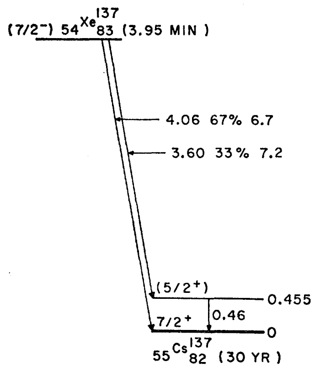

FIG. 7. Proposed decay scheme of Xe^{137}.

half-life of 3.82±0.23 min. A weighted average of these results in a half-life of 3.95±0.11 min for the decay of Xe^{137}.

All of the observed contaminants in the gamma-ray spectra are due to various isotopes of xenon with the exception of Ar^{40} and Al^{27}. Some of these contaminants are ascribed to isomeric transitions in Xe^{125}, Xe^{127}, and Xe^{135}. All of the gamma-ray peaks can be accounted for with some certainty, the only one due to Xe^{137} being a gamma ray of 0.455±0.003 MeV.

Two beta groups were found. The upper level in Cs^{137} is populated by 33%±3% of the transitions and the ground state is populated by 67%±3% of the transitions. The energies of these two groups are 3.60±0.06 and 4.06±0.06 MeV, respectively. From these data, the log*ft* values of the two transitions can be obtained. The log*ft* value for the ground-state transition is 6.7 and for the first-excited-state transition it is 7.2. These values fall most probably in the category of first forbidden nonunique transitions.

The foregoing data indicate the decay scheme shown in Fig. 7. The ground-state spin and the magnetic moment of Cs^{137} have been obtained by atomic beam methods,[10] giving a spin and parity of $\frac{7}{2}+$. From the log*ft* value and the shell model, the ground-state spin and parity of Xe^{137} can be assigned to be $\frac{7}{2}-$. The spin and parity of the first excited state of Cs^{137} is indicated to be $\frac{5}{2}+$ from the shell model and log*ft* value for the lower energy beta transition.

ACKNOWLEDGMENTS

We wish to thank the staff of the Research Reactor, and especially Douglas S. Vonada, for their generous and unfailing assistance with all of the measurements involved in this work.

[10] *Nuclear Data Sheets* (Printing and Publishing Office, National Research Council—National Academy of Sciences, Washington 25, D. C.).

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Study of the 7.285-MeV Level in Lead-208 Using a Rotor Technique

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The 7.285-MeV level in Pb^{208}, excited by thermal neutron capture gamma rays from iron, was studied using a rotating target to vary the energy of the gamma rays seen by the target. Energy shifts of −1.07, −1.75, +1.65, and +2.57 eV were achieved, and the observed changes in scattered intensity are consistent with the resonant Pb^{208} level lying 6.5±1 eV below the iron capture gamma-ray line.

INTRODUCTION

RESONANT scattering of gamma rays has recently been reported[1–5] using the high-energy gamma rays emitted by various nuclei in the capture of thermal neutrons. These scattering events occur when the energy of the capture gamma-ray line (corrected for target recoil) happens to lie close to a suitable resonance level in the target nucleus. Figure 1 shows schematically the Doppler broadened emission line and resonant level, with an energy separation of δ eV between the two maxima. The effective scattering cross section $\sigma_{\gamma\gamma}$ is given by the energy integral of the product of these two curves and hence is very sensitive to the value of δ. As the Doppler widths of these lines are usually of the

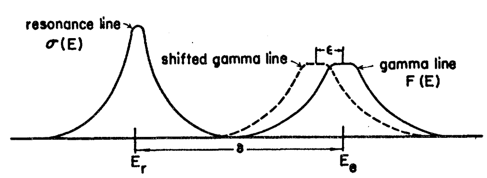


FIG. 1. Schematic representation of the resonance level and the capture gamma emission line. The dashed curve shows the shift produced by rotation of the target.

[1] G. Ben-David (Davis) and B. Huebschmann, Phys. Letters **3**, 87 (1962).
[2] C. S. Young and D. J. Donahue, Phys. Rev. **132**, 1724 (1963).
[3] H. H. Fleischmann and F. W. Stanek, Z. Physik **175**, 172 (1963).
[4] B. Arad (Huebschmann), G. Ben-David (Davis), I. Pelah, and Y. Schlesinger, Phys. Rev. **133**, B684 (1964).
[5] B. Arad, G. Ben-David, I. Pelah, and Y. Schlesinger, International Conference on Nuclear Physics with Reactor Neutrons, Argonne, October 15–17, 1963, ANL-6797 (unpublished).

order of a few eV no measurable scattering would be observed for separations greater than a few tens of eV.

Analysis of the scattered gamma intensity as a function of scatterer temperature[4] yields information on both the natural width Γ of the resonance line and on $|\delta|$ the energy separation. However, in some cases, two sets of values of Γ and δ satisfy the experimental results. This ambiguity could be resolved by a direct measurement of δ, and at the same time its sign could be determined. By varying the separation energy by a known amount ϵ, it should be possible to obtain an exact resonance condition, thus permitting measurement of the original separation δ. Two methods suggest themselves for varying the separation energy. The first is to rotate the scattering target. This causes a Doppler shift in the gamma energy seen by the scattering nucleus, equal to Ev/c, where E is the gamma energy, v the component of the scatterer velocity in the beam direction, and c the velocity of light. The sign of this shift can be changed by reversing the direction of rotation. If the practical rotor velocity is limited to 600 m/sec, the maximum energy shift lies in the range 15–20 eV for capture gamma rays between 6 and 9 MeV. A second method of varying the energy is to use capture gamma rays produced by epithermal neutrons. In this case there is no fixed upper limit to the magnitude of the energy shift, which depends only on the energy of the epithermal neutrons. However, from intensity considerations[6] we decided to use the former method.

To check the feasibility of the rotor technique, experiments were conducted with the 7.285-MeV resonance in lead. This resonance has been measured by the self absorption and temperature variation techniques, which gave the values $\Gamma=0.8\pm0.03$ eV and $\delta=8.0\pm1$ eV.[7] Preliminary results obtained with the rotor technique have already been reported.[8]

EXPERIMENTAL

The experimental arrangement is shown in Fig. 2. Source and target positions were similar to those in the original experiment,[1,4] but to permit accurate location

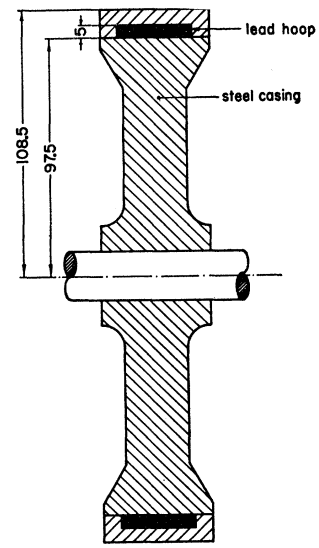


FIG. 3. Section of the scattering rotor.

of the beam with respect to the scattering rotor a different lead collimator was used, giving a gamma beam of rectangular cross section 50 mm wide and 10 mm high. The 7.285-MeV gamma rays responsible for the lead resonance were obtained from an iron capture gamma-ray source, in a thermal neutron flux of 10^{10} n/cm^2 sec.

The target consisted of a lead shell, of diameter 20 cm and thickness 5 mm, supported in a high tensile strength steel casing to withstand the high rotation speeds (see Fig. 3). The target was constructed by casting molten lead centrifugally into the outer casing to ensure a perfect airtight fit. The inner surface of the lead was then machined and the inner casing inserted by a shrink fit, after which the whole unit was dynamically balanced. An identical rotor containing a bismuth shell was used to measure the nonresonant background. The target assembly was rotated in a vertical plane by an ac motor drive (designed for a high-speed grinding wheel) which gave a maximum rotor peripheral velocity of 150 m/sec. The velocity was varied by discrete amounts, using different pulley combinations, or reversed by placing the rotor in either the "up" or "down" position. The angular velocity was monitored by an optical tachometer. Since the velocity was constant to within 2–3% it was not necessary to stabilize the rotation frequency.

The detector used was a 5-in. thick 5-in. diam NaI(Tl) crystal mounted on a 6363 photomultiplier, placed as close as possible to the rotor without intercepting the incident beam.

Measurements were taken at a reactor power level of 2 MW, the rotor velocity being changed manually every two hours. As the experiment continued over several days the neutron flux in the thermal column was monitored using lithium-coated solid-state detectors.[9]

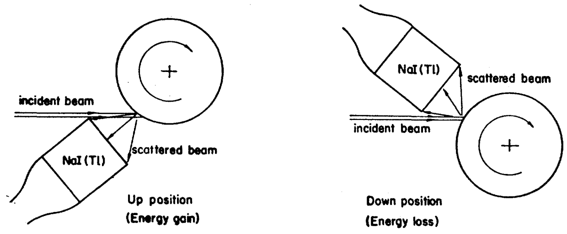


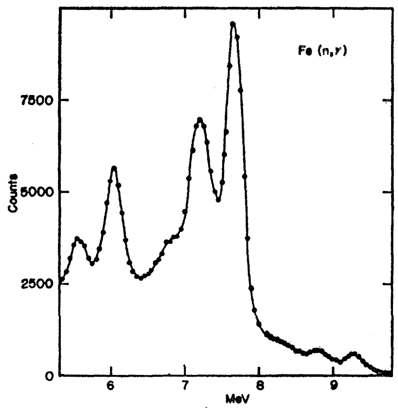
FIG. 2. Experimental arrangement.

[6] G. Ben-David (Davis), B. Arad (Huebschmann), and I. Pelah, Nucl. Instr. Methods 26, 209 (1964).

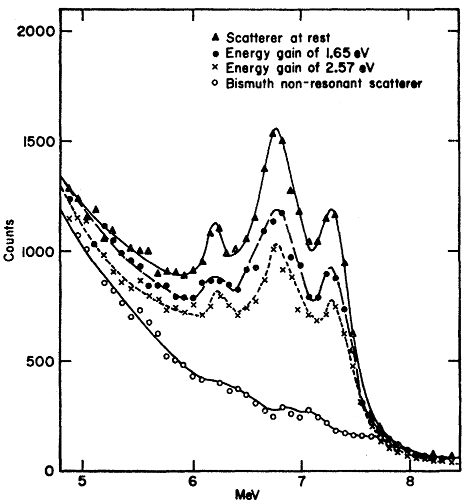
[7] In Ref. 4 the result was erroneously given as $\delta=8.5\pm0.5$ eV.

[8] G. Ben-David, B. Arad, and I. Pelah, International Conference on Nuclear Physics with Reactor Neutrons, Argonne, October 15–17, 1963, ANL-6797 (unpublished).

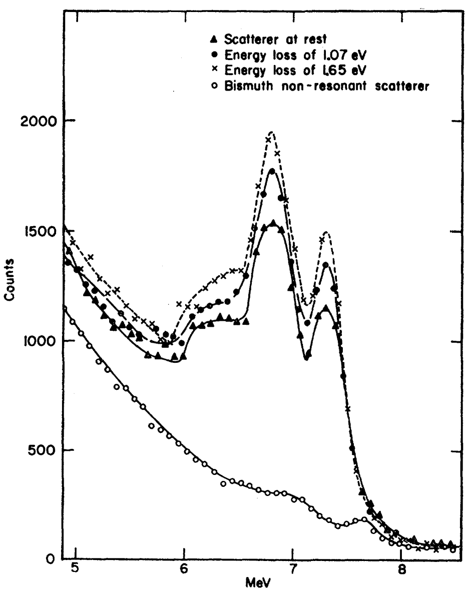
[9] B. Huebschmann and S. Alterowitz, Research Reac. J. 3, No. 2, 11 (1963).



(a)



(b)



(c)

FIG. 4. (a) Direct spectrum of neutron capture gamma rays from iron. (b) Scattered spectra of lead for increased energy separation of incident gamma line. (c) Scattered spectra of lead for decreased energy separation of incident gamma line.

The direct spectrum of Fe(n,γ) is shown in Fig. 4(a), and typical scattered spectra for different rotor velocities in Figs. 4(b) and 4(c).

It was of special importance in this experiment to ensure that the neutron background at the rotor be kept low, since neutrons absorbed in the iron constituent of the rotor would produce capture gamma rays and obscure the scattered radiation of similar energy. Addition of boron and paraffin shielding around the rotor showed no reduction in counting rate that could be attributed to external neutron contribution to the gamma flux. In addition, there was no sign in the scattered spectrum of the 7.64-MeV peak which is prominent in the direct spectrum.

ANALYSIS OF THE DATA

The scattered intensity I_{sc} from a target of thickness x cm in the incident beam direction can be shown[4] to be given by the following expression:

$$I_{sc}=K\int_0^\infty \frac{1-\exp\{-[\alpha\sigma_n(E)+(1+\beta)\sigma_e]Nx\}}{\alpha\sigma_n(E)+(1+\beta)\sigma_e}\times\sigma_n(E)F(E)dE, \quad (1)$$

where the constant K includes the detector solid angle and the ratio of the differential angular cross section to the total cross section, α is the fractional isotopic abundance of the resonance scattering isotope (0.503 in the case of Pb^{208}), $\sigma_n(E)$ is the nuclear cross section, σ_e the total electronic cross section, N the number of target atoms per cm^3, and $F(E)$ the spectrum of the incident gamma line. The parameter β is a geometrical factor of the scatterer, giving the ratio of the average path lengths of the scattered and incident beams reaching the detector. The value of β depends on the geometry of the beam, scatterer and detector, and was calculated to be 0.6 for the present experiment.

The nuclear cross section is given by[10]

$$\sigma_n(E)=\sigma_{\max}{}^0\Psi\left[\frac{2(E-E_r)}{\Gamma},\left(\frac{\Delta_r}{\Gamma}\right)^2\right], \quad (2)$$

where $\sigma_{\max}{}^0$ is the maximum value of the unbroadened Breit-Wigner line, the Ψ function is tabulated[11] and takes into account the thermal Doppler broadening of the level, E_r is the resonant energy, Γ the natural linewidth, and the Doppler width $\Delta_r=E_r(2kT_r/M_rc^2)^{1/2}$, k being the Boltzmann constant, T_r the effective temperature of the scatterer, M_r the mass of the scatterer atom, and c the velocity of light.

The spectrum of the incident photon line is given by the pure Doppler form,[12] since the natural linewidth is

[10] F. R. Metzger, Progr. Nucl. Phys. 7, 54 (1959).

[11] M. E. Rose, W. Miranker, P. Leak, L. Rosenthal, and J. K. Hendrickson, Westinghouse Atomic Power Division Report, WAPD-SR-506, Vols. 1 and 2 (unpublished).

[12] B. Arad (Huebschmann), G. Ben-David (Davis), and Y. Schlesinger, Nucl. Phys. (to be published).

negligible, and we can write

$$F(E)=A\ \exp\left\{-\left(\frac{E-E_r-\delta}{\Delta_i}\right)^2\right\}, \tag{3}$$

where δ is the energy separation between the gamma-line peak and the resonant energy (corrected for recoil) and Δ_i is the Doppler width of the source nuclei. The rotation of the scatterer gives a line shift ϵ equal to E_rV/c where V is the velocity component parallel to the incident beam. For the moving scatterer, Eq. (3) can be written:

$$F(E)=A\ \exp\left\{-\left[\frac{E-E_r-\delta-\epsilon}{\Delta_i}\right]^2\right\}. \tag{4}$$

For thin scatterers, it is possible to expand the exponent in Eq. (1) to terms of the first and second order, which considerably simplifies the analysis. However, in the present geometry, a thin rotating scatterer would have given too low a counting rate and this approximation could therefore not be made. Equation (1) was thus solved numerically, substituting Eqs. (2) and (4) for $\sigma_n(E)$ and $F(E)$. Values of Γ were taken close to the previously measured values of 0.80 eV, and the value of δ adjusted to give the best fit to the experimental results. The limits of the integration were extended to include over 99.9% of the total area.

RESULTS AND DISCUSSION

The integrated counting rate under the 7.285-MeV photopeak is given in Table I for the various values of ϵ obtained by scatterer rotation. Figure 5 shows the intensities, corrected for background, together with the normalized calculated curves.

TABLE I. Integrated intensities of the scattered spectra.

Scatterer \ ϵ(eV)	Energy gain 0	Energy gain 1.65	Energy gain 2.57	Energy loss 0	Energy loss 1.07	Energy loss 1.65
lead	25 910	21 350	18 780	27 420	30 350	32 120
bismuth	7480			8580		
lead-bismuth	18 430	13 870	11 300	18 840	21 770	23 540

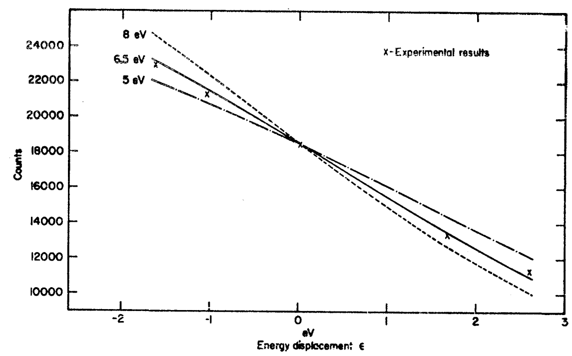


FIG. 5. Counting rate of the 7.285-MeV gamma rays scattered from Pb^{208}, as a function of the energy shift ϵ. The calculations were made taking $\Gamma=0.8$ eV for the level width and assuming the energy separation to be 5, 6.5, and 8 eV. X—the experimental results.

The experimental results were compared with the theoretical values by a χ^2 analysis, and found to be consistent with $\delta=6.5\pm1$ eV, the 7.285-MeV capture gamma line lying above the resonant level in Pb^{208}. Values of 0.7, 0.8, and 0.9 eV for Γ gave the same value of δ as above. The results were also insensitive to slight changes in the parameter β, showing that no inaccuracy was introduced by using the average β in the integration. The value obtained is within the experimental error of the previous result using the temperature-variation method, namely 8.0 ± 1 eV. The new method could be applied to the study of other resonances which are difficult to investigate by the former technique, and it is intended to carry out a thorough study of the resonances already reported[4,5] using an improved scattering rotor capable of yielding values of ϵ of up to ±8 eV.

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