The Behavior of Neutrons in Crystals

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A thermal neutron in a crystal behaves like a wave traveling in space. The neutron has three ways it can escape: (1) running out, (2) fusion with a nucleus, and (3) transformation into a proton by β decay. If these three are prevented from taking place, the neutron is stable in the crystal. Conditions for the stabilization of a neutron in a crystal is shown with its probable effects.

Introduction

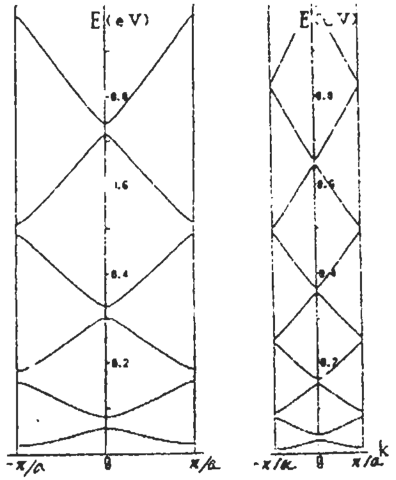
After its discovery in 1932, the nature of the neutron has been a major problem. Its magnetic moment was difficult to understand in Quantum Mechanics. Its decay was also a riddle. Even now, the problem of the nucleon — proton and neutron — is one of the central problems in elementary particle physics.

Though the interaction with atoms and molecules is weak, since the invention of the atomic pile the neutron has been used to analyze the structure of matter by diffraction. This was made possible by the discovery of the fission of ^{235}U by the absorption of a neutron, generating two or three neutrons. The neutron has thus played a key role in atomic piles and nuclear weapons. Even so, its nature is not well known.

In the history of cold fusion research it has been considered necessary to understand the nature of the thermal neutron in the crystal. In this paper, the stability of a neutron interacting with nuclei on a lattice (lattice nuclei) is investigated qualitatively to show the important role of the neutron in solid state - nuclear physics.

A neutron in a crystal

A thermal neutron destined to decay with the emission of an electron in



(a) (b)

Fig. 1. Energy bands of low energy neutrons in a one-dimensional solid with lattice constant α. Kronig-Penny attractive potential with zero width limit is used. The parameter $P = 3\pi/2$, $\alpha =$ (a) 10^{-8}, (b) $\sqrt{2} \times 10^{-8}$ cm.

about 900 s behaves as a wave in a crystal, interacting with lattice nuclei. We will treat three problems related with the neutron in a crystal in this section.

Trapping in a crystal

The thermal neutron with energy 0.025 eV corresponding to a temperature of 300°K has a de Broglie wave length 1.80 Å comparable to the lattice constants of crystals. This is the reason neutron diffraction is widely applied in technology and science using neutrons from the atomic pile. This situation also shows a possibility of neutron trapping in a crystal surrounded by another crystal with a different lattice constant.

A simple example of such a situation for trap neutrons is shown in **Fig. 1**. The neutron band was calculated by one-dimensional Kronig - Penny model with an attractive δ - function potential with lattice constants a = (a) 10^{-8} and (b) $\sqrt{2}$ x 10^{-8} cm. This model calculation shows clearly a shift of the energy band with a change of the lattice constant. Therefore, in principle, a neutron can be trapped in a crystal surrounded by another crystal with an appropriate lattice constant.

The trapped neutron in a crystal could be expressed by a standing Bloch wave with large amplitude at each lattice nucleus.

Stability against absorption by a nucleus

There is a possibility that the trapped neutron in a crystal is absorbed by a lattice nucleus (from a Bloch wave to a nucleon in a nucleus) only when the absorbed state has lower energy than before. Let's formulate this problem.

If the kinetic and potential energies of the neutron in the standing Bloch state are expressed as K_B and U_B, and in the absorbed state as K_A and U_A, respectively, the uncertainty principle tells us a following relation between K_A and the nuclear size Δx:

$$K_A \sim \frac{\mathbf{h}^2}{2m_n(\Delta x)^2} \sim \frac{\mathbf{h}^2}{2m_n r_o^{\,2} A^{2/3}} \text{ ....(1)}$$

where r_o is a constant length 1.2 x 10^{-13} cm, A is the mass number of the lattice nucleus and m_n is the neutron mass (m_n = 1.67 x 10^{-24} g).

Then putting numerical values into parameters in this equation, we obtain a relation between K_A and the mass number A;

$$K_A \sim \frac{\mathbf{h}^2}{2m_n r_o^{\,2}} A^{-2/3} = 14.3 A^{-2/3} (MeV) \text{.................(2)}$$

For $A = 100$, this relation gives $K_A \sim 0.68$ MeV. Therefore, the neutron Bloch wave trapped in a crystal is stable against the absorption by a lattice nucleus if U_B is not larger than U_A + 14.3 $A^{-2/3}$ in MeV (U_A + 0.68 MeV for $A = 100$);

$$U_B - U_A \leq 14.3\, A^{-2/3} \text{ ....(3)}$$

This criterion excludes crystals with a nucleus with a larger mass number than a threshold value A_o for effective trapping of thermal neutrons.

Stability against β decay

A neutron may stably stay in a crystal unless it disintegrates by β decay into a proton, an electron and a neutrino, when it is free to go out or be absorbed by a nucleus.

Let us assume that the neutron Bloch wave transforms into a proton Bloch wave when it suffers β decay. Furthermore, let us estimate the stability of the neutron wave by the neutron affinity of a nucleus *h* defined by the following relation[1]:

$$\eta \equiv -({}^{A+1}_{Z}M - {}^{A+1}_{Z+1}M)c^2 \text{......................} (4)$$

Here, ${}^{A}_{Z}M$ is the nucleus with a mass number A and a proton number Z composing the lattice nuclei. This definition tells us that the neutron affinity is a quantity expressing an energy difference of two nuclear states, one with an extra neutron and the other with an extra proton. The positive value of η means the former is lower in energy and more stable.

For a crystal, we define the neutron affinity of the crystal $<\eta>$ as an average of η over the lattice nuclei. Therefore, the neutron affinity of a crystal composed of an identical nucleus is the same to that for the nucleus. Furthermore, we may assume that when a neutron is trapped in a crystal with a positive neutron affinity $<\eta>$, then the neutron is stable against beta decay.

We have calculated $<\eta>$ for elements using their natural abundance to take an average and the result is tabulated in the Table 1 of the preceeding paper[1].

Interestingly enough, almost all cold fusion materials have positive neutron affinity where the thermal neutron is stable, as we assumed as its characteristic.

Effect of the stable neutron in crystal

The investigation given above is not at all rigorous nor quantitative. Even so, it shows a possibility of the stable neutron in a crystal if some conditions are fulfilled: (1) Trapping in a crystal by an appropriate configuration of crystals with different lattice constants (or compositions), (2) Stability against absorption by a nucleus, and (3) Stability against β decay.

Criterions for the conditions (2) and (3) are not deduced from the first principles and cannot be totally valid. Until a more advanced treatment of these problems is accomplished, we should consider that the criterions are phenomenological and have to be checked by experimental results. Let's try to analyze some cases for this check.

First of all, to illustrate a possible effect of a lattice on the phenomenon occurring in the nucleus, let us take up an experiment[2] showing a change of decay constant of tritium. Though the mechanism to reduce radioactivity of tritium in titanium is not known yet, the experimental results[2] show a possibility of the change of decay time by the influence of lattice nuclei and/or neutrons trapped there, from our point of view.

Second, it is well known from cold fusion experiments that materials showing the cold fusion phenomenon by occlusion of deuterium or hydrogen belong to elements with a mass number less than that of palladium ($A \sim 106.4$). This shows from the criterion Eq.(3) that at about this value of A, U_B becomes larger than $\sim U_A + 14.3\ A^{-2/3}$ (MeV). This means the threshold mass number A_0 is about 107;

Third, we can show a consistent explanation of several cold fusion experiments[3-5] by an assumption of the trapped neutron.

In an electrolysis experiment with a Ni cathode and Rb_2CO_3 electrolyte in H_2O, a correlated generation of excess heat and shift of the Sr isotope ratio were observed[3]. Assuming an existence of the trapped neutron in nickel and using a part of the experimental data, a consistent explanation of the remaining data was given[6]. And also the density N_n of the neutron in the sample was determined[6]: $N_n \sim 10^7\ \mathrm{cm}^{-3}$.

In an experiment[4] with a Pd cathode and LiOD + D_2O solution, the generation of excess heat and helium were observed with correlation. The density of the trapped neutron was determined[7] from the experimental data: $N_n \sim 10^{13}\ \mathrm{cm}^{-3}$.

In another experiment[5] with a Pd-black cathode instead of Pd rod in the above experiment, a huge excess heat and a large amount of helium generation ($10^{20} \sim 10^{21}\ \mathrm{cm}^{-3}$) were measured. In this case, the analysis[8] gave a neutron density of $N_n \sim 10^{15}\ \mathrm{cm}^{-3}$.

These values depend on the assumptions made in the calculation to supplement unwritten or unknown factors in the experiments and may vary one or two orders of magnitude. Even so, the explanations obtained there are consistent with each other and provide an insight into the physics of cold fusion.

It might be possible to confirm the existence of the trapped neutron by a neutron magnetic resonance (NMR) in a sample like the Pd-black used in the experiment[5] where the generated excess energy and helium were highly reproducible.

Conclusion

The cold fusion phenomenon has disclosed several facets of solid state - nuclear physics not noticed until a few years ago. One of the most impressive facets is the role of the thermal neutron, which is abundant on earth.

The neutron is difficult to touch, especially when its energy is thermally low. It is easily absorbed by a nucleus to produce a new stable or unstable nucleus. It decays, emitting an electron with an energy ~ 780 keV in about 900 s. The main part of the ambient neutron may be lost, thus not damaging living things.

On the other hand, looking at the long history of the life on the earth, the thermal neutron has been a part of the environment, like the air and water to which the life has accustomed itself. Thermal neutrons must be widely and profoundly involved in the phenomena around us, if we look at them with the new eyes of scientists. Perhaps, an era of the thermal neutron science has now been uncovered.

(The author would like to express his thanks to Messrs. M. Nomura, M. Ohta and S. Yamashita for their help in the preparation of this manuscript).

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