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Helium-filled proportional counter (~4.2 K) and possible application to high-resolution neutron position detector

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Abstract

Using a technique for the cryogenic helium-filled proportional counter, we are trying to develop a new neutron position-sensitive detector, of which resolution is expected to be below 1 mm. A basic idea for the position detector is described in this report.

Text

A counter, which is filled with pure helium gas, operates well in the proportional region at low temperatures near 4.2 K. This helium-filled proportional counter (HFPC) is often applied to the cryogenic conversion-electron Mössbauer spectroscopy for solid- state studies. In the Mössbauer measurements, HFPC is used to detect electrons resonantly scattered from the sample, which is mounted as a cathode of HFPC, and the whole of HFPC is cooled down to the low temperatures [1,2]. The performance of HFPC at the low temperatures has been examined in detail in a series of our studies [3-6]. With the counter technique for HFPC, we are now developing a new position-sensitive detector available for diffraction or scattering experiments of thermal and cold neutrons; the expected position resolution is below 1 mm.

A counter filled with ^{3}He gas is usually employed to detect thermal and cold neutrons. In the counter, the neutrons produce a proton, p, and a tritium, ^{3}H, through the nuclear reaction of

$$n + {}^{3}He \rightarrow {}^{3}H\,(191\ keV) + p\,(573\ keV) \qquad (1)$$

There are some merits to use ^{3}He as the counter gas. First, because the cross section of the reaction (1) is very large, i.e. 5500 barn, a detection efficiency for neutron become high. Second, the small atomic number of ^{3}He (Z=2) decreases a detection efficiency for γ ray comparing with other possible filling gases: the background of γ ray is relatively large in neutron scattering experiments.

The yiels of the reaction (1), i.e., ^{3}H and p, are emitted in the opposite direction each other, because the energy of an incident neutron is very small, e.g., 25 meV for thermal neutrons. When the ^{3}He-filled counter is applied to position detection of incident neutrons, the counter detects the position of the center of total electric discharge produced by ^{3}H and p. The range of a proton is much longer than that of ^{3}H, which causes a gap between the position of the reaction (1) and that of the center. This gap determines the limit of the position resolution. The FWHM of the position resolution is approximately given by

$$\Delta\,(\mathrm{FWHM}) \sim 0.8\, r_{p} \quad , \qquad (5)$$

where r_p is the range of a proton. The value of Δ (FWHM) becomes 39 mm in ^{3}He gas with a pressure of 1 atm at room temperature.

The range of charged particle in gas is inversely proportional to the number density of gas atoms or molecules. A way to improve the position resolution of the ^{3}He-filled counter is to increase the ^{3}He gas density. If ^{3}He gas with a pressure of 40 atm can be filled in the counter at room temperature, the range of p is decreased to about 1 mm in principle. However, the counter with such a highly pressurized gas is practically difficult to be fabricated. When ^{3}He gas with a constant number density is cooled down to low temperatures near 4.2 K, its pressure is drastically decreased. For example, the pressure of 40 atm at room temperature corresponds to 0.56 atm at 4.2 K. Therefore, it is expected that the cryogenic HFPC technique developed by us is available to develop a new neutron position-sensitive ^{3}He-filled proportional counter, in which the gas pressure is kept below 1 atm by cooling at 4.2 K. Since the cross section of the reaction (1) is very large, a gas mixture of ^{4}He and ^{3}He can be used as filled gas. According to the idea explained above, we are systematically examining the property of HFPC with high gas densities at 4.2 K, which correspond to 20～60 atm at room temperature.

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