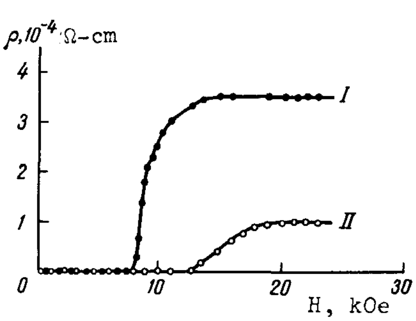

Fig. 2. Resistivity vs. transverse magnetic field intensity at T = 1.4°K.

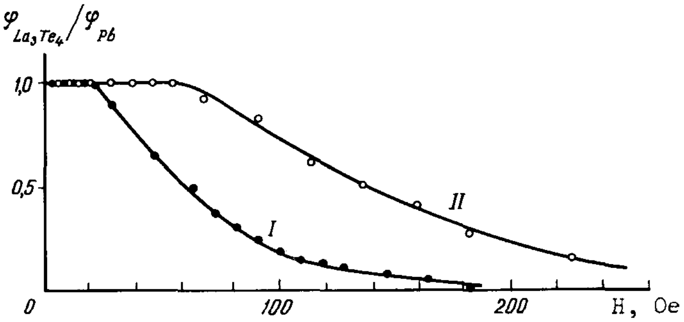

Fig. 3. Relative magnitude of the magnetic moment of La_3Te_4 (relative to lead) vs. longitudinal magnetic field intensity at T = 1.4°K.

the ratio of the deflection angle of the ballistic galvanometer, shown in Fig. 3, show that at 1.4°K the Meissner effect manifests itself in sample I in fields up to H_{c1} = 20 Oe, and in sample II in fields up to H_{c1} = 60 Oe.

We are grateful to A. I. Zaslavskii and T. B. Zhukova for the x-ray phase analysis.

[1] R. M. Bozorth, F. Holtzberg, and S. Methfessel, Phys. Rev. Lett. 14, 952 (1965).
[2] G. L. Guthrie and R. L. Palmer, Phys. Rev. Lett. 15A, 8 (1965).
[3] A. V. Golubkov, T. B. Zhukova, and V. M. Sergeeva, Neorganicheskiye materialy (Inorganic Materials) 2, No. 1 (1966).

MEASUREMENT OF THE DISTANCE TO THE MOON BY OPTICAL RADAR

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Optical ranging of celestial bodies can be used for purposes of astrometry. We describe below experience in measuring the distance to the surface of the moon with the aid of optical radar. The work constituted one stage in a series of measurements (see [1]) aimed ultimately at determining the parameters of the moon's orbit and figure as well as other astrometric constants, using eventually artificial light reflectors placed on the moon [2]. We therefore undertook, in addition to the main purpose - also the development of apparatus and a procedure.

The experimental set-up is shown in Fig. 1. A ruby laser 1 and a photomultiplier 2, which receives the light signal reflected from the moon, are installed in a fixed position at the Coude focus of telescope 3. A tuned interference filter 4 is placed in front of the photomultiplier cathode. The diaphragm 5 determines the field of view of the receiving part. An automatically tilting mirror 6 is used to switch the apparatus from transmission to reception. The pulses from the photomultiplier are shaped and amplified in block 7. The time

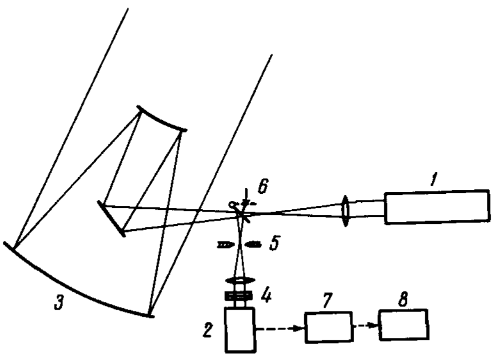

Fig. 1. Experimental set-up.

interval between the instants of transmission of the laser pulse and reception of the optical signal is measured by time-interval counter 8. The counter is triggered by the laser pulse by diverting part of the light-beam energy to the photomultiplier. Registration of the reflected signal (together with the background) is only during the gating pulse, the center of which is made to coincide with the calculated instant of arrival of the reflected signal. Since the path from mirror 6 to the time counter 8 is common to the transmitting and receiving signals, the error in the time measurement due to this part of the apparatus is eliminated.

Parameters of apparatus. The laser wavelength is $\lambda_g = 6943$ Å, the pulse energy $W_g = 5 - 7$ J, the pulse duration $\tau_g = 5 \times 10^{-8}$ sec, the beam diameter $d_g = 13$ mm, the diameter of the principal mirror of the telescope $D_t = 2.6$ m, the focal distance (Coude) $F_t = 104$ m, and the divergence of the beam on emerging from the telescope $\theta_t \cong 3''$. The bandwidth of the interference filter is $\Delta\lambda = 10$ Å, the quantum efficiency of the photomultiplier $k_{ph} = 0.04$, the apparatus time-measurement error $\delta t_a = \pm 10^{-7}$ sec, and the gating-pulse duration $T = 150$ μsec.

Estimate of expected signal magnitude and possible measurement errors. The ranged object was an area on the bottom of the Flammarion crater, whose center had selenographic coordinates $\lambda = 3.57°$ and $\varphi = 2.98°$. The magnitude of the reflected signal could be estimated from the formula

$$n_s = \frac{W_g \lambda_g D_t^2}{4R^2 hc} \rho k_{tr} k_{rec} k_{atm}^2 k_{ph},$$

where n_s is the number of photomultiplier-output pulses per transmitted pulse, h Planck's constant, c the velocity of light, R the distance to the moon, ρ the albedo of the moon, and k_{tr}, k_{rec}, and k_{atm} the loss coefficients in the transmitter, receiver, and in the atmosphere, respectively. For the parameters given above, assuming $\rho = 0.15$, $k_{tr} = 0.6$, $k_{rec} = 0.25$, and $k_{atm} = 0.8$, we obtain $n_s \cong 0.12$. During the time of the measurements, which were made on 19 October 1965 from 5:17 to 5:47, a total $n = 82$ pulses was sent. The response was expected to consist of $N_s = nn_s \cong 10$ pulses.

The time spread of the reflected signal was determined by the time-measurement apparatus error $\delta t_a \cong 10^{-7}$ sec, by the error connected with the data-reduction method $\delta t_T \cong 10^{-6}$ sec (see below), and the spreading due to the natural depth of the ranged object $\delta t_L = (\theta R/c)\tan\omega$, where $\theta \cong 5''$ is the total divergence of the light beam, including the errors caused by atmospheric scattering and by guidance errors, and $\omega \cong 4°$ is the angle of incidence of the beam on the area. From this we get $\delta t_L \cong 2 \times 10^{-6}$ sec. The expected total half-width of the signal distribution is $\delta t \cong 2.5 \times 10^{-6}$ sec.

The measurement results are shown in Fig. 2 in the form of a distribution of the quantity $t_e - t_T$, where t_e is the reading of the time counter and t_T the theoretically calculated

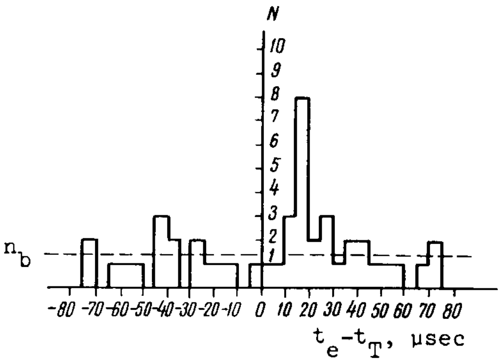

Fig. 2

time of propagation of the signal to the target and back. The t_T curve is so smoothed that within the limits of the measurement session the relative error is $\delta t_T \cong 10^{-6}$ sec. The average background over a 5×10^{-6} sec averaging interval is $N_b = 1.35$ (for $n = 82$). It was determined by multiple measurements at 10 sec intervals during the session. It is obvious that the center of the distribution of the useful signal lies within the interval $t_e - t_T = +15 - +20$ μsec. Bearing in mind the estimate of δt given above, it must be assumed that all the signal pulses are concentrated in the interval $t_e - t_T = +5 - +30$ μsec. The part of the histogram in this interval lying below N_b contains $N_e \cong 11$ points and has a distribution half-width $\delta t_e = 10^{-6}$ sec. We shall regard this value as an overestimate, since the interval $t_e - t_T$ contains an obvious margin. The ratio of useful signal to noise is ~5. The position of the center of the signal-point distribution was determined with an rms statistical measurement error $\Delta t_N = \delta t_e / \sqrt{N_e} = 1.2 \times 10^{-6}$ sec. In view of the impossibility of strictly separating the signal from the background, there is an additional uncertainty in the position of the center, connected with the fluctuations of the background in the signal interval of the histogram. The rms value of this deviation, estimated on the basis of the experimental data on the background, is $\Delta t_b \cong 0.5 \times 10^{-6}$ sec. The total error in the position of the center of distribution is $\Delta t \cong (\Delta t_b{}^2)^{1/2} \cong 1.3 \times 10^{-6}$ sec, corresponding to an error $\Delta r \cong 200$ m in the distance measurement.

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[1] A. Z. Grasyuk, V. S. Zuev, Yu. L. Kokurin, P. G. Kryukov, V. V. Kurbasov, V. F. Lobanov, V. M. Mozhzherin, A. N. Sukhanovskii, N. S. Chernykh, and K. K. Chuvaev, DAN SSSR 154, 1303 (1964), Soviet Phys. Doklady 9, 162 (1964).

[2] C. O. Alley, P. L. Bender, R. H. Dicke, J. E. Faller, P. A. Franken, H. H. Plotkin, and D. T. Wilkinson, J. Geoph. Res. 70, 2267 (1965).

[3] Yu. L. Kokurin, V. V. Kurbasov, V. F. Lobanov, V. M. Mozhzherin, A. N. Sukhanovskii, and N. S. Chernykh, Kosmicheskie issledovaniya (Outer Space Research), No. 4, 1966.