estimates. On the basis of detailed calculations[3] one can assume that here M_1 cannot be greater than three. The value $ft = 1014 \pm 20$ sec has been obtained from very precise measurements[2].

From this we obtain that $A_1 \leq 3600$ sec. This upper limit practically coincides with the very lower limit which can be derived from the lifetime of the free neutron measured by Robson[4] with a quoted error of ±18%. Evidently, the errors of measurement specified by Robson[4] are to be regarded as probable errors in the statistical sense, but not as outer limits of the error of measurement. Apparently, the actual error of these measurments[4] is larger, inasmuch as M_1^2 for triton must be less than three.

Thus, it turns out that the lifetime of the free neutron, at the precision with which it is known at present, yields practically nothing for the determination of the constant of beta-decay.

A lower limit for A_1 can at present be obtained only from astrophysical data. Among all the possible models of the sun, the pure hydrogen-helium model gives the lowest rate of heat production. In addition to this, the total heat production is provided by the hydrogen cycle, whose rate is determined by the triplet beta-process $H^1+H^2=H^2+e^2+\nu$. This is the only beta-transition for which the matrix element can be calculated accurately from theory, which has been done by Frieman and Motz[5] and also by Salpeter[6]. The observed energy production of the sun is provided by the hydrogen cycle alone with $A_1 = 2060$ sec, which can be regarded as a lower limit of the quantity A_1.

Thus, the value of A_1 must lie inside the limits

$$3600 \geq A_1 \geq 2060 \text{ sec},$$

and the ratio of the constants $R = G_1^2/G_0^2 = A_0/A_1$ is between the limits $3.18 \geq R \geq 1.82$.

All theories that require equality of the constants[7,8] are thus completely eliminated.

It should be emphasized that the present discussion is not about statistical errors but about upper and lower limits. Hence, the half-life of the free neutron must lie within the limits $600 \geq t \geq 370$ sec.

We can likewise estimate limits within which the values of M_1^2 for the simplest beta-transitions must lie. By substituting the experimental ft values, the known values of M_0^2 and A_0, and the limiting values of A_1 into (1), we obtain

	ft	M_0^2		
$He^6 - Li^6$	815	0	$4,4 \geqslant M_1^2 \geqslant 2,5$	(6)
$H^3 - He^3$	1014	1	$3.0 \geqslant M_1^2 \geqslant 1.7$	(3)
$N^{13} - C^{13}$	4700	1	$0,22 \geqslant M_1^2 \geqslant 0.12$	(1/3)
$O^{15} - N^{15}$	3750	1	$0,41 \geqslant M_1^2 \geqslant 0.25$	(1/3)
$F^{17} - O^{17}$	2420	1	$1,0 \geqslant M_1^2 \geqslant 0,52$	(7/5)
$Be^7 - Li^7$	2547	1	$0,87 \geqslant M_1^2 \geqslant 0,49$	(5/3)
$Be^7 - Li^{7*}$	3590	0	$1,00 \geqslant M_1^2 \geqslant 0,56$	(4/3)

For comparison, the reduced values of M_1^2 for the nearest pure states are given in parentheses.

The cited limits do not include the experimental error, which, however, is small for these transitions: in all cases the error in ft does not exceed 3%.

For N^{13} and F^{17} our estimates of M_1^2 differ markedly from the estimates cited in the literature[9,10], which were derived from magnetic moments.

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164

Consideration of the Nuclear Quadrupole Moment in Electron Scattering

V. A. MIAMLIN
Moscow Engineering-Physical Institute

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AT the present time many experiments have been carried out on the elastic scattering of electrons by nuclei. In this connection, it is of interest to estimate the influence on this effect of the nuclear quadrupole moment. The latter is taken into account in the present paper with the aid of the Born approximation according to the following considerations.

It was shown by Vachaspati[1] that, if account is taken of the first and second Born approximation, the results are in satisfactory agreement with exact scattering theory. Since the quadrupole moment forms only a correction to the interaction, it is appropriate to consider it in first approximation only.

Baranger[2] has given scattering curves obtained form the exact theory and from the Born approximation. It is evident from a comparison of these that, although they coincide only at certain points, they are close together, in order of magnitude, over a wide range of angles.

The discussion just given justifies the calculation that has been carried out. The effective cross section of the elastic scattering of an electron by a nucleus is written

$$d\sigma = \frac{1}{4\pi^2}\frac{E^2}{h^4c^4}\,|V_{ab}|^2\,dO, \tag{1}$$

where E is the energy of the scattered electron, V_{ab} is the matrix element of interaction, which has the form

$$V = Ze\varphi + \frac{1}{6}\sum_{i,k=1}^{3}\frac{\partial^2\varphi}{\partial x_i\partial x_k}D_{ik}. \tag{2}$$

here φ is the scalar potential[3]

$$\varphi = -\frac{4\pi ec}{q^2}\,a'^*\,a^0 e^{i\mathbf{q}\cdot\mathbf{r}}, \quad \mathbf{q} = \frac{\mathbf{p}-\mathbf{p}_0}{h}; \tag{3}$$

a'^*, a^0 are spinors which characterize the state of the electron before and after the scattering, D_{ik} is the quadrupole moment tensor, given by[4]

$$D_{ik} = \frac{3eD_0}{2L(2L-1)}\left(\hat{I}_i\hat{I}_k + \hat{I}_k\hat{I}_i - \frac{2}{3}\delta_{ik}\hat{I}^2\right), \tag{4}$$

D_0 is the constant known as the nuclear quadrupole moment (dimensions = cm^2), I_i are the operators of the nuclear spin, L is the quantum number of the total nuclear spin.

If $qa \ll 1$, where a is the nuclear radius, then the scattering cross section, summed over the original states, has the form

$$d\sigma = \left[1 + \frac{q^4D_0^2}{30(2l+1)(2L-1)^2Z^2}\left(\frac{2}{3}L^2(2L+1)(L+1)^2 - 3\sum_0^L M^2\right)\right]d\sigma_M. \tag{5}$$

Here $d\sigma_M$ is the effective cross section of elastic electron scattering by a point nucleus, and is given by Mott's formula. The second term in the brackets gives the contribution brought about by the presence of the quadrupole moment. We estimate the order of magnitude of this contribution. For unit spin, $L = 1$,

$$d\sigma = \left[1 + \frac{q^4D_0^2}{18Z^2}\right]d\sigma_M. \tag{6}$$

If we select a scattering angle of 30°, and electronic energy 60 mev, then $q \sim 10^{12}$ cm^{-1}; in such a case the condition $qa \ll 1$ is satisfied. If D_0 is considered to be of the order of 10^{-24} cm^2, which is correct for heavy nuclei, then the correction amounts to

$$q^4D_0^2/18Z^2 = 1/18Z^2.$$

For the deuteron, $D_0 = 10^{-27}$ cm^2, and the second term is considerably smaller:

$$q^4D_0^2/18 = 1/(18\times10^6).$$

Since there are at present some indications of the possibility of the creation of polarized nuclei, we give results of the calculation of some effective cross sections in this case. We assume that the nucleus, which has a spin L, is completely polarized, and that the projection of its spin moment in the direction of the polarizing field is also equal to L. The effective differential scattering cross section of the electron, when the projection of the nuclear spin does not change its value (transition $L - L$), has the form

$$d\sigma_{L-L} = \left(1 - \frac{D_0q^2P_2(\cos\theta)}{6Z}\right)^2 d\sigma_M. \tag{7}$$

Here $P_2(\cos\theta)$ is the Legendre polynomial, θ is the angle between the direction of the spin vector of the nucleus and the vector $\mathbf{q}$. It is evident that the effect of the nuclear quadrupole moment is determined by the term $D_0q^2/6Z$. If again $q = 10^{12}$ cm^{-1}, $D_0 = 10^{-24}$ cm^2, then we have $D_0q^2/6Z = 1/6Z$. For deuterons in this case, $D_0q^2/6 = 1/(6\times10^3)$.

To take into account imcomplete polarization of the nucleus, we introduce formulas which correspond to the following possible transitions. Let the spin L have a projection M in the direction of the field. The effective scattering cross section of the electron for the case of the same final state of nuclear spin (transition $M - M$) is given by

$$d\sigma_{MM} = \left\{1 - \frac{[3M^2 - L(L+1)]\,q^2D_0}{6L(2L-1)Z}\right. \tag{8}$$

$$\times P_2(\cos\theta)\Big\}^2 d\sigma_M.$$

For the effective cross section, averaged over all directions of the vector $\mathbf{q}$, we have

$$d\sigma_{MM} = \left\{1 + \frac{[3M^2 - L(L+1)]^2}{180L^2(2L-1)^2Z^2} q^4D_0^2\right\} d\sigma_M. \quad (9)$$

For the transition $(M, M+1)$ (initial spin state of the nucleus M, final, $M+1$) we have

$$d\sigma_{M,M+1} = \frac{q^4D_0^2(2M+1)^2(L+M+1)(L-M)}{16L^2(2L-1)^2Z^2} \quad (10)$$
$$- d\sigma_M(1-\cos^2\theta)\cos^2\theta.$$

The effective cross section, averaged over all directions of the vector $\mathbf{q}$, is given in the form

$$d\sigma_{M,M+1} = \frac{q^4D_0^2(2M+1)^2(L+M+1)(L-M)}{120L^2(2L-1)^2Z^2} d\sigma_M. \quad (11)$$

Finally, transitions $(M, M+2)$ are possible:

$$d\sigma_{M,M+2} = \frac{q^4D_0^2 d\sigma_M}{64L^2(2L-1)^2Z^2}(L+M+2) \quad (12)$$
$$\times (L-M-1)(L+M+1)(L-M)(1-\cos^2\theta)^2.$$

The expression, averaged over the directions $\mathbf{q}$, has the following form:

$$d\sigma_{M,M+2} = \frac{q^4D_0^2(L+M+2)}{120L^2(2L-1)^2Z^2} \quad (13)$$
$$\times (L-M-1)(L+M+1)(L-M)\, d\sigma_M.$$

In this case, when there is a certain distribution of the directions of the nuclear spin relative to the field, the effective differential cross section, averaged over the initial states and summed over the final, will have the form

$$d\sigma = \frac{1}{(2L+1)}\sum_M a_L(M)[d\sigma_{MM} + d\sigma_{M,M+1} + d\sigma_{M,M+2}],$$

where $a_L(M)$ is the probability of finding the nuclear spin L with projection M before scattering, $d\sigma_{MM}$, $d\sigma_{M,M+1}$, $d\sigma_{M,M+2}$ are given by the corresponding formulas (9), (11) and (13). The transitions $(M, M-2)$ $(M, M-1)$ are not considered here, since they correspond to inelastic scattering in the case of polarized nuclei.

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143

Nuclear Capture of a Negative Heavy Meson

E. A. Zamchalova, V. I. Karpova and M. I. Tret'iakova
The P. N. Lebedev Institute of Physics, Academy of Sciences, USSR
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There has been found in type R photographic plates with an emulsion thickness of 300 μ exposed in the stratosphere, an event, the microphotograph of which is represented in the drawing. The visible track of particle 1 consists of 495 μ. From the change in ionization and scattering along the track, it is obvious that particle 1 stopped at point A. From this point there start two tracks: one gray and one very short black track ($\sim 1\,\mu$). The presence of the short black track is evidence for nuclear capture of the first particle, which, therefore, can be either a negative π meson or a heavier negative particle.

Particle 2 leaves the emulsion after traveling 674 μ. Its ionization is 3.2 ± 0.3 times minimum. From this it follows that particle 1 is heavier than a π meson since, even if it is assumed that particle 2 is a proton, then its energy must be ~ 200 mev. A proton of such energy cannot be formed upon nuclear capture of a π meson.

A direct determination of the mass of the secondary particle from its ionization and multiple scattering leads to a value of $(350 \pm 200)m_e$. It is more realistic to consider this particle as a π meson. Then its energy is ~ 30 mev.

Comparison of the multiple scattering and gap count along the track of the first particle with the range indicates that its mass lies between that of the π meson and the proton.

All this is interpretable as the nuclear capture of a stopped negative heavy meson. Rather striking is the exceptionally small energy release and the production of a π meson with energy ~ 30 mev, the same as upon decay of a Λ^0 particle.

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181