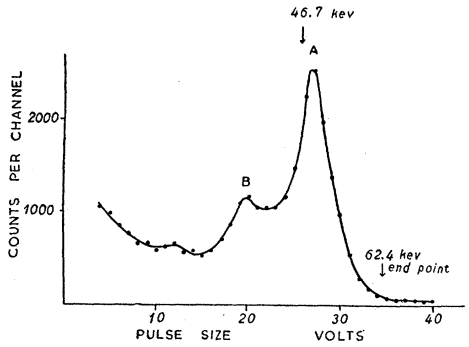

FIG. 1. Pulse-size distribution from proportional counter with RaD in the form of lead tetramethyl vapor.

amount of distortion of the shape of the β-spectrum associated with A. The necessary correction is small, and the curve closely approximates the shape of the β-spectrum except in the neighborhood of the maximum. A Fermi plot for an allowed transition (neglecting the effect of screening on the Coulomb factor for which no adequate calculations are as yet available to us), somewhat surprisingly, gives a good straight line from 3 kev to 13.0 kev. Extrapolation gives an end point corresponding to a maximum energy of 15.7 kev. From several determinations, the mean value for the end point was found to be 16.7 ± 1 kev, which is in good agreement with the value of 18 ± 2 kev reported recently by Bannerman and Curran[2] using scintillation counters. The residual tail of low intensity can be accounted for by the random superposition of pulses due to the finite pulse duration and high counting rate, and probably also to the presence of a very small amount of RaE, perhaps in the form of bismuth trimethyl.

The low energy part of the pulse distribution should include the pure β-spectrum (i.e., when all γ-rays coincident with the decay are unconverted and escape from the counter or if all the accompanying γ-rays are metastable). This was examined at higher amplifications down to 0.9 kev, and the results also indicate the existence of a maximum at 2.4 kev. Even after subtracting the maximum possible unaccompanied β-spectrum, using the shape obtained from the results at higher energy, as described above, the remaining pulse distribution extends appreciably down to 7 kev. A consideration of our detailed results, together with other published data, provide evidence, we believe, for a branching in the β-decay, so that in at least 10 percent of the disintegrations a β-spectrum of maximum energy 55.6 kev is followed by a 7.8-kev γ-ray.

A detailed account of these experiments and their interpretation is in preparation.

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Excitation in High Energy Nuclear Reactions*

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A QUANTITY of special interest in a high energy nuclear reaction is the energy transferred to the struck nucleus by the incoming nucleon. Because of the possibility of noncapture excitation at high energies,[1] the excitation of the nucleus immediately after the collision may be less than the maximum possible value which is obtained when the incident particle is captured to form a compound nucleus.

It is the purpose of this note to point out that direct evidence for this may be obtained, in the case of certain nuclear reactions, by measuring the range of the struck nucleus in the target foil. This has been done for the nuclear reactions $Al^{27}(p, 3pn)Na^{24}$ and $C^{12}(p, pn)C^{11}$ by determining the fractional loss of the residual nuclei, Na^{24} and C^{11}, from thin foils of the target element. The experimental arrangement makes use of 180° focused protons from the internal beam of the Harvard cyclotron.[2] The target assembly consists of a stack of absorbers, interspersed with target foils, each foil backed with a receptor foil of 0.001 in. polyethylene to catch the recoil nuclei.

Figure 1 shows preliminary results for the ratio of the activity in the receptor foil N_r, to the total activity N_t, plotted as a function of the incident proton energy for two nuclear reactions. The receptor foil itself has a strong activity after irradiation due to the $C^{12}(p, pn)C^{11}$ reaction, so the method is limited to reactions leading to residual nuclei having half lives long as compared to C^{11}. Beryllium foils might be used as receptors for shorter lived nuclei, since only a relatively weak activity due to Be^7 would be present. In the case of the $C^{12}(p, pn)C^{11}$ reaction, the difference between the counting rates per unit mass in the target and receptor foils was taken as the quantity N_r, resulting in considerably poorer statistics than for the Na^{24} reaction.

The dashed lines in Fig. 1 show the expected ratio N_r/N_t if it is

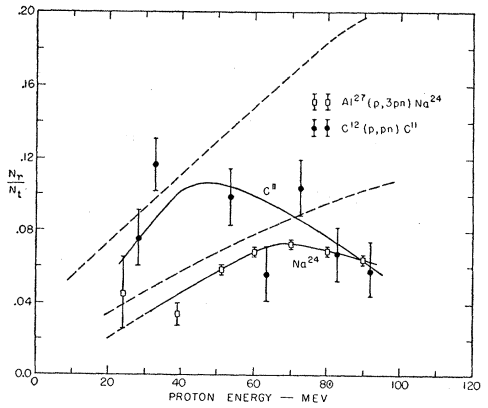

FIG. 1. Ratio of recoil to total activation.

assumed that the incident particle is captured to form a compound nucleus which subsequently de-excites by isotropic emission of particles. If particles are emitted preferentially forward, the range of the recoil fragments, and hence N_r, will be decreased. The ranges of the Na^{24} and C^{11} recoil ions in Al^{27} and polyethylene were calculated using the semi-empirical theory of Knipp and Teller[3] based on measurements of nuclear recoils in various gaseous mixtures by Blackett, Feather, and others. The ranges so calculated should be quite approximate since, in addition to the low accuracy of cloud-chamber measurements, the original data was presented in the form of "reduced air ranges." The reduction was accomplished by a comparison of the nuclear recoil tracks with the tracks of fast alpha-particles for which the electronic part of the stopping cross section alone is important. In the velocity range of this experiment roughly $\frac{1}{3}$ of the stopping cross section for heavy ions is due to nuclear effects. Thus the dashed curves should probably be renormalized so as to fit the experimental points at low energy where it is quite likely that the maximum energy transfer occurs and that the subsequent emission is isotropic.

It should be pointed out that the experiment does not give the nuclear recoil for typical nuclear collisions, but only for those in which the residual nucleus detected is produced. From Fig. 1 it can be seen that for the C^{11} reaction the region of noncapture excitation begins from 40–50 Mev, and for the Na^{24} reaction, about 65 to 70 Mev. For the reaction $Al^{27}(p, 3pn)Na^{24}$, a calculation based on the evaporation theory[4] gives 4 as the average number of particles emitted if the excitation lies within the range

corresponding to capture of protons of energy 53 to 75 Mev. Thus one expects, if the yield of Na^{24} is to vary slowly above 70 Mev as is observed,[2] that noncapture processes should become important above 75 Mev. A similar argument can relate the slow variation with energy in the C^{11} reaction above 40 Mev[5] to the observed departure of the C^{11} recoil range (Fig. 1) from its maximum value at approximately the same energy.

In order to calculate the actual nuclear excitation, W, from the recoil data of Fig. 1 a knowledge of the angular distribution of the recoil fragments is necessary. In the case of noncapture excitation, followed by isotropic emission of particles, the nuclear excitation is given by

$$W=W_m(2\gamma\cos\theta-\gamma^2), \quad (1)$$

where W_m is the relative kinetic energy in the center-of-mass system before collision, $\gamma=v_r/v_c$ is the ratio of the nuclear recoil velocity to the velocity of the center of mass, and θ is the nuclear recoil angle. Over the velocity range of this experiment the range varies approximately linearly with velocity, so that

$$N_r/N_t=\langle R\cos\theta\rangle_{Av}/t\simeq R(\langle v_r\cos\theta\rangle_{Av})/t, \quad (2)$$

where $R=R(v)$ is the range of the recoil fragment in the target foil whose total thickness is t. Placing $\theta=0$ in Eq. (1) gives the upper limit to W for a given γ. From the data of Fig. 1 this upper limit is approximately 80 Mev in the Na^{24} reaction and 55 Mev in the C^{11} reaction when $W_m=90$ Mev in both cases. If $\langle\cos^2\theta\rangle_{Av}$ is taken as 0.75, W becomes 50 Mev for C^{11} and 65 Mev for Na^{24}. Measurements of the angular distribution of nuclear recoils in photographic plates or cloud chambers would enable a more precise value of W to be calculated.

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(γ, α) Reactions on Li^7, O^{16}, and $Br^{79,81}$

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IN light as well as in middle-weight nuclei, (γ, α) reactions have exceedingly small cross sections ($\approx 10^{-29}$ cm^2). Therefore, an investigation of these processes needs a highly sensitive detecting device. The nuclear emulsion turned out to be very suitable to a study of (γ, α) reactions in the above mentioned elements, since emulsions can easily be loaded with lithium, and oxygen as well as bromine, form a great part of the emulsion itself.

1. Li^7.—200μ Kodak NT 1a plates loaded with lithium have been exposed to the ~6.13 Mev gamma-rays from the $F^{19}(p, \alpha)O^{16}+\gamma$ reaction at a bombarding energy of ~430 kev. About 600 events consisting of an α-particle ($E\cong 1.5$ Mev) and a triton ($E_T\cong 2$ Mev) emitted in opposite directions have been observed in 30 cm^2 of the emulsion. They belong to the reaction

$$Li^7(\gamma, \alpha)T^3(Q=-2.51 \text{ Mev}).$$

From the geometry of the arrangement, the number of tracks counted, and the absolute intensity of the gamma-rays measured according to the method of Fowler *et al.*,[1] the cross section has been determined to be

$$\sigma[Li^7(\gamma_{6.13}, \alpha)]=(2.65\pm 1.0)\times 10^{-29} \text{ cm}^2.$$

The angular distribution (350 tracks) of the tritons with respect to the incident gamma-rays is given by

$$J(\theta)=1-(0.1\pm 0.09)\cos\theta.$$

This result is in qualitative agreement with the following assumptions: $Li^7(^2P_{\frac{3}{2}}^-)$ absorbs in its ground state EQ and MD radiation. Both kinds of transitions lead to a $^2P_{\frac{1}{2}}^-$ state and accordingly to an isotropic distribution. From an admixture of ED absorption there results a $^2P_{\frac{3}{2}}^+$ state, which together with the $^2P_{\frac{1}{2}}^-$ state causes a $\cos\theta$ interference term in the angular distribution.

2. O^{16}.—200μ Kodak NT 1a plates have been irradiated by the 17.6-Mev gamma-rays from the $Li^7(p, \gamma)$ reaction. Figure 1 shows the energy-distribution of 600 α-particle tracks measured in 15 cm^2 of emulsion. As follows from the well-known masses of O^{16}, C^{12}, and He^4, the peak at 7.8 Mev corresponds to the $O^{16}(\gamma, \alpha)$ reaction leading to the ground state of the rest nucleus C^{12}. Since the first excited state of C^{12} lies at ~4.5 Mev, a second maximum at ~4.4-Mev α-particle energy could be expected from the 17.6-Mev gamma-line. This maximum would partially interfere with the 5.7-Mev α-particles from the 14.8-Mev gamma-line present in the lithium gamma-ray spectrum, as well as with polonium contamination tracks (5.3 Mev) always present in the emulsion. But since the number of α-tracks between 4 and 6 Mev is only 25 percent of the number of those between 7 and 9 Mev, one can say that the predominant part of the $O^{16}(\gamma_{17.6}, \alpha)$ transitions leads to the ground state of the C^{12} nucleus. From a comparison of the number of tracks which belong to this peak with the number of "carbon stars" arising from the reaction $C^{12}(\gamma, \alpha)2\alpha$, the following cross section ratio results:

$$\sigma[O^{16}(\gamma_{17.6}, \alpha)]/\sigma[C^{12}(\gamma_{17.6}, \alpha)]=0.82\pm 0.1.$$

A new determination of the carbon cross section has been made recently.[2] The result is $\sigma[C^{12}(\gamma, \alpha)2\alpha]=1.7\pm 0.3\times 10^{-28}$ cm^2 for γ-rays from lithium. Assuming this new value tentatively as correct, we get after a correction for the three Li γ-ray lines (17.6; 14.8; $\approx$12.5 Mev) an absolute value of the oxygen cross section:

$$\sigma[O^{16}(\gamma_{17.6}, \alpha)]=(1.8\pm 0.5)\times 10^{-28} \text{ cm}^2,$$

which is in agreement with a former determination.[3]

3. $Br^{79,81}$.—An interpretation of the peak at 10.2 Mev in the α-particle distribution is not possible by a (γ, α) process on one of the light elements of the emulsion, as calculations with the well-known masses show. Only bromine and silver remain. But the emission probability for an α-particle of 10 Mev from a silver

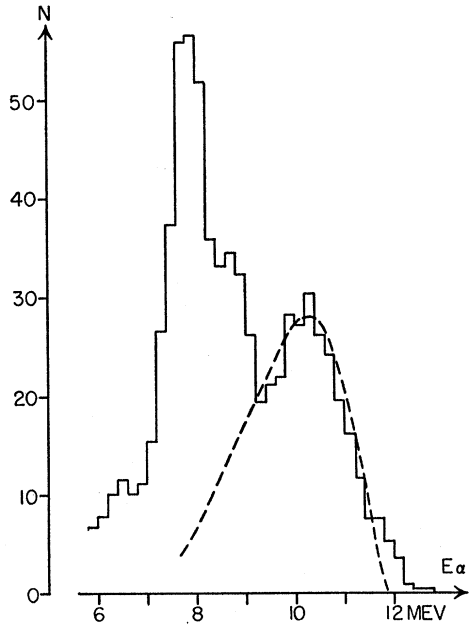

FIG. 1. α-particle distribution in a nuclear plate exposed to lithium gamma-rays. Block-diagram: experimental distribution; dashed curve: theoretical α-particle distribution for bromine.