Only the formulae for the thermodynamic quantities must be changed. Instead of formulae (3), (4)—(7) in [2] we have for the "roton" parts of the free energy, entropy, specific heat (per unit mass) and the density of the "normal liquid":

$$F_r = -\frac{2\mu^{1/2}(kT)^{3/2}p_0^2}{(2\pi)^{3/2}\rho\hbar^3}e^{-\Delta/kT}; \qquad (3)$$

$$S_r = \frac{2(k\mu)^{1/2}p_0^2\Delta}{(2\pi)^{3/2}\rho T^{1/2}\hbar^3}\left(1+\frac{3kT}{2\Delta}\right)e^{-\Delta/kT}; \quad (4)$$

$$C_r = \frac{2\mu^{1/2}p_0^2\Delta^2}{(2\pi)^{3/2}\rho k^{1/2}T^{3/2}\hbar^3}\times \times\left[1+\frac{kT}{\Delta}+\frac{3}{4}\left(\frac{kT}{\Delta}\right)^2\right]e^{-\Delta/kT}; \qquad (5)$$

$$\frac{(\rho_n)_r}{\rho} = \frac{2\mu^{1/2}p_0^4}{3(2\pi)^{3/2}\rho(kT)^{1/2}\hbar^3}e^{-\Delta/kT}. \qquad (6)$$

In such a form the theory contains three constants: Δ, p_0 and μ. It is, therefore, difficult to check it on the basis of the experimental data which are now available. For the values of Δ, p_0 and μ one gets:

$$\frac{\Delta}{k} = 9.6^\circ, \quad \frac{p_0}{\hbar} = 1.95\cdot 10^8 \text{ cm}^{-1}, \quad \mu = 0.77\, m_{He}. \quad (7)$$

Note that μ is of the order of the mass m_{He} of the helium atom and $\hbar/p_0$ is even less than the atomic dimensions. The values (7) have been used in drawing the curve in Fig. 1.

1 V. Peshkov, Journ. of Phys., 10, 389 (1946).
2 L. Landau, Journ. of Phys., 5, 71 (1941).

OBSERVATION OF REFRACTIONAL STRUCTURES

By S. Rytov and M. Jabotinsky

Lebedev Physical Institute, Academy of Sciences of the USSR

(Received July 6, 1946)

As it is well known, transparent objects which possess only refractional structure, *i. e.* which do not change practically the amplitude of a light wave passing through them but only its phase, cannot be observed visually or photographed. Many biological micropreparations, thermal flows, stresses in glasses, etc. are examples. For the microscopic observation of such structures apart from the methods connected with an influence upon the preparation itself (staining) purely optical methods are widely employed (as, for instance, the method of the darkened field of vision). For structures of large dimensions Toepler's method plays a similar rôle [1].

In 1934 Zernike showed that the usual methods of influence upon the light beam *e. g.*, as shutting off the direct beam or cutting off half of the diffraction pattern in the principal focal plane of the objective, do not remove the direct beam which, as it was assumed before, disguises the image of the structure, but simply influence the secondary sources so that the light becomes distributed in the image plane with alternating intensity. Zernike also demonstrated that the contrastness and brightness of the image increase if the phase of the central beam be turned by 90° instead of shutting off the beam. Zernike applied his considerations to the problem of detecting deviations of the surface of a concave spherical mirror [2].

In 1935 Zernike described the application of the phase method to the microscopical observation of refractional structures [3]. The method hat received some development in this direction and as present the phase microscopy is rather widely employed [4].

In about 1942 Prof. L. Mandelstam had drew the attention of one of us to the fact that the phase method may be successfully used not only in microscopy and in particular problem considered by Zernike, but also, in general, in all the cases of observation of refractional structures. In accordance with this remark we have undertaken an experimental investigation of images obtained from the refractional structures in an optical device which is a modification of Toepler's method. The object is illuminated by a parallel central beam while either ordinary diaphragms, used in Toepler's method, or transparent plates with etched portions on the surface, which change the optical length of the direct ray, are placed in the principal focal plane of a lens located behind the object.

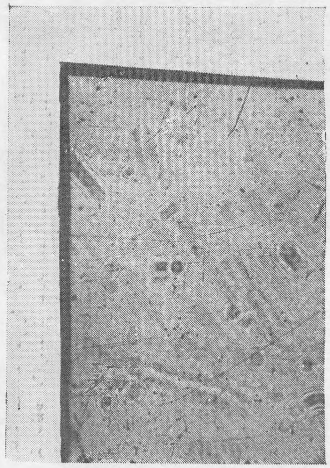
The theoretical treatment shows that the method of the darkened field of vision not only cannot detect weak refractional structures but sometimes even those with very strong phase modulation. In all these cases an image of the object can be obtained by applying the phase method. Besides, use of the method of the darkened field of vision may lead to the doubling of the structure (in the image of periodical structures), *i. e.* may give an image which is dissimilar to the object itself. This defect is absent in the phase method. Finally, the phase method allows one to reduce the time of exposition (as much as up to 40 times) as compared to that necessary in Toepler's method.

The data of preliminary experiments are in good agreement with the calculations.

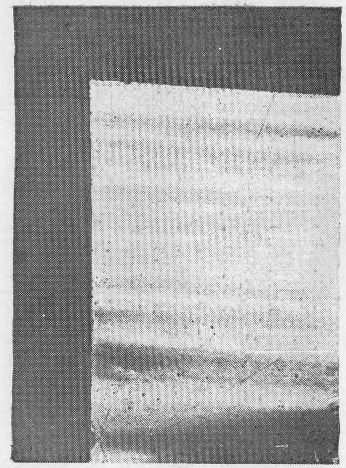
Fig. 1 represents the image of a part of a mirror glass: *a*—the ordinary photograph shows only the surface defects and contamination; *b*—the method of the darkened field of vision shows the internal inhomogeneities in a section of the glass and a number of the surface defects. The image appears as a light picture against a dark background; *c*—the phase method reveals a large number of internal inhomogeneities in all the parts of the glass plate. Surface defects, which were dark on photograph *a*, become bright here.

Fig. 2 shows the image of a grating etched on the plane plate of the optical glass by means of hydrofluoric acid (the upper part of the grating is etched three times as deep as the lower one): *a*—is an ordinary photograph; *b*—the method of the darkened field of vision reveals satisfactorily only strongly etched parts of the grating. The doubling of the structure is clearly visible, ghost lines having appeared between the true ones; *c*—the phase method gives a clear image of the grating with the correct periodicity.

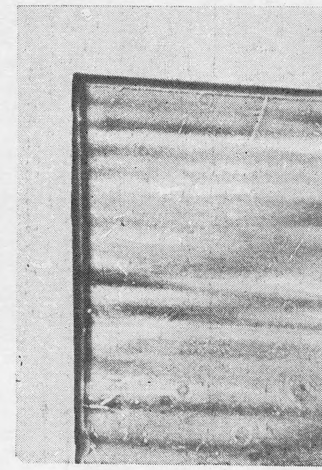
1 A. Toepler, Pogg. Ann., 131, 33 (1867).
2 F. Zernike, Physica, 1, 689 (1934); Monthly Notes, 94, 377 (1934).
3 F. Zernike, Phys. ZS., 36, 848 (1935).
4 A. Koehler u. W. Loos, Naturwiss., 29, 49 (1941); E. Linfoot, Nature, 155, 76 (1945); A. Cox, Nature, 155, 425 (1945).



a

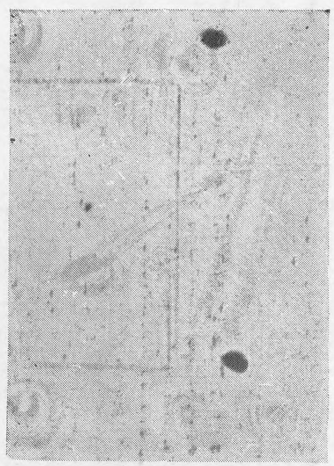


b

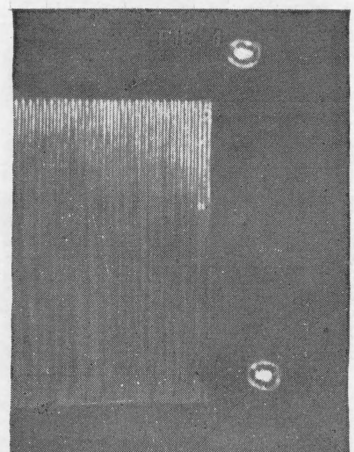


c

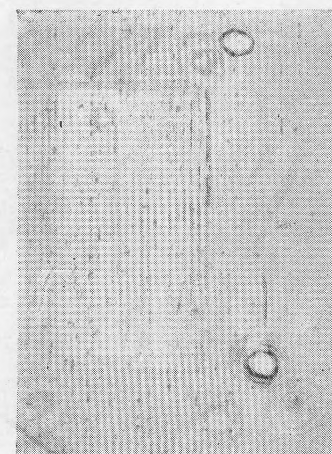
Fig. 1



a



b



c

Fig. 2