OBSERVATION OF RESONANCE ABSORPTION OF GAMMA RAYS IN Zn^{67}

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Experiments on the observation of recoilless resonance absorption of the 92-kev γ rays of Zn^{67} are described. A positive result was obtained for metallic zinc at liquid-helium temperature. However the effect is very small.

THE radioactive isotope Ga^{67} (half-life $T = 78$ hr) emits γ quanta with energy $E = 92$ kev, which appear in the transition of the Zn^{67} nucleus from its first excited state ($T = 9.3 \times 10^{-6}$ sec, relative width $\Gamma/E = 5.3 \times 10^{-16}$) to the ground state.[1] Resonance scattering of these quanta by Zn^{67}, using the Mössbauer effect,[2] is of considerable interest, for example, for the study of the gravitational red shift under laboratory conditions,[3,4] since the relative width of the Zn^{67} gamma line is three orders of magnitude smaller than that of the line in Fe^{57}, which has been used in various experiments.[5,6] In the present paper we describe the results of the first experiments undertaken to detect resonance scattering in Zn^{67}.

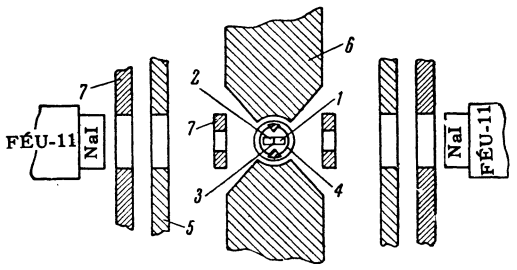
EXPERIMENTAL ARRANGEMENT

The resonance scattering effect was measured by the increase in intensity of the filtered radiation when the resonance condition was destroyed. A source of Ga^{67} was produced on one side of a sample containing Zn^{67} by a preliminary irradiation of this side with 6.7-Mev protons. The source thickness did not exceed 0.1 mm, while the rest of the sample (4 — 6 mm thick) served as a filter (cf. the figure). The resonance was destroyed by applying to the sample an inhomogeneous magnetic field with a maximum magnetic field strength of 1500 oe. As a result of the nuclear Zeeman effect, the magnetic field produced a shift of the emission line relative to the absorption line which was by a factor of ten greater than the natural line width. The detectors were FÉU-11B photomultipliers with NaI crystals 15 mm thick.

For the "poor geometry" shown here, Compton and resonance scattering of quanta in the detector reduces the observed effect by a factor of 2 — 3 compared to the effect in an ideal geometry. However we felt that this defect was compensated by two advantages: a) to a large extent, the possibility of relative motions of source and filter is eliminated; b) we reduce the danger of shifts of the emission and absorption lines resulting from nonidentical composition and treatment of source and filter.

The change in the amplification of the multiplier when the field was turned on did not exceed 10^{-5}. To eliminate errors resulting from drifts in the detection equipment, measurements with and without field were alternated every 20 — 40 sec. The time intervals were given by a quartz-stabilized frequency generator. After each switching on of the field, a demagnetization was carried out, so that the residual field did not exceed 1 oe.

The principal measurements were done at 4.2° and 300° K with a polycrystalline sample of zinc, enriched to 33% in Zn^{67}. As a control, we also measured the intensity of 92-kev radiation passing



Schematic of the experimental apparatus: 1 — sample of enriched Zn, 2 — sample of normal Zn, 3 — face of enriched sample, irradiated at cyclotron, 4 — shield at 80°K, with Armco iron pole pieces, 5 — magnetic shield (iron), 6 — pole of electromagnet, 7 — lead collimators. Samples 1 and 2 were soldered to the bottom of a container of liquid helium. The photomultipliers were surrounded by a permalloy screen 5 mm thick.

Relative change in intensity of filtered radiation when the magnetic field is applied ($10^2\,\delta$, %)

Series of measurements	4°K				300° K			
	Enriched Zn		Normal Zn		Enriched Zn		Normal Zn	
	E_γ=92 kev	180 kev	92 kev	180 kev	92 kev	180 kev	92 kev	180 kev
I	4,48±2.69		−1,36±2.85					
II	2,74±1,65		−0,75±1,83		0,84±1,40		−1,17±1,61	
III	2,22±1,04	−0.67±1,32	+1,35±1.12	0.09±1.18	0,63±0,84	−0,88±0,97	0,70±0.89	0,36±0,98
average	2,58±0,84	−0,67±1,32	0,55±0.91	0,09±1.18	0,68±0,73	−0,88±0,97	0,26±0,79	0,36±0,98

through a sample of normal zinc (4.1% Zn^{67}). In some of the experiments we also recorded the intensity of filtered 180- and 270-kev radiation, which should not undergo resonance absorption.

In addition to metallic zinc, we also investigated an ordered alloy of brass and normal zinc (β' brass, 50% Cu, 50% Zn) and an alloy of Cu + 1.5% Zn, with an enrichment to 71% in Zn^{67}. Within the limits of statistical accuracy of the measurements, which were 2.2×10^{-2} and 7.5×10^{-2}%, respectively, the brass and the Cu-Zn alloy showed no resonance absorption effect.

The results of the measurements with metallic zinc are shown in the table.

DISCUSSION OF RESULTS

As we see from the table, the intensity of the 92-kev radiation, filtered through enriched zinc at a temperature of 4.2° K, increases when the magnetic field is applied by an amount $\delta = (2.58 \pm 0.84) \times 10^{-2}$%. The sign of the change corresponds to the presence of a Mössbauer effect in zinc, and its magnitude is three times greater than the mean square statistical error of the measurements. At the same time, there was not a single control measurement in which δ exceeded the mean square error.

In computing the Mössbauer effect in zinc, we should not use the Debye approximation, since the Debye temperature of zinc depends very strongly on temperature.[7] Kazarnovskiĭ,[8] starting from experimental data on the specific heat of zinc, found that the effective Debye temperature of zinc for the Mössbauer effect is 213° K. Using this figure, taking account of the quadrupole splitting of the levels of Zn^{67} in the hexagonal zinc lattice, and introducing a factor of $\frac{1}{2} - \frac{1}{3}$ for the "dilution" of the effect because of the "poor geometry" of the experiment, we get an expected value for the effect of $\delta = (6 - 9) \times 10^{-2}$%. This is somewhat greater than the observed value, which may be explained by a broadening or shift of the Mössbauer line, or by an incorrect location of some of the atoms of Ga^{67} in the zinc lattice.

Recently Pound and Rebka[9] reported an unsuccessful attempt to detect resonance absorption in normal zinc. Obviously this result is in agreement with our data since even in enriched zinc the effect is four times less than the error in the experiments of Pound and Rebka, which was 0.1%. Craig et al.[11] have observed the resonance absorption in zinc oxide.

The low value of the resonance absorption effect in zinc makes difficult any further investigation or use by the filter method. At present we are preparing experiments for recording scattered Zn^{67} radiation, where for better separation from the nonresonant background we propose to use detectors with better energy resolution (xenon proportional counters) and to modulate the beam of γ quanta incident on the scatterer by means of a rotating chopper. Such a modulation is technically feasible because of the relatively long mean life of the isomeric level of Zn^{67}.

In addition one should consider the possibility of increasing the yield of the Mössbauer line by introducing the Zn^{67} into a material with high atomic weight. Using the classical theory of the Mössbauer effect,[10] one can see that for the case of a small amount of impurity the relative area of the Mössbauer line is determined not by the mass of the radiating atom but rather by the mass of the solvent atom and the Debye temperature of the solvent.

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