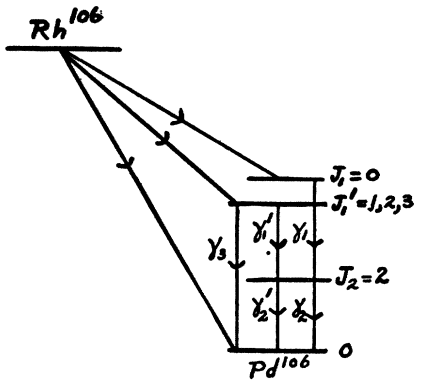

FIG. 1. Proposed level scheme of Pd^{106}.

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.

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[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.

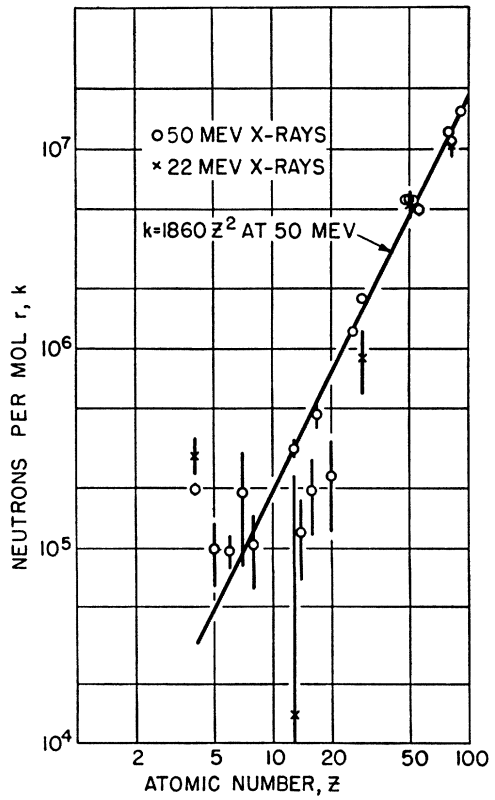

FIG. 1. Total neutron yield per mole of sample element, calculated from the yield at 90° to the x-ray beam, per unit x-ray intensity.

The resulting yield curve resembles the $Cu^{63}(\gamma, n)$ yield curve[5] up to the latter's maximum at 25 Mev, beyond which the former continues to rise to a maximum at 40 Mev. Above 40 Mev, k slowly decreases in the same manner as the (γ, n) yield, indicating that relatively few neutrons are generated by quanta above this energy.

The k-values in Fig. 1 are related to cross sections for photoneutron production, σ_n, by the formula

$$k = N \int_0^{50} \sigma_n(E)\phi(E)dE$$

where N is Avogadro's number and ϕ is the flux of quanta per r. This has been calculated[5] for 50-Mev x-rays to be $3.5\times10^7/E$. The carbon data give $\int \sigma_n dE = 1.4\pm0.3\times10^{-25}$ cm² Mev. As this is the value obtained by Lawson and Perlman for the (γ, n) cross section,[6] either no neutron-producing multiple disintegrations occur in carbon or this value of $\phi(E)$ is low.[7]

Measurements of the total cross section of graphite for neutrons detected by the rhodium-moderator combination employed indicate that the average energy of neutrons from carbon is nearly that of Ra-α-Be neutrons, and is appreciably higher than that of neutrons from lead.

[1] G. A. Price and D. W. Kerst, Phys. Rev. **76**, 182A (1949).
[2] W. F. Westendorp, Phys. Rev. **71**, 271 (1947).
[3] Quastler *et al.*, Am. J. Roentgenology Rad. Therapy **61**, 591 (1949).
[4] M. L. Perlman and G. Friedlander, Phys. Rev. **74**, 442 (1948).
[5] G. C. Baldwin and G. S. Klaiber, Phys. Rev. **73**, 1156 (1948).
[6] J. L. Lawson and M. L. Perlman, Phys. Rev. **74**, 1190 (1948).
[7] Recent measurements in this laboratory indicate that this value of ϕ may be low by a factor of three. (E. R. Gaerttner and M. L. Yeater, private communication.)

Neutron Binding Energies in Pb^{207}, Pb^{208} and in Bi^{210}

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THE energies of the gamma-rays arising from neutron capture in Pb^{206}, Pb^{207} and Bi^{209} have been measured with the aid of a coincidence pair spectrometer. The technique of energy measurement has been described briefly in an earlier letter.[1] The coincidence spectra obtained by using lead oxide in an aluminum container and pure metallic lead are shown in Fig. 1. The capturing isotope is indicated for each radiation. The energy of the radiation is obtained by adding about 25 kev to the energy found by extrapolating the high energy slope to zero. With metallic bismuth a single weak but unusually broad coincidence peak was found. The energies are: (a) from lead, 6.68±0.04 Mev and 7.37±0.02 Mev; (b) from bismuth, 4.170±0.015 Mev.

Since the energy set free in the capture of a neutron by a nucleus with even charge and even mass number is always less than that produced by an adjacent even-odd type, the binding energy released by capture in Pb^{206} will be less than that released by capture in Pb^{207}. This suggests that the 6.68 Mev γ-ray arises from capture in Pb^{206}. Further, its energy is in good agreement with the threshold energy of the (γ, n) reaction,[2] *viz.*, 6.85±0.20 Mev. The 7.37 Mev radiation therefore must originate in capture in Pb^{207}. Since the first excited state of Pb^{208} lies at the unusually high level of 2.62 Mev, the 7.37 Mev radiation must be due to the direct transition to the ground state and its energy is equal to the binding energy.

As pointed out by K. Way,[3] the binding energy of a neutron in Pb^{209} is probably much lower than in the other isotopes of lead. A radiation with this energy could not be detected by the present method because of the low neutron capture cross section of Pb^{208} and because of the reduced sensitivity of the spectrometer at low energies. The neutron binding energy of Pb^{209} may be deduced from the present results, the energy of the decay of Pb^{209}, and the energy set free in the disintegrations by which RaD (Pb^{210}) passes to Pb^{206}. We obtain 4.81±0.08 Mev for the binding energy of the neutron in Pb^{210} and 4.35±0.12 Mev for that in Pb^{209}. The latter figure and the present results are in agreement with those obtained recently in a study of the (d, p) reactions in lead and bismuth.[4]

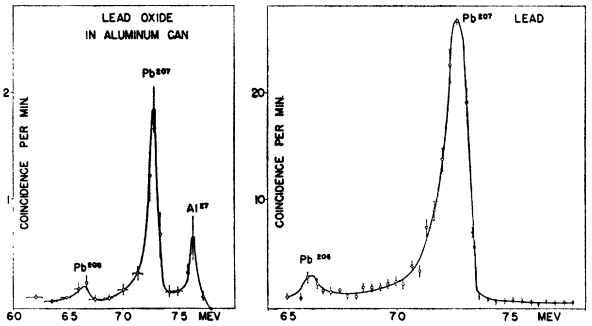

FIG. 1. Pair spectrogram of the neutron capture γ-rays produced by lead oxide and lead.

It is very surprising that no radiations of lower energy were observed in the spectrum of lead. The simplicity of the spectrum obtained is similar to that observed from the lightest elements; for example, from beryllium and carbon. No radiation was found at 4.75 Mev, which is the energy of the radiation to be expected from a transition to the 2.62 Mev level in Pb^{208}. Possibly such a radiation would be too weak to be detected unless the direct transition to the ground state was forbidden by selection rules. In the case of Pb^{208}, and possibly also of Pb^{207}, we conclude that the direct radiative transition to the ground state is allowed and that the level density in these isotopes is much less than at corresponding excitations in other heavy elements which we have studied, such as Au^{198}.

The ratio of the thermal neutron capture cross section of Pb^{207} to that of Pb^{206} can be estimated if it is assumed that only transitions to the ground state occur in significant amount. After correcting for the energy sensitivity of the pair spectrometer, we find this ratio to be about 7.

The unusual width of the bismuth peak may be due to the transitions to the low energy levels which are known to exist in Bi^{210} (RaE).

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[2] Hanson, Duffield, Knight, Diven, and Palevsky, Phys. Rev. **76**, 578 (1949).
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[4] J. A. Harvey, Bull. Am. Phys. Soc. **25**, No. 1, 41 (1950).

The Possible Existence of a Constant Third-Order Difference among the Nuclear Magic Numbers

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THERE seems to be some indication that a constant third-order difference may possibly exist among the nuclear magic numbers. If, according to the explanation afforded by the linear oscillator of the nuclear model,[1] these numbers are taken to be 14, 28, 50, 82, and 126, then the first-order differences among them are 14, 22, 32, 44; the second-order differences, 8, 10, 12; and the third-order difference is constant at a value of 2.

On the assumption that this constant value of the third-order difference is a fundamental fact, the magic number, M, is computable from the readily derivable expression $M=(N^3+5N)/3$ in which N assumes the integer values 1, 2, 3, 4, 5, 6, 7, 8, etc. Then, according to this rule, the magic numbers should be 2, 6, 14, 28, 50, 82, 126, 184, etc.; 8 and 20 are notably absent. The terminal point of the series occurs, of course, at the magic number beyond which all others are proven or known to be physically impossible.

[1] Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949).