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Detection of alignment of nuclear spins.

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Nuclear magnetism is a subject that interests nuclear physicists as well as low-temperature-physicists. For instance F. Simon discussed the possibility of attaining temperatures as low as 10^{-6} °K by adiabatic demagnetization of nuclear spins. The first step in this process was the alignment of the nuclear spins. A method to do this has been suggested by C. J. Gorter[1]). Here we shall deal with the problem how to detect any alignment of a system of nuclear spins. We shall discuss two different ways which under certain circumstances are suitable to detect the alignment.

A. With the aid of neutron absorption.

The absorption of a neutron by a nucleus depends on the relative spin-orientation of neutron and nucleus. Suppose that a nucleus has a spin J in the groundstate and that there exists a resonance level for slow neutron capture. The compound nucleus corresponding with this level has a spin $J + {}^1/_2$ or $J - {}^1/_2$. In order to explain the principle of the method let us suppose the nuclear spins to be completely aligned and the neutron beam to be completely polarized with spins parallel to the nuclear spins.

Now if the spin of the compound nucleus is $J - {}^1/_2$ no neutrons will be absorbed at all. Of course this is a strongly idealized example. In practice one can only work with a partly polarized neutron beam and a partly polarized absorber.

The most promising way to demonstrate the alignment of the nuclei with the aid of neutronabsorption would be to measure the transmission of a polarized neutron beam through a polarized absorber by a detector which is polarized too. Neutronpolarizations up to 40% have been obtained[2]), but in practice it is impossible to get a high polarized beam of sufficient intensity if a strong neutron source is not available.

However, the system of nuclear spins the alignment of which has to be detected, will act as a polarizer itself. A non-polarized neutron beam is equivalent to two completely polarized beams of half intensity with opposite directions of polarization. These two polarized beams will have different absorption coefficients in the polarized absorber. The deeper the neutrons penetrate into the absorber the larger the difference between the relative intensities of the polarized beams will be. A more detailed treatment gives that the total transmission is always greater for aligned nuclei than for random orientation.

The properties required for an element which can be used as polarizer-absorber are the following three:

1. The atom must have a paramagnetic moment. This is necessary for the alignment of the nuclei.
2. The nuclear spin must be non-zero.
3. There must be a strong resonance level for slow neutroncapture, preferably not far from thermal energy.

It appears then that Eu en Gd are the only suitable elements. Eu is hard to obtain, especially in a high grade of purity. So we are forced to use a Gd-absorber. This rare earth has a strong resonance level at thermal energy, so that a already small amount of it gives sufficient absorption.

As we have mentioned it is preferable to employ a polarized detector. Then the properties required for the detector element are the same three as for the absorber and moreover capture of slow neutrons should induce β-activity. Only Eu fulfills these four conditions but we have seen already that Eu cannot be obtained. So there is no possibility of using a polarized detector. Then the best element for the detector seems to be Rh.

The experiment has been carried out at the cryogenic Kamerlingh Onnes laboratory at Leiden. A 200 mc Ra + Be source was placed inside the cryostat. This source was surrounded by a 1.9 cm thick layer of paraffin. The absorber (Gadolinium-sulphate, mixed with chromalum) was contained in a vessel of German silver mounted around the paraffin cylinder.

The neutron detector, a Rh-foil, was placed at the outside of the cryostat. The cryostat was mounted between the pole-pieces of a strong electromagnet. The β-activity of the Rh-foil has been measured after five minutes of irradiation with and without cadmium and with and without alignment of the Gd-nuclei.

Two series indeed showed an increase of transmission when the nuclei were supposed to be aligned. A third measurement showed no change in transmission. It should be emphasized however, that there were troubles in maintaining the low temperatures.

B. Another method to detect alignment of nuclear spins is to investigate the distribution in space of the emitted radiation. As J. A. Spiers has pointed out[3]) there will be a certain non-isotropic angular distribution of the radiation with the magnetic field as an axis of symmetry if the nuclear spins are aligned.

In the same laboratory at Leiden we have tried to demonstrate this phenomenon. A sample of γ-active iron was placed inside the cryostat and the ratio of the intensities of the γ-radiation in the direction of the magnetic field and perpendicular to it has been determined with aligned iron nuclei and with random orientation of the nuclei. The largest effect found was $2 \pm 1\%$. A higher accuracy could not be ontained because of the short time of counting (about 10 minutes) as the low temperature could not be maintained longer.

It should be noticed that these two measurements were of a preliminary character. We will continue these measurements in the near future with an improved arrangement.

Bibliography.

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3) J. A. Spiers, Nature **161**, 807 (1948).