for molybdenum samples of different purity, with allowance for the influence of the current flowing through the sample.

It can thus be regarded as established that an experimental situation is possible wherein the existence of a Kondo effect and of superconductivity are observed.

[1] S. L. Ginzburg, ZhETF Pis. Red. 7, 96 (1968) [JETP Lett. 7, 72 (1968)].
[2] B. N. Esel'son, B. G. Lazarev, and A. D. Shvets, PTE No. 3, 198 (1962).
[3] I. G. D'yakov and A. D. Shvets, Zh. Eksp. Teor. Fiz. 49, 1091 (1965) [Sov. Phys.-JETP 22, 759 (1966)].

THE NATURE OF THE QUANTUM OSCILLATIONS OBSERVED UPON PROPAGATION OF HELICONS IN A METAL

E. P. Vol'skii and V. T. Petrashov
Institute of Solid State Physics, USSR Academy of Sciences
Submitted 16 April 1968
ZhETF Pis'ma 7, No. 11, 427-430 (5 June 1968)

The quantum-oscillation effects accompanying the propagation of helical magnetoplasma waves (helicons) in aluminum, indium, and in other metals were observed in a number of investigations [1,2].

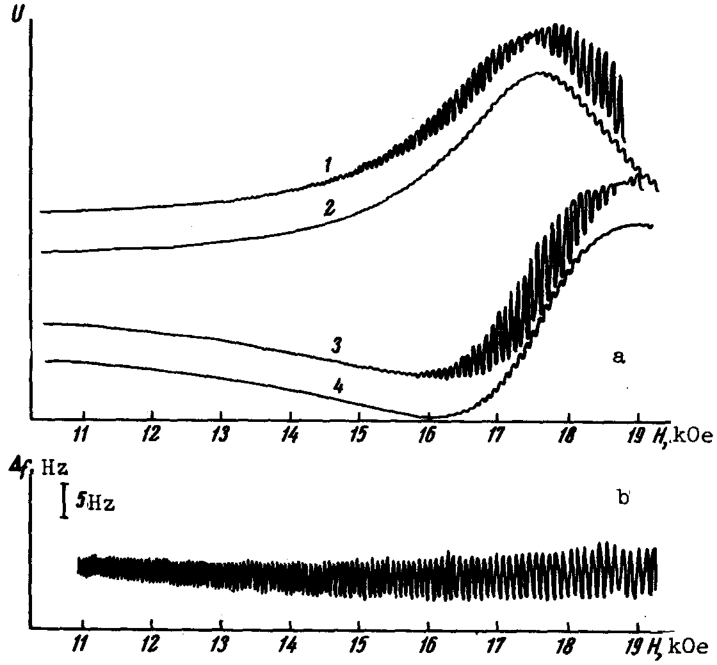
A theory of this phenomenon was presented in [3] under the assumption that the effect is brought about by oscillations of the conductivity-tensor components. A result of the theory is that the oscillations occur predominantly in the damping of the helicons.

The experiments described in the present paper show that the effect calls for a different interpretation.

The measurements were made on single-crystal aluminum in the form of a disc of 10 mm diameter and 1 mm thickness, with a fourfold axis normal to the surface. The sample was placed in crossed coils. An audio-frequency signal was applied to one of the coils. The signal from the receiving coil was fed through a narrow-band amplifier and a synchronous detector to the y-coordinate of an x-y recorder. The constant magnetic field was measured with a Hall pickup. The measurements were made in fields up to 20 kOe. The inclination of the field to the surface of the sample could be varied by rotating the magnet.

Figure a shows the experimental plots of the resonance corresponding to excitation in the sample of a standing wave of length equal to double the thickness. Depending on the choice of the phase of the synchronous detector, one can record either the dispersion curve or the absorption curve. The curves reveal quantum oscillations whose amplitude increases appreciably with decreasing temperature. The priod of the oscillations corresponds to the sections of the tubes of the Fermi surface of aluminum in the third zone. Attention is called to the following feature: the amplitude of the oscillations has a minimum near the extrema of the curves. When the phase of the synchronous detector or the frequency of the excitation signal is changed, the extrema shift in the field and the position of the minima of the amplitude shifts with them. If the damping of the wave oscillates, i.e., the Q of the resonance, then there should be no fading of the oscillations at the extrema.

The effect can be explained by assuming that the wavelength oscillates. In order to verify this assumption, we performed the following experiment:



a - Resonance of a helicon in an aluminum sample in the form of a disc of 10 mm diameter and 1 mm thickness. The frequency is 160 Hz, and the constant magnetic field is directed along the (110) axis and is inclined 45° to the normal to the surface of the sample. 1 - absorption curve obtained at 1.4°K, 2 - absorption curve at 4.2°K, 3 - dispersion curve obtained at 1.4°K, 4 - dispersion curve at 4.2°K; b - oscillations of the resonant frequency of the sample at $T = 1.4$°K and at the same orientation of the constant field as in Fig. a.

The exciting coil was connected to the input of an amplifier similar to that described in [4], and the receiving coil to the output. In a magnetic field, such a system is excited at the frequency of the first helicon resonance. The generation frequency is determined by the dispersion relation for the helicons and should vary linearly with the magnetic field, since the wavelength is fixed by the thickness of the sample. In [4] this setup was proposed for use as a magnetometer. In our experiments we observed oscillations of the frequency of such a generator (Fig. b), superimposed on the linear variation of its frequency with the magnetic field. To record the dependence of the generator frequency on the magnetic field, we used a Ch3-7 frequency meter, whose signal was fed to the y-coordinate of the recorder. The monotonic variation of the frequency was compensated for by a suitably chosen signal from an additional Hall pickup.

When the magnetic field changed from 10 to 20 kOe, the amplitude of the oscillations of the frequency on this curve increased from 1 to 2%.

The described effect was observed at different directions of the magnetic field, making angles 0 - 45° with the normal to the surface of the sample.

At directions close to normal ([100] axis) the amplitude of the oscillations decreases appreciably, in agreement with the results of I. P. Krylov [2]. Unfortunately, we were unable to direct the field precisely along the normal, owing to the inaccuracy of the mounting of the sample in the instrument.

The foregoing experimental data show that the dispersion relation connecting the frewuency and the wave vector of the helicon wave contains an oscillating increment. The expression for it can be readily obtained by putting $\vec{B} - 4\pi\vec{M}(\vec{B})$ in lieu of $\vec{H}$ in Maxwell's equations, which assume the following form:

$$\mathrm{curl}\, e = -\frac{1}{c}\frac{\partial \sigma}{\partial t}, \tag{1}$$

$$\mathrm{curl}\,[b - 4\pi(b\nabla)_{B=B_0} M(B)] = \frac{4\pi}{c}\hat{\sigma} e, \tag{2}$$

where $\vec{e}$ and $\vec{b}$ are the vectors of the electric field and magnetic induction of the wave, $\vec{B} = \vec{B}_0 + \vec{b}$, $\vec{B}_0$ is the constant field in the sample, and $\hat{\sigma}$ is the conductivity tensor.

The dispersion relation obtained from (1) and (2) for a spherical Fermi surface is

$$k^2 = \frac{4\pi N e \omega}{c\sqrt{q} H \cos\theta}, \tag{3}$$

$$q = 1 - 4\pi \sin^2\theta \frac{\partial M}{\partial B}, \tag{4}$$

where θ is the angle between $\vec{k}$ and $\vec{B}_0$.

Since the vector $\vec{b}$ of the wave is always parallel to the surface of the metal, the second term in the left side of (2), which is responsible for the observed oscillations, is equal to zero for a spherical Fermi surface if the field $\vec{B}_0$ is directed along the normal. If part of the Fermi surface has an elongated nearly cylindrical form, then the contribution to the oscillations made by this part is zero if the axis of the cylinder is directed along the normal. These conclusions agree with the experiments of [2,3].

Thus, on the basis of the presented experimental results and their interpretation, we can state that the oscillations observed in the propagation of helicons in metals are in the local limit a manifestation of the de Haas - van Alphen effect. The relative amplitude of the oscillations of the resonant frequency of the sample (Fig. b) makes it possible, as follows from (3) and (4), to measure directly the amplitude of the oscillations of $\partial\vec{M}/\partial\vec{B}$.

In conclusion, the authors are indebted to V. F. Gantmakher for a discussion of the results, to I. P. Krylov for useful discussions and for supplying the still-unpublished experimental data, and to S. F. Kosterev for technical help.

[1] C. C. Grimes, Plasma Effects in Solids, Dunod, 1965, p. 87.
[2] I. P. Krylov, Zh. Eksp. Teor. Fiz. 54, 1738 (1968) [Sov. Phys.-JETP 27, in press].
[3] P. B. Miller and P. C. Kwok, Phys. Rev. 161, 629 (1967).
[4] Y. R. Houck and R. Bowers, RSI 35, 1170 (1964)

STIMULATED SCATTERING OF LIGHT BY A LIQUID SURFACE

F. V. Bunkin, A. S. Samokhin, and M. V. Fedorov
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 19 March 1968; resubmitted 9 April 1968
ZhETF Pis'ma 7, No. 11, 431-433 (5 June 1968)

In spontaneous scattering of low-intensity light from thermal fluctuations of a liquid surface there is no reaction of the electromagnetic field on the interface [1-3]. However, if the intensity of the light is sufficiently large, such a reaction, which is nonlinear in