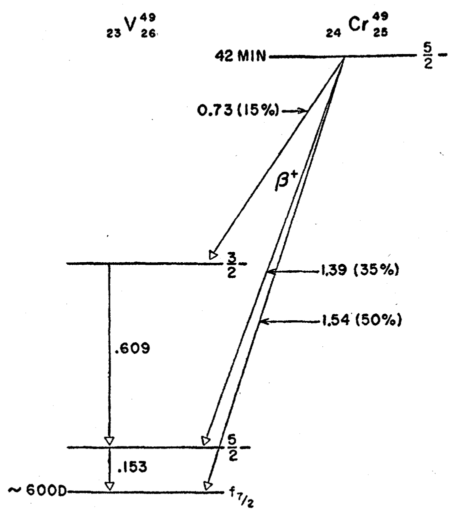

FIG. 1. Decay scheme for Cr^{49} (energies in Mev).

netic dipole gamma-rays. The lack of an observable crossover transition to the ground state agrees with this scheme. This assignment of spins and parities may well result from different coupling of the $(f_{7/2})^3$ proton configuration.

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[1] O'Connor, Pool, and Kurbatov, Phys. Rev. **62**, 413 (1942).
[2] Huber, Lienhard, and Wäffler, Helv. Phys. Acta **17**, 195 (1944).
[3] M. Mayer, Phys. Rev. **78**, 16 (1950).

The Scattering of Slow Neutrons by *Ortho*- and *Para*-Hydrogen

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THE triplet and singlet scattering amplitudes of the neutron-proton interaction may be determined by measurement of the slow neutron cross sections of *ortho*- and *para*-hydrogen.[1] These cross sections, previously measured by Sutton *et al.*[2] and others,[3,4] have been remeasured at the Cavendish Laboratory.

The attenuation of a beam of slow neutrons passing through a specimen of hydrogen gas was measured by moving the specimen in and out of the beam. The specimen, 80 cm long was maintained at a temperature of 20.4°K. Neutrons with various energies between 0.002 and 0.014 ev were selected with the slow neutron velocity selector.

Measurements were made first with specimens of normal hydrogen, 75 percent *ortho* and 25 percent *para*, and secondly with specimens of 99.8 percent *para*-hydrogen, the equilibrium mixture at 20.4°K. Considerable attention was paid to the determination, via thermal conductivity analysis, of the *ortho-para* composition of the specimens.

Absorption and *para*-hydrogen scattering contribute about 3 percent to the normal hydrogen cross section; hence relatively approximate values of these cross sections are sufficient to determine the *ortho*-hydrogen cross section. In the almost pure *para*-hydrogen, however, absorption accounts for about 30 percent of the total so that the value chosen for the absorption cross section affects considerably the value obtained for the *para* cross section.

The elastic scattering cross section of *para*-hydrogen is proportional to f^2 where f, the coherent scattering amplitude, is given by

$$f=2(\tfrac{3}{4}a_t+\tfrac{1}{4}a_s).$$

a_t and a_s are the triplet and singlet scattering amplitudes respectively.

If the absorption cross section σ_{abs}, at 2200 m/sec, is taken[5] to be $\sigma_{\text{abs}}=(0.330\pm0.007)\times10^{-24}$ cm², our results give a value of the coherent scattering amplitude:

$$f=-(3.80\pm0.05)\times10^{-13}\text{ cm}.$$

The quoted error of 1.2 percent is the combination of 0.5 percent from the uncertainty in σ_{abs} and 1.1 percent from our experimental measurements. Our value of f may be compared with $f=-(3.90\pm0.12)\times10^{-13}$ cm obtained by Sutton *et al.* in a *para*-hydrogen experiment, and with the value $f=-(3.78\pm0.02)\times10^{-13}$ cm given by Burgy, Ringo, and Hughes[6] from liquid mirror experiments.

The free proton cross section,

$$\sigma_f=4\pi(\tfrac{3}{4}a_t^2+\tfrac{1}{4}a_s^2),$$

calculated from our results for the *ortho*-hydrogen cross section, is

$$\sigma_f=(20.41\pm0.14)\times10^{-24}\text{ cm}^2,$$

which may be compared with the value $\sigma_f=(20.36\pm0.10)\times10^{-24}$ cm² obtained by Melkonian.[7]

A more detailed account of the experiment will be published elsewhere.

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[1] J. Schwinger and E. Teller, Phys. Rev. **52**, 286 (1937).
[2] Sutton, Hall, Anderson, Bridge, DeWire, Lavatelli, Long, Snyder, and Williams, Phys. Rev. **72**, 1147 (1947).
[3] Halpern, Estermann, Simpson, and Stern, Phys. Rev. **52**, 142 (1937).
[4] Brickwedde, Dunning, Hoge, and Manley, Phys. Rev. **54**, 266 (1938).
[5] *Neutron Cross Sections*, U. S. Atomic Energy Commission Report AECU 2040 (Technical Services Division, Department of Commerce, Washington, D. C., 1952).
[6] Burgy, Ringo, and Hughes, Phys. Rev. **84**, 1160 (1951).
[7] E. Melkonian, Phys. Rev. **76**, 1744 (1949).

Noncentral Force Matrix Elements for the Nuclear d^2 Configuration

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A STUDY by the writer of the tensor operator algebra of Racah[1] has led to the derivation of expressions for the matrix elements, between two-nucleon states, of the purely orbital operators of the two-body tensor and spin orbit interaction operators:

$$\text{Tensor:}\quad J_t(r)T_{12}\{(\boldsymbol{\sigma}_1\cdot\mathbf{r})(\boldsymbol{\sigma}_2\cdot\mathbf{r})/r^2-\tfrac{1}{3}(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\}.$$
$$\text{Spin-orbit:}\quad J_s(r)T_{12}\{(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)\cdot(\mathbf{r}\times\mathbf{p})\}.$$

The Slater method of expanding the distance dependence has been used, and the results obtained involve linear combinations of radial integrals in which no particular wave functions or interactions are specified.

In their most general form these results are cumbersome because the coefficients of the radial integrals are Wigner coefficients and the W functions of Racah. Considerable reduction, however, is possible under a restriction to equivalent nucleons or direct and exchange matrix elements. It is hoped that a more detailed report on these formulas will appear elsewhere.

The noncentral force matrix elements for the $(3d)^2$ configuration[2] have been calculated using harmonic oscillator radial wave functions. Results for diagonal and nondiagonal elements in states of lowest total angular momentum J, using a charge symmetric operator, $T_{12}=(\boldsymbol{\tau}_1\cdot\boldsymbol{\tau}_2)$, are expressed in Table I in terms of radial integrals defined later.

TABLE I. Noncentral force matrix elements for $(3d)^2$ configuration with harmonic oscillator wave functions and symmetric charge operator.

	Tensor force				Spin-orbit force			
$\langle^{2T+1,2S+1}L_J\|^{2T+1,2S+1}L_J'\rangle$	I_1	I_2	I_3	I_4	I_1	I_2	I_3	I_4
$\langle^{33}P_0\|^{33}P_0\rangle$	$\frac{7}{6}$	$-\frac{5}{3}$	$+\frac{7}{6}$		-7	$+10$	-7	
$7^{-\frac{1}{2}}\langle^{13}S_1\|^{13}D_1\rangle$	$-\frac{31}{60}$	$+\frac{19}{12}$	$-\frac{17}{12}$	$+\frac{3}{4}$				
$\langle^{13}D_1\|^{13}D_1\rangle$	$\frac{14}{15}$	$-\frac{65}{84}$	$-\frac{7}{6}$	$+\frac{3}{4}$		$\frac{51}{2}$	-21	$\frac{27}{2}$
$7^{\frac{1}{2}}2^{-\frac{1}{2}}\langle^{33}P_2\|^{33}F_2\rangle$		1	$-\frac{7}{5}$					
$\langle^{33}F_2\|^{33}F_2\rangle$	$\frac{1}{5}$		$-\frac{1}{5}$		$-\frac{2}{3}$		$-\frac{22}{3}$	
$3^{-\frac{1}{2}}\langle^{13}D_3\|^{13}G_3\rangle$	$-\frac{3}{10}$	$+\frac{33}{98}$	$-\frac{1}{2}$	$+\frac{9}{14}$				
$(28)^{-1}\langle^{13}G_3\|^{13}G_3\rangle$		$+\frac{55}{7}$		$+15$		210		630

1. The corresponding matrix elements for the remaining allowed values of J are given by the relations:

Tensor force	Spin orbit force
$\langle^{33}P_0\rangle=-2\langle^{33}P_1\rangle=10\langle^{33}P_2\rangle$	$\langle^{33}P_0\rangle=2\langle^{33}P_1\rangle=-2\langle^{33}P_2\rangle$
$2\langle^{13}D_1\rangle=-2\langle^{13}D_2\rangle=7\langle^{13}D_3\rangle$	$2\langle^{13}D_1\rangle=6\langle^{13}D_2\rangle=-3\langle^{13}D_3\rangle$
$5\langle^{33}F_2\rangle=-4\langle^{33}F_3\rangle=12\langle^{33}F_4\rangle$	$3\langle^{33}F_2\rangle=12\langle^{33}F_3\rangle=-4\langle^{33}F_4\rangle$
$28\langle^{13}G_3\rangle=-20\langle^{13}G_4\rangle=55\langle^{13}G_5\rangle$	$4\langle^{13}G_3\rangle=20\langle^{13}G_4\rangle=-5\langle^{13}G_5\rangle.$

2. Results for a neutral charge operator $T_{12}=1$ may be derived from the above by multiplying matrix elements involving singlet charge states by -3^{-1}, and leaving triplet charge state elements unaltered.

3. The radial integrals $I_l(a,b)$ are functions of the force range a and wave function parameter b, and are defined as follows:

$$I_l(a,b)=\int_0^\infty R_l^2(r,b)V(r,a)dr.$$

The single particle wave functions,

$$R_l(r,b)=N_l\exp[-(r/2b)^2]r^{l+1},$$

are subject to the normalizing condition

$$\int_0^\infty R_l^2(r,b)dr=1,$$

which yields

$$N_l^2=2[(2l+1)!!b^{2l+3}(2\pi)^{\frac{1}{2}}]^{-1}.$$

4. For a Yukawa type distance dependence, i.e., $V(r,a)=Be^{-r/a}(r/a)^{-1}$, the integrals $I_l(ab)$ may be calculated either by the method of Talmi[3] or from the Hh functions tabulated in the British Association Mathematical Tables, Vol. I (1931), by using the relation

$$I_l(a,b)=2^{l+1}l!\exp(b^2/2a^2)(a^2/2\pi b^2)^{\frac{1}{2}}Hh_{2l+1}(b/a).$$

Values of the $I_l(a,b)$ for the distance dependence suggested by Case and Pais,

$$V(r,a)=\frac{-Ba^2}{r}\frac{d}{dr}(e^{-r/a}(r/a)^{-1}),$$

may be obtained from those evaluated for Yukawa by using a relation established by Elliott:[4] Replace each function $Hh_{2l+1}(b/a)$ by $(a^2/b^2)\{(2l)^{-1}Hh_{2l-1}(b/a)-Hh_{2l+1}(b/a)\}$.

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[1] G. Racah, Phys. Rev. **62**, 438 (1942).

[2] An account of an application of these results to early d shell nuclei is given in a thesis for the degree of PhD (London) which the author proposes to submit shortly.

[3] I. Talmi, Helv. Phys. Acta **25**, 185 (1952).

[4] J. P. Elliott, Ph.D. thesis, London, 1952 (unpublished).

Observation of V^0 Particles Produced at the Cosmotron*

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TWO definite examples of V^0 particles similar to those found in cosmic rays by many workers[1] have been observed in a cloud chamber exposed to a neutron beam from the Cosmotron. These two cases, in addition to several other less definite ones, were found in a total of about 4000 photographs scanned up to date. Further work is in progress.

The events were observed when the machine was operating with a circulating beam of 10^8 to 10^9 protons per pulse, reaching an energy of about 2.2 Bev. The protons were allowed to strike carbon targets 1.25 in. and 2.5 in. thick. Neutrons emerged through a 1-in.×2-in. hole in the shielding wall, located at 0° to the proton beam direction. The number of the neutrons can only be estimated very roughly, and their energy distribution is not known at the present time except that the maximum energy is 2.2 Bev. The neutron beam passed through a permanent magnet which deflected charged particles away from the cloud chamber, and then through 1.5 in. or 3 in. of lead into the cloud chamber. A diffusion cloud chamber was used, filled with hydrogen at 18 atmospheres and methyl alcohol vapor. A pulsed magnetic field of 11 000 gauss was applied.

The V^0 particles show the characteristic inverted V-shaped track originating in the cloud-chamber gas. Their identification follows from the usual arguments.[1] In this case the identification is especially certain because neutron-proton collision processes in hydrogen can only result in events with an odd number of prongs rather than 2-prong events such as V particles. The amount of alcohol present is less than that used in expansion cloud chambers, very few stars produced in the alcohol were seen, and it is very unlikely that "alcohol stars" could have the appearance of V particles.

The photographs are shown in Figs. 1 (event A) and 2 (event B).

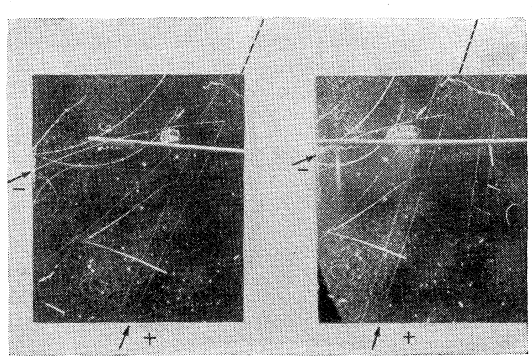

FIG. 1. Stereoscopic photograph of V^0 decay "A." Its apex is just above the horizontal bar across the picture, which is a sweeping field electrode suspended above the sensitive layer of the cloud chamber. The tracks pass underneath this electrode, not through it. The dashed line at the top of the picture points toward the part of the lead shield struck by the neutron beam. Information concerning the V^0 is given in Table I.