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NEW APPLICATIONS OF ULTRA COLD NEUTRON PHYSICS IN MAGNETIC AND GRAVITY FIELDS

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Résumé - Deux propositions concernant des expériences avec neutrons ultra froids (UCN) sont décrites. La première proposition est celle d'un ralentisseur magnétique à neutrons fonctionnant sur le principe de changements de spin adiabatiques et successifs dans des champs magnétiques forts qui produiront une haute densité de neutrons ultra froids polarisés. La seconde proposition est celle d'un spectromètre basé sur la focalisation par le champ de gravité offrant la possibilité d'obtenir l'angle de diffusion aussi bien qu'une très haute résolution en énergie des neutrons.

Abstract - Two proposals are described concerning the ultra cold neutron (UCN) experiments. The first is a magnetic neutron decelerator working with the principle of successive adiabatic spin flips of neutrons in strong magnetic fields which will produce high density polarized UCN through the multiple decelerations of cold or very cold neutrons. Another one is a fall focussing gravity spectrometer with a capability of scattering angle analysis as well as the very high energy resolution of UCN.

I. Introduction

Ultra cold neutrons (UCN) with the energy below about 1 μeV can be used in various fundamental physics experiments such as the EDM observations, the neutron lifetime measurements and so on. Furthermore, the use of UCN provides the possibility of very high resolution of neutron spectroscopy due to their low energy and the resulting intensity gain factor¹⁾. One of the most important requirements at present in this field of UCN experiments is the necessity of an intense UCN source for the developments of these various possibilities of UCN applications.

In the present paper, two possible applications of UCN physics which should serve to improve these intensity

situations will be described. The first is the proposal of a new principle of neutron magnetic deceleration by using adiabatic spin flips in strong magnetic fields, which should open the possibility of successive slowing down of neutrons from a wide energy region into a narrow energy region of UCN. The second part concerns a new version of the gravity spectrometer²⁾—i.e. the method of a fall focussing of UCN which improves the geometrical efficiency without noticeable deteriorations of the high energy resolution^{3,4)}.

II. Neutron magnetic decelerator

2-1. Principle

A neutron entering a magnetic field experiences positive or negative potential according to the polarization with the parallel or anti-parallel spin, respectively, to the direction of the magnetic field. Therefore, if the neutron spin can be converted from the initial state to the other in the midst of the magnetic field, then neutron deceleration or acceleration will occur when the neutron passed through the field. Recently, Rauch et al. developed such kind of a experiment showing the neutron energy shift due to the spin flip in a magnetic field by using the magnetic resonance method⁵⁾. The resonance method works well only for neutrons with a definite velocity which spend a certain time for the spin turn in the magnetic resonance coil, and thus the Rauch's method is exactly available for monochromatized neutrons.

In the present principle described below, the adiabatic method of spin flip^{6,7)} takes the place of the resonance method for the purpose of the efficient spin flips of neutrons in a wide energy region. A strong magnetic field with

a slight gradient in the magnitude is applied to the inside of the neutron guide tube, as shown in Fig.1. A high frequency coil is also prepared around the guide tube. The angular frequency ω of the coil should satisfy the relation

$$\omega = \gamma H_C \quad , \quad (1)$$

where $\gamma = 2\mu/\hbar = 18210 \text{ s}^{-1} \text{ G}^{-1}$ is the gyromagnetic ratio with μ the magnetic moment of a neutron, and H_C the magnetic field at an arbitrary point within the region of the slight gradient in the magnitude. Then, a spin flip occurs for the passage of neutrons in a wide velocity region satisfying the adiabatic condition ⁶⁾,

$$\gamma H_a^2 / (v |dH_C/dZ|) \gg 1 \quad , \quad (2)$$

where H_a is the amplitude of the high frequency field perpendicular to H_C .

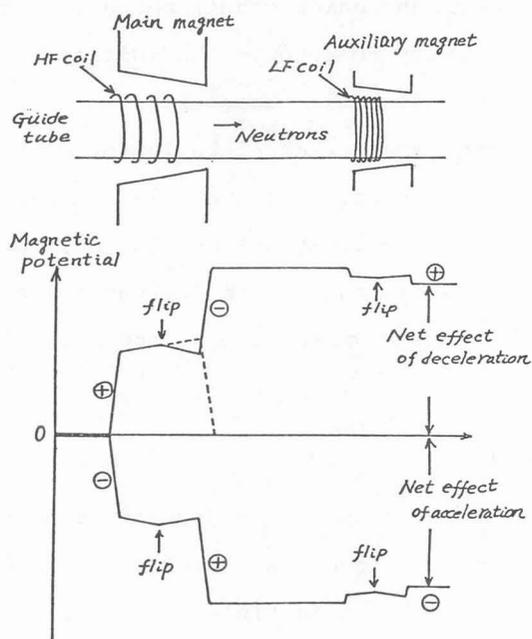


Fig.1 - A schematic structure and the magnetic potential variation in a neutron magnetic decelerator.

As the result, the initially parallel spin neutrons are decelerated with the amount of an energy difference of $2\mu H_c$, while the initially anti-parallel ones accelerated with the same amount of the energy difference. When the neutrons are going out of the field, there comes another point which satisfies again the relation (1), but making the field gradient at that point much steeper than the main point with the slight gradient, the occurrence of the double flips can be avoided for the neutrons within the velocity region of our interest. The same result will, of course, come out in a reversed arrangements of both the field gradient and the coil.

After passing through the deceleration (or acceleration) stage in the main magnet, neutrons should enter the auxiliary stage consisting of a much weaker magnet and a coil for a lower frequency in order to recover the initial spin state for the realization of successive decelerations (or accelerations). Due to a much smaller acceleration (or deceleration) effect in the auxiliary stage, we can obtain the net effect of the deceleration (or acceleration) per the unit process through the coupled stages, and we can further repeat the same processes until the neutrons arrive at the desired energy region.

2-2. UCN production

It will be possible to apply the present principle for the production of polarized UCN from initially cold or very cold neutrons through the multiple decelerations in a device with a number of units mentioned above, or by the cyclic passages of neutrons in a looped guide tube with a single or a few deceleration units. In the limit of

the slowing down, the neutron velocity should approach to the value of a limit velocity which satisfies the adiabatic condition in the region of the steeper field gradient also. Then, the effective deceleration will not occur any more, and as the result a final distribution of the neutron velocity will be built up in the device.

In the extreme case that the energy of the neutrons with such a limit velocity is smaller than the maximum value of the magnetic potential felt by the neutrons, then the decelerating neutrons will be repelled at last before the appearance of the above-mentioned situation of the double flips. Anyway, a balancing density of the decelerated neutrons will be realized at the lowest energy region in an actual condition of a finite feed intensity and a finite storage time of neutrons in the device.

2-3. A preliminary experiment

A preliminary experiment is now being carried out by using a simple device and the UCN output produced by the supermirror neutron turbine at KUR^{8,9)}, as shown in Fig. 2. In the present experiment, the turbine is modified to produce pulsed UCN output and we observed the time-of-flight spectra of neutrons transmitted through a straight rectangular guide tube with the inner size of 5 cm x 2 cm and the inside coated with copper.

A typical result of the comparison between the spectra for the high frequency coil current alternatively changed off and on so often is shown in Fig. 3 for the experimental conditions of the field $H_c = 2.16$ kG (i.e. $\nu = \omega/2\pi = 6.30$ MHz), the field gradient $dH/dz = 53.3$ G/cm, the high frequency current $I_{pp} = 15$ A and the effective flight path length of about 28 cm. As for the polarizer and the analyzer, Co 92% and

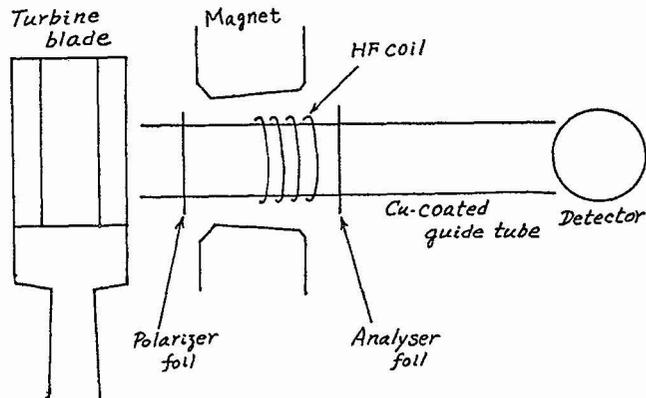
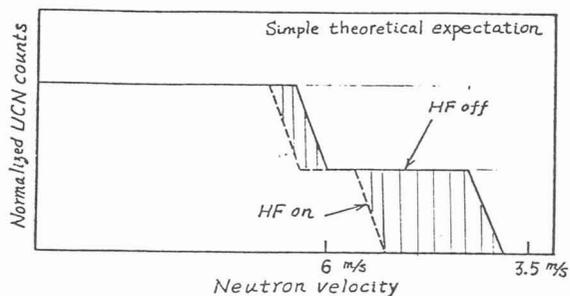


Fig.2 - Set up of a preliminary experiment for a neutron magnetic decelerator.

Fe 8% alloy evaporated on thin aluminium foils were used.

Although the statistics are not sufficiently good in the Figure, the result shows the effects of the adiabatic spin flip occurring for neutrons in the velocity region below about 6 m/s. The expected deceleration or acceleration effects could not be discussed definitely in the present result because of the low countings and the moderate strength of the magnetic field. Further measurements are carried out in order to make the deceleration effects more clear, and furthermore, an advanced experimental set-up with a much stronger magnetic field of ~ 10 kG is also in preparation.



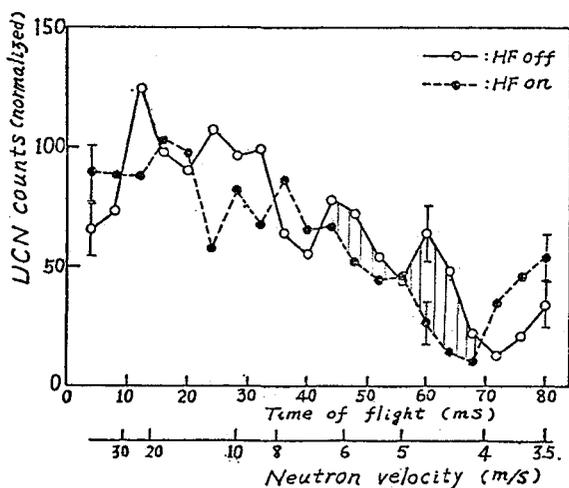


Fig.3 - Preliminary result showing the comparison between the repeated alternative measurements of the high frequency current off and on.

III. Gravity spectrometer with fall focussing of UCN

The gravity brings significant effects on the trajectory of UCN, and therefore an ultra high resolution spectrometer can be developed for UCN with the principle utilizing the gravity effects. Actually, Steyerl's reach focussing gravity spectrometer named NESSIE²⁾ is now working at FRM reactor with the highest energy resolution of $\Delta\varepsilon \approx 17$ neV. Now, we are proposing another type of a gravity spectrometer working in the principle of fall focussing of UCN which provides a higher geometrical efficiency for the neutrons^{3,4)} With the present principle of the fall focussing, it will become possible to analyse the scattered neutron energy distributions for several scattering angles at once by using the device as shown in Fig.4. Some numerical studies are now carried out for a typical case of the proposed structure.

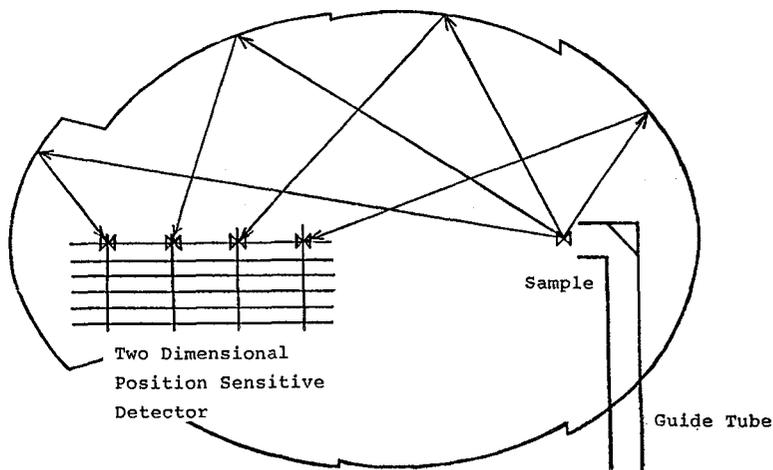


Fig.4 - A schematic design of the fall focussing gravity spectrometer with scattering angle analyses.

The present principle of the fall focussing of UCN requires the preparation of a specially designed curved mirror system, but the preparation of such mirrors with required sizes and with the satisfactory surface accuracy was found to be possible. A test experiment by using a small part of such a mirror is starting at the site of the supermirror turbine mentioned above.

IV. Concluding remarks

Employment of the adiabatic spin flip gets rid of the problems of the high magnetic field uniformity and the high stability which should become severe requirements in the case of the resonance method. Further, by using the principle of the magnetic deceleration, it can also be thought possible to use fully the source neutrons for multiple UCN productions. For the gravity spectrometer proposed, shielding from the possible background neutrons due to multiple scattering and diffuse reflections will be required to carry out an accurate

experiment. Anyway, for both proposals described above, experimental verifications of the applicability will be the most important subject, and they are now under progress.

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