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ON THE HALL EFFECT AND RESISTIVITY OF CADMIUM SINGLE CRYSTALS

by
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Abstract. *Hall effect and resistivity measurements were conducted on seven Cadmium single crystals and two polycrystaline specimens. Hall components $R_{//}$ and $R_{\perp}$ were determined as $R_{//}=1.40$ and $R_{\perp}=0.38$ (10^{-10} m^3/Cb) while the resistivity components were calculated as $\varrho_{//}=7.61\mp0.173$, $\varrho_{\perp}=6.33\mp0.167$ (10^{-8} $\Omega.m$). The temperature dependence of resistivity found to be linear.*
Hall effect and resistivity components were predicted by using empirical formulae.

In defining galvanomagnetic effects in anisotropic materials one usually writes | 1 | for the electric field:

$$E = \rho_{ik}\left(\vec{B}\right) j_k \tag{1}$$

where $\rho_{ik}\left(\vec{B}\right)$ is the electrical resistivity tensor and j_k the current density.

Assuming $\vec{B}$ to be small enough in the areas of interest, one expands $\rho_{ik}\left(\vec{B}\right)$ as a Taylor series in terms of the components of $\vec{B}$ yielding:

$$\rho_{ik}\left(\vec{B}\right) = \rho^{(0)}_{ik} + R^{(1)}_{ikp} B_p + R^{(2)}_{ikpq} B_p B_q + \ldots\ldots\ldots$$

where

$$\rho^{(0)}_{ik} = \rho^{(0)}_{ki}$$

$$R^{(1)}_{ikp} = \left| \frac{\partial \rho_{ik}\left(\vec{B}\right)}{\partial B_p} \right|_{\vec{B}=0}$$

$$R^{(2)}_{ikpq} = \frac{1}{2} \left| \frac{\partial^2 \rho_{ik}\left(\vec{B}\right)}{\partial B_p \partial B_q} \right|_{\vec{B}=0}$$

If following Casimir |2| we refer the corresponding components to a suitable rectangular coordinate system we get:

$$E_i = \sum_j \rho_{ij} j_j + (\vec{r} \times \vec{j})_i \qquad (2)$$

where $\vec{r}$ is the Hall vector such that

$$\vec{r}(\vec{B}) = -\vec{r}(-\vec{B})$$

Taking into account the effects of microscopic reversibility and crystal's symmetry, it can be shown |2,3,4| that from the 27 existing components of the Hall tensor only two are independent and the same applies to the resistivity tensor.

Those components are usually designated as $R_{//} (= -R^{(1)}_{123}$ and $R_\perp (= -R^{(1)}_{231} = -R^{(1)}_{321}$ where $R_{//}$ represents |5|, the Hall effect when the magnetic induction is parallel to the hexad (c) axis (the specimen current and the Hall voltage are orthogonal to each other and to the magnetic induction lying in the basal plane), whereas $R_\perp$ represents the Hall effect when the magnetic induction is normal to the hexad axis.

$p_{//}$ and $p_\perp$ represent the zero field resistivities measured perpendicular and parallel to the principal axis respectively.

Stringer and coworkers |6,7,8| developed an experimental method which enables the Hall tensor components to be determined in the low field condition ($\omega_c \tau \ll 1$).

In Fig. (1) the experimental arrangement is depicted. The sample's plane is the xy-plane, ε, δ being the angles defining the position of the hexad axis, γ is the induction's azimuth.

If the Hall voltage is plotted against the rotation γ, a sinusoidal curve results, which in the case of anisotropic materials, is phase shifted by an angle ψ, due to the differing ratio of $R_{//}$ to $R_\perp$ in the signal as the hexad axis is rotated relative to the magnetic field.

The Hall, voltage could be represented by the equation

$$V(\gamma) = V_{max} \sin(\gamma + \psi) \qquad (3)$$

where ψ is given by the equation

$$\psi = \arctan V_y / V_x$$

and

$$V_y = V_{//} \sin^2\varepsilon + V_\perp \cos^2\varepsilon$$

$$V_x = \frac{1}{2} \mid V_{//} - V_\perp \mid \sin\delta \sin 2\varepsilon$$

and

$$V_{max} = \mid V_x^2 + V_y^2 \mid^{1/2}$$

Solving equation (3) for two values of γ e·g $\gamma = \pi/2$ and 0 one gets for the components of the Hall tensor $R_{//}$ and $R_\perp$:

$$\left.\begin{aligned} R_{//} &= \frac{V_{//}t}{BI} = R\left(\frac{\pi}{2}\right) + R(0)\frac{\cot\varepsilon}{\sin\delta} \\ R_\perp &= \frac{V_\perp t}{BI} = R\left(\frac{\pi}{2}\right) - R(0)\frac{\tan\varepsilon}{\sin\delta} \end{aligned}\right| \qquad (4)$$

where

$$R\left(\frac{\pi}{2}\right) = R_{max}\cos\psi$$

$$R(0) = R_{max}\sin\psi$$

One could therefore determine $R_{//}$ and $R_\perp$ experimentally having obtained first the peak value of the Hall voltage V_{max} and the phase shift ψ, through equations (4).

As far as the resistivity tensor components are concerned it has been shown | 6 | as well that it is given by the equation:

$$\rho = \rho_{//} \cos^2\varepsilon\cos^2\delta + \rho_\perp (1 - \cos^2\varepsilon\cos^2\delta) \qquad (5)$$

meaning that if two at least crystals of different orientations are available, one could eliminate $\rho_{//}$ and $\rho_\perp$ solving the simultaneous equations, resulting from equation (5).

Hall effect measurements on single crystals of cadmium have been earlier reported by Noskov | 9 |, Stringer et al | 6,7,8 |. The results of Noskov and Stringer et al, exhibit a marked difference, the results of the latter being considerably higher than those reported by Noskov. The experiments of those workers were conducted on six single crystal specimens which though were of approximately the same orientation.

The difference in the values of $R_{//}$ and $R_\perp$ quoted by the various

authors may result from a variety of reasons, the main of which are: errors in the determination of the angles ε, δ, ψ. Lane et al | 6 | discussed in some detail the result of such errors.

As far as resistivity measurements are concerned there are no more known than those quoted by Hurd | 1 | and no resistivity measurements versus temperature are reported.

EXPERIMENTAL

As starting material, 5N pure metal rods were used, supplied by Koch Light Lab.

Single crystal specimens were grown by a modified Bridgmann technique. The apparatus used is shown in Fig. (2). The charge was inserted into a graphite split mould which was inserted inside a quartz tube, 4 cm in diameter and 164 cm in length. The quartz tube was lowered into a three winding furnace and the charge melted under protective argon atmosphere, flowing into the mould's recessed groove of a approximately 1 mm in depth and 0.4-0.5 cm wide. The as grown specimen was then removed from the split graphite mould, polished and replaced again in place, the mould being polished as well.

The graphite mould was then put again into the quartz tube, suspended by a cord attached to an axle driven by a low speed motor and lowered into the vertical furnace. The specimen passed through a temperature gradient of approximately 40° C with a speed varying to 2-5 cm/h-.

In order to avoid stressing the crystal, the as grown specimen was cut by an acid saw rather than by spark machining it. A very dilute solution of nitric acid was found to be of adequate cutting speed.

The single crystal specimen of 3×0.45 cm² dimensions was then etched using 1% NITAL. Any twins observable on the bright etched surface of the crystal led to reject the specimen.

After routine metallographic tests to secure the single crystallinity of the specimen, the orientation of the crystal was determined by a standard back reflection Laue technique. All specimens showing appreciable asterism were rejected.

The technique and apparatus used for measuring the Hall effect was a conventional d.c. method schematically depicted in Fig. 3.

The specimen mounted on the sample holder was placed in the magnetic field and fed with the longitudinal current produced by a heavy duty lead battery, through a Tinsley current stabiliser, with

a stability 1 part per million. In order to avoid thermal gradients in the sample an upper limit of 1 Amp. was set, for all measurements.

The Hall probes were spot welded in place by discharging a bank of condensers through the contact. The leads used, were shellaced copper wires, 1.125 mm in diameter. The Hall voltage was measured by a Tinsley Diesselshorst thermoelectric free potentiometer, with 10^{-7} V discrimination ability. The out of balance signal was fed to a photocell amplifier and displayed on a Kipp chart recorder.

Variation of the magnet's power supply induced in some cases unwanted noise in the Hall leads. This was balanced out by using a modified thermal compensator and a search coil, 30.000 cm^2 in area, plastered on one end of the magnet. This was proved to be quite satisfactory a method, though selten used, since the quality of the signal was usually very good. The overall sensitivity of the apparatus was better than 2×10^{-9} V.

The various thermomagnetic effects | 10 | were eliminated by taking measurements in the four possible permutations of the directions of current and magnetic induction. Reversal of the latter was implied by rotating the magnet by 360° in increments of 30°.

The resistivity measurements were performed by a four method technique, on the same specimens. The current used was 0.1 Amp. The probes were spot welded on the same side of the specimen at an approximate distance of 1 cm, of one another. The measurement at a certain temperature was repeated for the two opposite current directions.

A silicone oil bath was used for the resistivity versus temperature measurements. The temperature of the bath suitably controlled and stability of temperature proved to be critical on the signal's stability. All measurements for a temperature variation larger than 0.5° C were rejected.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results for cadmium are shown in TABLE I along with the results of previous workers.

The most probable sources of error are those of the definition of the angles ε, δ and ψ as well as those involved in measuring the thickness of the specimen.

It is quite evident that a large error might be involved in calculating the pbase shift ψ, which in many previous works was rather

TABLE I:

Hall effect and resistivity of cadmium

No	Orientation		shift	$R_{//}$	$R_{\perp}$	ρ	$\rho_{//}$	$\rho_{\perp}$	
	ε	δ	degrees	$(10^{-10}\ \frac{m^3}{Cb})$	$(10^{-10}\ \frac{m^3}{Cb})$	$(10^{-8}\ \Omega.m)$	$(10^{-8}\ \Omega.m)$	$(10^{-8}\ \Omega.m)$	
1	65°	145°	9.8	1.26	0.39	6.45			
2	38.5	-30	-17.0	1.44	0.41	6.93			This
3	34	-4	-5.4	1.39	0.46	7.25	7.61±0.173	6.33±0.167	investigation
4	72	20	3	1.26	0.44	6.39			(197° K)
5	71	34	7	1.47	0.47	6.38			
6	42	88	35.4	1.49	0.30	6.28			
7	36	6	1.7	1.31	0.75	7.19			
1				1.20	0.32				Noskov
2				1.45					[9]
3				1.32	0.00				
1				1.34	0.32				
2				1.43	0.29				
3				1.43	0.39				Lane
4				1.30	0.46				et Al
5				1.36	0.34				[6]
6				1.46	0.42				
1	61.5	95		1.43	0.67				STRINGER
2	43.5	35		1.20	0.34				-HILL
									HUGLIN [7]

visually calculated rather, than fitting by some statistical method the experimental curve.

In order to more accurately determine the phase shift ψ we have tried here here to minimize the error function

$$s_j = \sum_j \{ V_i - W\sin(\theta + \psi) - c\}^2$$

where W: is the experimental determined Hall peak voltage, c is the Ohmic drop due to the misaligment of the contacts.

The method followed here was the «steepest descent» method | 11 |.

The main idea of the method is that: given a function $f(x)$ where x is the vector $x = |\, x_1, x_2, \ldots, x_n \,|^T$ we have to provide with an initial guess, x^0, to the minimum and let x^k be the value of x at the k-th step of the process, then setting $x^{k+1} = x^k - a_k p^k$, where a_k is a scalar and p^k a vector we try to find values for which

$$f(x^k - a_k p^k) < f(x^k)$$

If this happens, x^{k+1} is a better estimate to the minimum. The vector $-p^k$ is chosen as the direction of maximal local rate of decrease of

$$f, \qquad \text{i.e} \qquad p^k = \vec{\nabla} f(x_k)$$

After defining p^k, $f(x^k - a_k p^k)$ becomes a one dimensional function in a_k and applying some method, for example $df/da = 0$ we find a value for a_k minimizing f.

Starting with x^{k+1} we repeat the above process until we reach a point were the value of x doesn't change i.e. we have reached the minimum of the function. A computer program realising the method was made, giving directly $R_{//}$ and $R_\perp$ and it is attached as Appendix I of this work.

In Fig. 4-9 the dependence of $R_{//}$ and $R_\perp$ versus the angular errors in ε, δ for a bandwidth of 10° is plotted. It is evident that for some of the crystals studied, the determination of $R_{//}$ and $R_\perp$ depends critically on the errors of ε, δ. This is especially true for some crystals e.g. 6 where one could see that for an angular variation of 3°, the change in the calculated componet might be as much as 50%.

An additional source of error is the determination of the specimen's thickness. The latter was determined by an anvil micrometer and the error involved is estimated to be as high as 3%.

The distance of the resistivity contacts was determined by a travelling microscope and the error shouldn't be larger than 1%.

In commending the effect of annealing the single crystal specimens Lane et al | 6 | stated that for some crystals the Hall signal increased with annealing time after 24 hours, in other cases the signal decreased to a steady value and in others there was no significant change.

In our study we found that an annealing time of 72 hours at 100° C was necessary for the signal to reach a steady value, having first decreased steadily. Especially crystal No 7 has shown a peculiar temperature dependence (Fig. 9a). $R_{//}$ was increasing while $R_\perp$ was decrea sing starting with 1.31 and 0,75 (10^{-10} m^3/Cb) respectively to end with 1.49 and 0.58 (10^{-10} m^3/Cb) after 72 hours at 100° C.

This behaviour could well be attributed to grain boundaries movement during heating and results concerning this crystal should be treated with extreme sceptisism.

As far as resistivity measurements are concerned they are shown in Table I.

The two resistivity components $\rho_{//}$ and $\rho_\perp$ were calculated by means of eq. (5) and consistently came out to be $\rho_{//} = 7.61 \pm 0.173$ and $\rho_\perp = 6.33 \pm 0.167$ (10^{-8} Ω·m) against $\rho_{//}=7.66$, $\rho_\perp=6.32$ (10^{-8} Ω·m) quoted by Hurd | 1 |.

In trying to fit the empirical formulae proposed by Lane | 6 | and Meaden | 12 | and Volkov et al | 13 | concerning Hall effect and resistivity of polycrystalline material, measurement of both quantities were conducted on two different cadmium polycrystals with widely ranging textures, the results are shown in Table II.

TABLE II:

Experimental and predicted valnes of Hall effect and resistivity in polycrystaline cadminm.

Sample	n	$R_{H\ exper.}$	$\rho_{exp.}$	$R_H = nR_{//} + (n-1)R_\perp$	$R_H = \frac{1}{3} R_{//} + \frac{2}{3} R_\perp$	$\rho = \frac{1}{3}\rho_{//} + \frac{2}{3}\rho_\perp$
No. 1	0.28	0.660	6.84	0.665	0.72	6.75
No. 2	0.40	0.730	6.86	0.780	0.72	6.75

The temperature dependence of the resistivity in the three single crystals studied, is shown in Fig. 10,11,12 in the temperature range 239-420° K.

The temperature dependence of the resistivity proved to be consistently linear in the entire range of temperature studied, within the experimental error limit, uot exceeding 4% in any case.

DISCUSSION

According to experimental data so far obtained, one could assume as a «best value» for the two Hall tensor components the figures $R_{//} = 1.40$ and $R_1 = 0.38$ ($10^{-10} m^3/Cb$) against the free electron value of -0.647.

The picture for the Fermi surface of cadmium resulting from Hall effect measurements should be [1] considered as consisting of hole cylinders parallel to the hexad axis, $R_{//}$ and R_1b eing positive (hole conduction).

The picture is of course a rather oversimplified one, the corresponding electron like surface should result in cylindrical form as well, giving the right order of magnitude for $R_{//}$, while R_1s hould be zero.

A rather more elaborate model was tried my Tsuji and Kunimune [14] starting from a rather simplified Fermi surface, in which hole states are represented by three ellipticall toroids of ellipticall cross section. The electron like surface is assumed to be an ellipsoid of revolution. The model provides the two bands with different effective masses and relaxation times, associated with $\vec{k}$ through $E(\vec{k})$ only.

The model using arbitrarily a range of five carrier concentrations and using experimenaly obtained resistivity data resulted in much larger Hall coefficients than the experimentaly obtained ones, but proved to be efficient in predicting the temperature dependence of the Hall effect in cadmium.

It is also predicted quite accurately the linear relationship of the resistivity and temperature through the changes in carrier concentration.

This linear dependence is also confirmed by the model used by Case and Gueths [15] who used a nearly free electron model, with spherical Fermi surface which extents beyond the boundaries of the Brillouin zone, with conductivities differing along the direction of the crystallographic axes.

Another hint is coming through the work of Kuvandikov-Cheremushkind and Vasil'eva [16], who studied resistivity of cadmium as a function of temperature on polycrystalline specimens of unknown history and found also this dependence to hold.

If one uses the empirical formula of Lane [6] for predicting the Hall coefficient of polycrystalline specimen.

$$RH = nR_{//} + (1-n)R_1$$

where n is the «texture weighting factor» and using $n = 0.28$ and 0.4 used as a «reasonahle estimate» of the texture weighting factor, the agreement proves to be satisfactory while the empirical formula

$$R_H = \frac{1}{2} R_{//} + \frac{2}{3} R_\perp$$

used by Volkov | 13 | gives rather poor results.

One of course wanders what the possible use of those empirical formulae should be. The case of predicting the Hall coefficient of polycristalline material through its «texture weighting factor» seems more justified.

ACKNOWLEDGMENTS

One of authors (I.A.T.) wishes to thank Mr. Linardis for his considerable help in the computer program project and Mr. D. Vlachavas for the drawings.

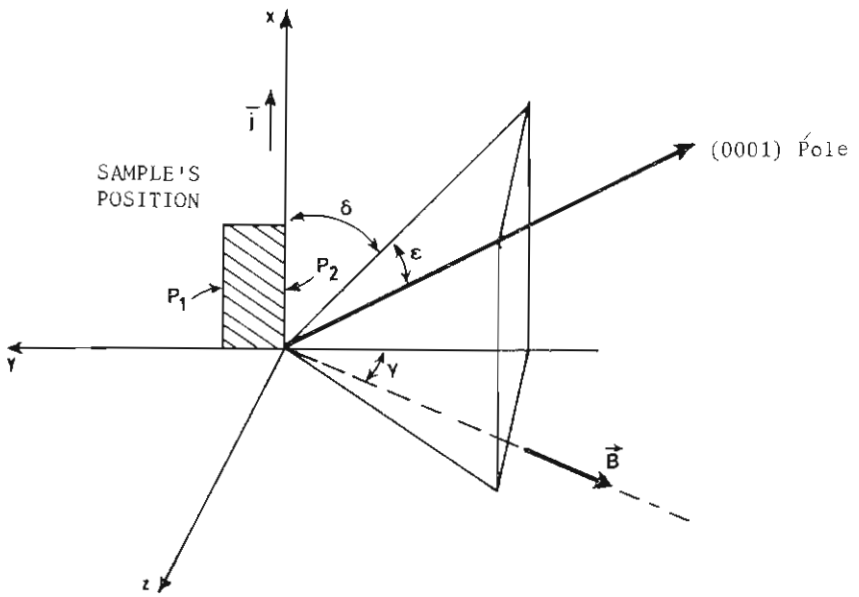


Fig. 1: Experimental arrangement depicting sample's, induction's and (0001) pole's position.

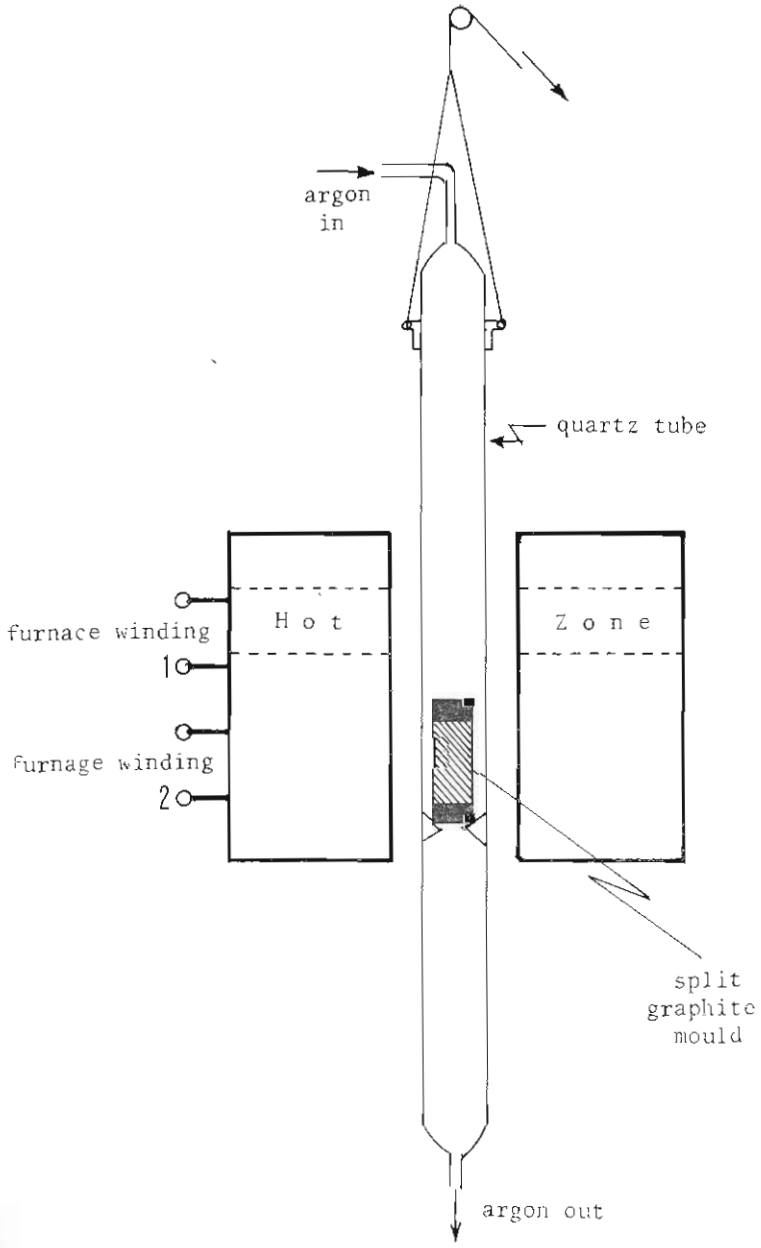


Fig. 2: Apparatus for the Modified Bridgmann technique.

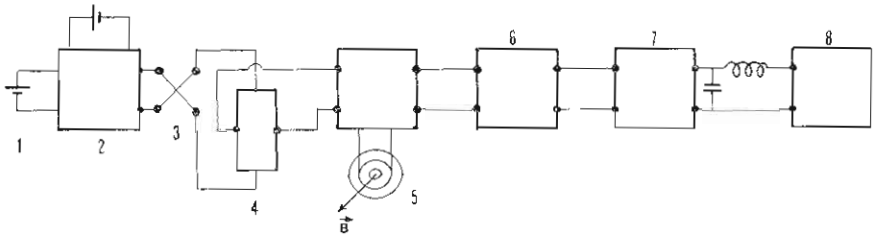


Fig. 3: Experimental set up used.

1. *10 V battery.*
2. *Current stabilizer.*
3. *Reversing switch.*
4. *Specimen.*
5. *Modified Thermal Compersator.*
6. *Diesselhorst Potentiometer.*
7. *Photocell Amplifier.*
8. *Chart recorder.*

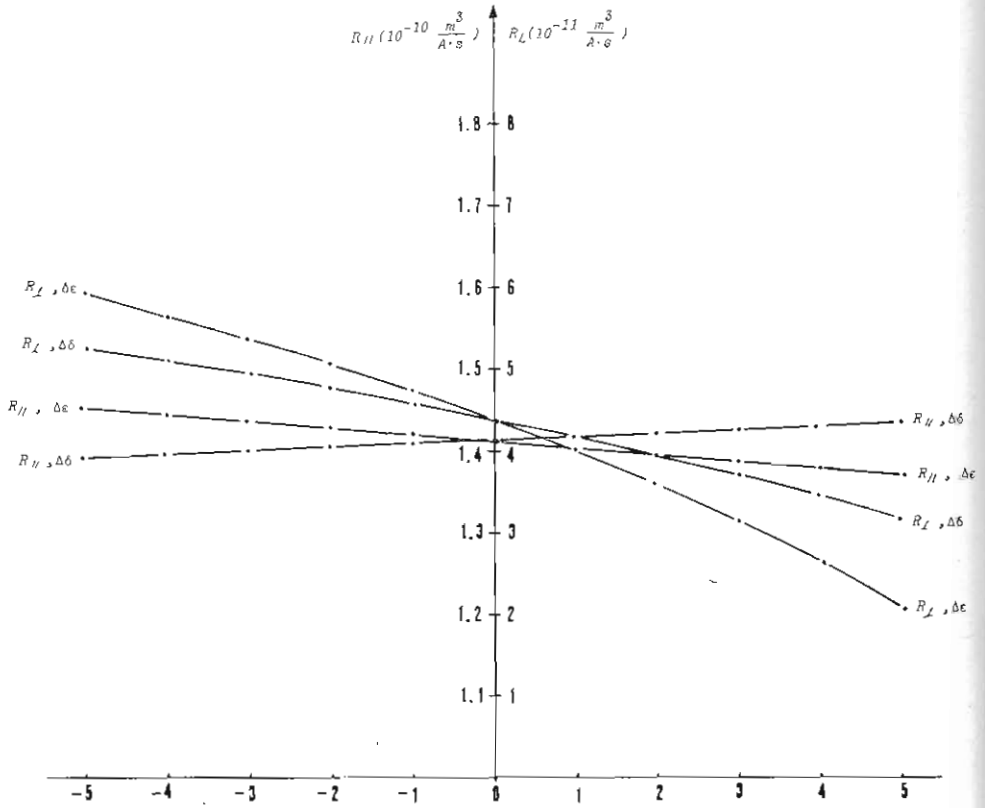


Fig. 4: Dependence of $R_{//}$ and $R_{\perp}$ on angular errors of ε, δ. Crystal No. 1

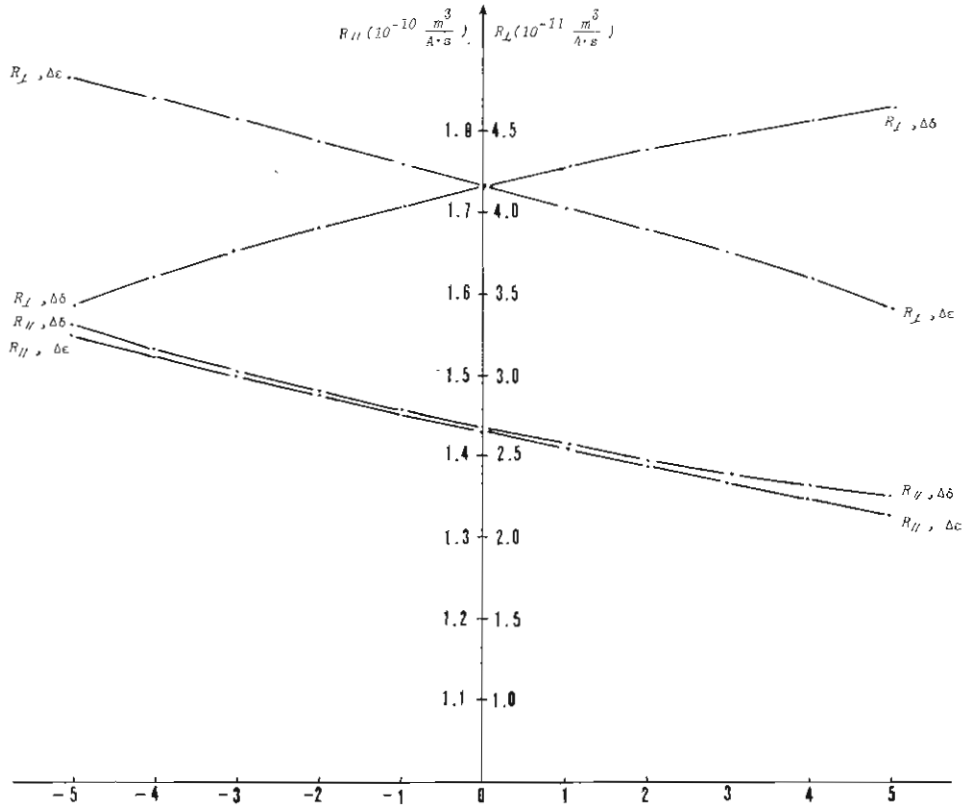


Fig. 5: Dependence of $R_{//}$ and $R_{\perp}$ on angular errors of ε, δ. Crystal No. 2

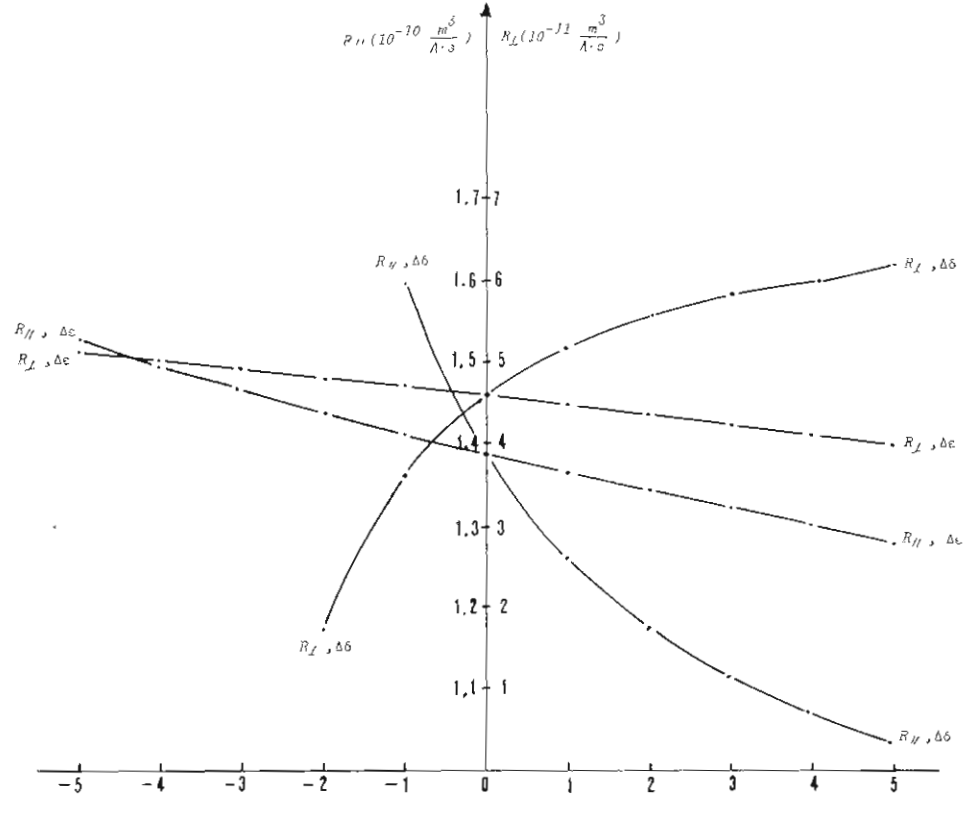


Fig. 6: Dependence of $R_{//}$ and $R_{\perp}$ on angular errors of ε, δ. Crystal No. 3

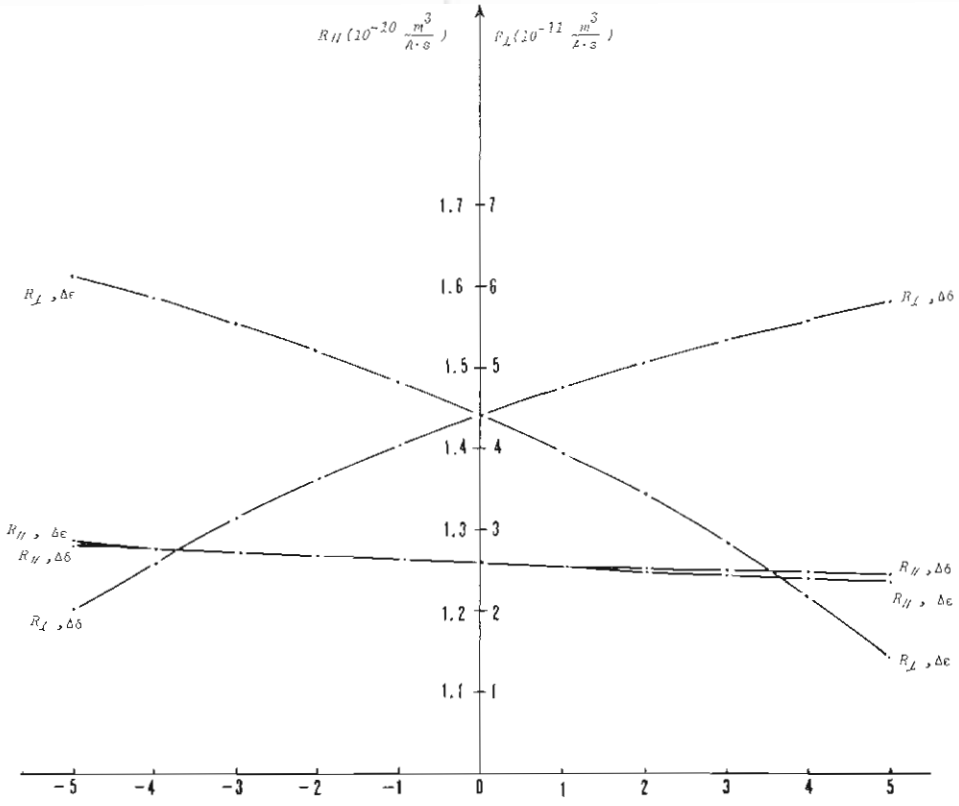


Fig. 7: Dependence of $R_{//}$ and $R_{\perp}$ on angylar errors of ε, δ. Crystal No. 4

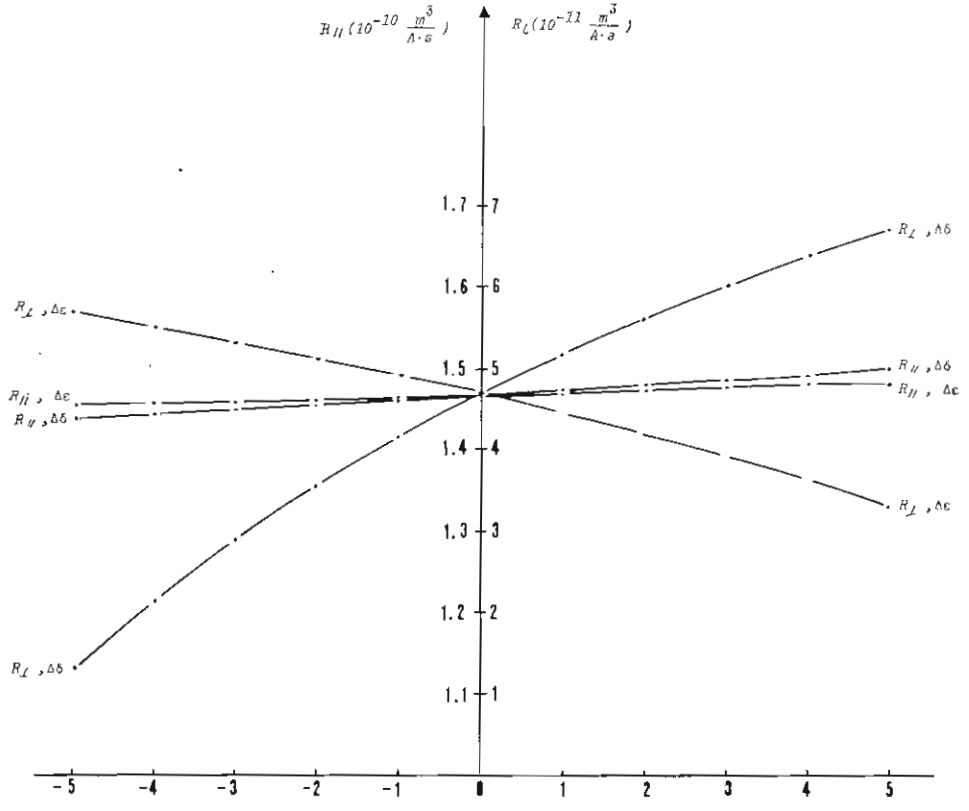


Fig. 8: Dependence of $R_{//}$ and $R_{\perp}$ on angular errors of ε, δ. Crystal No. 5

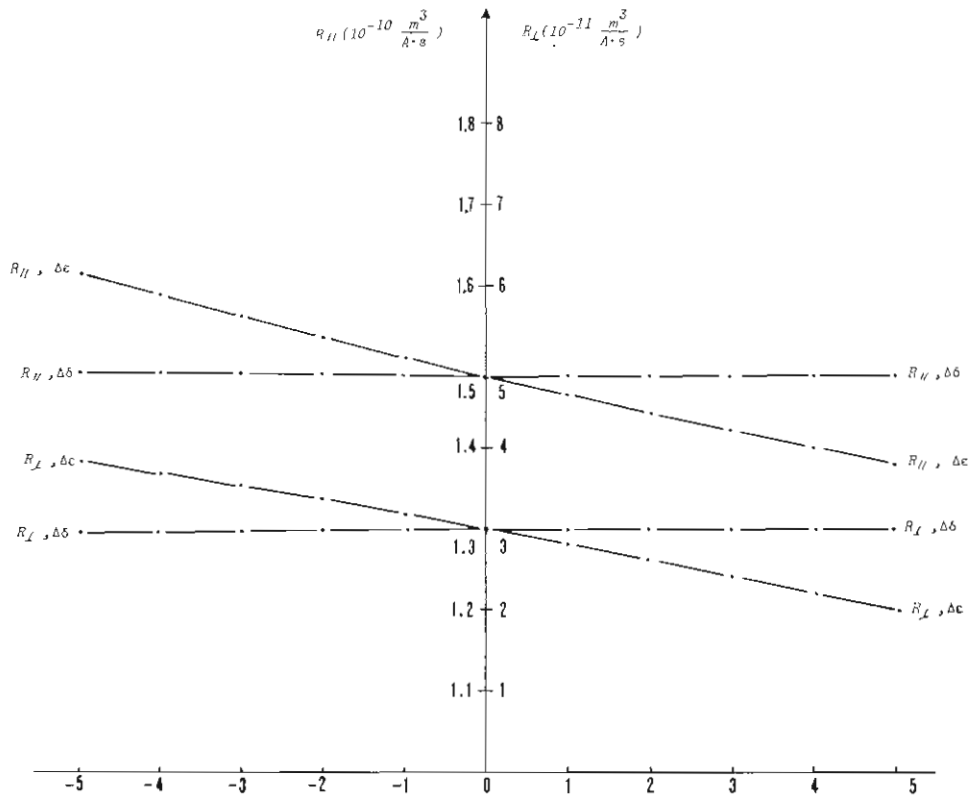


Fig. 9: Dependence of $R_{//}$ and $R_{\perp}$ on angular errors of ε, δ. Crystal No. 6

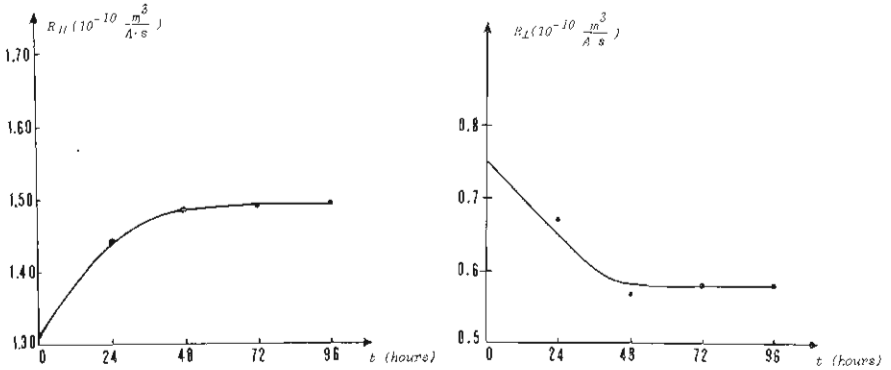


Fig. 9a: Dependence of $R_{//}$ and $R_{\perp}$ on annealing time. Crystal No. 7

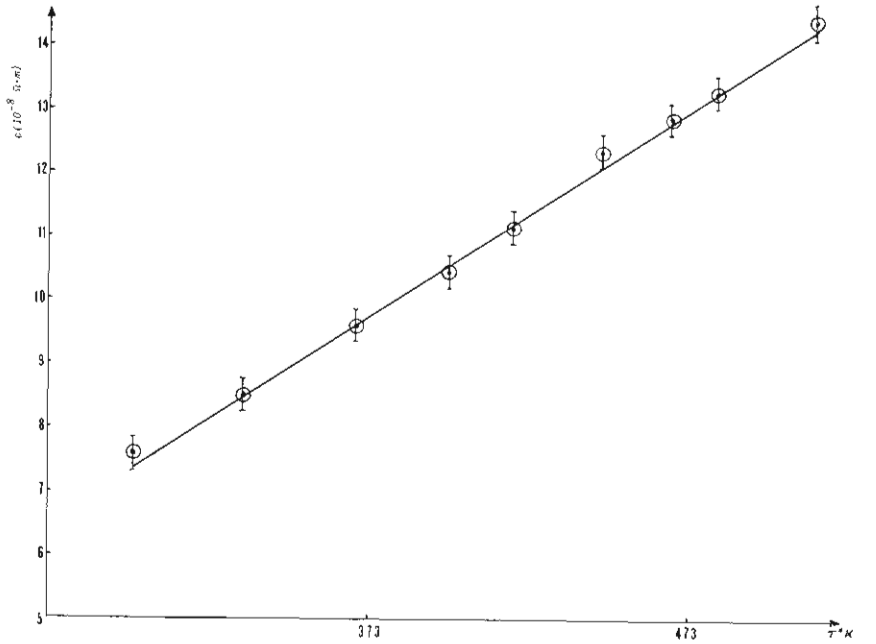


Fig. 10: Temperature dependence of the resisticity in Cadmium. Crystal No. 5

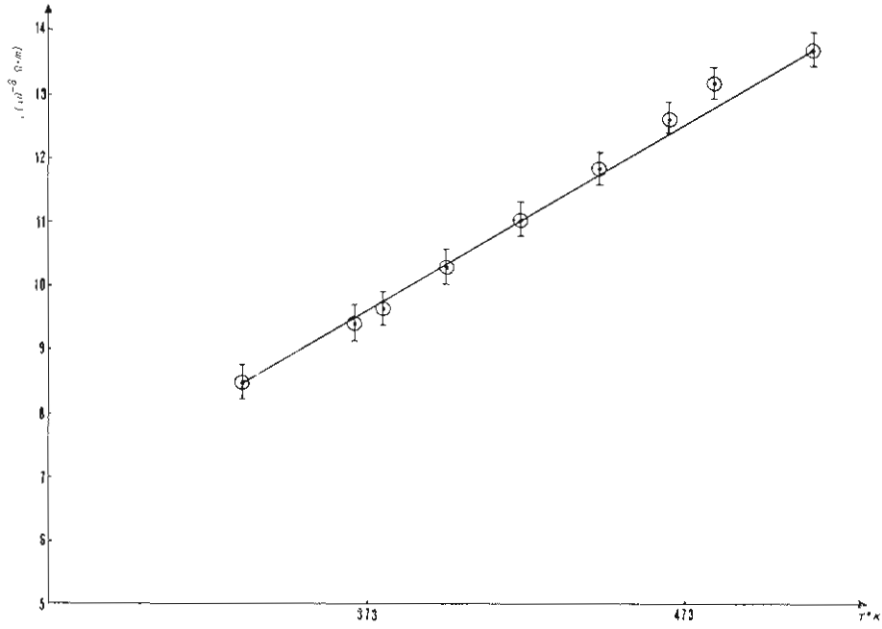
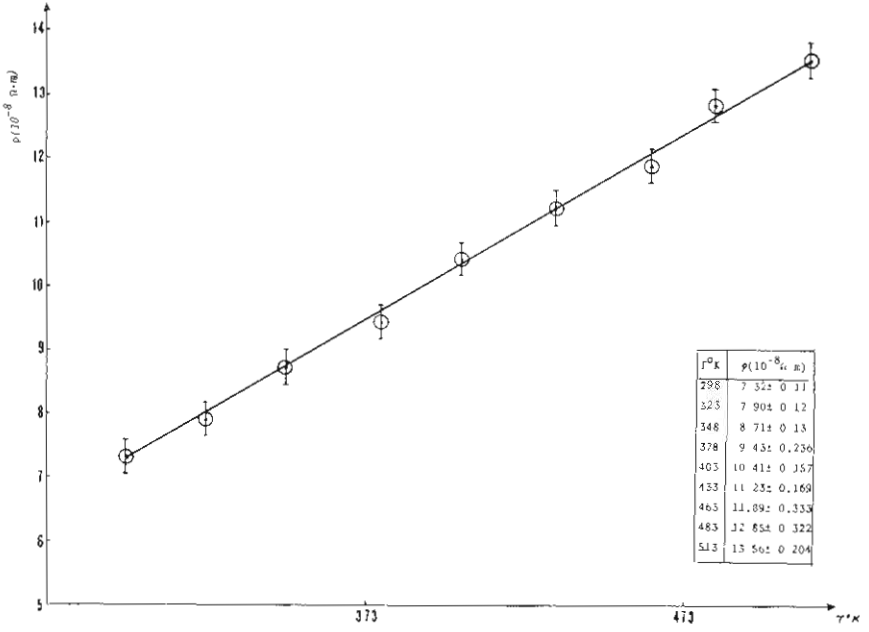


Fig. 11: Temperature depedence of the resistivity in Cadmium. Crystal No. 2



T°K	ρ(10⁻⁸ Ω m)
298	7 32± 0 11
323	7 90± 0 12
348	8 71± 0 13
378	9 43± 0.236
403	10 41± 0 157
433	11 23± 0.169
463	11.89± 0.333
483	12 85± 0 322
513	13 56± 0 204

Fig. 12: Temperature dependence of the resistivity in Cadmium. Crystal No. 7

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APPENDIX I

```
MANCHESTER FORTRAN COMPILER - 18/03/75

PROGRAM (MFOR) COMPILED ON 23/07/76 AT 14/33/06

 0          PROGRAM (MFOR)
 1          INPUT 5=CR0
 2          OUTPUT 6=LP0
 3          END



            C      IOANNIS TSOUKALAS                    LIVERPOOL     21.04.76
            C      FIRST PART
            C      THIS PROGRAM MAKES A LEAST SQUARES FIT OF THE CURVE
            C      W*SIN(THETA*PSI)+CONST    INTO EXPERIMENTAL DATA
            C      PROVIDES THE VALUES OF      W,PSI,CONST
            C      AN INITIAL GUESS TO THESE PARAMETERS IS REQUIRED
10.                  DIMENSION VOLT(20),THETA(20),PAR(9) ,TITLE(4)
11.                  DATA PI/3,14159/,ACC/0.0001/,AA/-1.0/
            C      READ DATA
13.                  READ(5,1)  AN,PEAK,PSI,OHMIC,(TITLE(I),I=1,4)
14.              1   FORMAT(F6.0,4X,3E10.3,4A8 )
15.                  N=AN

            C      PREPARE STARTING VALUES
17.                  ALPHA=PEAK*COS((PI*PSI)/180.0)
18.                  BETA=PEAK*SIN((PI*PSI)/180.0)
19.                  WRITE(6,11)  (TITLE(I),I=1,4)
20.             11   FORMAT(2X,8HTITLE:   ,4A8//)
21.                  IF(N.LE.0) GO TO 12
22.                  READ(5,2) (THETA(I),VOLT(I),I=1,N)
```

```
23.          2     FORMAT(2E20.5 )
             C     SET UP PARAMETERS
25.                DO 3 I=1,9
26.          3     PAR(I)=0.0
27.                DO 4 I=1,N
28.                S=SIN((PI*THETA(I))/180.0)
29.                C=COS((PI*THETA(I))/180.0)
             C     SUM OF VOLT
31.                PAR(1)=VOLT(I)+PAR(1)
             C     SUM OF VOLT**2
33.                PAR(2)=VOLT(I)**2+PAR(2)
             C     SUM OF SIN(THETA)
35.                PAR(3)=S+PAR(3)
             C     SUM OF COS(THETA)
37.                PAR(4)=C+PAR(4)
             C     SUM OF COS(THETA)*SIN(THETA)
39.                PAR(5)=S*C+PAR(5)
             C     SUM OF SIN(THETA)**2
41.                PAR(6)=S**2+PAR(6)
             C     SUM OF COS(THETA)**2
43.                PAR(7)=C**2+PAR(7)
             C     SUM OF VOLT*SIN(THETA)
45.                PAR(8)=VOLT(I)*S+PAR(8)
             C     SUM OF VOLT*COS(THETA)
47.                PAR(9)=VOLT(I)*C+PAR(9)
48.          4     CONTINUE
49.                WRITE(6,10) (PAR(I),I=1,9)
50.         10     FORMAT(2X,9E12.5)
             C     SCALE THE ACCURACY
52.                ACC=ACC*ABS(PEAK)
             C     STEEPEST DESCENT
54.                DO 5 IT=1,50
```

```
C       DERIVATIVES
56.       DALPHA=2.0*(ALPHA*PAR(6)-PAR(8)+BETA*PAR(5)+OHMIC*PAR(3))
57.       DBETA=2.0*(BETA*PAR(7)-PAR(9)+ALPHA*PAR(5)+OHMIC*PAR(4))
58.       DOHMIC=2.0*(OHMIC*AN-PAR(1)+ALPHA*PAR(3)+BETA*PAR(4))
C       CALCULATE  AA
60.       S=PAR(6)*DALPHA**2+PAR(7)*DBETA**2+2.0*PAR(5)*DALPHA*DBETA
          1   +AN*DOHMIC**2+2.0*PAR(3)*DALPHA*DBETA+2.0*PAR(4)*DBETA*DOHMIC
62.       C=PAR(6)*ALPHA*DALPHA+PAR(7)*BETA*DBETA-PAR(8)*DALPHA
          1   -PAR(9)*DBETA+(ALPHA*DBETA+DALPHA*BETA)*PAR(5)+AN*OHMIC*DOHMIC
          2   -DOHMIC*PAR(1)+(ALPHA*DOHMIC+DALPHA*OHMIC)*PAR(3)
          3   +(BETA*DOHMIC+DBETA*OHMIC)*PAR(4)
66.       AA=-C/S
C       UPDATE VALUES
68.       ALPHA=ALPHA+AA*DALPHA
69.       BETA=BETA+AA*DBETA
70.       OHMIC=OHMIC+AA*DOHMIC
C       ACCURACY CHECK
72.       IF(ABS(DALPHA).GT.ACC) GO TO 5
73.       IF(ABS(DBETA).GT.ACC) GO TO 5
74.       IF(ABS(DOHMIC).GT.ACC) GO TO 5
75.       GO TO 6
76.     5 CONTINUE
77.       WRITE(6,7)
78.     7 FORMAT(20H0CONVERGENCE FAILED     )
79.       STOP
80.     6 PEAK=SQRT(ALPHA**2+BETA**2)

81.       PSI=90.0
82.       IF(ABS(ALPHA/PEAK).GE.0.0001) PSI=ATAN(BETA/ALPHA)*180.0/PI
83.       IF(ALPHA.LT.0.0) PSI=PSI+180.0
84.       WRITE(6,9)
85.     9 FORMAT(7H0 ITER.,9X,9HPEAK HALL,7X,10HSHIFT(DEG),10X,5HOHMIC )
```

```
 86.                 WRITE(6,8) IT,PEAK,PSI,OHMIC
 87.           8     FORMAT(2X,I3,3X,1P3E17.5)
               C     SECOND PART
               C     THIS PROGRAM CALCULATES THE COEFF. R1,R2 FOR A SET OF VALUES
               C     OF PARAM.  EPS,DELTA
 91.          12     CONTINUE
 92.                 READ(5,13) DELTA,EPS,(VOLT(I),I=1,3)
 93.          13     FORMAT(5E10.3)
               C     VOLT(1)=THICKNESS IN CM, (2)=CURRENT IN AMPS, (3)=MAG. FIELD IN GA
               C     R(0)=PEAK HALL *SIN(PSI)*THICK/CURR/FIELD
               C     R(PI/2)=PEAK HALL *COS(PSI)*THICK/CURR/FIELD
               C     COEFF.  R(PI/2)
 98.                 PAR(1)=ALPHA*VOLT(1)/VOLT(2)/VOLT(3)
               C     COEFF.  R(0)
100.                 PAR(2)=BETA*VOLT(1)/VOLT(2)/VOLT(3)
101.                 WRITE(6,14) PAR(2),PAR(1)
102.          14     FORMAT(9H0 COEFF.,:,2X,5HR(0)=,1PE13.5,6X,8HR(PI/2)=,E13.5//
              1     35X,5HDELTA,17X,3HEPS,18X,2HR1,18X,2HR2 )
               C     VARIATION OF EPS,DELTA  FROM=5 TO +5 DEG.
105.                 PAR(9)=PI/180.0
106.                 DO 22 I=1,11
107.                 C=(EPS-6.0+FLOAT(I))*PAR(9)
108.                 VOLT(I)=SIN(C)
109.                 THETA(I)=COS(C)
110.          22     CONTINUE
               C                       R1=R(PI/2)+R(0)/TAN(EPS)/SIN(DELTA)
               C                       R2=R(PI/2)-R(0)*TAN(EPS)/SIN(DELTA)
               C     1 DEG. INCREMENTS
114.                 DO 15 IT=1,11
               C     DELTA
116.                 PAR(7)=DELTA-6.0+FLOAT(IT)
117.                 VOLT(4)=SIN(PAR(7)*PAR(9))
```

```
                    IF(VOLT(4).EQ.0.0) GO TO 17
                    DO 16 I=1,11
              C     EPS
                    PAR(5)=EPS-6.0+FLOAT(I)
                    IF(VOLT(I).EQ.0.0.OR.THETA(I).EQ.0.0) GO TO 21
                    R1=PAR(1)*PAR(2)*THETA(I)/VOLT(I)/VOLT(4)
                    R2=PAR(1)-PAR(2)*VOLT(I)/THETA(I)/VOLT(4)
                    WRITE(6,18) PAR(7),PAR(5),R1,R2
           18       FORMAT(20X,1P4E20.5 )
                    IF(PAR(7).EQ.DELTA.AND.PAR(5).EQ.EPS) WRITE(6,19)
           19       FORMAT(13H* HALL COEFF=  )
                    GO TO 16
           21       WRITE(6,20) PAR(7),PAR(5)
           16       CONTINUE
                    GO TO 15
           17       PAR(5)=EPS-5.0
                    WRITE(6,20) PAR(7),PAR(5)
           20       FORMAT(20X,1P2E20.5,5X,9HILLEGAL**    )
           15       CONTINUE
                    STOP
                    END

END OF MAIN PROGRAM


 IMPLICIT VARIABLES
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ΠΕΡΙΛΗΨΙΣ

ΕΠΙ ΤΟΥ ΦΑΙΝΟΜΕΝΟΥ HALL ΚΑΙ ΤΗΣ ΕΙΔΙΚΗΣ ΗΛΕΚΤΡΙΚΗΣ ΑΝΤΙΣΤΑΣΕΩΣ ΜΟΝΟΚΡΥΣΤΑΛΛΩΝ ΚΑΔΜΙΟΥ.

Ὑπὸ

ΙΩΑΝΝΟΥ Α. ΤΣΟΥΚΑΛΑ - Ε. ΠΑΠΑΔΗΜΗΤΡΑΚΗ - ΧΑΙΧΑΙΑ

(Ἐργαστήριον Γ' Ἕδρας Φυσικῆς)

Εἰς τὴν παροῦσαν ἐργασίαν μελετᾶται τὸ φαινόμενον Hall καὶ ἡ εἰδικὴ ἠλεκτρικὴ ἀντίστασις ἐπὶ ἑπτὰ μονοκρυσταλλικῶν δειγμάτων Καδμίου καὶ δύο πολυκρυσταλλικῶν.

Αἱ συνιστῶσαι τοῦ τανυστοῦ Hall $R_{//}$ καὶ $R_{\perp}$ προσδιωρίσθησαν, αἱ δὲ τιμαί των εὑρέθησαν $R_{//}=1.40$ καὶ $R_{\perp}=0.38$ $(10^{-10}\ m^3/Cb)$ ἀντιστοίχως.

Αἱ συνιστῶσαι τῆς εἰδικῆς ἠλεκτρικῆς ἀντιστάσεως εὑρέθησαν ὡς $\rho_{//}= 7.61\pm0.173$ καὶ $\rho_{\perp}=6.33\pm0.167$ $(10^{-8}\ \Omega\cdot m)$.

Ἡ ἐξάρτησις τῆς εἰδικῆς ἠλεκτρικῆς ἀντιστάσεως ἐκ τῆς θερμοκρασίας εὑρέθη ἀκολουθοῦσα γραμικὴν σχέσιν.

Ἐξ ἐμπειρικῶν νόμων ἀποπειρᾶται ἡ πρόβλεψις τοῦ συντελεστοῦ Hall καὶ τῆς εἰδικῆς ἠλεκτρικῆς ἀντιστάσεως τῶν πολυκρυσταλλικῶν δειγμάτων, ἐκ τῶν αὐτῶν μεγεθῶν προσδιορισθέντων εἰς τὰ μονοκρυσταλλικὰ δείγματα.