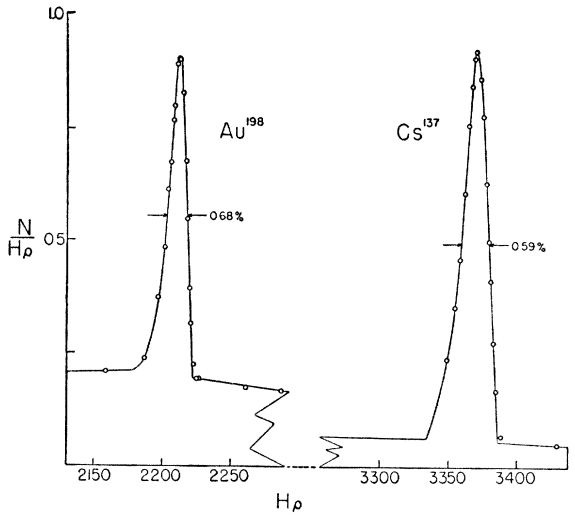

FIG. 1. Internal conversion electrons from Au^{198} and Cs^{137}.

from the extrapolated high energy edge, a small correction was made for the finite resolution by using for ρ, one-half the minimum distance between source and detector slit. In all cases the magnetic field was measured immediately below and above each line by means of a flip coil and ballistic galvanometer as well as by balancing the voltage picked up by a continuously rotating search coil against that picked up in a standard Helmholtz field. The interpolation of points actually on the lines was made in terms of the energizing current of the magnet which was stabilized electronically to about 0.01 percent and measured by means of a type K potentiometer and standard resistance. In any one run, the magnet current was varied only in one direction. On the basis that the electrons from the Au^{198} gamma-ray correspond to an extrapolated high energy edge of $H\rho=2219.6$ gauss-cm, the electrons following the Cs^{137} disintegration are observed at $H\rho=3381$ gauss-cm. The corresponding kinetic energy of the electrons is 0.6239 Mev and the energy of the gamma-radiation is 0.6614 $\pm$0.0007 Mev.

Additional runs were made on the Cs^{137} conversion lines with the same source but with the detector slit reduced from 0.40 cm to 0.20 cm. The profiles of the lines are shown in Fig. 2. Even with

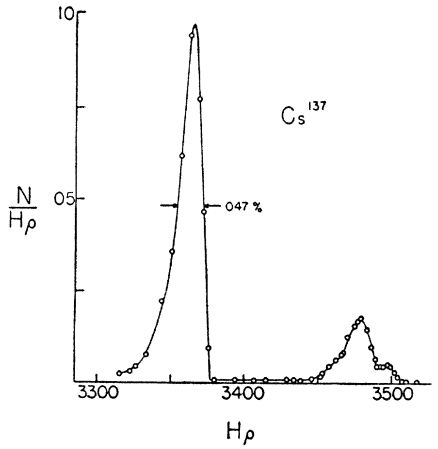

FIG. 2. Internal conversion electrons from Cs^{137}.

the extremely high resolution employed, the broadening of the lines because of backing and source thickness is such that the individual L and M lines are not sufficiently separated to be useful for additional calibration purposes. The calibration in terms of the K line is summarized in Table I.

TABLE I. Gamma-ray energies.

	H gauss-cm	Electron energy Mev	K binding Mev	Gamma-energy Mev
Au^{198}	2219.6	0.3280	0.0832	0.4112
Cs^{137}	3381	0.6239	0.0375	0.6614 $\pm$0.0007

* This work was assisted by a grant from the Frederick Gardner Cottrell fund of the Research Corporation and by the Joint Program of ONR and AEC.

[1] DuMond, Lind, and Watson, Phys. Rev. **73**, 1392 (1948).
[2] L. M. Langer and C. S. Cook, Rev. Sci. Inst. **19**, 257 (1948).

On the $\gamma-\gamma$-Angular Correlation in Pd^{106}

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WE denote the successive γ-emissions and nuclear spins in Pd^{106} by

$$\xrightarrow{\gamma_2} \quad J_1 \xrightarrow{\gamma_1} J_2 \xrightarrow{} 0$$

the ground state of Pd^{106}, (even-even), being taken to have zero spin. The measured angular correlation[1] of γ_1 and γ_2 is given by

$$W(\theta)=1-1.66\cos^2\theta+2.16\cos^4\theta.$$

As Ling and Falkoff[2] have shown, this cannot be explained theoretically on the assumption that γ_2 is pure quadrupole ($J_2=2$) and γ_1 pure quadrupole ($J_1=0$) or mixed dipole-quadrupole ($J_1=1, 2, 3$). Also γ_2 cannot be dipole ($J_2=1$) or there would be no $\cos^4\theta$-term in $W(\theta)$.

The author[3] has calculated the correlation to be expected on the assumption that γ_2 is pure octupole ($J_2=3$) and γ_1 pure octupole ($J_1=0$), pure quadrupole ($J_1=1$) and mixed dipole-quadrupole ($J_1=2, 3$). Using the obvious notation WJ_1J_20 we obtain:[4]

$$W_{030}=1+111\cos^2\theta-305\cos^4\theta+225\cos^6\theta,$$
$$W_{130}=1+(47/54)\cos^2\theta-(15/27)\cos^4\theta,$$
$$W_{230}=2|\alpha|^2(23-9\cos^2\theta)+5|\beta|^2(8-3\cos^2\theta+5\cos^4\theta)+6(30)^{\frac{1}{2}}R(1-3\cos^2\theta),$$
$$W_{330}=16|\alpha|^2(13+9\cos^2\theta)+(48/9)|\beta|^2(51+3\cos^2\theta-20\cos^4\theta)+96R(1-3\cos^2\theta).$$

None of these functions fits the facts; for instance, none of them has a $\cos^4\theta$-term whose coefficient is or can be made positive and of order of twice the constant term.

Higher values of J_1 ($J_1=4, 5, 6$, with $J_2=2, 3$) were also tried, with the same result.

It is possible however to account for $W(\theta)$ in a very simple manner if we are willing to suppose that one of the excited levels of Pd^{106} consists in fact of two levels with different spins but sufficiently close together in energy not to have been resolved. $W(\theta)$ is then a superposition of two correlation functions sharing a common value of J_1 (or J_2).

One at least of these two functions must have a $\cos^4\theta$-term whose coefficient is positive and twice the constant term. Of all the functions with $J_2=2, 3$, and $J_1=0$ to 4, only W_{020} satisfies this condition. The second function cannot then have $J_1=0$ also, since this would forbid completely the observed crossover transition γ_3; we are left with functions of the form WJ_120, the upper excited level being the one that is in fact two levels, with spins $J_1=0$ and $J_1'=1, 2, 3$, respectively (see Fig. 1).

Assuming for a start that γ_1' is a pure dipole, and taking $J_1'=1$, we have

$$W(\theta)=AW_{020}+BW_{120}$$
$$=A5/4(1-3\cos^2\theta+4\cos^4\theta)+B3/8(3-\cos^2\theta),$$

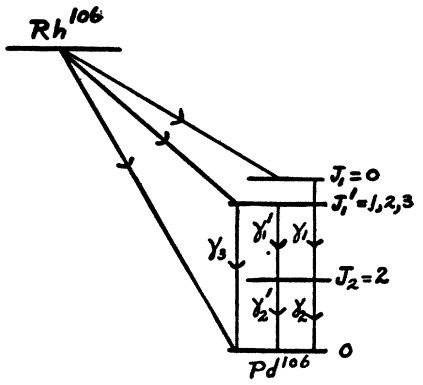

FIG. 1. Proposed level scheme of Pd^{106}.

where B/A = intensity of γ_1'/intensity of γ_1, and the constants 5/4, 3/8 are for normalization of the respective correlation functions.

If we choose B/A to give correctly the observed coefficient of $\cos^2\theta$, we obtain $B/A=1.12$, and $W(\theta)=1-1.66\cos^2\theta+2.0\cos^4\theta$. Similarly $J_1'=2$ yields, for $B/A=0.91$, $W(\theta)=1-1.66+2.4\cos^4\theta$, while $J_1'=3$ yields, for $B/A=1.04$, $W(\theta)=1-1.66\cos^2\theta+2.15\cos^4\theta$.

Thus all three assumptions $J_1'=1, 2, 3$ enable the observed $W(\theta)$ to be accounted for, with γ_1' a pure dipole. *A fortiori*, the same holds if γ_1' is a dipole-quadrupole mixture; i.e., if we are free to adjust the parameters $|\alpha|^2$, etc., as well as B/A.

Higher values of J_1' may also be consistent with the observed $W(\theta)$, though these are less likely for other reasons.[5]

Parities of the levels.—If, as Peacock's considerations of β-decay[5] suggest, the upper excited levels have the same parity as the ground state, then the measured correlation between direction of emission and polarization of γ_1 and γ_2[6] requires that the intermediate level have the same parity as the others. On Hamilton's theory[7] the proposed scheme of Fig. 1 then gives the same theoretical curve as that calculated in reference 6 for two successive electric quadrupoles; opposite parity would give the reciprocal of this curve.

The scheme of Fig. 1 is, of course, purely tentative unless the doubling of the upper excited level can be confirmed by further experiments.

[1] E. L. Brady and M. Deutsch, Phys. Rev. **72**, 870 (1947); **74**, 1541 (1948).
[2] D. S. Ling and D. L. Falkoff, Phys. Rev. **76**, 431 (1949); **76**, 1639 (1949).
[3] J. A. Spiers (to be published).
[4] For the meaning of $|\alpha|^2$, $|\beta|^2$ and R see reference 2.
[5] W. C. Peacock, Phys. Rev. **72**, 1049 (1947).
[6] M. Deutsch and F. Metzger, Phys. Rev. **74**, 1542 (1948).
[7] D. R. Hamilton, Phys. Rev. **74**, 782 (1948).

Neutron Production in Various Substances by 50-Mev X-Rays

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MEASUREMENTS of rates of production of neutrons by 22-Mev x-rays in various materials have been reported by Price and Kerst.[1] The present measurements were made by an essentially identical technique. Fast photo-neutrons emitted at 90° were detected after moderation by the 44-sec. Rh^{103} activity. The moderator, a 6-in. cube of paraffin, was surrounded on all sides by a cadmium-lined paraffin shield 8 in. thick; a 3-in. cadmium-lined hole in the shield allowed neutrons from a sample placed in the x-ray beam from a 50-Mev biased betatron[2] to enter the detector. An aperture in a lead shielding wall defined a beam 8.3 cm in diameter at the sample position, 3 m from the target. As the detector was 1 m from the beam axis no photo-neutrons were generated in the detector or shield and it was found unnecessary to enclose the entire betatron in a neutron shield. Whenever possible samples were shaped so as to utilize the entire beam. Liquid samples were held in a 350-cm^3 aluminum container. Samples were exposed for 3 min. and counted from 44 to 220 sec after irradiation. An R Thimble in a 1/8-in. lead intensifier on the beam axis at 4.69 m was used in conjunction with a monitoring rhodium foil placed close to the betatron to determine the exposure, transmission and absorption of radiation by the sample. All readings were corrected for background measured without sample.

Absolute neutron yields were computed from these data after a calibration exposure with a 200-mC Ra-α-Be source at the sample position. Computation of k, the neutron yield per mole per unit beam intensity ($1r$ measured in 1/8-in. of lead) included allowance for attenuation of the radiation in the thick samples. Neutron yields are given in Fig. 1. For 50-Mev x-rays they can be fitted closely by the relation $k=1860Z^2$ neutrons per mole r.

Several points shown in Fig. 1 taken at 22 Mev to check the relation $k=50Z^3$ found by Price and Kerst,[1] can be fitted by $k=(25\pm5)Z^3$. The coefficient in the Illinois data is reduced from 50 to 28 when corrected for the ratio, 1.75, on intensification by lead and Bakelite.[3] The agreement is good.

Relative yields of (γ, n) reactions at 50 Mev, determined by Perlman and Friedlander,[4] show the same trend as the present data although individual yields vary more widely from the Z^2 relation.

It is noteworthy that for lead the yields at 50 and at 22 Mev are equal; it is to be presumed from this that the neutron-generating processes in lead are induced mainly by quanta below 22 Mev. Values of k for copper were determined at a series of x-ray energies.

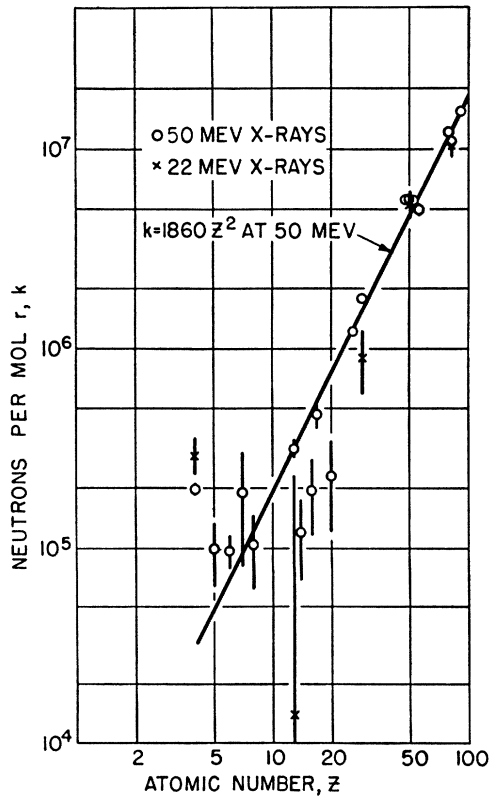

FIG. 1. Total neutron yield per mole of sample element, calculated from the yield at 90° to the x-ray beam, per unit x-ray intensity.