The separation of the lenses should be considerably less than four focal lengths, the theoretical maximum. The individual lens separations and focal lengths should be held constant with respect to the average to a tolerance of about 1 percent for an average machine to avoid catastrophic resonance effects as the high transverse oscillation frequency corresponding to the relatively strong low-energy focusing force is gradually reduced with increase in the particle energy. It is of course necessary to provide the usual transverse field focusing at high energies.

Preliminary tests of twelve lenses equally spaced on the Naval Research Laboratory small aperture accelerator (radius $2\frac{1}{2}$ feet, aperture cross section 30-mm diameter) gave excellent focusing and evidence of many electron circuits through the tube on a fluorescent screen inserted into the path of the particles. This behavior was not possible at the injection energy of about 30 kv prior to the use of lens focusing.

A paper dealing with the theoretical aspects of the problem as well as with experimental results using more accurately spaced and wound lenses will be issued when the latter information has been obtained.

The Electron Neutron Interaction

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A WEAK, attractive interaction between neutrons and electrons has been observed experimentally.[1-4] From a qualitative point of view, such an effect is in accord with meson theory, for if a neutron can dissociate into charged particles,

$$N \leftrightarrow P+\pi^-,$$

it should have some interaction with an electric field. However, although several authors[5-8] have treated this problem in detail, there has been some confusion as to just what value meson theory gives for this interaction. For instance, using the same type of theory—pseudoscalar mesons, pseudoscalar coupling, with the usual weak coupling perturbation theory carried to second order in the meson-nucleon coupling—different methods of calculation have produced different answers. Thus, Slotnick and Heitler, and Dancoff and Drell obtain values about four times larger than do Case and Borowitz and Kohn. Moreover, Foldy's phenomenological treatment[9] gives a value lying between these two results.

Of course, meson theory weak coupling calculations of such effects cannot be taken too seriously—for instance, they do not even give the correct neutron to proton magnetic moment ratio. Nevertheless, in view of recent interest in the electron-neutron interaction[10,11] it seems desirable to state definitely just what value pseudoscalar meson theory does predict for this effect and to explain the relation of the various results referred to above. This note summarizes the results of an investigation aimed at settling these questions. A calculation of the electromagnetic properties of neutrons has been carried out with special attention to the matter of interpretation of the terms obtained from field theory. A more detailed account will be submitted for publication shortly.

As in previous calculations, the meson-nucleon coupling term in the Hamiltonian density is taken to be

$$\mathcal{H}'=g\sqrt{2}(\psi_N{}^\dagger\gamma^5\psi_P\phi^*+\psi_P{}^\dagger\gamma^5\psi_N\phi),$$

where ϕ is the charged meson field and ψ_P, ψ_N are the nucleon fields. (The electromagnetic properties of neutrons are the same for both charged and symmetric meson theories.) With the usual Feynman-Dyson techniques it can be shown that as a consequence of this coupling, the (first-quantized) Dirac equation for a single neutron becomes

$$(m\beta+\boldsymbol{\alpha}\cdot\mathbf{p}+H_1)\psi=i\dot{\psi}, \tag{1}$$

where, dropping terms which contain higher order derivatives of the external potential A_μ or higher powers of g,

$$H_1=-\tfrac{1}{2}\mu\beta F_{\mu\nu}\sigma_{\mu\nu}-i\lambda\beta\Box^2A_\mu\gamma^\mu,$$

with

$$\begin{aligned}\mu&=-(eg^2/8\pi^2M)f_0(\eta),\quad \lambda=(eg^2/8\pi^2M^2)f_1(\eta),\\ f_0(\eta)&=1-\eta\log\eta^{\frac{1}{2}}+(\eta-2)\eta^{\frac{1}{2}}(4-\eta)^{-\frac{1}{2}}\cos^{-1}(\eta^{\frac{1}{2}}/2),\\ f_1(\eta)&=(13-4\eta)(12-3\eta)^{-1}+(\tfrac{1}{4}-\tfrac{2}{3}\eta)\log\eta\\ &\quad+\eta^{\frac{1}{2}}(4-\eta)^{-\frac{3}{2}}(-35/3+17\eta/2-4\eta^2/3)\cos^{-1}(\eta^{\frac{1}{2}}/2).\end{aligned} \tag{2}$$

M is the nucleon mass, and η is the square of the meson to nucleon mass ratio.

An unambiguous interpretation of the additional term H_1 can best be obtained by considering the two-component Pauli equation to which (1) reduces in the nonrelativistic limit. (The experiments always use slow neutrons.) This is

$$[M+p^2/2M-\mu\mathbf{H}\cdot\boldsymbol{\sigma}-(\mu/2M+\lambda)\,\mathrm{div}\mathbf{E}]\psi=i\dot{\psi}, \tag{3}$$

showing that while the first term of H_1 alone is responsible for the magnetic moment, both terms contribute to the interaction with an electric field—in fact, as shown below, the two contributions are of the same order of magnitude. (An additional Thomas type term has been omitted from (3) since it cannot contribute to the observed scattering effects.[1])

To express these results in conventional form, take the source of $\mathbf{E}$ to be an electron, so that $\mathrm{div}\mathbf{E}=-4\pi e\rho_0$, where ρ_0 is the electron particle density, $\int d\tau\rho_0=1$. Then the effective potential which the neutron sees is

$$V=(e^2g^2/2\pi M^2)(-\tfrac{1}{2}f_0+f_1).$$

The conventional "equivalent well depth," V_0, defined in terms of the classical electron radius $r_e=e^2/m$, is

$$V_0=\int d\tau V\Big/\frac{4\pi}{3}r_e{}^3=\frac{3}{2\pi}\frac{g^2}{4\pi}\left(\frac{m}{M}\right)^2\frac{m}{e^4}(-\tfrac{1}{2}f_0+f_1). \tag{4}$$

Using $\sqrt{\eta}=0.151$[12] for the meson-nucleon mass ratio gives $f_0=0.820$; $f_1=-0.131$; $(-\frac{1}{2}f_0+f_1)=-0.541$. Adjusting g so that the neutron magnetic moment μ is given correctly[13] by (2) leads to

$$g^2/4\pi\hbar c=7.33, \tag{5}$$

so that

$$V_0=-5.38\text{ kev}, \tag{6}$$

in fair agreement with the recent experimental figures of (5300 $\pm$1000)[3] and (4100$\pm$1000)[4] electron volts.

The relation of these results to those of other authors can be expressed quite simply. Case and Borowitz and Kohn neglect the contribution of the first term of H_1 to the electron-neutron interaction. This is equivalent to replacing $(-\frac{1}{2}f_0+f_1)$ in (4) by just f_1, which, with the choice (5) for the coupling constant, gives

$$V_{C;B,K}=-1.30\text{ kev}. \tag{7}$$

On the other hand, a phenomenological treatment like Foldy's, in which the magnitude of the electron-neutron interaction is deduced from the value of the magnetic moment only, corresponds to using just $\frac{1}{2}f_0$ in (4), leading to

$$V_F=-4.08\text{ kev}. \tag{8}$$

Finally, the calculations by Slotnick and Heitler, and Dancoff and Drell of the matrix element for neutron scattering in an electric field in nonrelativistic approximation give, with the present choice of coupling constant,

$$V_{S,H}=-4.99\text{ kev},\quad V_{D,D}=-6.10\text{ kev}. \tag{9}$$

These nearly agree with the value (6), thus supporting Foldy's suggestion that neglect of the first term in H_1 is largely responsible for the discrepancy between (7) and (9).

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[1] E. Fermi and L. Marshall, Phys. Rev. **72**, 1139 (1947).
[2] Havens, Rabi, and Rainwater, Phys. Rev. **72**, 634 (1947); Phys. Rev. **75**, 1295 (1949).
[3] Havens, Rainwater, and Rabi, Phys. Rev. **82**, 345 (1951).
[4] Hamermesh, Ringo, and Wattenberg, Phys. Rev. **85**, 482 (1952).
[5] M. Slotnick and W. Heitler, Phys. Rev. **75**, 1645 (1949).
[6] K. M. Case, Phys. Rev. **76**, 1 (1949).
[7] S. M. Dancoff and S. D. Drell, Phys. Rev. **76**, 205 (1949).
[8] S. Borowitz and W. Kohn, Phys. Rev. **76**, 818 (1949).
[9] L. L. Foldy, Phys. Rev. **83**, 688 (1951).
[10] G. Breit, Proc. Natl. Acad. Sci. **37**, 837 (1951).
[11] D. J. Hughes, Bull. Am. Phys. Soc. **27**, 31 (1952).
[12] Barkas, Smith, and Gardner, Phys. Rev. **82**, 102 (1951).
[13] Bloch, Nicodemus, and Staub, Phys. Rev. **74**, 1025 (1949).

Spin and Parity of the First (603-kev) Excited State of Te^{124}†

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SIXTY-DAY Sb^{124} and 4-day I^{124} decay into Te^{124} by β^- emission, and by β^+ emission and K-capture, respectively. Both decays are rather complex, especially the disintegration of Sb^{124}. However, it seems well established that the 603-kev gamma-ray, which is the most intense gamma-ray in both decays, is the transition from the first excited level to the even-even ground state of Te^{124}.

In the Sb^{124} decay the number of conversion electrons due to the 603-kev gamma-ray is 0.2 percent of the total number of beta-rays.[1,2] Assuming practically all the disintegrations of Sb^{124} to go through the 603-kev state, Langer, Moffat, and Price[2] identified this ratio of conversion electrons to beta-rays with the conversion coefficient of the 603-kev transition. They concluded that the 603-kev gamma-ray was electric dipole and therefore assigned spin one, odd parity, to the first excited state of Te^{124}, thus providing one of the few exceptions to Goldhaber and Sunyar's rule.[3]

TABLE I. Comparison of the theoretical conversion coefficients for the 603-kev gamma-ray in Te^{124} with the experimental value.

	Electric dipole	Magnetic dipole	Electric quadrupole	Experimental value
$10^3\times\alpha_K$	1.6	5.6	4.3	4.25 ± 0.3

New interest in the properties of the 603-kev level arose in connection with the observation of a large beta-gamma angular correlation in Sb^{124}.[4] The two most recent investigations[5] of this correlation are in good agreement with one another, both with respect to energy dependence and magnitude of the correlation. Both authors consider the assignments 1–1–0 and 3–2–0 the most probable ones.

We have determined the K-conversion coefficient of the 603-kev gamma-ray using the following method: A beta-ray source and a photoelectron source were prepared and their activities compared by counting the gamma-rays with a scintillation counter. The K-conversion and K-photoelectron lines due to the gamma-ray of interest were then measured in a beta-ray spectrometer. The efficiency of the standardized photoelectron arrangement was determined using gamma-rays with known conversion coefficients.

From the relative source strength, the converter efficiency, and the ratio of the areas under the conversion and photoelectron lines, one obtains the conversion coefficient N_e/N_γ without reference to the decay scheme.

Using this method we find for the K-conversion coefficient of the 603-kev gamma-ray in Te^{124} the value $\alpha_K=(4.25\pm0.3)\times10^{-3}$. In Table I this experimental value is compared with the theoretical conversion coefficients given by Rose, *et al.*[6]

The 603-kev gamma-ray is thus unambiguously characterized as electric quadrupole and the first (603-kev) excited state of Te^{124} as 2, even.

A comparison of the measured conversion coefficient with the above mentioned ratio of conversion electrons to beta-rays indicates that the 603-kev gamma-ray is only connected with 40–50 percent of the Sb^{124} disintegrations. The presently accepted decay scheme therefore will have to be revised as soon as better data regarding the relative intensities of the gamma-rays are available.

Concerning the ground state of Sb^{124}, one is inclined to accept the spin value 3, as suggested by the correlation experiments. The large ft-value (10.3) of the 2.29-Mev transition, the deviation from the allowed shape,[7] and the presence of two isomeric states indicate that, here too, further studies will be necessary.

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[1] Kern, Zaffarano, and Mitchell, Phys. Rev. **73**, 1142 (1948).
[2] Langer, Moffat, and Price, Phys. Rev. **79**, 808 (1950).
[3] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[4] S. L. Ridgway, Phys. Rev. **78**, 821 (1950).
[5] D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951); E. K. Darby, Can. J. Phys. **29**, 569 (1951).
[6] Rose, Goertzel, Spinrad, Harr, and Strong, Phys. Rev. **83**, 79 (1951).
[7] See reference 2 and also Nakamura, Umezawa, and Takebe, Phys. Rev. **83**, 1273 (1951); L. M. Langer, Phys. Rev. **84**, 1059 (1951).

The Emission of Deuterons from the Nucleus

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THREE experiments have been carried out which indicate that deuterons are emitted in photonuclear reactions very much more easily than would be expected from considerations of the statistical theory of nuclear reactions.[1] The reaction $S^{32}(\gamma, d)P^{30}$ may be readily detected at energies down to the photodeuteron threshold;[2,3] at only one Mev above this threshold the (γ, d) to (γ, p) cross section ratio has already reached the value 0.001. Byerly and Stephens[4] have observed that the ratio of deuterons to protons produced in copper irradiated with 24-Mev x-rays is 0.31. For 65-Mev bremsstrahlung this ratio has risen to 0.5 ± 0.15.[5] These ratios are several orders of magnitude larger than the statistical theory would predict.[4]

These facts indicate that there might be some mechanism by means of which low energy deuterons may penetrate potential barriers more easily than can a single particle such as a proton. Schiff[6] has suggested that deuterons may be more easily emitted from the nucleus if they are radially polarized, with the neutron component of the deuteron forming a "bridge" to the nucleus which causes a lowering of the potential barrier in the neighborhood of the outgoing deuteron.

It is the purpose of this note to suggest an experiment which might test this hypothesis. The first excited level of the deuteron is a singlet state about 64 kev above the dissociation energy.[7] If a deuteron in this first excited level were emitted from the nucleus, the neutron and proton resulting from its subsequent disintegration would travel in nearly the same direction, since only a small transverse momentum would be imparted by the break-up. The angle between the directions of motion of the neutron and proton would range up to 40° for deuteron kinetic energies of 4 Mev and greater. One might expect that deuterons in the excited and ground states would have emission probabilities in somewhat less than the ratio of the multiplicities of the levels (1:3), since there would be less residual energy of nuclear excitation following the emission of the singlet deuteron. However, even if the emission probability of a singlet deuteron were less than that for the independent emission of a proton and a neutron by a little more than an order of magnitude, such emission could readily be detected in a