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Recent progress in TOP spectrometer

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ABSTRACT

We have continuously improved the polarized cold neutron spectrometer which is named TOP. Several methods for polarized cold neutron experiments can be considered, and in the depolarization measurement we have currently obtained the excellent results. In the present development, we modified the spectrometer for the purpose of the achievement of small angle neutron scattering (SANS) experiment to the practical level.

I. Introduction

The TOP spectrometer (Time-of-flight spectrometer with Optical Polarizer) was constructed at the pulsed cold neutron source (KENS) at the National Laboratory for High Energy Physics (KEK) to study mesoscopic magnetism in 1980[1),2)], and the wide mesoscopic scale is covered by various methods. We are aiming to obtain complementary informations over the wide scale.

To investigate the magnetic structure of the mesoscopic system, polarized cold neutrons are advantageous, and we can consider several methods using the TOP spectrometer as follows;

SANS	
integrated intensity	(already established)
scattering function	(present development)
polarization analysis	(under construction)
Reflection	(under construction)
Depolarization	(already established)

In the previous TOP spectrometer, the depolarization method has been achieved to the practical level and the excellent results have been obtained for the studies of magnetization process of ferromagnets or spin glass[3)]. In the SANS experiments, we obtained good results for the studies where the integrated intensities were discussed, for instance, the study of helical spin structure[4)], however, the scattering functions could not be discussed due to poor resolution. Therefore we decided to modify the spectrometer using a position sensitive detector (PSD) system and improved both resolution and total counting rate. We mainly report the development of the SANS system.

II. Overall layout

The typical SANS system where the resolution and the intensity are optimized consists of the moderator, the sample and the ditector[5]. In the TOP spectrometer, there exist a neutron guide tube and a polarizer between the moderator and the sample. Neutrons are propagated by total reflection in the guide tube and the polarizer. Since the divergence of neutron beams propagated by total reflection are not changed, the moderator surface can be replaced by the outlet of the polarizer. On the basis of the optimization for the geometry mentioned above, we modified the TOP spectrometer introducing a PSD system. PSD's adopted in our development are 1/2 inch in diameter and 24 inches in effective length with ^3He of 10 atm in pressure. Three PSD's are parallely arranged and essentially one-dimensional measurements are aimed, since the measurements of the magnetic scattering are mainly performed and the magnetic scattering occurs one-dimensionally for an applied field. The positional resolution at PSD's is 1.1 cm and the width of a timing channel in the time analyzer is 1.536 msec.

The overall layout of the TOP spectrometer is displayed in Fig.1. The polarizer and the spin flipper were already established[1),2)]. We mainly designed a new scattering chamber to minimize the air scattering effect, so that we can assemble the detecting system in the vacuum chamber at 0.01 Torr in pressure.

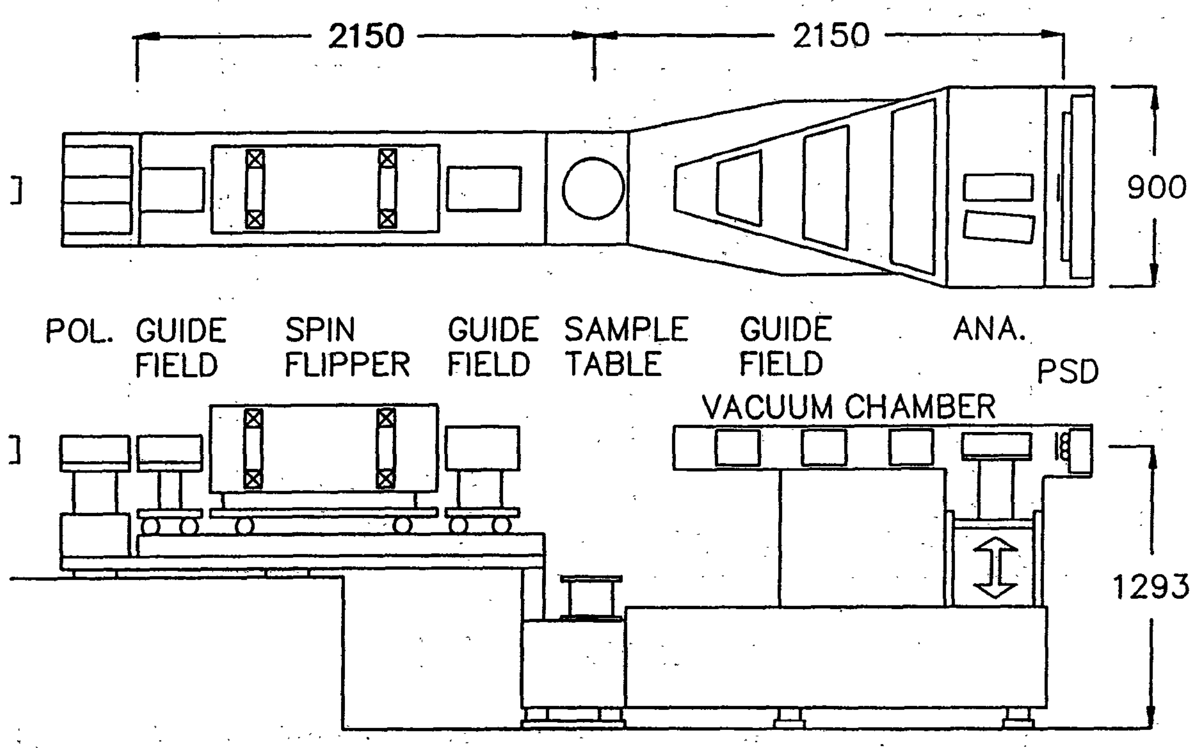

Fig.1 Schematic drawing of the TOP spectrometer.

We also mounted preamplifires, polarization handling devices such as spin analyzers and guide magnets with a uniform field of 30Oe, a mechanical elevator for setting the analyzers, and a beam stopper system in front of PSD's in the compact scattering chamber. We mounted two analyzers for transmitted beams and for scattered beams. The analyzer for scattered beams is mounted at one position of 5°, 6°, 7° and 8° in the scattering angle. Two analyzers are on a table and the reflecting angle of neutrons within the analyzer is set by rotation of the table. The analyzers are removed downward in the experiment without analyzers.

Moreover, we developed data acquisition system in the introduction of PSD system, which was already reported[6].

III. Characteristics of SANS system

First we estimate the Q-range and its resolution in the SANS experiment with the typical experimental condition. In the typical condition, the ranges of the scattering angle and the wavelength are ϕ=1.0~8.1° and λ=3~9Å, respectively, and their resolutions are $\Delta\phi$=14mrad and $\Delta\lambda$=0.19Å, respectively. Figure 2 shows the calculated Q-range and its resolution ΔQ for the typical condition. The Q-range between 0.012 and 0.29 $Å^{-1}$ is covered, practically 0.02~0.28 $Å^{-1}$ is covered. ΔQ shows weak dependence on scattering angle ϕ and λ, and ΔQ=0.01 for 9Å in wavelength.

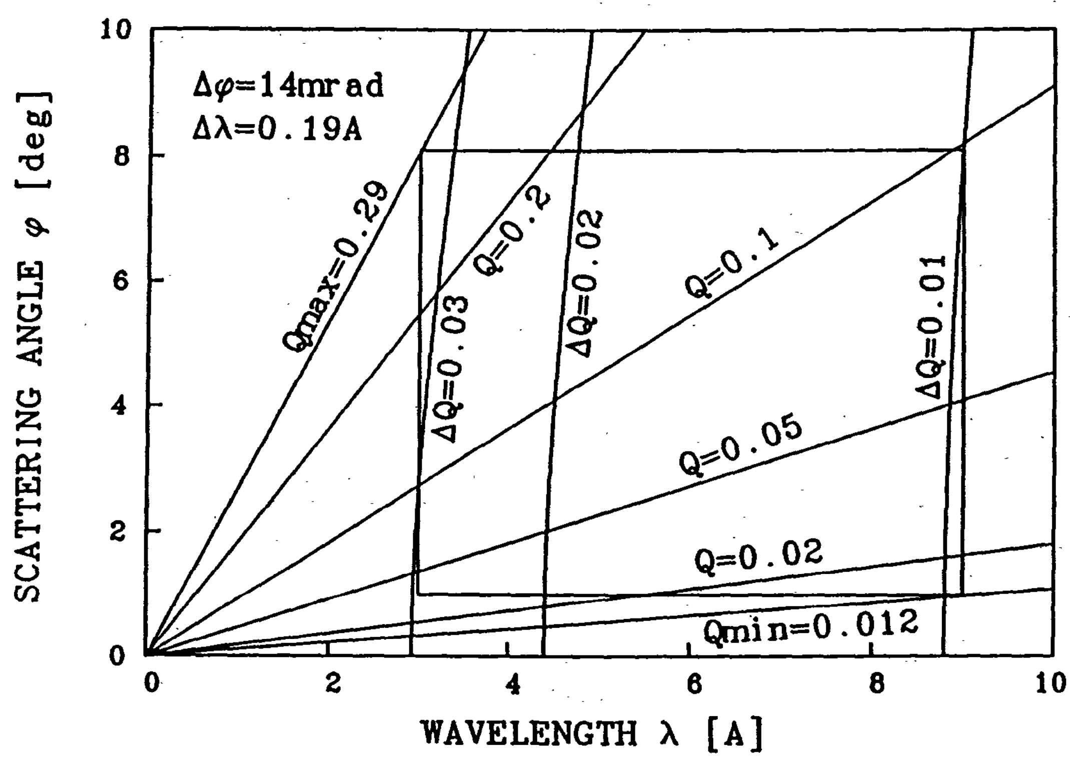

Fig.2 The Q-range and its resolution ΔQ calculated for the typical experimental condition. The inside region of the rectangle is available.

Next, Figure 3 shows the intensity against the positional channel of PSD's, integrated over the timing channels and reduced to the intensity at the sample position. The sample is H_2O of 1mm in thickness. The divergence of the incident beams is 7mrad both vertically and horizontally. The divergence is corresponding to the collimation determined by the area of the polarizer outlet and the beam cross section of the sample.

Additionally we also improved the polarization using supermirrors. The quality of polarized neutrons consists of polarizing efficiency of the polarizer P_P, that of the analyzer P_A and the flipping efficiency of the spin flipper f. Figure 4 shows the polarizing qualities $P_P P_A$ and f determined by the measurement of transmitted beams. The flipping efficiency f is almost unity in the whole range of wavelengths. The polarization efficiency $P_P P_A$ in the present development is greater than that of the previous TOP spectrometer. In the measurement, the analyzer was the supermirrors for the present status and the previous type mirrors[2)] for the previous status, and the polarizer was the previous type mirrors for each status. The principle of the previous type mirrors is based on the spin-dependent total reflection. Therefore the difference of $P_P P_A$ between the present TOP and the previous TOP is the difference between the supermirrors and the previous type mirrors. We are planning to use a supermirror polarizer in no distant future.

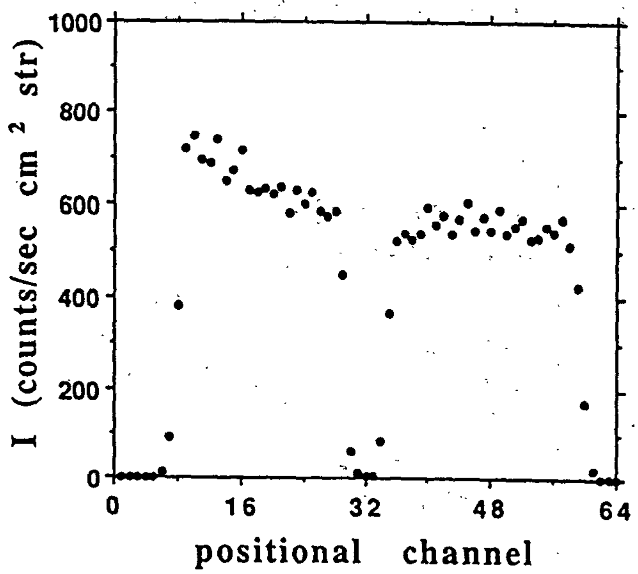

Fig.3 Normalized intensity against the positional channels of PSD's, integrated over the timing channels and reduced to the intensity at the sample position.

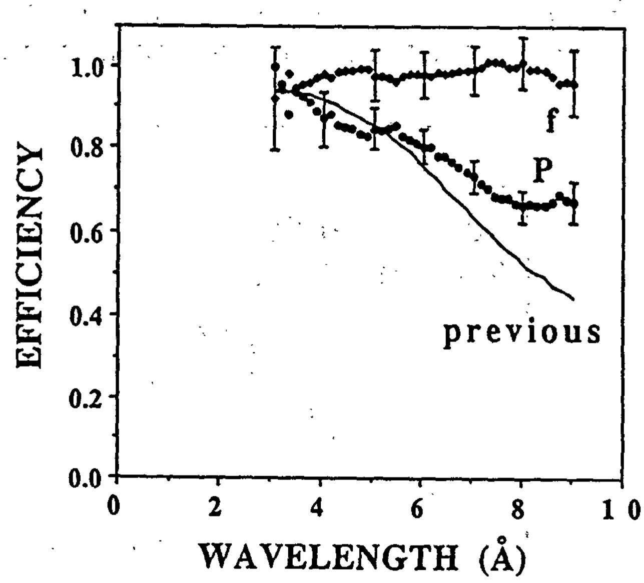

Fig.4 Wavelength dependence of the polarizing efficiency $P_P P_A$ and the flipping efficiency f. The solid line is the polarizing efficiency of the previous TOP spectrometer.

IV. Demonstration

Now we demonstrate an example of the SANS experiment. Figure 5 shows the scattering intensities from a cobalt ferrofluid[7]). The beam cross section is $1cm^2$ and the sample thickness is 1mm. It spent about 2 hours to measure each scattering curve. The shoulder on the intensity is corresponding to the interparticle correlations. Ferrofluids are colloidal suspensions of ferromagnetic particles of about 100Å in diameter and a suitable system for polarized SANS experiments.

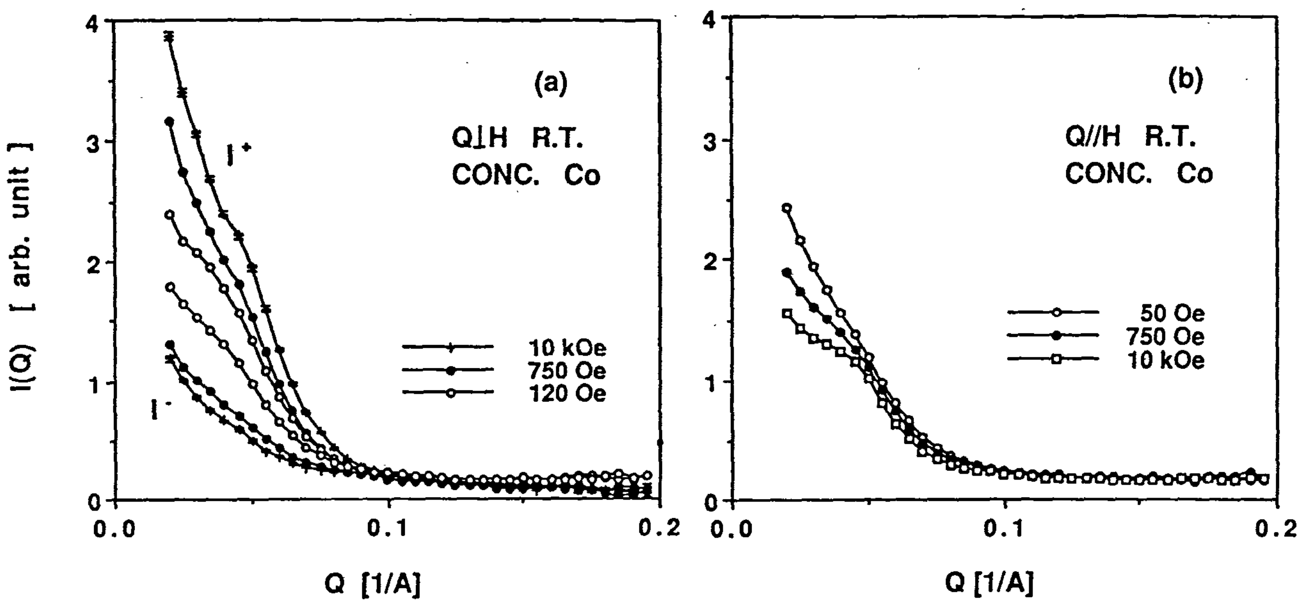

Fig.5 The observed scattering intensities from a cobalt ferrofluid. It spent about 2 hours to measure each scattering curve.

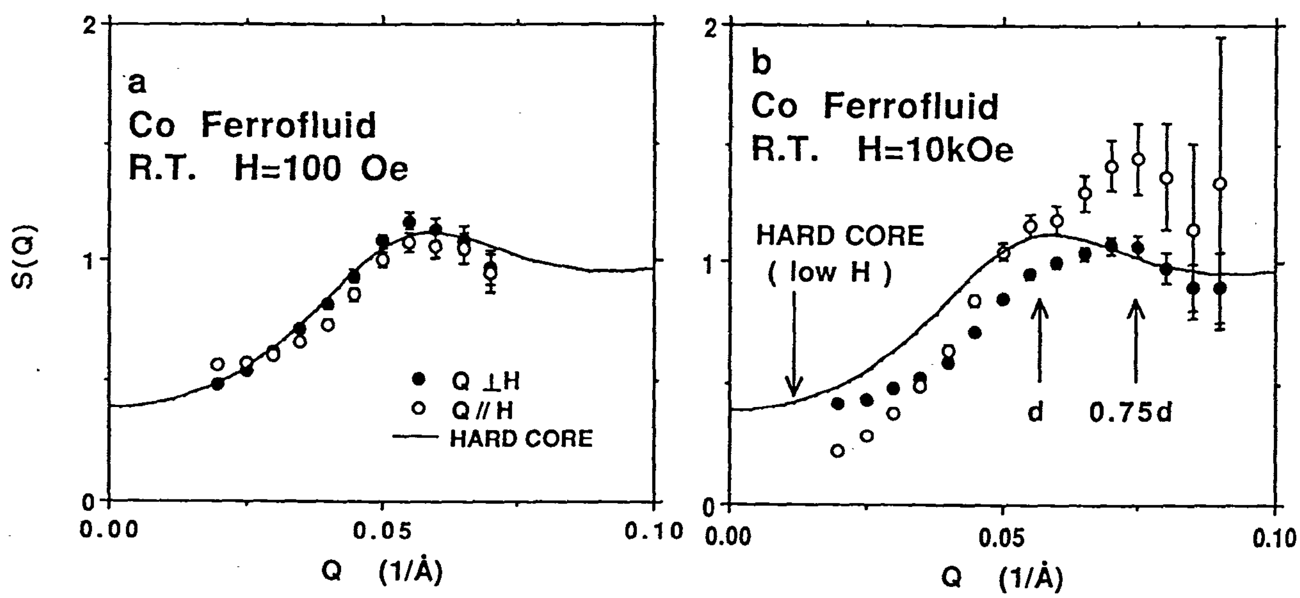

Fig.6 Distinguished structure factors under Q⊥H (closed circle) and Q//H (open circle). The interparticle correlations are isotropic under the weak external field of 100Oe (a) and anisotropic under the strong field of 10 kOe (b).

The structure factors distinguished from the intensities are shown in Fig.6. The interparticle correlations are isotropic under 100Oe but anisotropic under 10 kOe. First, the structure factors under the weak field are well approximated to random distribution of spherical particles, so-called Percus-Yevick approximation[8]. The solid line in Fig.6 is the calculation for the parameters of the volume fraction including surfactants η=0.11 and the diameter d=90Å which are experimentally determined. Next, the structure factors are anisotropic under the strong field and each structure factor has a main peak in the position corresponding to the particle-particle distance 0.75d and a shoulder corresponding to d. This result indicates that the particles are aggregated densely and the aggregation is stretching along the strong filed.

V. Conclusion

We have continuously improved the TOP spectrometer. The SANS experiments have achieved to the practical level by the present development and we have obtained excellent results. By the depolarization method, excellent results have been currently obtained as in the past.

Our next step is the development of the polarization analysis of the SANS system and the reflection method. In the present status of polarization analysis of SANS, the smallest scattering angle is 5°. If the analyzer can be placed at the position of smaller angle, for instance 2°, polarization analysis will work for the strong small angle scattering. Further developments are required and it is now under construction. The reflection method was listed above as another possible experiment using polarized neutrons. This method is known to be useful for studies of surface magnetism. Well-collimated beams are required for the realization of this method, it is also under construction. After these construction, we will achieve our purpose.

References

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Q(J.B.Hayter): Does the polarization efficiency drop at longer wavelength because of depolarization effects somewhere in the instrument (perhaps in the Drabkin flipper)? Normally, it is easier to obtain good efficiency at long wavelength, unless q is small enough that (q/λ) becomes very small.

A(S.Ito): For the Soller type magnetic mirrors, spin dependent critical wavelengths $\lambda_c^{\pm} \sim (b \pm p)^{-1/2}$ exist, neutrons are polarized in the range of $\lambda_c^{+} < \lambda < \lambda_c^{-}$. If we could ideally choose as $b = p$, $\lambda_c^{-} \rightarrow \infty$, however, λ_c^{-} becomes finite because of the difference between b and p. Therefore beam is depolarized by the neutrons in other spin state.

Q(R.Pynn): Why does the polarization decrease with wavelength on TOP?

A(S.Ito): N/A