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Abstract

Full Text

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RESONANCE SCATTERING OF GAMMA QUANTA BY Mg^{24} NUCLEI

(Presented by Academician D. V. Skobeltsyn, 18 III 1958)

In recent years the phenomenon of resonance scattering of γ -quanta has been successfully applied to the measurement of short lifetimes (10^{-10} sec and shorter) of excited nuclear states (¹). The effective cross section of this process is proportional to the width of the excited level; therefore the range of applicability of the method is not limited on the side of short lifetimes.

In the present work, resonance scattering of γ -quanta accompanying the decay $Na^{24} \rightarrow Mg^{24}$ by Mg^{24} nuclei was investigated, with the aim of measuring the lifetime of the first excited state of the Mg^{24} nucleus with energy 1.37 MeV. In emission and absorption, part of the energy of a 1.37 MeV quantum is lost owing to nuclear recoil. This energy loss is relatively small (in the present case it is 84 eV), but it is much greater than the width of the excited level. In order for resonance scattering to occur, it is necessary to restore the energy of the quanta to the resonant value. Such restoration of the energy in the present case occurs owing to the presence, in the decay scheme of Na^{24} , of a β - γ cascade preceding the emission of the 1.37 MeV quantum. After emission of the β -particle and of the first γ -quantum (2.75 MeV), the excited Mg^{24} nucleus comes into motion, and emission of the 1.37 MeV quantum already takes place from a moving nucleus. Owing to the Doppler effect, the energy of the quantum changes by an amount

$$\delta E = E_0 \frac{v}{c} \cos \vartheta, \quad (1)$$

where $E_0 = 1.37$ MeV, v is the velocity of the recoil nucleus, and ϑ is the angle between the directions of emission of the γ -quantum and of the motion of the nucleus. In this way, for some fraction of the γ -quanta the energy is restored to the resonant value.

For such a mechanism of energy restoration to take place, it is necessary that the free-flight time of the recoil nuclei be sufficiently large: the 1.37 MeV quantum must be emitted before the recoil atom loses its velocity as a result of collisions with neighboring atoms of the source material. This condition is satisfied only in a gaseous source; therefore, in the present experiment, vapors of radioactive

sodium, obtained by heating metallic sodium to a temperature of 800-900°, served as the source of γ -quanta.

The effective cross section for resonance scattering in the present case has the form (2)

$$\sigma = \frac{2I_1 + 1}{2I_0 + 1} \frac{\hbar^2 c^2}{4E_0^2} \Gamma f(E_0), \quad (2)$$

where I_0 and I_1 are the spins of the ground and excited states of the nucleus; Γ is the width of the excited level; $f(E_0)$ is the distribution function of the incident quanta in energy (the “microspectrum”), calculated for the resonance energy E_0 . Since the final distribution of recoil nuclei over velocities depends on the distribution over velocities of the recoil nuclei after β -decay, the form of the microspectrum will depend on the variant of the theory of β -decay. The variant of the theory of β -decay is unknown, and this introduces a certain uncertainty into the calculation of the effective cross section. However, this uncertainty amounts to only a few percent and is immaterial in the present experiment. Figure 1 shows the microspectrum of the incident quanta in the case of the scalar variant of the theory of β -decay.

The width (and consequently the lifetime) of the level is determined by compar-

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by comparing the experimentally measured effective cross section with that calculated from formula (2). The measurements were carried out on an apparatus analogous to that already used earlier for measuring resonance scattering of γ -quanta (3). Metallic sodium, irradiated in a reactor by thermal neutrons, was placed in a steel container, from which the air was then pumped out. The tightly closed container was heated to a temperature of 800-900°. The temperature was measured with a thermocouple. The scatterer was a hollow magnesium cylinder 40 cm high, 44 cm in diameter, and 1.2 cm thick. For comparison an aluminum scatterer of similar dimensions was used. During the measurements the magnesium and aluminum scatterers were interchanged every 5 min. The scattered quanta were detected by a NaJ(Tl) crystal 4 cm high and in diameter and by an FEU-29 photomultiplier connected to a pulse analyzer. The analyzer window was set to the 1.37 MeV photopeak. The detector was shielded from the direct radiation of the source by a lead cone 35 cm high. The counting rate of the resonance scattering at the beginning of the measurements, at a temperature of 860°, was on the average 20 pulses per minute. The resonance effect increased with increasing temperature, since the mass of the sodium vapor increased at the same time. The measured dependence of the effect on temperature agrees exactly with the theoretically calculated one.

Fig. 1. Microspectrum of the incident quanta ($E_0 = 1.37$ MeV), calculated in the scalar version of beta-decay theory.

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Figure 1: Fig. 1. Microspectrum of the incident quanta ($E_0 = 1.37$ MeV), calculated in the scalar version of beta-decay theory.

The measured effective cross section of resonance scattering was found to be $(1.14 \pm 0.23)10^{-26}$ cm², which gives for the lifetime of the 1.37 MeV excited state of Mg²⁴ the value

$$\tau = (1.7 \pm 0.4) 10^{-12} \text{ sec.} \quad (3)$$

Recently data have been obtained (4) which testify in favor of the rotational nature of the first excited state of Mg²⁴. This makes it possible to determine, from the measured lifetime, the value of the quadrupole moment Q_0 and the deformation parameter β of the Mg²⁴ nucleus by the formulas (5)

$$B(E2) = \frac{e^2 Q_0^2}{16\pi}, \quad Q_0 = \frac{3}{(5\pi)^{1/2}} Z R_0^2 \beta (1 + 0.16\beta), \quad (4)$$

where $B(E2)$ is the reduced probability of the electric quadrupole transition 1.37 MeV; $R_0 = 1.2 \cdot 10^{-13} A^{1/3}$ cm. Hence the quadrupole moment is found to be 0.7 barn, and the deformation parameter $\beta = 0.59$, which exceeds the deformation parameters of elongated nuclei in the region of the rare earths. If the assumption about the rotational nature of the first excited state of Mg²⁴ is correct, then this nucleus proves to be strongly deformed, despite the fact that it is located comparatively close to filled nucleon shells.

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