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:

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

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:

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

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 $B^{10}(n,\alpha)Li^7$ 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 $Be^9(d,\alpha)Li^7$ and $Li^6(d,p)Li^7$ 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 $Li^6(d,n\gamma)Be^7$ at about 1.5 Mev bombarding energy[8] and $Li^7(p,n)Be^7$ 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.

It has become apparent in discussions with Maria Goeppert Mayer and Dieter Kurath that just such a combination of non-exchange and space-spin-exchange terms seems also to be needed to understand the nuclear spins of Li^6 and B^{10} in the $j-j$ model, and less satisfactorily that, as a result of the first-order mixing of the $I=3/2$ states, the magnetic moment of Li^7 is about seven percent low with non-exchange forces symmetrical between all pairs of nucleons.

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Crucial Experiment Demonstrating Single Domain Property of Fine Ferromagnetic Powders

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It is now well known that fine ferromagnetic powders have high coercivities and this has been explained on the supposition that a sufficiently fine particle will consist of a single magnetic domain, as suggested by domain theory. The objection is sometimes raised that it might be possible to explain the high coercivity without the single-domain assumption, by supposing that internal strains are very large in fine powders, and that the strains hinder and retard magnetization changes by domain boundary displacement, thereby giving high coercivity. It may seem difficult to prove that the internal strain hypothesis will not account for the observed corecivities of 200 and 600 oersteds in fine nickel and iron powder, although it appears most improbable that strains are responsible for the unusually high coercivities observed in fine powders of MnBi ($H_c=12{,}000$ oersteds) and FePt ($H_c=20{,}000$ oersteds).

We have, however, devised and carried out a simple experiment applicable to iron and nickel by which single-domain effects have been clearly distinguished from the ordinary processes of bulk magnetization. We consider the field required to saturate a specimen consisting of a dilute solid suspension of magnetic particles embedded in a non-magnetic matrix. If the degree of dilution is sufficient the magnetic interactions between particles may be neglected, and each particle will behave as if it were alone. In this limit the field required to saturate a spherical particle of nickel or iron will be very considerably larger in a multi-domain particle than in a single-domain particle. We shall show this by considering the magnetization of: (A) a particle so small that it never forms a domain wall or closed-flux arrangement and thus is always a single domain; and (B) a larger particle which normally consists of a large number of domains.

(A) The energy of orientation of the magnetization arises from crystalline and shape anisotropy; therefore if the particle is spherical it will saturate for $H_s(A)\approx 2K/I_s$, while agglomeration may tend to increase this value. We observed $H_s=550\pm 50$ oersteds for a sample of fine nickel particles in 0.1 percent concentration in a 0.01-cc matrix of paraffin wax. The particles were prepared by decomposition of nickel formate in dimethyl phthlate at 250°C and were determined with an electron microscope to be nearly spherical in shape and of diameter 200±50A.

(B) In order to saturate the particle it will be necessary to overcome the maximum demagnetizing field of the particle on itself, which is $4\pi I_s/3$ for a sphere. If the material is magnetically hard H_s may be still larger, so that we have $H_s(B)\geq 4\pi I_s/3=2100$ for Ni. We observed $H_s=2100\pm 100$ oersteds for a 0.1 percent solid suspension of commercial carbonyl process nickel particles in the form of spheres about 8×10^{-4} cm in diameter.

If the particles agglomerate into chains of spheres, oriented at random, $H_s(B)\geq \pi I_s$. There appears to be no way in which the energy density required to saturate a random distribution of multi-domain crystals can be made less than about πI_s^2, so that the samples discussed in (A) must consist of single-domain particles (or at least of particles so very close to single-domain particles that the exchange energy is comparable with the demagnetizing energy).

The expected dividing line in nickel below which the single-domain state is lowest in energy[1] occurs at a diameter of about 600A, which is between (A) and (B).

We may summarize the idea of the experiment by saying that a saturated sphere in isolation must always have a demagnetizing energy density of $\frac{1}{2}NI_s^2=2\pi I_s^2/3$; with multi-domain particles this energy must be supplied by the external magnetic field, whereas with single-domain particles this amount of energy is always present.

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Effect of Exchange Interaction on Ferromagnetic Microwave Resonance Absorption

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It is well known that exchange forces have no effect on the ferromagnetic resonance frequency in a uniformly magnetized specimen, as a consequence of the fact that the magnetization operator $\sum_i S_i^x$ commutes with the exchange operator $\sum_{i,j}' \mathbf{S}_i\cdot\mathbf{S}_j$; in classical language,[1] the Weiss molecular field $\mathbf{H}_w=q\mathbf{M}$ is always parallel to the magnetization $\mathbf{M}$, and hence the torque $\mathbf{M}\times q\mathbf{M}$ must vanish. In the most common experimental arrangement for studying ferromagnetic resonance the specimen is in the form of a thin plate, and the microwave field penetrates only partially into the plate, perhaps to a depth of the order of 10^{-5} to 10^{-4} cm. The microwave component of the magnetization in these conditions is non-uniform and the exchange energy will play a role in determining the resonance frequency and the line width. It turns out that at microwave frequencies the exchange effects are not likely to be of importance in pure metals at room temperature, or in alloys at any temperature; at low temperatures, however, the exchange effects must be considered in pure metals, the skin depths being smaller.

The exchange energy density in a body-centered cubic lattice may be written semi-classically[2] as

$$f_{\mathrm{ex}}=(A/M_s^2)(\nabla\mathbf{M}\cdot\nabla\mathbf{M}), \tag{1}$$

where $A=2JS^2/a\cong 2.0\times 10^{-6}$ erg/cm for iron. We shall treat the exchange energy as a small perturbation on the motion of the system. Taking the plane of the plate as the x–z plane, the unperturbed state of the system is described by H_x, M_x, $M_y\sim e^{-ky}$, where $k^2=j\mu(4\pi\omega/\rho c^2)$. At resonance $\mu_1=0$ and $\mu=-j\mu_2$, so that

$$k_0=(4\pi\omega\mu_2/\rho c^2)^{\frac{1}{2}}=1/\delta \tag{2}$$

is real, where δ is the classical skin depth for permeability $2\mu_2$. As the phenomenon is essentially a modified Zeeman effect, we