Diffraction-grating neutron interferometer

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(Submitted 3 March 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **33**, 392–395 (5 April 1981)

A neutron interferometer using diffraction gratings is described. An optimization of the interferometer increases its luminosity by a factor of more than 30. Estimates show that this interferometer could be used in experiments in medium-flux reactors.

PACS numbers: 29.30.Hs, 28.40.Nw

According to the principle of coherent splitting of the incident beam, all neutron interferometers may be classified as devices in which the wavefront is split up in a spatial sense (for example, the biprism interferometer of Ref. 1) or in an amplitude sense (for example, the perfect-crystal interferometer of Ref. 2).

There is yet another way to arrange a coherent amplitude splitting of wavefronts: by using diffraction gratings. In this letter we analyze the possibility of developing a neutron interferometer which uses this method for splitting and recombining neutron beams.

The neutron diffraction gratings used in the present experiments were photolithographed diffraction gratings on glass with a rectangular surface relief, on which a Ni^{58} film ≈ 2000 Å thick was deposited (Fig. 1b). When a neutron beam was incident at an angle smaller that the critical angle for the coating material, the reflection coefficient became modulated (it vanished for the vertical parts of the profile), and the structure became a reflection diffraction grating.

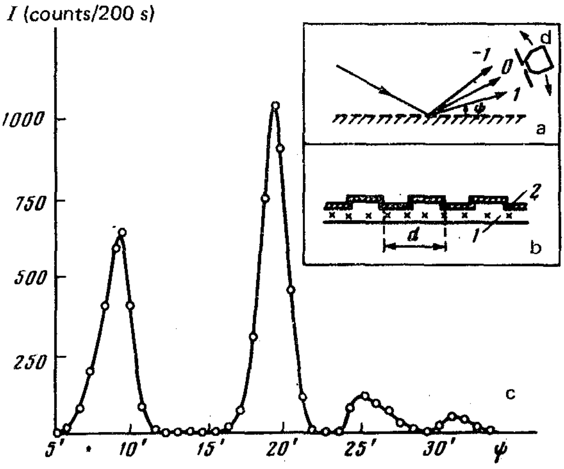

FIG. 1. Diffraction of a beam of monochromatic neutrons by a neutron diffraction grating. (a) Experimental arrangement. (b) Neutron diffraction grating. 1–Photolithographed diffraction grating on glass; 2–Ni^{58} film, ≈ 2000 Å thick (c) Angular distribution of the intensity in the reflected beam of monochromatic neutrons ($\lambda = 2.7$ Å, $\Delta\lambda/\lambda = 0.045$). The grating period is $d = 0.021$ mm.

Figure 1c shows the angular intensity distribution in a reflected beam of monochromatic neutrons ($\lambda = 2.7$ Å, $\Delta\lambda/\lambda = 0.045$), which was incident at an angle ≈ 19′ on a grating with a period $d = 0.021$ mm. The diffraction efficiencies were 4.5% and 7.3% for diffraction orders +1 and 0, respectively, in good agreement with the results achieved with ruled neutron diffraction gratings.[3]

The interferometer arrangement is shown in Fig. 2. An incident beam of monochromatic neutrons is diffracted by coherent beam splitter BS, and two mutually coherent beams, 1 and 2, are formed. These two beams are deflected by mirrors M_1 and M_2 to device A, at which the beams are brought back into spatial coincidence by diffraction. A change produced in the phase relationship between the beams (by inserting a phase shift into one of the beams or by inserting different phase shifts into the two beams) causes an amplitude modulation of the output beam:

$$I(\Delta\phi) = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \Delta\phi,$$

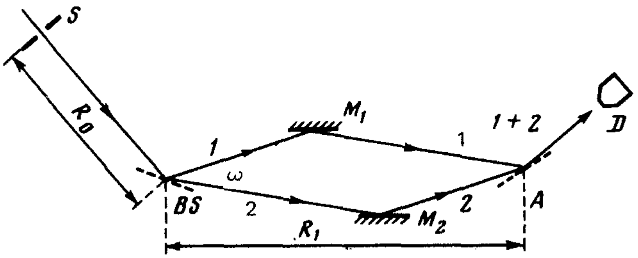

FIG. 2. The neutron interferometer. M_1, M_2–Neutron mirrors; BS, A–diffraction gratings; S–diaphragm which determines the size of the source; D–detector.

where $\Delta\phi$ is the phase difference that is introduced.

There is no fundamental restriction on which diffraction orders may be used to form beams 1 and 2, but at the neutron fluxes presently attainable we are essentially limited to using orders 0 and +1 for beams of adequate intensity, and we shall assume below that these orders are being used.

The angular divergence ω of the diffracted beams (Fig. 2) determines the spatial separation Δ of the beams for given dimensions R_1 of the interferometer itself. For the characteristics of the arrangement given above, for example, we would have $\Delta = 1.35$ mm at $R_1 = 1$ m and $\Delta = 2.7$ mm at $R_1 = 2$ m.

One of the most important measures of the quality of an interferometer is the visibility V of the interference fringes that are detected. This visibility becomes the governing factor at marginal intensities of the input beams and hence of the output beams. The visibility may be reduced if the intensities are different or if the interfering wavefronts are not identical. None of the optical elements would distort the propagating wavefronts (at least in the ideal case) in ordinary optical interferometers, with mirrors as beam splitters. Furthermore, in ordinary optics it is always possible to form a plane incident beam, but with neutrons this could be done only at the cost of a substantial intensity loss. It therefore seems best to use a source of finite size; since diffraction gratings distort a spherical wavefront, this distortion must be analyzed.

We have shown elsewhere[4] that the wave aberration of interfering wavefronts is proportional to the square length of recombining device A. As a result, interference fringes appear in the cross section of the detected beam, and the visibility of the interference pattern is reduced. Figure 3 is a plot of this visibility as a function of the dimensions of the source (s) and of the recombining devices (α).

To estimate these intensities, we can use the value of the neutron spectral flux density at the end of a reactor channel; this flux density for the VVR-M reactor is[5] 5.8×10^{11} n/(s • cm^2 • Å • sr) at $\lambda = 2.7$ Å. For $\Delta\lambda/\lambda = 0.045$ and for an entrance slit with dimensions 3×0.03 cm, the detected neutron intensity would be about 40 n/s (for the experimental values of the diffraction efficiency of the grating).

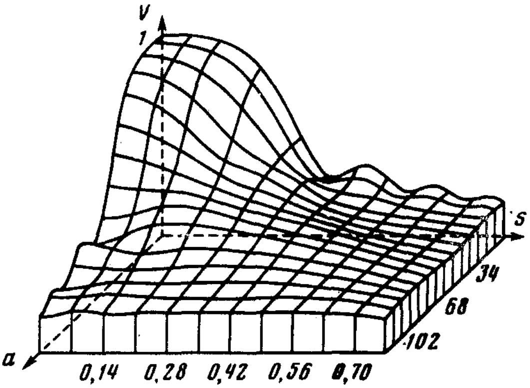

FIG. 3. Three-dimensional plot of the visibility of the interference pattern as a function of the dimensions of the recombining device (α) and of the source (s). $R_0 = 10$ m, $R_1 = 1$ m.

Analysis of the efficiencies of this interferometer and of the perfect-crystal interferometer[4] leads to the conclusion that their theoretical luminosities are comparable. Furthermore, optimization of the grating interferometer may result in a decrease in its angular selectivity. If the minimum permissible visibility is $V_{\min} = 0.4$, then the entrance slit could be widened to 0.075 cm. In addition to increasing the diffraction efficiency to the theoretical value, this measure would make it possible to increase the detected intensity by a factor of more than 30. Phase diffraction gratings have a higher diffraction efficiency, and they could potentially increase the luminosity of the interferometer fourfold.

In summary, this grating neutron interferometer has poorer geometric parameters (the dimensions and the spatial separation of the beams) than the perfect-crystal interferometer, but it has a comparable luminosity. Since the cross-sectional area of the output beam is small, it is possible to achieve an extremely high signal-to-background ratio (by surrounding the detector with shielding with a long slit diaphragm), so that this grating interferometer could also be used in medium-flux reactors.

We thank A. A. Dovzhikov and M. M. Agamalyan for assistance in the experiments and V. A. Ruban for useful discussions.

1. H. Maier-Leibnitz and T. Springer, Z. Phys. **167**, 386 (1962).
2. U. Bonse and M. Hart, Z. Phys. **194**, 1 (1966); H. Rauch, W. Treimer, and U. Bonse, Phys. Lett. 47A, 369 (1974).
3. H. Kurz and H. Rauch, Z. Phys. **220**, 419 (1969).
4. A. I. Ioffe, Yu. G. Turkevich, and G. M. Drabkin, Preprint LIYaF-643, Leningrad Insitiute of Nuclear Physics, 1981.
5. A. P. Bulkin, V. A. Kezerashvili, *et al.*, Preprint LIYaF-505, Leningrad Institute of Nuclear Physics, 1979.

Translated by Dave Parsons
Edited by S. J. Amoretty