Some considerations on TOF-NSE

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Recently a future plan of a huge spallation neutron source has been proposed in a framework of the Japan Hadron Project (JHP), in which accelerated protons with 100-200 μA and 1-2 GeV will be used for the production of neutrons. Here, as a new concept, a unique cold moderator is considered, which can produce high intense pulsed-cold-neutrons with the extreme wide burst-width. If it will be realized, it will confer benefits on elastic scattering TOF-instruments, such as SAN in KENS, which does not require high time-resolution. However, it is a "devil" for ordinary inelastic scattering TOF-spectrometers with high energy-resolution, such as LAM in KENS. In these inelastic spectrometers, high time-resolution is required and the energy-resolution is approximately given by 2(burst-width)/(time-of-flight). It means that the ordinary inelastic scattering spectrometer with $\varepsilon/E_i = 0.005$ must be constructed much farther from this moderator, at about 300 m.

Because the area of JHP is very small, it is hard to prepare such a long flight path. Even if it could be constructed with the long flight path, the available band-width of neutron wavelength becomes very small. For our future plan, many attempts should be performed to "invent" a new type of the TOF-spectrometer, which can realize the high energy-resolution even in the condition of a short distance and a wide burst-width on various spectrometers, including the ordinary one.

The TOF spin-echo method (TOF-NSE) is one candidate for these trials. The pure spin-echo method[1] has been already realized on the steady state sources, and many low energy excitations in magnetic systems, polymers and so on, have been observed. TOF-NSE was proposed by Mezei in 1979[2] but not still realized at the spallation neutron sources. At KENS, we constructed a test machine of TOF-NSE in 1983.

If incident polarized neutrons with velocity V_1 is used in NSE, the polarization observe dby the analyzer, $P(V_1)$, can be written as

$$P(V_1) = \int d\epsilon S(\epsilon) cos(\omega_1 t_1 - \omega_2 t_2), \qquad (1)$$

where $\epsilon = m(V_1^2 - V_2^2)/2$, $t_1 = l_1/V_1$,$t_2 = l_2/V_2$ and $\omega_{1,2} = \gamma H_{1,2}$. m is the neutron mass, $H_{1,2}$ a magnetic field in pressesion section I and II, and V_2 is the velocity of scattered neutrons. $S(\epsilon)$ is a scattering function of a sample. If $V_1 - V_2 \ll V_1$ and $l = l_1 = l_2$ and $H = H_1 = H_2$, Eq.(1) is written as

$$P(V_1) = \int d\epsilon S(\epsilon) cos(\tau\epsilon) = S'(\tau), \tag{2}$$

where $\tau = \gamma l/(mV_1^3) \cdot H$. In principle, it is possible to measure $S'(\tau)$ in two kinds of neutron sources; the steaty state source and the pulsed source. In the case of the steady state source, τ can be represented as a function of H because of $V_1 =$ constant, and $S'(\tau)_{steady}$ can be observed by changing magnetic field H. In the case of the pulsed source, pulsed white neutrons are used as incident neutrons. Here, V_1 is determined as $V_1 = L/t$ and τ can be written as $\tau = \gamma Hl/(mL^3) \cdot t^3$, where L is the total flight-path length and t the time-of-flight. This means $S'(\tau)_{TOF}$ can be automatically observed as a function of t^3 in the constant magnetic field H. This is a most useful nature of TOF-NSE.

A schematic layout of TOF-NSE is shown in Fig.1. Here we assume that π-turner and $\pi/2$-turners perfectly work for every neutron verocity, and that $l_3 = l_4 = l_5 = l_6 = l_7 = 0$ and $\delta l_0 = 0$ in order to simplify the equation. The observed TOF-spectrum, I(t), is written as

$$I(t) = 1/2 \int P^t P_1^l P_2^l P_1^\omega P_2^\omega \delta(t - t_0 - t_1 - t_2)(1 + cos(\omega_1 t_1 - \omega_2 t_2))$$

$$S(\epsilon)\delta(E_i - E_f - \epsilon) dt_0 dt_1 dt_2 d\omega_1 d\omega_2 d\epsilon. \tag{3}$$

Here, $P_{1,2}^l$ and $P_{1,2}^\omega$ represent are fluctuations of the lengths and the presession frequency in presession sections (i = 1,2), respectively. E_i and E_f are incident and scattered neutron energies, respectively. P^t is a pulse shape function of the neutron burst. Let's represent $P_{1,2}^l$, $P_{1,2}^\omega$ and P^t by Gaussian as

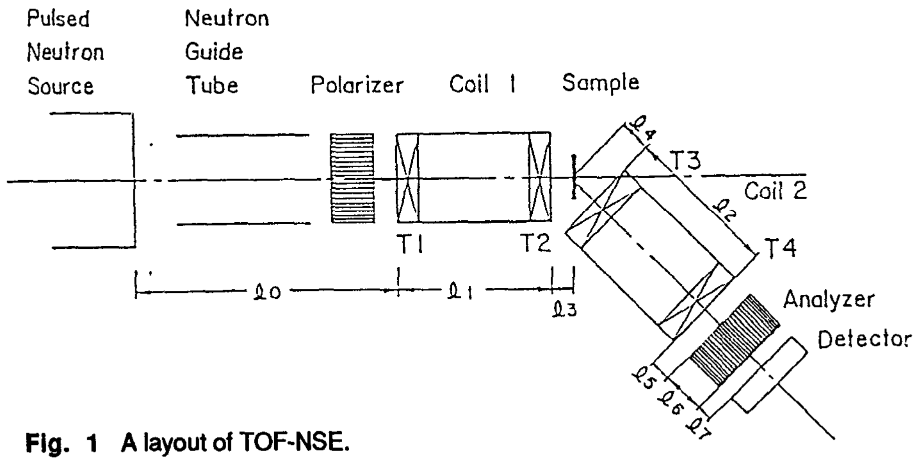

Fig. 1 A layout of TOF-NSE.

$$P^t = (\sqrt{2\pi}\sigma_t)^{-1} exp(-(t_0 - t_0^0)^2/2\sigma_0^2), \tag{4}$$

$$P^{\omega}_{1,2} = (\sqrt{2\pi}\sigma_{\omega_{1,2}})^{-1} exp(-(\omega_{1,2} - \omega^0_{1,2})^2/2\sigma^2_{\omega_{1,2}}) \tag{5}$$

and

$$P^l_{1,2} = (\sqrt{2\pi}\sigma_{l_{1,2}})^{-1} exp(-(l_{1,2} - l^0_{1,2})^2/2\sigma^2_{l_{1,2}}), \tag{6}$$

where t_0^0, $\omega^0_{1,2}$ and $l^0_{1,2}$ are mean values of t_0, $\omega_{1,2}$ and $l_{1,2}$. σ_0 corresponds to the neutron burst-width. If $\sigma_{l_{1,2}}/V_1 \ll \sigma_0$, I(t) can be written as

$$I(t) = (2\sqrt{2}\pi\sigma_0)^{-1} \int dt_0 d\epsilon exp(-(t - t_0^0 - t_1^0 - t_2^0)^2/2\sigma_0^2)$$

$$[1 + \Psi(a_1, a_2)\Phi(a_1, a_2)]S(\epsilon)\delta(E_i - E_f - \epsilon). \tag{7}$$

Here,

$$\Psi(a_1, a_2) = a_1 a_2/\sqrt{(a_1^2 + g_1^2 h_1^2)(a_2^2 + g_2^2 h_2^2)}$$

$$\cdot exp(-(g_1^2 + h_1^2)/(a_1^2 + g_1^2 h_1^2) + (g_2^2 + h_2^2)/(a_2^2 + g_2^2 h_2^2)) \tag{8}$$

and

$$\Phi(a_1,a_2) = cos(a_1/(a_1^2+g_1^2h_1^2) - a_2/(a_2^2+g_2^2h_2^2)) \qquad (9)$$

where $t_0^0 = l_0/V_1$, $a_i = V_i/\omega_i^0 l_i^0 = 1/\omega_i^0 t_i^0$, $g_i = \sigma_i^l/l_i^0$ and $h_i = \sigma_i^\omega/\omega_i^0$.

$\Psi(a_1,a_2)$ and $\Phi(a_1,a_2)$ are a damping factor and an oscillation factor, respectively. Since $V_1 \sim V_2$, $\Psi(a_1,a_2)$ is described by

$$\Psi(a_1,a_2) = \Psi_g(a_1) = a_1^2/(a_1^2+g^4)exp(-2g^2/(a_1^2+g^4)). \qquad (10)$$

where $g = g_1 = g_2 = h_1 = h_2$ is assumed in order to simplify. $\Psi_g(a_1)$ was calculated as a function of $H \cdot l$ in the case of $\lambda_1 = 9A$, and is shown in Fig.2. Here, λ_1 is a wavelength of incident neutron. Furthermore $\Psi_g(a_1)$ was calculated as a function of λ_1 in the case of $H \cdot l = 120$ Oe, and is shown in Fig.3. If $g > 10^{-4}$, $\Psi_g(a_1)$ goes down drastically as λ_1 or $H \cdot l$ increase. These results indicate $g < 10^{-4}$ is required to obtain a good neutron economy. In the same assumption, the oscillation factor Φ is described by

$$\Phi(a_1,a_2) = \Phi_g(a_1,a_2) = cos(a_1/(a_1^2+g^4) - a_2/(a_2^2+g^4)). \qquad (11)$$

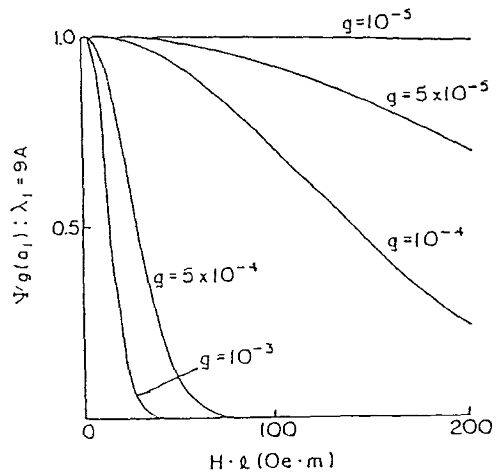

Fig. 2 Damping factor Ψ_g and H · l. The solid lines are calculated with $\lambda_1 = 9$ Å.

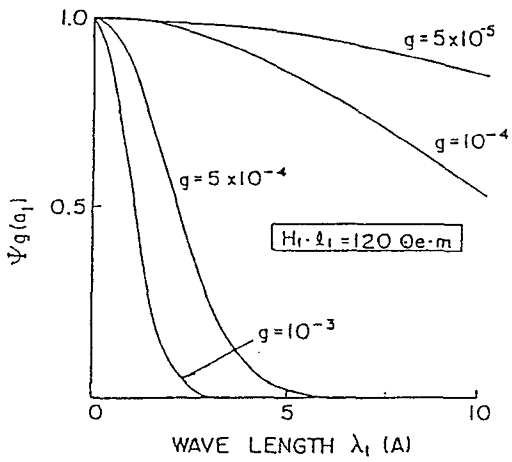

Fig. 3 Damping factor Ψ_g and wavelength λ_1. The solid lines are calculated with $H \cdot l = 120Oe \cdot m$.

In the case of $S(\epsilon) = (\delta(\epsilon - \epsilon_0) + \delta(\epsilon + \epsilon_0))/2$, $H \cdot l = 120Oe \cdot m$ and $g = 10^{-4}$, $\Phi_g(a_1, a_2)$ was calculated with $\epsilon_0 = 2\mu eV$ and $\epsilon_0 = 10\mu eV$ and shown in Fig.4. This results show the oscillation of $\Phi_g(a_1, a_2)$ with $\epsilon > 2\mu eV$ can be observed in the range $2.5A < \lambda_1 < 10A$.

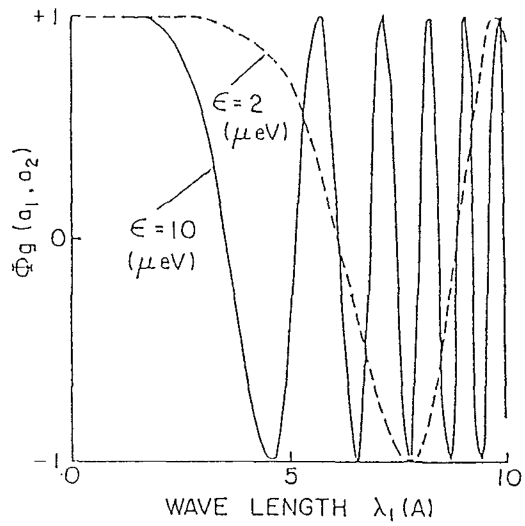

Fig. 4 Oscillation factor Φ_g and wavelength λ_1. The solid line is calculated with $\varepsilon = 10$ μeV and $H \cdot l = 120Oe \cdot m$. The dashed line is calculated with $\varepsilon = 2$ μeV and $H \cdot l = 120Oe \cdot m$.

The effect of the burst-width on the TOF-NSE should be discussed using Eq.(7). As is obvious from this equation, if the burst-width is much smaller than a period of Φ_g one can expect no effects on TOF-NSE spectrum. Since Ψ_g changes very slowly under g = 10^{-4} as shown in Figs.2 and 3, it is possible to consider that Ψ_g is not affected by the burst-width. In order to observe a clear oscillation of $S'(\tau)_{TOF}$ under $l_0 = 18m$ and $0 < \lambda_1 < 9A$, the following condition is at least required:

$$3\epsilon\omega l \cdot (burst - width)/(2l_0 \cdot 1000) \sim 0.1 \ll 1 \quad (12)$$

In the case of $(burst - width) \sim 200\mu sec$ (KENS-I) and $H \cdot l = 120Oe \cdot m$, the ' no effect ' can be realized in the range $\epsilon < 17\mu eV$. Under these results, our test machine was designed with $g \sim 10_{-4}$ and $H \cdot l = 120Oe \cdot m$. It is shown by the photograph (see Fig.5). In the case of $(burst - width) \sim 1000\mu sec$ (JHP) and $H \cdot l = 120Oe \cdot m$, one can observe the clear oscillation only in the range $\epsilon < 3\mu eV$. These results indicate that the TOF-NSE spectrum is much affected by the burst-width and can give correct information on $S(\epsilon)$ only in very small range. If one constructs TOF-NSE under the wide burst-width, the complete determination of many parameters mentioned above and the precise data correction will be necessary.

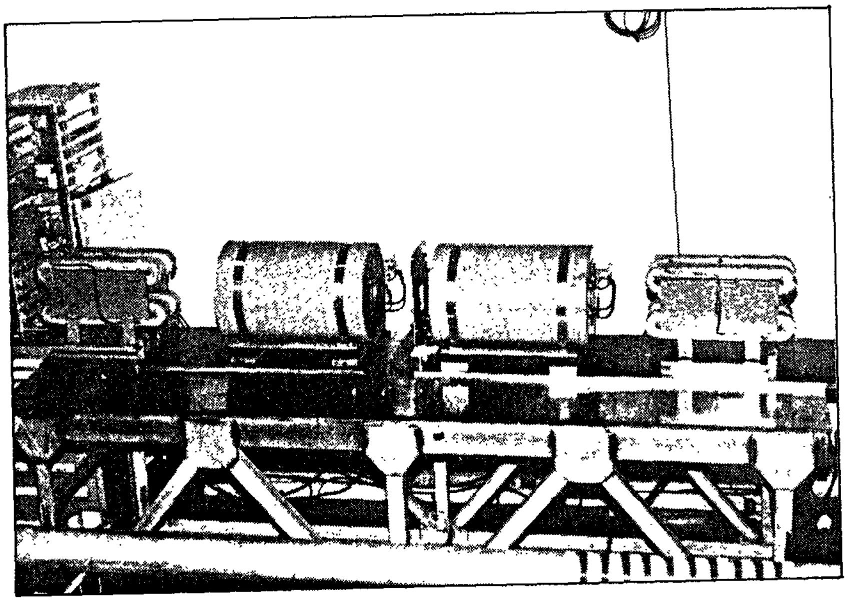

Fig. 5 Photograph of the test machine.

References

1. F. Mezei, Z. Physik 255 (1976) 146.
2. F. Mezei, Nucl. Instru. Methods 164 (1979) 153.