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THE TUNNEL EFFECT ON SINGLE-CRYSTAL TIN

ZAVARITSKY, USSR

The author studied the tunnel effect between single crystals of tine and tine films. The thickness of the films was less than 1000 Å. The current-voltage and current- $\frac{dV}{dJ}$ characteristics of Sn (film) — Sn (oxide) - Sn (crystal) sandwich were measured. The sandwich resistances are 0,5 + 50 ohm/mm^2.

From the B.C.S. theory /4, 5/ it may be seen/1-3/ that for two superconductors there is a noticeable jump in the tunnel current at $eV = \Delta_1 + \Delta_2$, even at finite temperatures.

The experimental results for different orientations of crystals are shown in Figs.1a, 1b, 1c. The results shown in Fig. 1a agree satisfactorily with the B.C.S. theory. Another type of characteristics give Figs. 1b and 1c. Here several separated jumps in the current- voltage or σ (v) -voltage characteristics ($\sigma = J_s / J_n$) and several minima in $\frac{dV}{dJ}$ are observed. The transition from 1a type to 1b, 1c type is observed when the normal to the surface of tin crystals deviates from the [001] orientation. From experiments /2, 3/ we know that in the case of thin films only one jump in the J-V curve is observed. Hence, we may conclude that several jumps observed in present experiments (see Figs. 1b, 1c) are due to the properties of the single-crystal tin.

At present only speculations on the origin of the characteristics of second type are possible. Recent experiments /6-8/ demonstrated the presence of several parts of the Fermi surface of tin. It is possible that these parts have in the superconducting state different energy gaps. Then the jump in the current or σ (v) should be at $eV = \Delta_1 + \Delta_2^K$ where Δ_2^K is the energy gap of some electron group which play an important part in the tunnel current for a given orientation of the crystal.

From the jump of σ (v) characteristics we found, in addition to $\Delta_2^1 = 0{,}56 \div 0{,}58$ meV which is particular to every orientation, $\Delta_2^2 = 0{,}45$ meV, $\Delta_2^3 = 0{,}65$ meV for several orientations.

The above results are obtained at temperatures 1,36°K. At higher temperatures the second type jumps are not observed only in the interval about 0.3° from T_c. In Fig. 2 the temperature dependence of Δ_2^1 is shown for specimens of different orientation. These data are in excellent agreement with the B.C.S. theory.

References

1. Giaever I., Megerle K. Phys. Rev., 122, 1101 (1961).

2. Zavaritsky N.V., Zhurn. Exp. Teor. Phys., 41, 657 (1961).

3. Giaever I., Hart H.R., Jr., Megerle K. Phys. Rev., 126, 941 (1962).

4. Bardeen J., Cooper L.N., Schrieffer J.R. Phys. Rev., 108, 1175 (1957).

5. Bogolyubov N.N., Tolmachev V.V., Shirkov D.V. A new theory of method in the superconduction. Moscow. (1958).

6. Gold G.E., Priestly M.G. Phil. Mag., 5, 1089 (1960).

7. Khaikin M.S., Zhurn. Exp. Teor. Phys., 42, 27, 43, 59 (1962).

8. Gantmakher V.S. Report to the IX Low Temperature Physics Conference. Leningrad. (1962).

Captions

Fig. 1. Tunnel effect for single-crystal-tin specimens of different orientation. The angles of the normal to the surface of tin crystals ϑ and the [001] direction are $a - \vartheta = 22^\circ$, $\beta - \vartheta = 60^\circ$, C .. ϑ -V characteristics, — $\frac{dV}{d}$.

Fig. 2. $\Delta_1 + \Delta_2^{1}$ temperature dependence for specimens of different orientation. - - - B.C.S. theory with $2\Delta = 1{,}12$ meV at $T = 0^\circ$ [2].

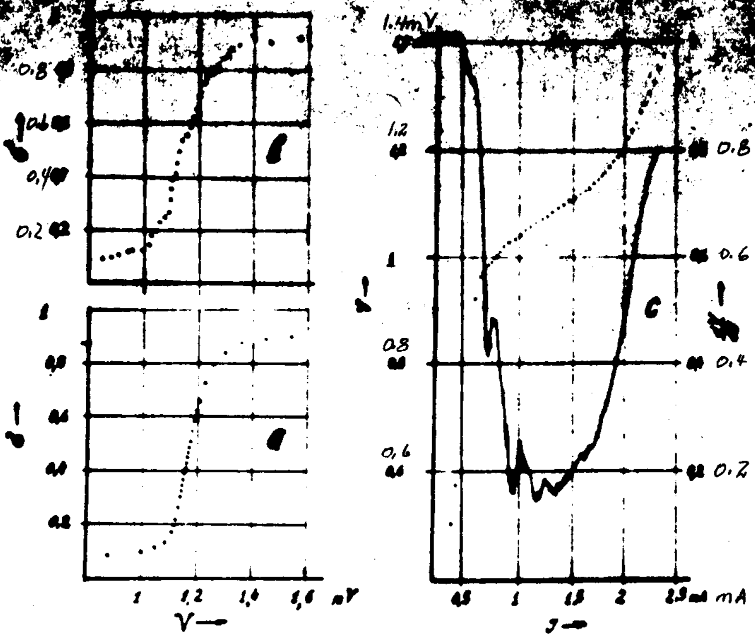

FIG.1

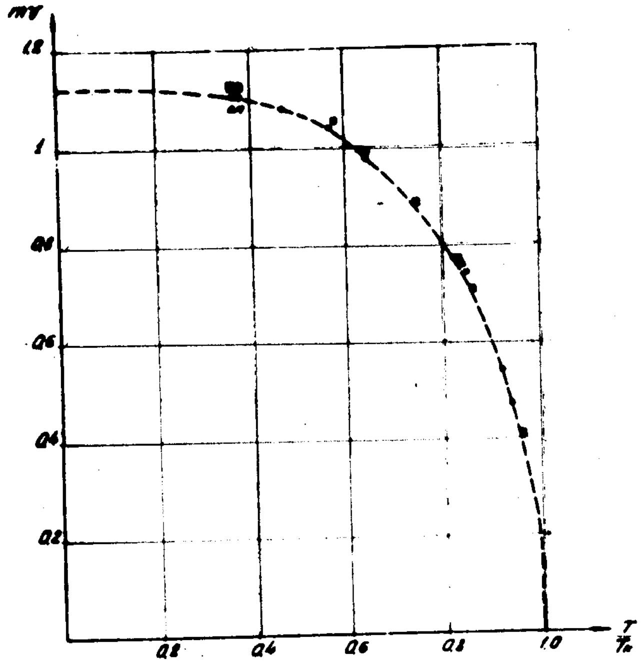

FIG.2

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MAGNETOACOUSTIC OSCILLATIONS AND FERMI SURFACE IN ALUMINUM.

P.A.Besugly, A.A.Galkin, A.I.Pushkin

The anisotropy of magnetoacoustic oscillations for wave vector directions of sound wave $\vec{q}$ along the principal [III], [IOO], [III] crystallographic directions has been investigated on aluminum specimens at 4.2°K, ultrasonic frequency 183 Mc/s and 223 Mc/s and in magnetic fields of 2500 oersteds. Experimental results agree with Fermi surface for second zone, deduced for aluminum by Harrison on the base of nearly free electron model, representing its size and shape, and at the same time point out at the absence of sharp intersections at the surface of second zone.

INTRODUCTION

The experimental investigations of oscillation anisotropy of ultrasonic absorption coefficient are of great interest because they allow to determine the experimental diameter of Fermi surface for electrons in a metal and for some cases completely restore its shape /I/. Here one should not forget, that the fenomena of geometrical resonance will be observed, if the condition $ql \gg qr \gtrsim I$ (l -mean free path of electrons in metal, r-radius of electron orbit) is fulfilled. Thus, the number of oscillations and hence the reliability of extreme Fermi surface dimensions are given by ql value. This means that the study of oscillation anisotropy of iltrasonic absorption coefficient has to be made with single crystal metals of high purity, using ultrasonic frequency of possibly high frequency.

This paper is devoted to magnetoacoustic effects in aluminum. At present two papers devoted to experimental study of magnetoacoustic effects in this metal are known. In the work of Morse and Bohm /2/ the oscillations of sound absorption coefficient were not observed. For the first time the oscillations of ultrasonic absorption coefficient in aluminum were observed by Roberts /3/, who studied absorption coefficient dependence of magnetic field for longitudinal waves at IO to IOO Mc/s frequency. The shortcoming of these studies, which, as it is shown by Roberts, are in qualitative agreement with Fermi surface model, proposed by Harrison/4-5/, is that the value of limiting pulse was determined with small accuracy, as not more than two insufficiently sharp oscillations were observed by the author. It was interesting therefore to carry out investigations on aluminum specimens of higher purity, increasing at the same time the ultrasonic frequency.

EXPERIMENTAL PROCEDURE AND SPECIMENS

The investigation of magnetic field dependence of ultrasonic wave absorption coefficient was carried out by a pulse method, described earlier/6/. The experiments were accomplished by using longitudinal sound at $T=4.2^{\circ}K$ in magnetic field up to 2500 oersteds at two frequencies: 183 Mc/s and 223 Mc/s on aluminum specimens for which

$$\frac{R_{293^{\circ}K}}{R_{4.2^{\circ}K}} = 14000 - 20000$$

As the sound absorption coefficient in aluminum at helium temperatures and frequencies used is fairly large, the aluminum specimens were used in the form of disks of 10 mm diameter and about 2 mm thick. The application of comparatively thin specimens involved a delay element, the latter being used to separate the last sound pulse from the probe pulse. A bar of crysalline quartz of square section has 8 mm side and 10 millimeters length, which together with aluminum specimen was arranged between the transmitting and receiving quartz was used as a delay element.

Following specimens were used: specimen I with a deflection of the normal to the disk surface from the [II0] crystallographic direction not exceeding 2° and specimen 3 with the deflection of the normal to the disk surface from [III] crystallographic direction not exceeding 2°. The sound wave vector $\bar{q}$ coincided with the direction of the normal to specimen plane. The velocities of longitudinal sound wave distribution in aluminum for different orientations were taken from Roberts' paper/3/.

The magnetic field dependence of absorption coefficient of longitudinal ultrasonic wave in aluminum specimen was recorded by means of two-coordinate recorder/6/.

RESULTS

The studies of absorption coefficient oscillation anisotropy α were carried out when the waves vector $\bar{q}$ was directed along one of crystal axes - [II0], [I00] and [III], and the magnetic field vector $\bar{H}$ was rotating around $\bar{q}$. For the safety of good reproduction of results the α (H) dependence by a given direction of sound distribution and a given direction of magnetic field vector $\bar{H}$ was recorded twice. In all cases the obtained oscillation curves appeared identical.

I. $\bar{q}$ along [II0]; ν = I83 Mc/s.

The particular feature of the results for this orientation is the availability of a large number of oscillations (to 15 oscillations) for a number of directions of magnetic field vector $\bar{H}$, that indicates at long mean free path of carriers. The second circumstance, indicating at the large ql value (for some directions ql > 200), is the mode of dependence of α (H): absorption coefficient value at saturation is essentially greater than that without megnetic field.

A large number of sharp oscillations with a good periodicity in a reversed field were observed $\bar{q}$ [II0], $\bar{H}$ [II0] orientation; i.e. for such direction of magnetic field $\bar{H}$ towards wave vector $\bar{q}$, for which in Roberts' experiments /3/ the oscillatory behavior of absorption coefficient was not mentioned. The dependence mode of α (H) (here and further α is expressed in arbitrary units) for this direction is given on fig.I.

With the change of the direction of magnetic field vector $\bar{H}$ the oscillation period in reversed field changed: at first the decrease of period was observed, then its increase was observed. Fig.2. gives the run of α (H) dependence for the case, when the magnetic field vector $\bar{H}$ made an angle of 35° with [II0] direction. The simple comparison of oscillation curves in figs.I and 2 shows that the oscillation period in the second case is larger than in the first one.

Simultaneously with the short period oscillations the long period oscillations are observed by the directions of magnetic field, making an angle of 0° - 25° with [00I] direction. Because of superposition of oscillations of different periods, the interpretation of α (H) dependence curves appears fairly difficult, that is why in the mentioned directions it was possible to estimate periods in the reversed field only for long period oscillations not exceeding 10 per cent. Long period oscillations are also observed in the case when magnetic field vector makes an angle of $15^\circ - 25^\circ$ with [IIO] direction. Under these conditions however, it appeared possible to determine the value $\Delta \left(\frac{1}{H}\right)$ only for short period oscillations.

The distinct oscillatory behavior of absorption coefficient is also observed for $\vec{q}$ [IIO], $\vec{H}$ [OOI] orientation, for which in Roberts' experiments /3/ the oscillations were not mentioned. The particular feature of this orientation was absence of short oscillations. For this direction of the field with a period $\Delta \left(\frac{1}{H}\right) = (6,4 \pm 0,3).10^{-4}$ ae were distinctly observed. The α (H) dependence made for this case is given in fig.3.

Let us compare experimental data obtained with Fermi surface model for aluminum, proposed by Harrison. Aluminum belongs to metals with face-centered cubic lattice, for which the first Brillouin zone has a form, shown in fig.4a by dotted line. According to Harrison /4,5/, the first Brillouin zone, completely filled with electrons, is surrounded by pockets of holes of second zone, the surface boundaries of which are shown in fig.4a by solid lines. The third zone (see fig.4b) has an interrelated set of arms with varying cross sections.

As it is known /I,7/ the oscillation period $\Delta \left(\frac{1}{H}\right)$ is connected with extreme distances $\vec{K}$ to Fermi surface ($\vec{K}$ is normal to $\vec{q}$ and $\vec{H}$) by a simple ratio

$$\hbar K = \frac{\lambda e}{2c\Delta\left(\frac{1}{H}\right)} \quad \ldots\ldots\ldots \qquad (I)$$

where $\hbar = \frac{h}{2\pi}$ (h Plank constant),

λ - the length of sound wave,

e - electron charge,

c - velocity of light.

If now, using ratio (I), the K values are expressed in K_o units ($K_o = \frac{2\pi}{a_o}$, where $a_o = 4.04 \cdot 10^{-8}$ cm), found by oscillations periods in reversed field for each direction $\vec{H}$, they will represent the distance in wave numbers space from the center of Brillouin zone to Fermi surface of corresponding zone.

Fig.5 gives the projection of Brillouin zone onto the plane, normal to [IIO] axis, where the form of central section of Fermi surface for second zone by a plane, also normal to [IIO] direction, is given on corresponding scale.

In the same figure the values, obtained from experiment based on ratio (I) are given. The attention is drawn to the fact, that the short period oscillations, for which the larger K values are responsible, the form of Fermi surface central section for given direction $\bar{q}$ on the whole represent well, thus supplying proof of Harrison model. As to long period oscillations, for which the angular dependence of projection of extremal diameter on [IIO] plane is given in fig.6, the question about their origin needs further more profound analysis. Probably for these oscillations non-central sections in the vicinity of zone boundary in [IIO] direction are responsible.

II. $\bar{q}$ along [IOO], ν = 183 Mc/s

The reliable oscillatory behavior of absorption coefficient is found practically for all directions of magnetic field $\bar{H}$, normal to wave vector $\bar{q}$. Unlike to previous case however, when the sound was directed along [IIO] axis, the number of observed oscillations was not great (4-5 oscillations). The second particular feature of oscillations, observed for the given wave vector $\bar{q}$, is their comparatively large period. In fact, if at frequency ν = 183 Mc/s for the case when sound wave vector $\bar{q}$ was directed along [IIO] axis, the oscillations period, reproducing the central section of Fermi surface second zone by rotating $\bar{H}$ from 0^o to 180^o, changed in the range of $2.03 \cdot 10^{-4} - 3.04 \cdot 10^{-4}$ oe $^{-I}$, then in our case the oscillations period changed in the range of $6.I \cdot IO^{-4}$ - $7.35 \cdot IO^{-4}$ oe^{-I}, i.e. the period was 2,5-3 times larger. It means, that for these oscillations non-central orbits are responsible.

At the same time it should be noted that for the orientations in the vicinity of $\bar{q}$ [IOO], $\bar{H}$ [OOI] and $\bar{q}$ [IOO], $\bar{H}$ [OĪO] orientations with long period oscillations short period oscillations were observed. Naturally, because of superposition of oscillation of different periods, the accuracy of $\Delta\left(\frac{I}{H}\right)$ determination for short period oscillations was not good enough (5-10 per cent).

As an illustration of oscillatory dependence of absorption coefficient, when $\bar{q}$ is directed along [I00] axis, a record of α (H), when $\bar{H}$ makes an angle of 50° with [00I] direction, is given in fig.7.

Fig.8 gives the central section of Brillouin zone by the plane, normal to [I00] axis, at which the central sections of the second zone surface and two other sections, situated from the central section along the perpendicular at the distance of $0,75K_o$ and $0,90K_o$ ($K_o = \frac{2\pi}{a_o}$) are represented in proper scale. As it is seen from the figure the short period oscillations, observed in a small interval of angles, represent well the dimensions of central section in [0I0] and [00I] directions, and short period oscillations mainly represent the form of section at $K = 0.9K_o$, thus indicating the absence of sharp intersections in accordance with completed Harrison's theory/5/.

Magnetoacoustic effects in aluminum in the direction of sound along [I00] axis were studied at two frequencies: 183 and 223 Mc/s; the values obtained at these two frequencies being in good agreement.

III. $\bar{q}$ along [III] ; ν = 223 Mc/s

As in above mentioned case, the trustworthy oscillating behavior of absorption coefficient was practically observed for all directions of vector $\bar{H}$ in the angular interval 0° - 180°. Because the number of oscillations was not large in this case the accuracy in determination of K (see eq.(I)) was about 10 per cent. The measurement at a given direction of wave vector $\bar{q}$ were carried out at frequencies 183 Mc/s and 223 Mc/s. In view of the fact that the values of measurements at these frequencies gave a good agreement, and taking into account that the oscillations of absorption coefficient at ν = 223 Mc/s appeared more distinct; further the comparison with the form of the surface, proposed by Harrison, will be based on results, obtained at 223 Mc/s.

The shape of Brillouin zone along [III] directions is given in fig.9. The shape represents the central section of Fermi surface by [III] plane for second zone and two non-central sections at the distance of $0.6K_o$ and $0.7K_o$ from central section. Values given in the same figure and calculated after measured oscillation periods on the base of eq.(I) in the range of experimental error are in good agreement with the form of section, corresponding to level $0.6K_o$.

DISCUSSION

The above comparison of experimental values, obtained in this paper, with the shape of Fermi surface for aluminum, proposed by Harrison on the base of nearly free electrons model, shows, that both dimensions of second zone and its shape can be well reproduced by values of magneto-acoustic measurements. The discrepancy, as a rule, is in experimental limit of error, with the exception of sharp edges of Fermi surface; the results of present study testify on behalf of completed calculation of Harrison/5/; the latter introducing no essential changes in the dimensions of second zone Fermi surface, lead to rounding its sharp edges. Unfortunately it was not possible to carefully study it in just these parts of Fermi surface. At those directions of wave vector $\bar{q}$ and magnetic field vector $\bar{H}$, that had to give information about the dimensions of Fermi surface in the directions of sharp intersections, the oscillations of absorption coefficient proved to be bad. Apparently it's due to small electron state density in indicated directions.

In this paper it was possible to state the character of anisotropy of short period oscillations, representing the central section of Fermi surface of second zone for wave vector $\bar{q}$ directions along [IIO] and [IOO] axes more or less in detail. Also we succeeded in clearing up the character of oscillation anisotropy with 2.5-3 times larger period which represents non-central sections of second zone Fermi surface. At the same time for some directions of $\bar{q}$ and $\bar{H}$ the oscillations with still larger period, which were earlier mentioned in our short note/8/, were studied. To estimate their period with enough authenticity and the more so to study the character of anisotropy of their period for the present is not possible, although to find them is very interesting. The study of anisotropy of period of these most long period oscillations (which is a hard but evidently not a hopeless task) will, probably, throw some light on the structure of third zone.

Explanations to the figures to the paper

"MAGNETOACOUSTIC OSCILLATIONS OF FERMI SURFACE IN ALUMINUM"

by P.A.Besugly, A.A.Galkin and A.I.Pushkin.

Fig.I. Record of magnetic field dependence of absorption coefficient at $\vec{q}$ along [IIO] and $\vec{H}$ along [IIO]; ν = 183 Mc/s.

Fig.2. Record of magnetic field dependence of absorption coefficient at $\vec{q}$ along [IIO] and $\vec{H}$ direction, making 35° angle with [IIO]; ν = 183 Mc/s.

Fig.3. Record of magnetic field dependence of absorption coefficient at $\vec{q}$ along [IIO] and $\vec{H}$ along [OOI]; ν = 183 Mc/s.

Fig.4. Fermi surface in aluminum after Harrison:

a) Regions of holes in second zone;

b) Regions of electrons in third zone.

Fig.5. The projection of Brillouin zone onto the plane, normal to [IIO] axis and the form of central section of Fermi surface for second zone, ⊙ —┼— measurements data (⊙ - 2-3 per cent accuracy, —┼— 5-10 per cent accuracy) Roberts' results /3/.

Fig.6. Angular dependence of projection of extremal diameter onto the [IIO] plane, obtained from $\Delta\left(\frac{1}{H}\right)$ long-period oscillations measurements.

Fig.7. Record of magnetic field dependence of absorption coefficient at $\vec{q}$ along [IOO] and $\vec{H}$ direction, forming 50° angle with [OOI]; ν = 183 Mc/s.

Fig.8. The central section of Brillouin zone by the plane, normal to [IOO] axis, on which the contours of sections of Fermi surface for second zone are shown. The levels are given in K_0 units.

⊙, —┼— - values from long period oscillations measurements (⊙ - about 5 per cent accuracy) —┼— - about 10 per cent accuracy) △, ▲ - values from short period oscillations measurements (△ - 223 Mc/s ▲ - 183 Mc/s) ├─⊡─┤ - Roberts' results /3/.

Fig.9. The projection of Brillouin zone onto the plane, normal to [III], in which the contours of section of Fermi surface for second zone are drawn. The levels are given in K_0 units.

├─⊡─┤ - Roberts' results /3/.

REFERENCIES

1. 37, 71, 1959.
2. R.W.Morse, H.V.Bohm, Proc. of the Forth International Conf. on Low Temperature Physics and Chemistry, Madison, Wisconsin, 1957.
3. B.W. Roberts, Phys.Rev., 119, 1889, 1960.
4. W.A. Harrison, Phys. Rev., 116, 555, 1959.
5. W.A. Harrison, Phys. Rev., 118, 1882, 1960; 118, 1191, 1960.
6. 6, 199, 1960.
7. M.H.Cohen, M.J.Harrison, W.A.Harrison, Phys.Rev., 117, 937, 1960.
8. 42, 84, 1962.

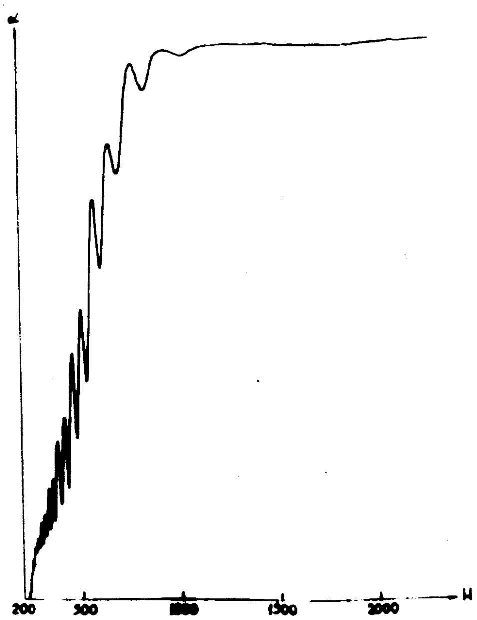

FIG.1.

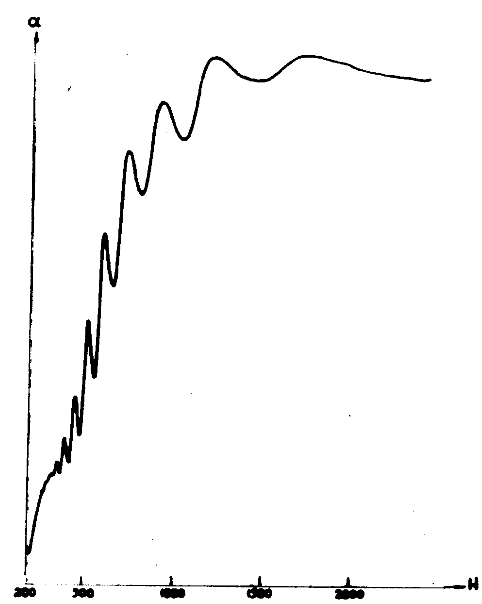

FIG.2.

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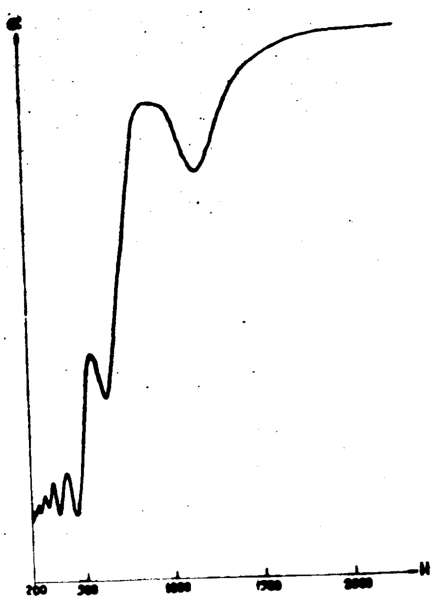

FIG.3.

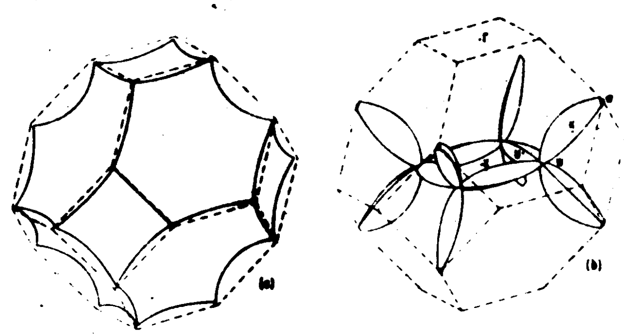

FIG.4.

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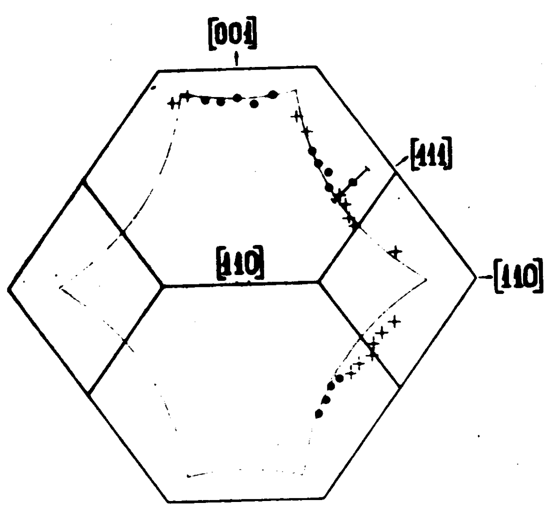

FIG.5.

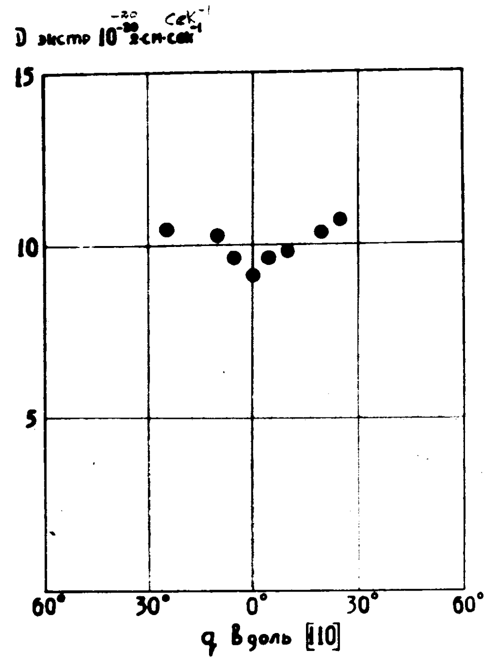

FIG.6.

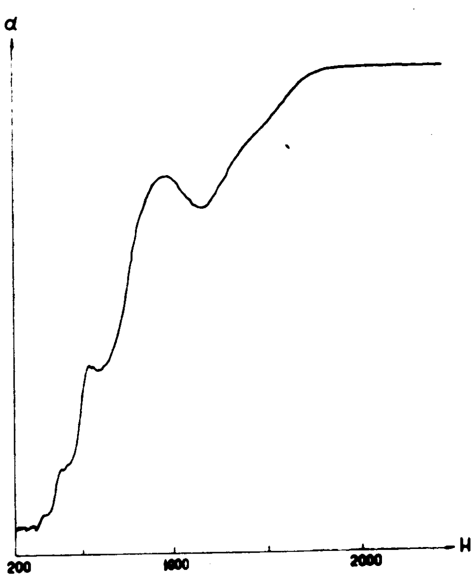

FIG.7.

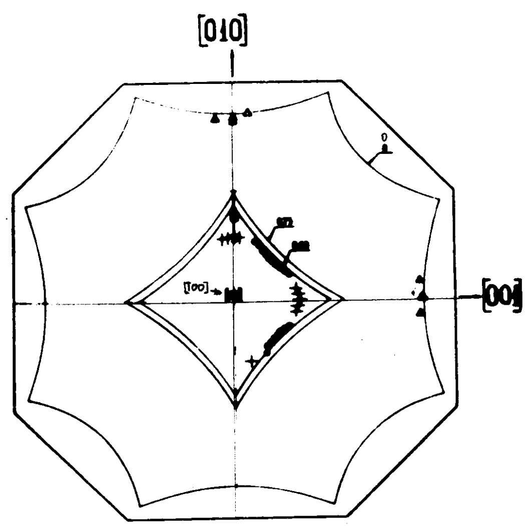

FIG.8.

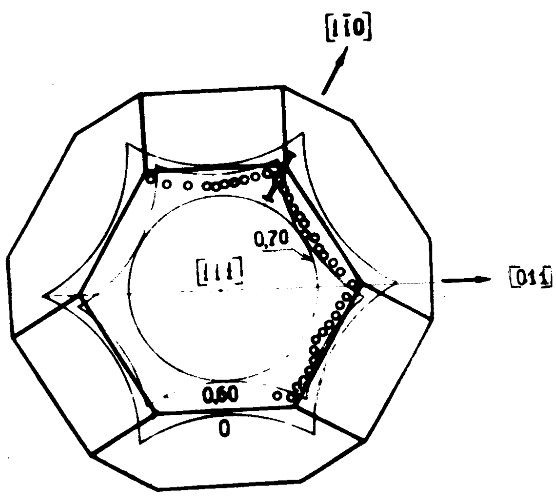

FIG. 9.

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