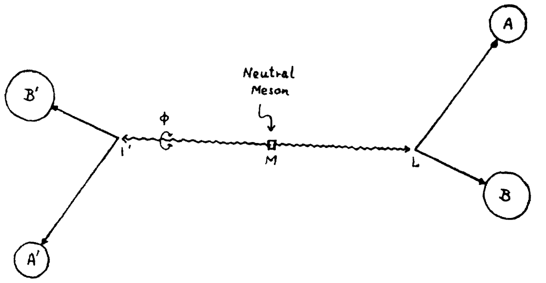

FIG. 1. Schematic diagram of experiment (angles *ALB*, *A'L'B'* much exaggerated).

around the axis *LML'* through an azimuthal angle ϕ and the fourfold coincidence rate *N* plotted against ϕ.

The calculation of the theoretically expected dependence of *N* on φ is rather straightforward, but somewhat complicated. The result is

$$N=\alpha(1\pm\beta^2\cos 2\phi)\quad \begin{array}{l} +\text{ for scalar meson} \\ -\text{ for pseudoscalar meson,} \end{array}$$

where β^2 is a positive constant dependent on the geometry of the counters *A* and *B* with respect to the points *M* and *L*. One sees that

$$^{N}\phi=0^\circ > {}^{N}\phi=90^\circ \quad \text{for scalar meson,}$$
$$^{N}\phi=0^\circ < {}^{N}\phi=90^\circ \quad \text{for pseudoscalar meson.}$$

To get an idea of the order of magnitude of β^2, the hypothetical case that the counters *A* and *B* are infinitesimal in size is considered in detail. If the angles *MLA* and *MLB* are equal, the value of β^2 is approximately $\frac{1}{16}$ for all values of the angle *MLA* for which pair production is abundant. In such a case

$$\frac{^{N}\phi=0^\circ}{^{N}\phi=90^\circ}=\frac{17}{15}=1.13 \quad \text{for a scalar meson,}$$

$$\frac{^{N}\phi=0^\circ}{^{N}\phi=90^\circ}=\frac{15}{17}=0.88 \quad \text{for a pseudoscalar meson.}$$

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Neutron Capture Gamma-Rays from Be^9, C^{12}, and N^{14}

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MATERIALS containing carbon and nitrogen were exposed to a high flux of thermal neutrons in the Chalk River pile. The radiations emitted were examined with the aid of a coincidence pair spectrometer similar to that described by Walker and McDaniel.[1]

In our method the coincidence counting rate between two counters recording positrons and negatrons is obtained for a series of values of the magnetic field. The field is measured by means of a proton resonance magnetometer. In a plot of coincidence rate against field strength a homogeneous gamma-ray appears as a sharp peak which falls rapidly to zero toward high field strengths. The upper limit of the peak corresponds to pairs which are produced at the center of the radiator, the components having equal energy. The energy of the gamma-ray can be calculated, to a first approximation, from the distance between the inner edges of the slits covering the counters and the value of the magnetic field obtained by extrapolating the high field slope of the peak to zero. The true energy of the gamma-ray is obtained by adding a correction of about 25 kev computed from the pair production cross section and from the geometry.

With a graphite sample in the pile a conspicuous radiation was identified as resulting from neutron capture in C^{12} which must be the direct transition to the ground state of C^{13}. The energy of this radiation is 4.947±0.008 Mev. Another value for this energy may be obtained by the addition of the following equations:

$$C^{12}+H^2=N^{13}+n-0.281\pm0.003\text{ Mev}^2, \qquad (1)$$
$$N^{13}=C^{13}+2m_0c^2+1.198\pm0.006\text{ Mev}^3, \qquad (2)$$
$$n+H^1=H^2+2.230\pm0.007\text{ Mev}^4, \qquad (3)$$
$$n-H^1=0.782\pm0.002\text{ Mev.}^5 \qquad (4)$$

The result is:

$$C^{12}+n=C^{13}+4.951\pm0.010\text{ Mev.} \qquad (5)$$

A recent measurement of the energy balance in the $C^{12}(d,p)C^{13}$ reaction gives $Q_0=2.729\pm0.009$ Mev.[6] From this result, together with (3), we find:

$$C^{12}+n=C^{13}+4.959\pm0.012\text{ Mev} \qquad (6)$$

in agreement with our own figures and with (5). Taking into account the probable errors of these three results the mean energy is:

$$4.951\pm0.006\text{ Mev.} \qquad (7)$$

Nitrogen was investigated with the aid of samples of beryllium nitride, urea, and beryllium oxide. From the spectra of these compounds nine radiations due specifically to nitrogen were identified. These radiations are given in Table I and can be fitted to the level scheme of Fig. 1 which, with the exception of the levels at 7.16 and 9.16 Mev, has already been published.[7],[8]

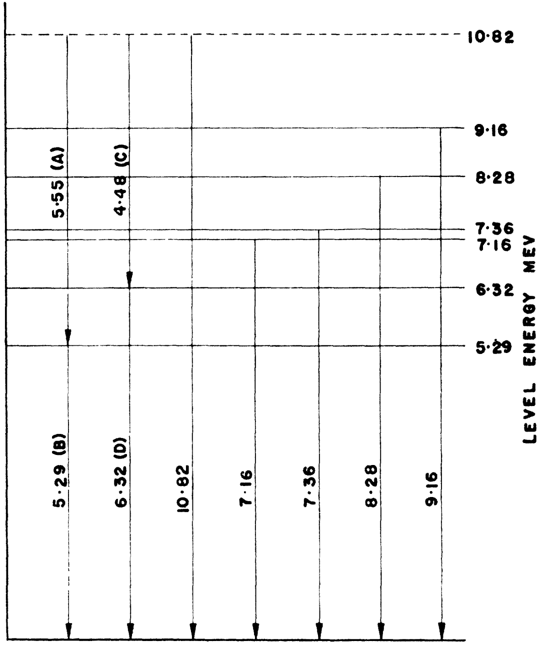

FIG. 1. Capture gamma-radiation from nitrogen.

Rough values for the relative intensities appearing in Table I were obtained from the heights of the coincidence peaks after corrections had been made for the variation with energy of the pair production cross section and of the angular distribution of the electron pairs.

By comparing the intensities of the nitrogen and beryllium radiations from beryllium nitride we estimate that the radiative capture cross section of nitrogen is about 100 millibarns. This

TABLE I. Gamma-rays from nitrogen under neutron bombardment.

Energy Mev	Relative intensity
10.816±0.015	1.0
9.156±0.030	0.1
8.278±0.016	0.4
7.356±0.012	0.8
7.164±0.010	0.1
6.318±0.010	2
5.554±0.010	4
5.287±0.010	5
4.485±0.010	3

follows from the capture cross section of beryllium, 9 millibarns, and our observation that only one radiation is emitted, its energy being 6.80±0.01 Mev. Now the total absorption cross section of nitrogen is about 1.7 barns[9] and the penetrability of the Coulomb barrier for a proton of 600 kev is about 0.03. If, then, the radiation width is of the order of a few volts,[10] the proton width without barrier must be of the order of a kilovolt, a very low result.

Another surprising feature is the relative weakness of the direct transition to the ground state. If, as seems likely, the parities of the ground states of N^{14} and N^{15} are even and odd, respectively, the transition is of the electric dipole type. It is, however, no more intense than the radiation of 5.55 Mev which competes with it and has about half the energy.

Correcting for recoil, the energy of the direct transition to the ground state of N^{15} is found to be 10.820±0.015 Mev. The sums of the corrected energies of the two pairs of cascading transitions (AB) and (CD) in Fig. 1 are:

$$A+B=10.843\pm0.014\ \text{Mev},$$
$$C+D=10.805\pm0.014\ \text{Mev}.$$

The average of the three determinations is:

$$\mathrm{N}^{14}+n=\mathrm{N}^{15}+10.823\pm0.012\ \text{Mev}. \qquad (8)$$

The neutron binding energies of C^{13} and N^{15} may be used to calculate the values of certain mass differences which may be compared with mass spectrographic measurements. From (4), (7), and (8), we obtain:

$$\mathrm{C}^{12}\mathrm{H}^1-\mathrm{C}^{13}=44.78\pm0.06\times10^{-4}\ \text{mu},$$
$$\mathrm{N}^{14}\mathrm{H}^1-\mathrm{N}^{15}=107.85\pm0.11\times10^{-4}\ \text{mu}.$$

The first of these two results is significantly higher than that obtained directly by Ewald,[11] *viz.*, $44.10\pm0.08\times10^{-4}$ mu. Our measurement of the binding energy of the neutron in C^{13} therefore confirms a discrepancy between the transmutation and mass spectrographic data indicated by the results (5) and (6). For the nitrogen difference, Ewald obtained $107.76\pm0.20\times10^{-4}$ mu, which is in agreement with our results.

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On the Low States of Li^7 and Be^7

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TO the problem of interpreting the ground level and 480 kev level of Li^7, recent experiments[1] have added as a new feature the necessity of understanding the apparent lack of further levels up to at least 3.6 Mev, with a similar but not quite so clear-cut situation in the mirror nucleus Be^7.

This scarcity of levels might be considered to favor a return to the original interpretation,[2] in terms of a rather extreme $L-S$ coupling scheme with a ^2P splitting of 480 kev and the ^2F elevated now about 4 Mev or more above this. The most striking experimental evidence[3] against this interpretation,[4] the intensity ratio of the $\mathrm{B}^{10}(n,\alpha)\mathrm{Li}^7$ transitions, could then be attributed to a minor misbehavior of incalculable matrix elements. It would be a further concession to accept such extreme $L-S$ coupling in these light nuclei, unless an adequate theory of the large spin-orbit coupling could be found much less sensitive to nuclear radius than is the inadequate theory that has been discussed.[2] (It varies about as l^3R^{-4}, to be compared with lR^{-3} for the competing integral[5] of the inter-nucleon attraction.) We wish therefore to examine an alternative.

In a description of the low states of Li^7 in the $j-j$ coupling scheme, the two p-neutrons, each having individual $j=3/2$, form a total neutron moment $J_\nu=0$ or 2, of which $J_\nu=0$ is presumably associated with the ground state. In zeroth order the low excited states are then described[6] by coupling this moment $J_\nu=2$ with the proton moment $j=3/2$, to make the nuclear moment $I=7/2$, 5/2, 3/2, and 1/2. In first order the state with $I=3/2$ is mixed with the ground state. The relative energies of these various states are most easily studied phenomenologically in terms of the familiar non-exchange (Wigner), space-spin-exchange (Heisenberg), space-exchange (Majarana) and spin-exchange (Bartlett) interactions. It is a rather remarkable and intriguing fact that the states with $I=7/2$, 5/1, and 1/2 remain degenerate in first order with an arbitrary combination of non-exchange and space-spin-exchange terms of arbitrary range. The excited $I=3/2$ state lies somewhat higher. In second order, as one departs from extreme $j-j$ coupling, admixture of states with higher spin-orbit energy begins to lift the degeneracy, but it seems possible that the departure from $j-j$ coupling might be small enough to leave the second-order splitting unobserved with present resolution, if one identifies the degenerate level as the 480 kev level. Its complexity satisfies the simple demands of relevant intensity-ratio, lifetime, and angular-distribution data.[6]

In addition to a narrow triple level at 480 kev, we would then have a single level (with "statistical weight" 1/4 as great) probably one or several hundred kev higher. The fact that it has not been observed[1,7] in the two sufficiently exoergic reactions $\mathrm{Be}^9(d,\alpha)\mathrm{Li}^7$ and $\mathrm{Li}^6(d,p)\mathrm{Li}^7$ would have to be attributed to unexpected behavior of the transition intensities, which seems no more implausible than the other alternative.

In the excited spectrum of Be^7, observations of the reactions $\mathrm{Li}^6(d,n\gamma)\mathrm{Be}^7$ at about 1.5 Mev bombarding energy[8] and $\mathrm{Li}^7(p,n)\mathrm{Be}^7$ at several bombarding energies[9] up to almost 4 Mev have revealed the level at 430 kev, but no other level up to the limit of the observations, perhaps 1 Mev. The latter reaction with cyclotron bombardment[10] at 5 Mev seems to show a level near 700 kev, in addition to the one near 430 kev (and still another less consistently resolved near 200 kev). This observation of an additional level (or two), if verified by more extensive investigation at high bombarding energies, would indeed demonstrate unexpected behavior of the transition probabilities and encourage attempts to find a mirror level and to resolve the multiple level.

The separation of the 480 kev level from the ground level arises mainly from the separation of $J_\nu=2$ from $J_\nu=0$ by the like-nucleon attraction, and the corresponding separation is less in Be^7 (430 kev) because the like-nucleon attraction is there weakened by the Coulomb repulsion of the two protons.

This interpretation would require mainly non-exchange interaction with, perhaps, an additional weak space-spin exchange term (even weaker between like nucleons, in order to leave $J_\nu=0$ below $J_\nu=2$, than suggested for unlike nucleons by the deuteron states). Saturation would then be attained not by exchange but perhaps by interactions between three nearly coincident nucleons which might be relatively unimportant for the three loosely bound nucleons here discussed. Such an origin of saturation is characteristic of pair theories of nuclear forces, and there is a rather attractive μ-meson pair theory (with π-mesons as pairs in the same field), according to recent discussions of Gregor Wentzel.