In Memory of the Centennial Birthday
of
Prof. Dr. Mahmoud A. El Sherbini

Prof. Dr. Mahmoud Ahmed El-Sherbini (1909 - 1998)

He was born in Menia Al Kamh, Sharqia, January 22nd 1909 and died June 11th 1998. Professor El-Sherbini is considered one of the pioneers of physics in Egypt. In 1926, he joined the one year old Faculty of Science of the Egyptian University and was awarded the B. Sc. degree with honor, in Physics and Mathematics in 1930. His M. Sc. degree (1932), entitled "*Third Order Terms in The Theory of Stark Effect and Three Dimensional Periodic Orbits in The Field of Non-Neutral Atoms*" was supervised by Professor Ali Moustafa Mosharafa. He joined King's College in London (1932) to work on his Ph. D. thesis under the supervision of the Nobel Laureate, Sir O. W. Richardson, on "*Electron Reflection in The Low Energy Region*".

On his return to Egypt in 1935, he was appointed lecturer in the Physics Department, Faculty of Science, the Egyptian University. He was the first graduate of the Egyptian University to obtain a Ph.D. degree in Physics. He became assistant professor in 1945 and he left the Egyptian University in Cairo (named University of Fouad The First, at that time) to join University of Farouk The First, in Alexandria (named Alexandria University in 1952), to become the head of the Physics Department. In 1949 he became Professor of Physics at the Faculty of Science, Alexandria University, (the first graduate of the Egyptian University to be Professor of Physics), Vice Dean (1950 – 1952) and Dean (1957 – 1961). Professor El-Sherbini was the head of the Physics Department, which he founded, for more than 20 years (1945 – 1969), he was Emeritus Professor till 1998. He established the Physics Department and is one of the founders of the Faculty of Science, Alexandria University.

Professor El-Sherbini has a great contribution to physics teaching and research in Egypt. His work on Stark effect for strong fields was recognized as one of the most accurate in this area (Quantum Mechanics, Pauling and Wilson, McGraw- Hill). His pioneering work on crystal rectification is among the best of its type and was the first research work on Solid State Physics in Egypt. His discovery of inverse rectification at low temperatures was the base for the theory developed by Holten in 1951. He established a centre for nuclear studies at Alexandria University equipped with a Cockcroft and Walton accelerator, the first accelerator in Middle East universities.

Professor El-Sherbini has established the Egyptian Physical Society and the Egyptian Journal of Physics in 1968, and was elected the first president of the Society and the first editor in chief.

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THE EFFECT OF COOLING AND OF MAGNETIC FIELDS ON CRYSTAL RECTIFICATION

BY M. A. EL SHERBINI, M.Sc., Ph.D.

AND

Y. L. YOUSEF, B.Sc.

Physics Department, Faculty of Science, The Egyptian University

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ABSTRACT. The effect of temperature on rectification has been studied in the case of six different crystals. The effect of temperature variations on crystal rectification in the interval −75 to +30° C. is especially interesting in the cases of silicium and molybdenite. In the former case there is a very marked increase in rectification at the higher temperature, and in the latter case the sign of the rectification is changed. The presence of a magnetic field appears to have no effect on rectification.

§ 1. INTRODUCTION

THE effect of heat on crystal rectification was studied by Flowers[1], who observed that the rectifying action of galena decreases with rise of temperature and vanishes at about 270° C. Khastgir and Gupta[2] repeated Flowers's experiments at 30 and 100° C., and found that at the higher temperature rectification decreases for all crystals and disappears for pyrites and galena. Working on the same subject, Sen[3] noticed, in contradiction to the results of the former experimenters, that points having good rectifying properties may exist in galena at temperatures as high as 270° C.

In the present work, crystal rectification for direct current and for alternating current of 1000 c./sec. has been investigated, particularly in the low-temperature region from −75 to +30° C. In some cases this range has been extended up to 150° C. The experiments were made on the crystals mentioned in table 1.

Table 1

Crystal	Source
Zincite with calcite	Franklin, N. Jersey, U.S.A.
Molybdenite	Norwegen
Copper pyrites	La Gardette, Dep. Isère, France
Silicium with a little iron	—
Galena	Joplin, Missouri
Bornite with chalcocite	Butte, Montana, U.S.A.

§ 2. APPARATUS

The crystal is clamped by a copper holder, and a copper spring forms the whisker. The combination is centrally suspended in an air cryostat, figure 1, made of a triple-walled pyrex-glass enclosure surrounded by a cold bath of solid carbon dioxide and acetone. The innermost tube *H* has a diameter of 1·5 cm., and can be electrically heated by means of a coil wound non-inductively over its exterior and covering a length of 16 cm. The mean distance between two consecutive turns is 0·25 cm., and local non-uniformity in heating is prevented by covering the coil with a film of cellulose. An exploring thermocouple shows almost no temperature-gradient throughout the middle third of the radiator.

Before immersion of the concentric tubes in the cold bath, the enclosure is dried by being pumped out and refilled with dry air through the side tubes *GG*.

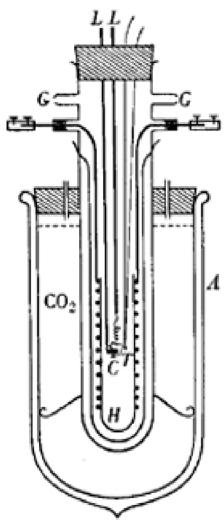

Figure 1.

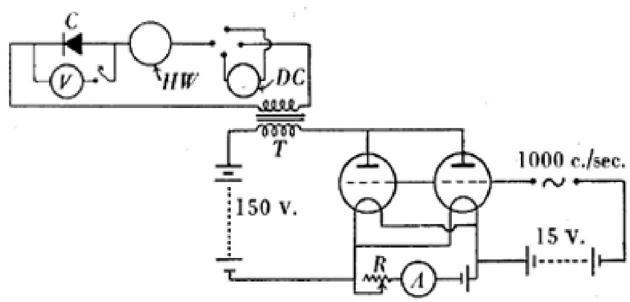

Figure 2. *V*, voltmeter; *HW*, hot-wire milliammeter; *DC*, d.-c. milliammeter; *C*, crystal.

Any particular temperature above that of the bath can be easily maintained, without disturbance of the crystal, by simply adjusting the heating current to a predetermined value obtained from a curve connecting the heating current and the corresponding equilibrium temperature. The concentric tubes assist in producing evenness, and increase the efficiency by nearly insulating thermally the heater from the bath.

The temperature of the crystal is indicated by means of a constantan-steel thermoelement *T*, connected to a high-resistance microammeter calibrated in degrees. The steady state can be reached in less than 10 min. by first passing a large heating current until the temperature approaches the required level, and then reducing the current to the value corresponding to the desired temperature.

The crystal circuit used in d.-c. rectification is of the usual potentiometric type. The a.-c. circuit is illustrated in figure 2. The voltage across the crystal is adjusted by controlling the amplification of the two power valves by means of the filament current.

§ 3. PROCEDURE

As far as possible, small currents of short duration were sent through the crystal in order to avoid electrical heating. Readings of voltage and current were taken first at the lowest temperature and then at higher temperatures. The crystal was afterwards recooled to its initial temperature, and the first set of readings was checked. In all cases it has been noticed that the currents regain very nearly their original values.

The rectification ratio in d.-c. measurements was calculated by dividing the difference between the currents I_1 and I_2 in the two directions by the larger current. In a.-c. measurements, N was taken as i/I, where i is the rectified component, measured by the d.-c. milliammeter, and I is the effective a.c. measured by the hot-wire milliammeter.

§ 4. RESULTS

Typical results are given in tables 2, 3, 4 and 5. In zincite and silicium, I_1 is the current from the whisker to the crystal, while in all other cases I_1 is the current in the reverse direction. The unit in which the currents are expressed is 0·04 mA. except for copper pyrites, bornite and galena, for which the unit is 5 mA.

Table 2. Typical results at −75 and +30° c.

Crystal	Voltage	At −75° c.			At +30° c.		
		I_1	I_2	N	I_1	I_2	N
Copper pyrites	2·4 1·44 0·48	37·7 13·3 4·2	0·2 0 0	0·995 1 1	32 11·7 3·5	0·3 0·1 0	0·990 0·989 1
Bornite	1·6 0·96 0·32	16·5 8·1 2·6	0·48 0·16 0·02	0·971 0·981 0·993	22 11·5 3·1	0·8 0·3 0·08	0·964 0·974 0·974
Galena	1·7 1·02 0·34	24·8 11·4 3·4	1 0·2 0	0·960 0·982 1	25·1 11 2·1	2·1 0·6 0	0·917 0·945 1
Zincite	4 2·4 0·8	38 19·2 4·2	10 4 1·8	0·74 0·79 0·57	42·5 21·9 4·1	8·5 3·2 1·6	0·80 0·85 0·62
Silicium	3·6 2·16 0·72	8·8 3·4 0·2	4 0·6 0	0·55 0·83 1	24 10 0·9	4·3 0·8 0	0·82 0·92 1
Molybdenite	2·5 1·5 0·5	0·757 0·235 0·005	0·313 0·118 0·0025	0·587 0·497 0·500	2·5 1 0·1	7·2 3 0·8	−0·652 −0·667 −0·875

It will be noticed from table 2 that copper pyrites, bornite and galena show, in general, a decrease in rectification as the temperature is raised, as a result of an increase in the electrical conductivity in the direction of the smaller current. With galena further tests have been carried out at 25° and 150° C. by heating the crystal in an electric furnace. It has been observed, table 3, in contradiction to Khastgir

Table 3. Results for galena at 25 and 150° C.

Voltage	At 25° C.			At 150° C.		
	I_1	I_2	N	I_1	I_2	N
1·4	21	3·9	0·813	21·5	0·3	0·986
1·12	14	1·8	0·871	14·2	0·1	0·993
0·84	9	0·9	0·900	9·2	0	1
0·56	4·9	0·3	0·939	5	0	1
0·28	1·4	0·1	0·929	1·3	0	1

and Gupta's observations which indicate no rectification at 100° C., not only that points having very good rectifying properties may exist above 100° C., as was found by Sen, but also that N may increase with temperature, chiefly owing to a decrease in the smaller current.

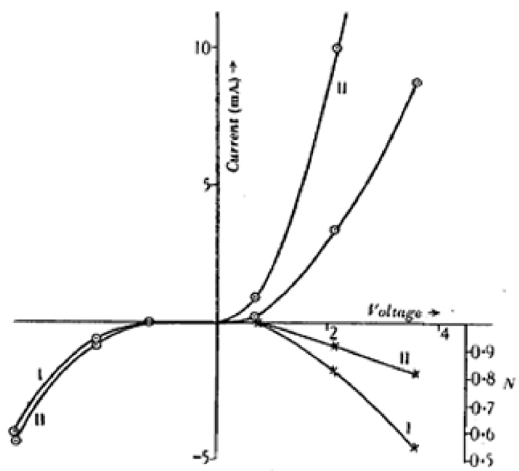

Figure 3. Rectification by silicium. ⊙, current; ×, current ratio N; I at −75° C.; II at +30° C.

Zincite shows a slight increase in N with temperature, due to an increase in I_1 and a decrease in I_2, while silicium always shows a very marked increase both in rectification and in electrical conductivity. Curves are drawn, figure 3, for silicium from the data in table 2.

Molybdenite, tables 2 and 5, is very sensitive to temperature variations, notably in the low-temperature region, for the direction of the larger current is reversed below 0° C., figures 4 and 5. This result is confirmed by a.-c. tests, table 4, figure 6. Further, the electrical conductivity in both directions rapidly increases with temperature. Between 0 and 100° c. there is no reversal, and in general N increases at a gradually diminishing rate.

Table 4. A.-c. test for molybdenite at −75 and +30° c.

Voltage	At −75° c.			At +30° c.		
	i	I	i/I	i	I	i/I
12·5	0·55	5·75	0·094	−15	85	−0·177
10	0·375	4·75	0·079	−12	66·5	−0·180
7·5	0·28	2·75	0·101	−7·3	45	−0·161
5	0·10	1·75	0·057	−4	25·5	−0·157
2·5	0·05	0·50	0·100	−1·7	8·25	−0·204

Table 5. Variation of rectification of molybdenite with temperature

Voltage	At −70° c.			At −3° c.			At +58° c.			At +100° c.		
	I_1	I_2	N	I_1	I_2	N	I_1	I_2	N	I_1	I_2	N
6·2	1·2	0·9	0·25	9·3	13·1	−0·29	25	39	−0·36	32·5	58·5	−0·44
4·96	0·9	0·7	0·22	6·7	8·3	−0·19	16	27	−0·41	22·5	42·5	−0·48
3·72	0·5	0·4	0·20	4·2	4·5	−0·07	10·2	17	−0·40	14·5	26·3	−0·45

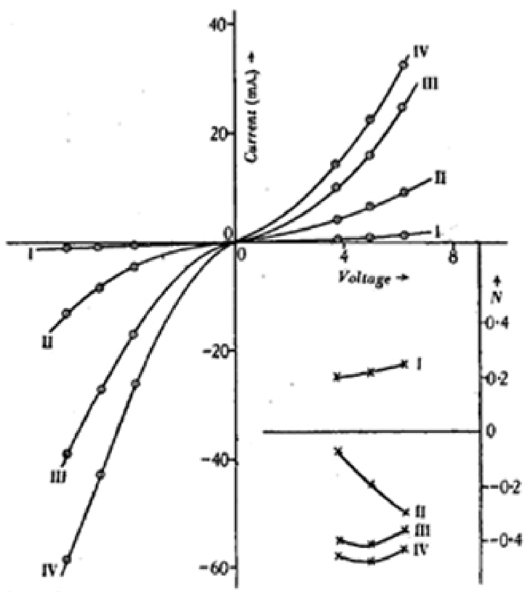

Figure 4. Change of sign of rectification by molybdenite. ⊙, current; ×, current ratio N; I at −70° c.; II at −3° c.; III at +58° c.; IV at +100° c.

The temperature coefficient of resistance of a molybdenite crystal made in the form of a resistance thermometer was determined by Pierce[4]. The specimen showed no evidence of rectification, but it showed a very rapid decrease in resistance as the temperature is raised.

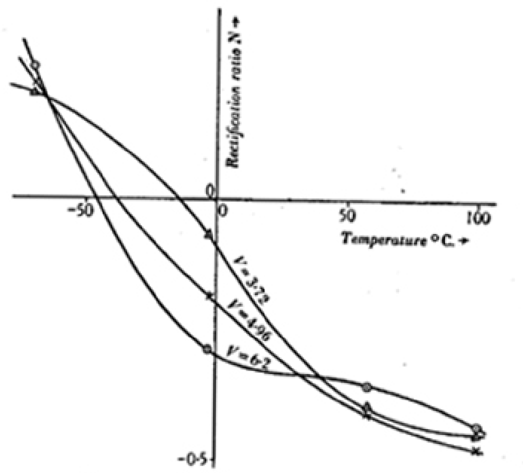

Figure 5. Rectification by molybdenite.

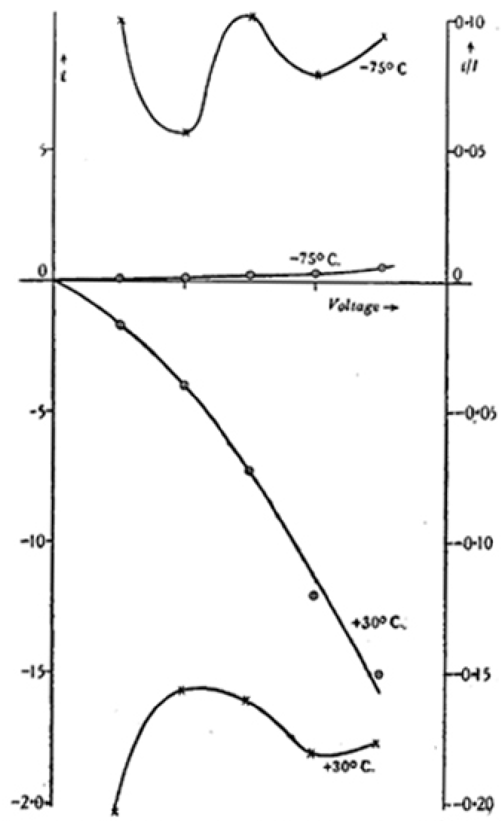

Figure 6. A.-c. test of molybdenite. ⊙, current; ×, current ratio N.

§ 5. EFFECT OF MAGNETIC FIELD

The small magnetic field created within the heating coil of the cryostat suggested the study of crystal rectification under the action of a magnetic field. Experiments were made on silicium in a field of 2280 gauss, produced by a Du Bois electromagnet, the lines of force being in one case parallel to the direction of the current through the crystal and in another case perpendicular to it.

The results showed that over a range from 0·8 to 4·0 V., corresponding to a range of I_1 from 0·02 to 6·00 mA., the change from $H=0$ to $H=2280$ and vice versa produced no changes in the values of N that exceeded the experimental error, which was about 1 per cent. The slight observed variations in the currents could not be attributed with certainty to the effect of the field, as they were not exactly reproducible.

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