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Nuclear Elastic and Inelastic Scattering of Iron Capture Gamma-Rays from Lead and Nickel*

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An experimental study of some highly excited individual nuclear levels near the threshold for particle emission was carried out employing capture gamma-rays from iron, through nuclear resonant scattering measurements. The experiments were performed at a direct-beam tube facility of the IEA-R1 reactor. A large volume Ge(Li) detector installed on a rotating table was used to perform the measurements. The energies of the elastically and inelastically scattered gamma-rays, as well as the angular distribution of the elastically scattered gamma-rays from lead and nickel are presented. The spins of the resonant levels were determined and found to be in agreement with previous determinations.

Através de medidas de espalhamento ressonante, foi feito um estudo experimental de alguns níveis nucleares altamente excitados, próximos a região da barreira de emissão de partículas, utilizando-se a radiação gama de captura do ferro. As medidas foram efetuadas com um detetor de Ge(Li) de grande volume, instalado em uma mesa girante. A energia da radiação gama espalhada elástica e inelasticamente, bem como a distribuição angular dos gamas espalhados elasticamente pelo chumbo e níquel, são apresentados e os spins dos níveis ressonantes determinados. Os resultados obtidos concordam com os já existentes na literatura.

1. Introduction

The use of thermal capture gamma rays as a source of monoenergetic photons is a relatively new tool for the study of individual nuclear levels near the neutron binding energies[1-3]. When these monoenergetic photons, strike a target, nuclear resonant' scattering occurs, if the energy of one of these photons (after correction for target recoil) happens to overlap a nuclear level in the target nucleus. In previous work on nuclear elastic scattering, the photons were produced either as bremsstrahlung from betatron electrons[4] or by charged particle reactions (p, gamma)[5]. The above experiments gave scattering cross sections averaged over energy intervals

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of between 100 Kev and a few hundred eV.

The neutron capture gamma rays have a linewidth of the order of a few eV's at normal temperatures, determined predominantly by the thermal Doppler broadening. These photons are therefore a suitable probe for studying the nature and the properties of individual levels of the elements.

The nuclear level spacing is usually small in the vicinity of the neutron threshold, and an incident radiation with a narrow energy band (a few eV's) is required in order to excite isolated levels. The excitation and consequent transitions from highly excited bound nuclear levels allow a study of the various nuclear properties of such levels, such as the energy, spin, parity and total and partial radioactive widths.

In the present work, the capture gamma-rays from iron (about 7 Mev) were used to excite individual nuclear levels in lead and nickel.

The elastic and inelastic scattering were studied with a high energy resolution (2.5 kev for 1.3 Mev) Ge(Li) spectrometer, and partial decay schemes were determined.

Angular distribution measurements of the elastically scattered radiation were also carried out for the determination of the spin of the resonance levels.

2. Experimental Arrangement

The experimental arrangement is shown in horizontal section in Fig. 1. The gamma ray source consisted of 7000 g of natural iron placed near

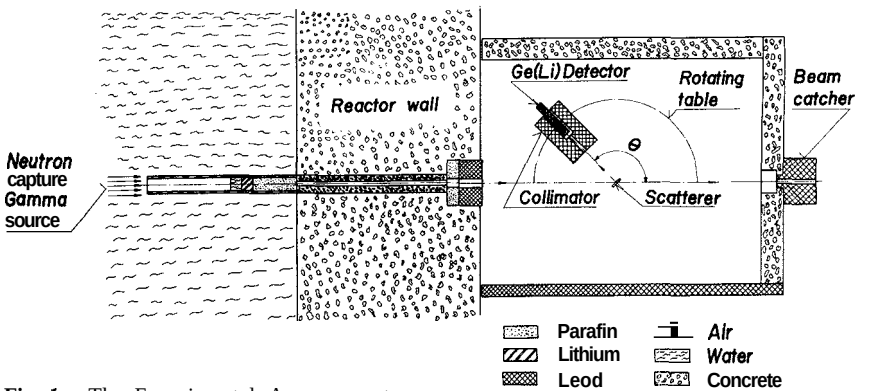

Fig. 1 - The Experimental Arrangements

the core of the IEA-R1 reactor[6] (2 Mw swimming pool-type reactor).

The resulting capture gamma-ray beam from the iron source is collimated with a 160-cm-thick concrete collimator with an aperture of 5.08 cm. Paraffin, lithium and water shields are used to reduce neutron contamination at the exit of the beam. The disk-shaped scattering sample (target) is placed at the center of this collimated beam. The detector was mounted on a graduated rotating arm pivoted around a perpendicular axis passing through the scatterer.

The design of the system permitted the variation of the distance between the detector and the scatterer as well as the one from the scatterer to the reactor shielding wall. With the reactor operating at 2 Mw, the neutron flux near the iron source is about 10^{13} neutron/cm^2/s, yielding gamma intensities of the order of 5.10^7 monoenergetic photons/cm^2/s on the target. The scattered radiation was measured usually at an angle of 140" with the incident gamma ray beam, by a 40 cc Ge(Li) diode, surrounded by 15-cm- of lead to reduce the background produced by (n, gamma) reactions in the vicinity of the detector. A piece of iron 5 cm thick was placed in front of the detector, in the path of the scattered beam to filter out the large number of low energy photons obtained from atomic interactions of the direct gamma beam with the scatterer.

In order to measure the incident gamma-ray spectrum, the detector was rotated to the 0° position in line with the beam. The direct gamma intensity was too high for the detector, overloading the electronic equipment. For these measurements either the power level of the reactor was reduced, or, alternatively, an additional collimator of 4 mm aperture was inserted inside the main collimator. Both the direct and scattered spectra were recorded in a 4096 multichannel analyser. The overall stability of the system was guaranteed by a digital stabilizer.

During long runs it was necessary to monitor the intensity of the incident gamma-ray beam taking into account the fluctuation of the reactor power. For this purpose a fission-chamber was placed near the gamma-ray source.

3. Experimental Procedure

A. Spectrum of Capture Gamma-Rays from Iron (Direct Spectrum of Iron)

The iron capture gamma-ray spectrum was measured in the position of

the scattering target with a 40 cc Lithium-drifted germanium detector in the zero degree posítion. These data were collected at a reduced reactor power of 200 watts, using a 4 mm-diameter collimator inside the main collimator.

This spectrum is shown in Fig. 2. The dominant double escape peak of the 7.64 Mev, and the other less intense lines of 9.298, 7.277, 6.018, 5.926 Mev[7] can be seen.

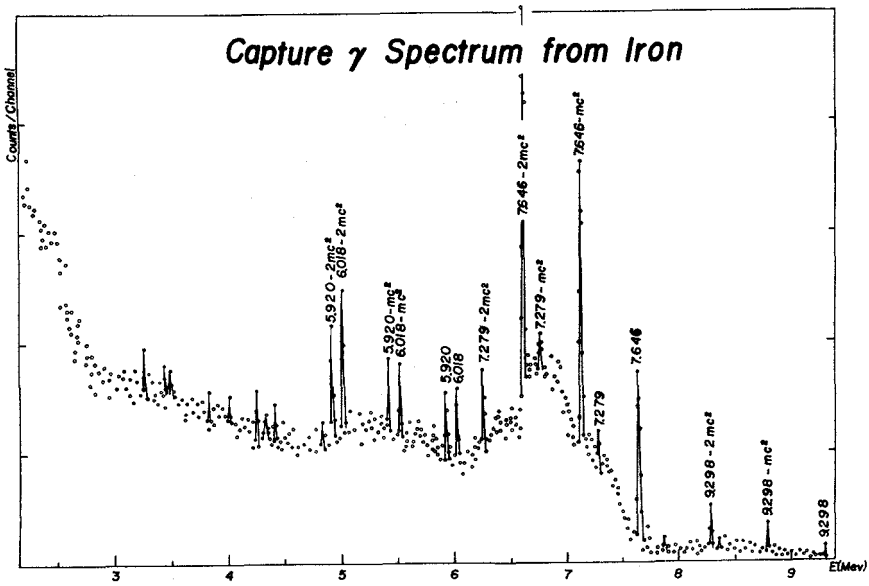

Figure 2 - Direct spectrum of capture gamma radiation, in Iron Fe(n, γ).

The energy calibration of the detector was carried out with reference to the 7.64 Mev peak. The first and second escape peaks of the stronger lines served as a measure of the differential gain over the whole energy region.

B. Spectrum of Resonantly Scattered Photons

The spectrum of the photons scattered from the samples of lead and nickel at 140° are shown in Figures 3 and 4. At the same scattering angle the background scattering was also measured using comparison targets of

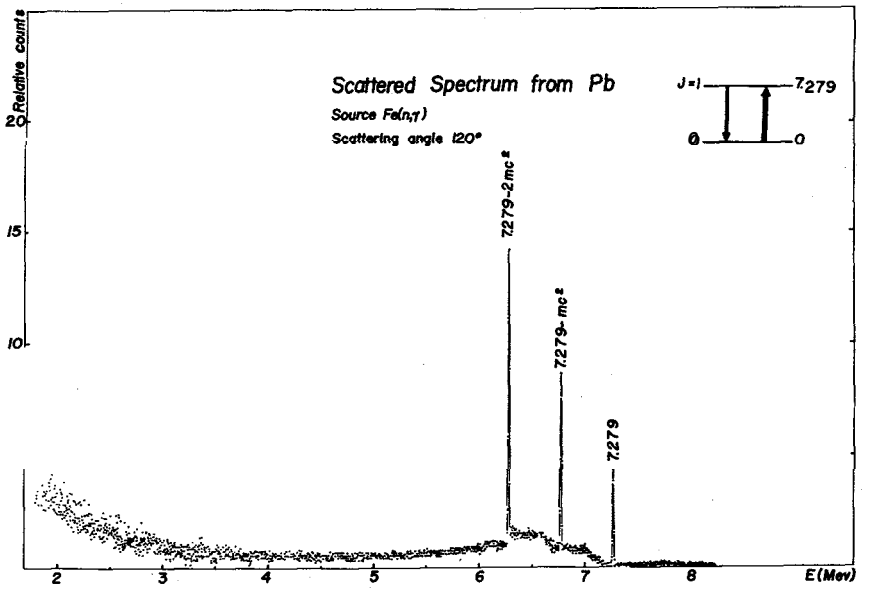

Fig. 3 - The spectrum of resonantly scattered photons from a lead sample. The line at 7.279 Mev is the elastic transition. Energies denoted by 7.279-mc^2 and 7.279-$2mc^2$ refer to first and second-escape peaks respectively.

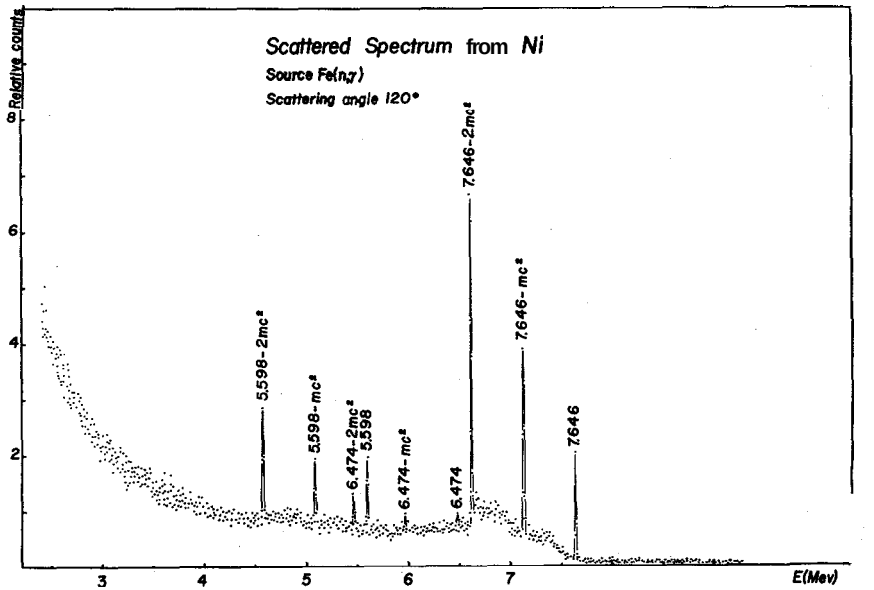

Fig. 4 - Scattered gamma spectrum at an angle of 120 degrees from the nickel sample. The line at 7.64 Mev is the elastic transition. The other lines are inelastic transitions.

Bi and Fe, with their thicknesses matched in electronic absorption. These backgrounds were not subtracted from the original spectrum.

C. Angular Distribution

In an elastic resonance fluorescence process, one deals with a cascade of the form $J_0 \rightarrow J \rightarrow J_0$, while in an inelastic process, the cascade is of the form $J_0 \rightarrow J \rightarrow J_i$, where J_0, J and J_i, are the spins of the ground state and low lying levels respectively.

The angular distribution of this process can be represented by the expression

$$W(\theta) = 1 + A_2^2(J_0, J, L) P_2(\cos\theta), \qquad (1)$$

where L is the multipolarity of the transition and A_2 is a tabulated function[8], and $P_2(\cos\theta)$ is the second order Legendre Polynomial.

The experimental data consisted of counting rate versus scattering angle for the elastic line. The counting rate was considered to be the number of counts lying in the two highest energy peaks of the elastic scattering triplet. A simple analysis of the results was performed through a least-squares fit of the corrected data to the function (1), where A_2 is the adjustable parameter.

4. Results

i) Lead Scatterer

The scattered spectrum from lead can be seen from fig. 3 to consist of a single elastic component, at 7.277 Mev. The properties of this scattering level were studied previously by several investigators[9-10]. It was found that Pb^{208} is the isotope responsible for resonance scattering, and the effective cross section is about 4100 mb. The dipole character of the radiation was established by measuring the angular distribution and a spin of 1 was assigned to this level. With these known results we used this line as a check for the energy calibration of the detection system and the corresponding angular distribution to work out geometric correction factors. This geometric factor is obtained by using the foliowing procedure: for a given geometric shape of the scatterer, the angular distribution was measured at 5 degrees intervals from 90" to 140" degrees with respect to the incident beam direction; a polynomial of degree n is then adjusted to the experimental points by least-squares fitting. As it is well established

that the angular distribution must have the form $W(\theta) \sim 1 + A_2^2 P_2(\cos 0)$, for each angle the geometric factor is given by the ratio between $W(\theta)$

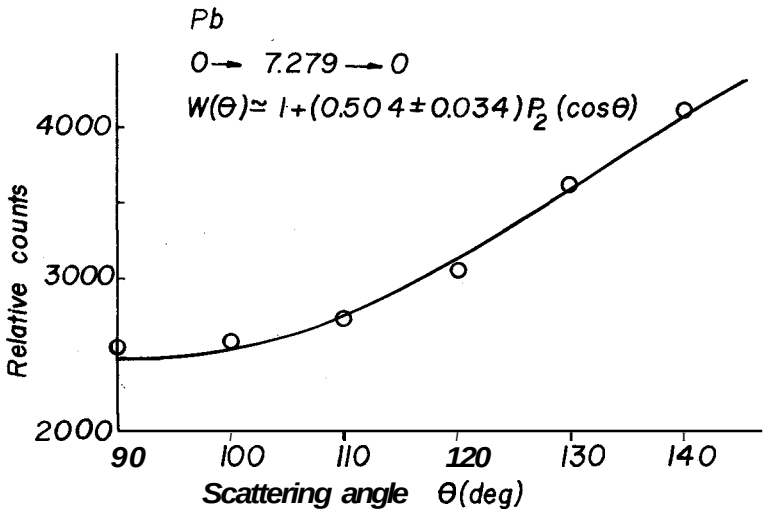

Fig. 5 - Angular distribution of the 7.279 Mev line resonantly scattered in Pb. The solid line is the least-squares fit through the data points. The estatistical errors are included in the circles.

and the polynomial. Figure 5 shows a typical angular distribution for the elastic scattering from the 7.279 Mev level in Pb^{208}. The solid line shows a theoretical dipole distribution for a spin 1 value of the resonance state.

2. Nickel Scatterer

The scattering target was metallic nickel of natural isotopic abundance. It can be seen in Figures 2 and 4 that the only line that occurs in both the direct and scattered spectra is at 7.64 Mev. It is assumed that this line is emitted in the transition from a nuclear level at this energy to the ground state (elastic component). The other lines of 6.46 and 5.58 Mev, are emitted in transitions from this level to low-lying states (inelastic components).

A study of the reported decay schemes[11] of the different Ni isotopes shows that the Ni^{62} is the only one having low-lying levels which can account for the inelastic components from the 7.64 Mev level. The suggested decay scheme is shown in Figure 6.

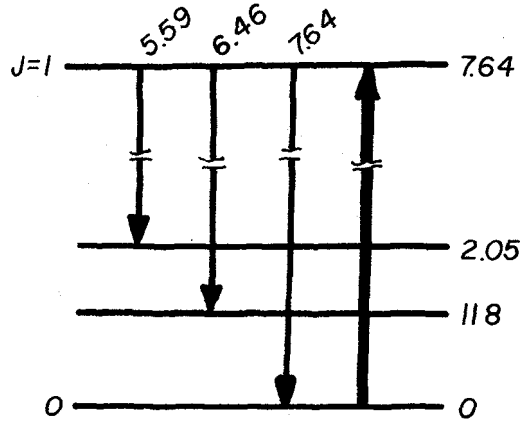

Fig. 6 - Decay scheme of Ni^{62} excited by iron capture gamma-rays.

In order to determine the multipolarity of the strong transition at 7.64 Mev, the angular distribution was measured by the same procedure previously described.

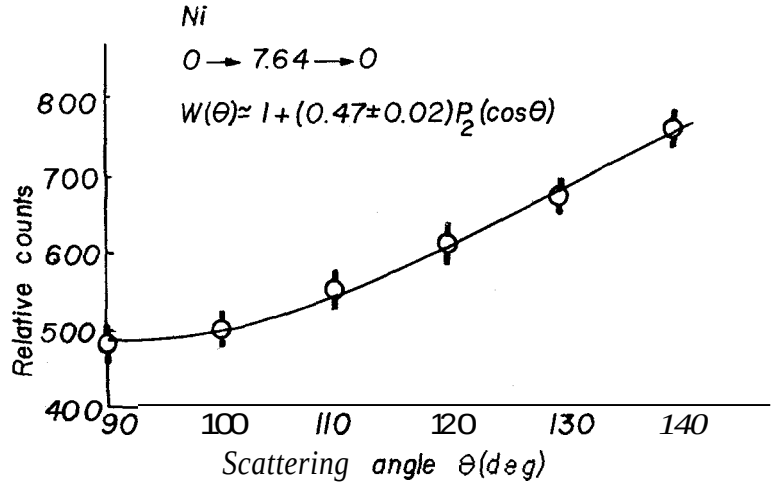

Fig. 7 - Angular distribution of the 7.64 Mev line resonantly scattered in Ni. The solid line is the least-square fit through the data points.

The observed angular distribution

$$W(\theta) = 1 + (0.47 \pm 0.03) P_2 (\cos \theta)$$

fits the theoretical distribution $W(\theta) = 1 + 0.49\, P_2(\cos\theta)$ for the sequence 0(1)1(1)0, Figure 7. This is in agreement with all previously reported angular distributions[10]. The spin at the 7.64 Mev resonant level in Ni is therefore equal to 1.

At the present time, the above resonances in Pb and Ni are being studied systematically using temperature variation and, where possible, self-absorption techniques so as to obtain the widths of the various levels responsible for the resonant scattering. This will be reported elsewhere.

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References

1. H. Fleischmann, Ann. Physik **12**(1963)133.
2. C. S. Young and D. J. Donahue, Phys. Rev. **132**(1963)1724.
3. G. Ben David, B. Arad, J. Balderman and Y. Schlesinger, Phys. Rev. **146**(1966) 852.
4. E. G. Fuller and E. Hayward, Phys. Rev. **101**(1956)692.
5. K. Reibel and A. K. Mann, Phys. Rev. **118**(1960)701.
6. A. C. Penteado and M. D. S. Santos - Publicação IEA-44 (1961).
7. Nuclear Data - Section A(1967) vol. 3 - pg. 502.
8. K. Siegbahn - Beta and gamma ray spectroscopy - North-Holland Publishing Co. - Amsterdam - 1955.
9. C. S. Young, and D. J. Donahue, Phys. Rev. **132**(1963)1724.
10. B. Agad, G. Ben-David, I. Pelah, and Y. Schlesinger, Phys. Rev. 133B (1964)684.
11. Nuclear Data Sheets - part 2 - 1959-1965 - Academic Press - N. Y.