JOINT INSTITUTE FOR NUCLEAR RESEARCH
Dubna, 1966

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E-2834

ON MEASURING THE MAGNETIC DIPOLE AND ELECTRIC QUADRUPOLE MOMENTS OF THE COMPOUND NUCLEUS RESONANCES STATES

Рукопись поступила
в издательский отдел
„14" VII 1966г.

Prepared for the IAEA Panel on Research Applications
of Repetitively-Pulsed Reactors and Boosters, Dubna,
July 18-22, 1966.

A lot of data havebeen accumulated in the last years about positions, spins, parities and widths of highly excited nuclear states appearing as resonances in neutron cross sections. To deepen our understanding of the nature of these states, it is of importance to know also their electromagnetic moments. These may be determined through the small but still in some cases detectable shift of the resonances due to the superfine interaction of the compound nucleus with the electron shell.

Let us put down some formulas for the simplest case of a magnetized ferromagnet with zero nuclear spin having a resonance at neutron energy E_0 with negligible Doppler broadening. With account for the magnetic superfine interaction the total neutron cross section may be written as

$$\sigma = \frac{\sigma_0}{1 + (x + \delta x_0)^2} \tag{1}$$

with

$$x = \frac{2(E - E_0)}{\Gamma}$$

$$\delta x_0 = \pm \frac{2\mu H}{\Gamma} \tag{2}$$

Here μ is the magnetic dipole moment of the compound nucleus, H is the effective magnetic field acting on the nucleus in the ferromagnet, E is the kinetic energy of the neutron outside of the magnetic field. The two signs + and - refer correspondingly to parallel and antiparallel orientations of the neutron spin and the field H. Due to the shift δx the neutron transmission of a sample for polarized neutrons will depend on the neutron spin orientation. For a sample of thickness n nuclei per cm^2, the relative difference of the transmissions for parallel and antiparallel orientations will be equal to

$$\frac{\delta T}{T} = \frac{4 n \sigma_0 x}{(1+x^2)^2} \delta x \qquad (3)$$

The counting time for the given statistical accuracy in δx reaches its minimum at $x = \pm 1$, $n\sigma_0 = 4$. By making measurements simultaneously at both sides of the resonance (at $x = 1$ and $x = -1$) and taking the difference, the measured effect is doubled and, for optimal sample thickness, becomes

$$2\left(\frac{\delta T}{T}\right)_{max} = 16 \frac{\mu H}{\Gamma} \qquad (4)$$

For some of the rare earths the effective field H amounts up to nearly 10^7 Oe ; substituting in (4) this figure and the values of 2 nuclear magnetons for μ and 0.1 eV for Γ one obtains a value of 1% for the effect to be measured [x].

Of course, the resonance shift due to magnetic interaction will exist also for nuclei with non zero spin with the difference that in

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[x] Note that in total cross section measurements with polarized neutrons the interference between nuclear resonance scattering and magnetic scattering will also contribute to the asymmetry of the resonance line. To exclude this effect, one has to measure the capture cross section instead of the total one or carry out the transmission measurements in a poor geometry so that the small angle magnetic scattering will not relax the beam.

this case the effect will depend not only on the magnetic moment of the compound nucleus but also on the magnetic moment of the target nucleus.

The superfine interaction may be detected also in measurements with non polarized neutrons, but in this case a polarized nuclear target is necessary: the transmissions of the sample at $|x| \sim 1$ are to be compared for zero and non zero nuclear polarization. The order of magnitude of the effect expected is the same as for polarized neutrons. This method is applicable also for measurements at the electric quadrupole interaction and for this purpose aligned nuclei can be used.

Interesting phenomena will occur in coherent elastic scattering of neutrons in antiferromagnetic crystals. The mentioned above shift of the resonance due to the superfine interaction of the compound nucleus (and of the target nucleus if it has a nonzero spin) and also the polarization of the target nuclei lead to occurrence of a scattering amplitude component which changes its sign when the orientation of the spin of the electron shell of the atom is reversed. This component, unlike to the independent on H main nuclear scattering amplitude, will contribute to the pure magnetic reflections existing in antiferromagnetic crystals; it will interference with magnetic scattering by the electrons. Because of that, some resonance structure will be seen in the energy dependence of a pure magnetic reflection intensity measured at a fixed value of $\sin\theta/\lambda$. The detection of this resonance structure allows the determination of both the spin and the magnetic moment of the corresponding compound nucleus state. As both interfering amplitudes - the nuclear magnetic and the electron magnetic, the first one being much smaller than the second, - are proportional to the magnetic field, the relative magnitude of the interference term is independent of the field. This is a substantial advantage. In this case the magnitude of the measured effect is also not larger than several per cent.

A more detailed consideration of all mentioned problems will be given in a separate paper.

Conclusion . The superfine interaction gives rise to effects in the counting rate for good resolution neutron spectrometry measurements amounting in favourable cases up to 1 per cent (magnetic interaction) and up to 0.1 per cent (electric inter action).

Detection of these effects will enable one to determine the magnetic dipole and the electric quadrupole moments of low lying resonances of a number of nuclei. One can hope that the widely discussed new intense pulsed neutron sources for neutron spectrometry will give adequate possibilities for such experiments.