting might correspond to a resonance in the cross section above the kinematic threshold. In that case the threshold would lie at a lower integrator setting—even as much as 30 units (200 kev) lower.

The present results on the yield-curve breaks are compared to the results of Katz *et al.*[3] in Table I. The error which is quoted for the latter's results was estimated from published curves. The agreement is not satisfactory. This is especially true if one considers that in each case the $C^{12}(\gamma,n)C^{11}$ threshold was used to calibrate the energy scale.

TABLE I. Comparison of $C^{12}(\gamma,n)$ yield-curve breaks with those observed by Katz *et al.*

	Break energy (Mev)		Mev above threshold	
	Present results	Katz *et al.*[a]	Present results	Katz *et al.*[a]
Threshold (cal pt)	18.73 ±0.03	18.73 ±0.03	0.00 ±0.04	0.00 ±0.05
First break	19.10 ±0.05	19.30 ±0.05	0.37 ±0.05	0.57 ±0.05
Second break	19.55 ±0.05	19.75 ±0.05	0.82 ±0.05	1.02 ±0.05

[a] See reference 3.

A possible explanation for the discrepancy can be derived from a consideration of Fig. 2. Suppose that the whole yield curve had been determined in the manner indicated by the open circles—that is, with similar spacing of points and statistical errors. It is easy to imagine that the extension of the region above the first break could be mistaken for the threshold.

This error was made by us on two occasions prior to the measurements shown in Fig. 1. On these occasions the threshold was taken to be at the positions shown by the two arrows in Fig. 2.

If then, a setting of 7–277 was taken for the threshold, the energy scale would be in error by 0.28 Mev near the carbon threshold. Then an energy of 19.27±0.05 Mev would have been assigned to the break at 7–354. This value agrees very well with the value of 19.30 ±0.05 Mev which Katz *et al.*[3] assigned to their first break.

CONCLUSIONS

According to the results of the present measurements there is a break in the $C^{12}(\gamma,n)C^{11}$ yield curve 370±50 kev above the threshold. This result is in disagreement with previous work[3] in which the first break was measured to be 570±50 kev above the threshold. Since the C^{12} threshold was used as an energy calibration point in both the previous and the present work, the disagreement is attributed to difficulties in determining the C^{12} threshold.

The disagreement amounts to 280 kev which is in itself not too serious. However, it has been customary to fix the energy scale above 19 Mev by extrapolating the calibration curve from lower energies through the C^{12} threshold. The discrepancy could then be as large as 600 kev at 23 Mev.

It seems clear that the practice of calibrating the energy scale by measuring thresholds in light elements should be abandoned, or at least the data should be supplemented with a careful series of magnetic field measurements.

[4] B. M. Spicer and A. S. Penfold, Rev. Sci. Instr. **26**, 952 (1955).