CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Determination of Hall Coefficients

R_H in 10^{-11} volt-cm/amp-gauss. Negative signs indicate electron conduction, positive signs indicate hole conduction.

Table 4-1

Hall Voltage and Hall Coefficient of Bi Thin Films

Bi Film Thickness 682 Å

B gauss	I = 5mA.		I = 10mA.		I = 15mA.		I = 20mA.	
	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H
3100	520	22.9	1000	22.0	1530	22.4	2060	22.7
5325	850	21.8	1670	21.4	2580	22.0	3300	21.1
6590	1080	22.4	2090	21.7	3190	22.0	4190	21.7
7460	1190	21.7	2350	22.3	3580	21.8	4680	21.4
8290	1280	21.3	2550	21.0	3850	21.1	4990	20.5
8900	1350	20.7	2660	20.4	4030	20.6	5240	20.1

Bi Film Thickness 1020 Å

B gauss	I = 5mA.		I = 10mA.		I = 15mA.		I = 20mA.	
	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H
3100	360	23.7	720	23.7	1140	25.0	1390	22.9
5325	620	23.7	1180	22.6	1850	23.6	2490	23.8
6590	790	24.5	1520	23.6	2250	23.3	3110	24.2
7460	880	24.0	1720	23.5	2670	24.4	3540	24.2
8290	950	23.4	1830	22.5	2840	23.4	3770	23.2
8900	1000	22.9	1930	22.1	3000	23.0	3980	22.8

Bi Film Thickness 1960 Å

B gauss	I = 5mA.		I = 10mA.		I = 15mA.		I = 20mA.	
	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H
3100	180	22.8	350	22.2	690	29.0	920	29.1
5325	320	23.6	620	22.8	1100	27.0	1470	27.1
6590	410	24.4	790	23.5	1390	27.6	1800	25.8
7460	470	24.7	880	23.2	1570	27.5	2010	26.5
8290	510	24.2	970	23.0	1680	26.5	2130	25.2
8900	530	23.4	1020	22.3	1770	26.0	2260	24.9

Bi Film Thickness 2680 Å

B gauss	I = 5mA.		I = 10mA.		I = 15mA.		I = 20mA.	
	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H
3100	-340	-58.8	-610	-52.8	-1040	-59.9	-1300	-56.1
5325	-560	-56.4	-1050	-58.1	-1650	-55.2	-2090	-52.6
6590	-700	-56.9	-1320	-53.6	-2070	-56.0	-2640	-53.6
7460	-780	-56.0	-1490	-53.4	-2290	-54.6	-2950	-52.9
8290	-830	-53.6	-1590	-51.3	-2460	-53.0	-3180	-51.4
8900	-870	-52.3	-1670	-50.2	-2550	-51.1	-3310	-49.8

Bi Film Thickness 2950 Å

B gauss	I = 5mA.		I = 10mA.		I = 15mA.		I = 20mA.	
	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H	V_H μV	R_H
3100	-110	-20.9	-260	-24.7	-350	-22.2	-460	-21.9
5325	-210	-23.2	-420	-23.2	-590	-21.8	-740	-20.5
6590	-270	-24.2	-530	-23.7	-740	-22.1	-940	-21.1
7460	-300	-23.7	-610	-24.1	-820	-21.6	-1060	-20.9
8290	-320	-22.8	-640	-22.8	-880	-20.9	-1140	-20.3
8900	-340	-22.5	-670	-22.2	-920	-20.3	-1300	-20.6

4.2 Determination of Electrical Conductivity and Hall Mobility

Table 4-2

Conductivity and Hall Mobility of Bi Thin Films.

Thickness Å	I mA.	V_{AB} volts	σ $(\Omega\text{-cm})^{-1}$	μ_H cm^2/volt-sec
682	5	1.00894	2.91×10^3	6.35×10^{-7}
	10	2.02910	2.89×10^3	6.22×10^{-7}
	15	2.12251	2.90×10^3	6.30×10^{-7}
1020	5	0.58889	3.34×10^3	7.91×10^{-7}
	10	1.14249	3.44×10^3	7.91×10^{-7}
	15	1.70039	3.47×10^3	8.26×10^{-7}
1960	5	0.25450	4.02×10^3	9.60×10^{-7}
	10	0.51429	3.98×10^3	9.06×10^{-7}
	15	0.76284	4.02×10^3	10.99×10^{-7}
	20	1.01426	4.04×10^3	10.68×10^{-7}
2680	5	0.40200	1.86×10^3	10.55×10^{-7}
	10	0.81465	1.83×10^3	9.75×10^{-7}
	15	1.22912	1.82×10^3	10.00×10^{-7}
	20	1.64637	1.81×10^3	9.55×10^{-7}
2950	5	0.35660	1.90×10^3	4.35×10^{-7}
	10	0.70980	1.91×10^3	4.49×10^{-7}
	15	1.05225	1.94×10^3	4.18×10^{-7}
	20	1.42220	1.91×10^3	4.00×10^{-7}

In the preceding table, V_{AB} is the voltage in volts across the A,B ends of the bismuth film as shown in Fig. 11. σ is the electrical conductivity of the bismuth in $(\Omega\text{-cm})^{-1}$. μ_H is the Hall mobility in cm^2/volt-sec.

4.3 Discussion

4.3a Measurement of Hall Mobility

Bi Film Thickness Å	Hall Mobility cm^2/volt-sec
682	0.06×10^{-5}
1020	0.08×10^{-5}
1960	0.10×10^{-5}
2680	0.10×10^{-5}
2950	0.40×10^{-5}

These compare with the values for single crystal of pure bismuth, as given in Seitz (3),

$$\mu_{H_{\parallel}} = 2.1\times10^{-5} \quad cm^2/\text{volt-sec}$$

$$\mu_{H_{\perp}} = 9.1\times10^{-5} \quad cm^2/\text{volt-sec}$$

The subscript $H_{\parallel}$, or $H_{\perp}$ means that the magnetic field is parallel or perpendicular to the principal axis of the bismuth lattice. The measured values for thin films are smaller than those of bulk meterial.

Since $$\mu_H = |R_H|\,\sigma = \frac{|R_H|}{\rho} ,$$

this result is at least in qualitative agreement with the theoretical result that the resistivity for thin film is greater than that for bulk material.

The values of electrical conductivity in Table 4-2 are also smaller than the bulk values (3):

$$\rho_H = 143\times10^{-6} \quad \text{ohm-cm}$$

$$\rho_H = 109\times10^{-6} \quad \text{ohm-cm}$$

$$\sigma_H = 7.0\times10^{3} \quad (\text{ohm-cm})^{-1}$$

$$\sigma_H = 9.2\times10^{3} \quad (\text{ohm-cm})^{-1}$$

Experimental values are

Thickness Å	σ $(\text{ohm-cm})^{-1}$
682	2.9×10^{3}
1020	3.4×10^{3}
1960	4.0×10^{3}
2680	1.8×10^{3}
2950	1.9×10^{3}

4.3b Measurement of Hall Coefficients

The reported values (3) for pure bismuth singlecrystal are

$$R_{H\perp} = -1000\ 10^{-11} \quad \text{volt-cm/amp-gauss}$$

$$R_{H\parallel} = +300\ 10^{-11} \quad \text{volt-cm/amp-gauss}$$

and $R_H = -4.1\ 10^{-11}$ volt-cm/amp-gauss as calculated in the electron gas model.

The present experiment obtained the values:

Thickness Å	R_H in 10^{-11} volt-cm/amp-gauss
682	21.6
1020	23.5
1960	25.1
2680	-54.2
2950	-22.2

An obviously interesting aspect of the result is that for film thickness smaller than 1960 Å , the Hall coefficients are positive, indicating hole conduction and are fairly independent of film thickness. For the two largest thicknesses studied the Hall coefficients are negative, indicating electron conduction and the larger of the thickness has the numerically smaller value of Hall coefficient.

The disagreement with reported values is that for our evaporated sample, the specimens are not single crystal, but are more likely to be of layer structure or polycrystalline. Thus the magnetic field cannot be specifically oriented with respect to the trigonal axis of the bismuth lattice. The measured values should, and do, lie between $R_{H_\perp}$ and $R_{H_\parallel}$. The change of sign at greater film thickness is probably due to the influence of different manner of deposition on the crystallite orientation.

Actually to be more complete, this thesis should include an x - ray diffraction analysis of the crystallographic structure of the thin films, so as to gain some insight into the interesting change of sign of the Hall coefficient when the film thickness becomes larger. But due to many unforseen experimental difficulties, e.g., water shortage, and the difficulty of theoretical interpretation, the x -ray analysis result is not included.

Should any further study of the topic be comtemplated, the author suggests more accurate measurements of film thickness, a more detailed study of the Hall coefficient as a function of film thickness, i.e. a larger number of film thickness, especially in the region where the Hall coefficient changes sign.

However, inherent in these experimental values are a number of errors in measurement. The largest single source of error is the thickness measurement which should be apparent from the description of the experimental procedure.

The values of Hall voltages, V_H, are plotted against values of magnetic field and film current. The straight line curves obtained demonstrate the linear dependence of Hall voltage on these quantities.

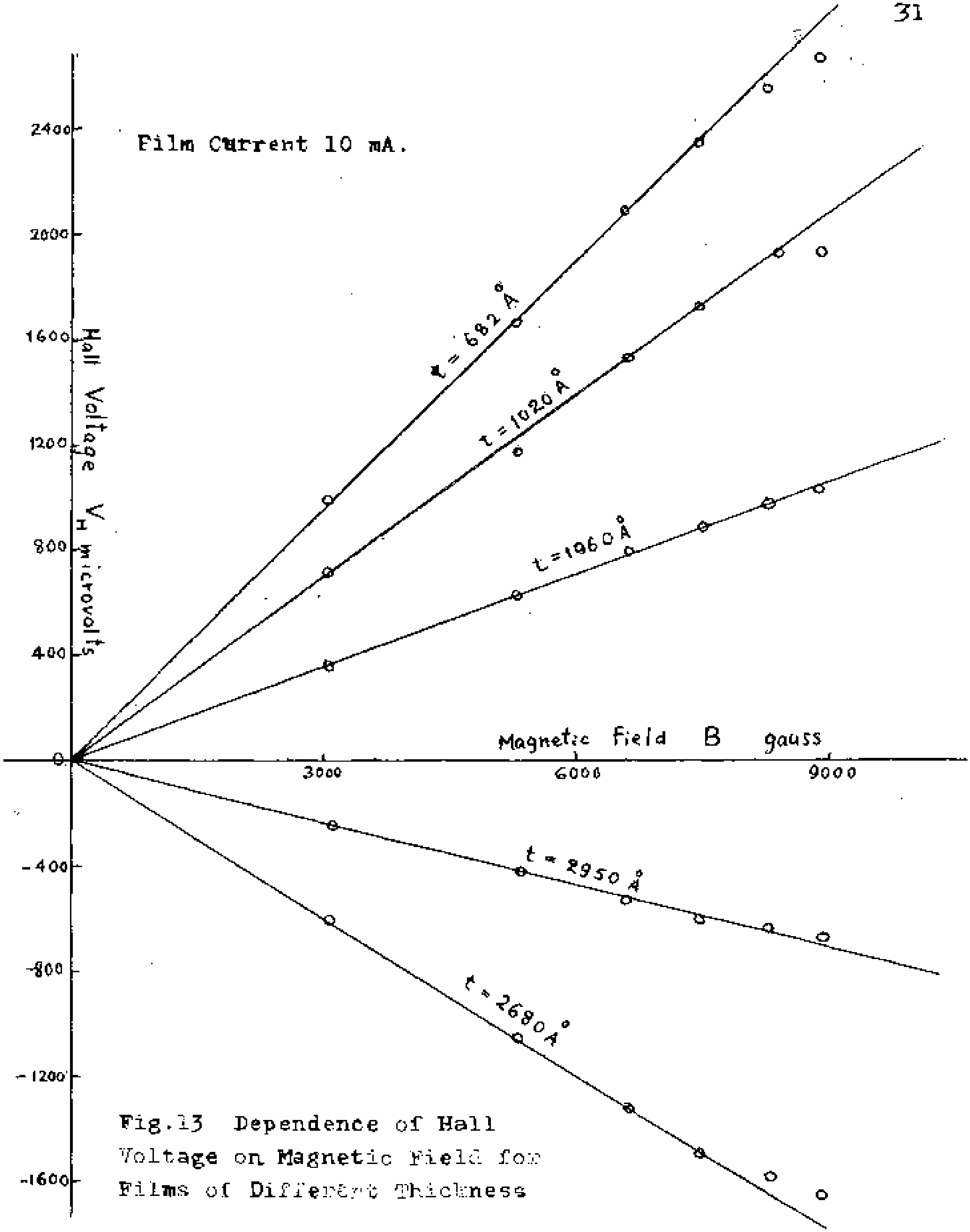

Fig.13 Dependence of Hall Voltage on Magnetic Field for Films of Different Thickness

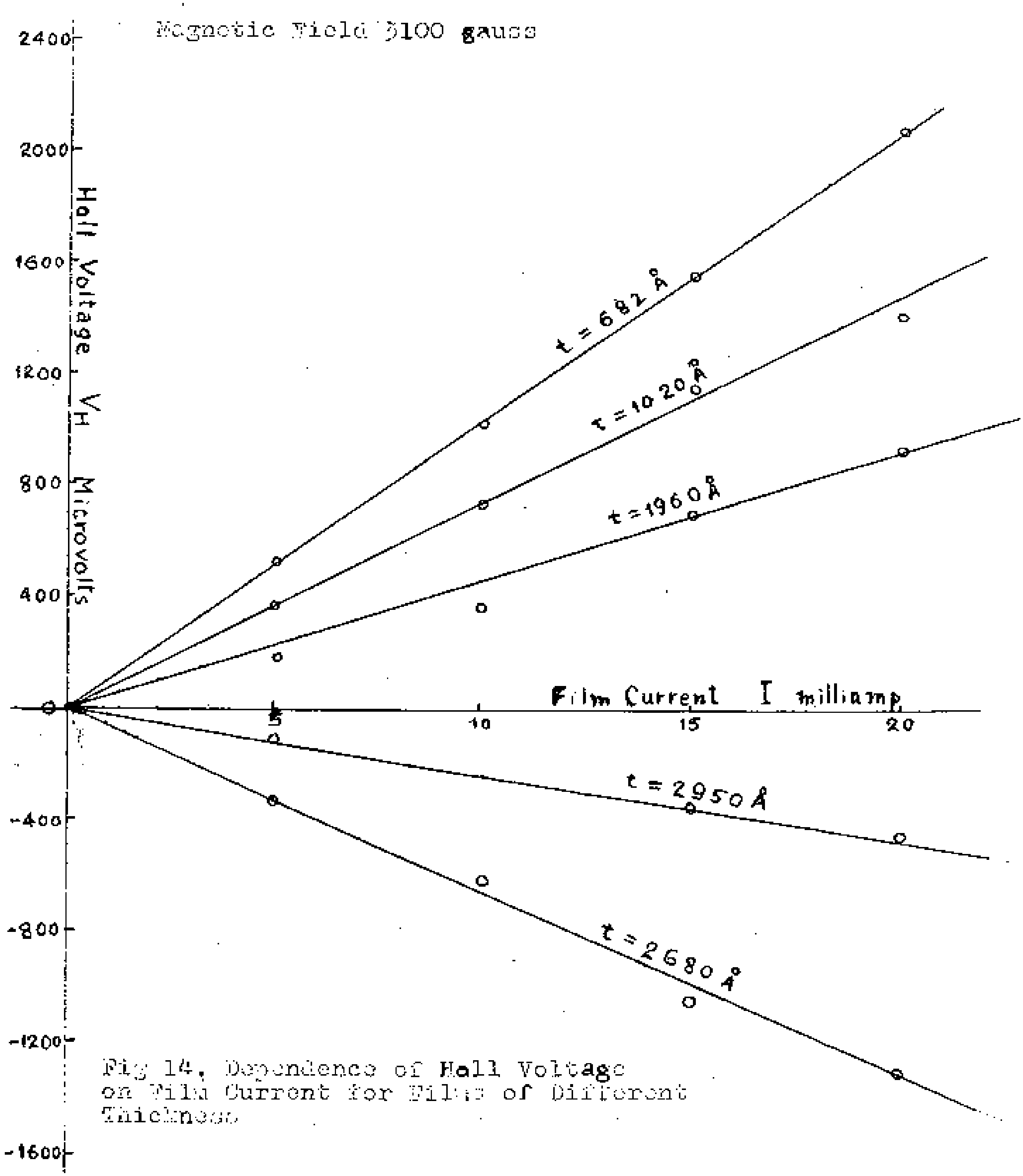

Fig 14, Dependence of Hall Voltage on Film Current for Films of Different Thickness