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I hereby recommend that the thesis prepared under my supervision by Sukhum Sritanyaratana

entitled Characteristics of a Greenockite Conduction Counter

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

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CHARACTERISTICS OF A GREENOCKITE CONDUCTION COUNTER

A dissertation submitted to the

Graduate School of Arts and Sciences
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by

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TABLE OF CONTENTS

	Page
List of Figures	iii
Acknowledgement	v
INTRODUCTION	1
PURPOSE	4
THEORY	5
Mechanism of the crystal counter	5
Hall effects	9
Electrical conductivity of semi-conductor	12
Space charge effect or polarization	16
EXPERIMENTAL ARRANGEMENTS	19
EXPERIMENTAL RESULTS	35
WL-759 characteristics	35
Effects of temperature on greenockite	38
Effects of lights on greenockite	40
Effects of x-rays on greenockite	43
DISCUSSION OF EXPERIMENTAL RESULTS	48
CONCLUSION	52
REFERENCES	54

LIST OF FIGURES

		Page
1.	Energy band diagram.	6
2.	Hall effect in solid	10
3.	Energy levels in semi-conductor.	14
4.	Experimental arrangement for studying the conduction amplifier of crystal.	18
5.	The amplitude discriminator.	20
6.	6SN7 scaler unit.	21
7.	6SL7 sclaer unit.	22
8.	Register circuit.	23
9.	Power supply for model 200 pulse counter . . .	24
10.	WL-759 tube circuit.	26
11.	Crystal mounting.	30
12.	Experimental arrangement showing model 200 pulse counter, electromagnetic recorder, interval timer, stop clock and applied voltage power supply connection outside x-ray chamber. . . .	31
13.	Experimental arrangement showing x-ray tube and WL-759 circuit shield with lead box. . . .	32
14.	Experimental arrangement showing WL-759 circuit shield by the lead box.	33
15.	Experimental arrangement showing temperature control insulating box.	34
16.	WL-759 characteristic. Variation of no. of counts/min. with applied voltages.	35
17.	WL-759 characteristic. Variation of no. of counts/min. with starting anode currents.	36

Page

18. Effect of x-ray on carbon resistor 2020 meg. 37

19. Effect of temperature on greenockite crystal 38

20. Graph showing the relation between natural logarithms of no. of count/sec. and 1/absolute temperature. 39

21. Effect of ordinary light on greenockite . . . 40

22. Effect of sodium light on greenockite. . . . 41

23. Effect of ultraviolet light on greenockite. . 42

24. Effect of x-rays on greenockite. Variation of no. of counts/sec. with time . . 43

25. Effect of x-rays on greenockite. Variation of no. of counts/sec. with x-ray tube currents. 44

26. Effect of x-rays on greenockite. Variation of no. of counts/sec. with x-ray tube voltage. 45

27. Effect of x-rays on greenockite. Relation between logarithms of x-ray tube voltages and aluminum thickness required to produce zero no. of counts. 46

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CHARACTERISTICS OF A GREENOCKITE CONDUCTION COUNTER

INTRODUCTION

The recent interest in conductivity crystal counters started in 1945 when van Heerden[1] published a thesis describing the successful detection of single alpha particles and gamma rays by a single crystal of silver chloride. Detailed review articles on this subject can be found in References 2, 3, and 4.

Van Heerden, using a modern amplifier, tried to count single particles using crystals known to be good photoconductors. He did not succeed in obtaining pulses from diamond and zinc blends but was successful when he used silver chloride at low temperatures. Using beta particles, he confirmed the assumption that the energy of these particles could be measured in this manner.

Since the publication of van Heerden's work in 1945, many crystals have been found that count, e.g. diamond (5,6), zinc sulfide (7), cadmium (8), sulfur (9), silver and thallium halides (10,11,12), solid and liquid argon (13,14). Amplification of the current in a thin film of selenium resulting from continuous electron bombardment also has been reported (15).

During continuous operation of a crystal counter, the

electrons, or holes, caught at trapping centers give rise to a space charge. Space charge effects have been mentioned in numerous papers relating to both conductivity (16), conduction amplifiers (15,17,18), and conduction counters (2,6,19,20,21). However, very little has actually been said concerning space charge effects other than that they reduce the effective field. It has been suggested that space charge effects can be eliminated by using an A.C. field (22). Heat and light have also been suggested for their removal (22). A.C. Chynoweth (23) removed the effects of space charge which accumulated during alpha bombardment by irradiating the diamond with light from a Nernst filament. Work on photoconductivity indicates that a crystal can be brought back to its original condition by heating or irradiating with light in the absence of an applied electric field (16). The use of silicon and n-p type germanium (4) has been reported as highly satisfactory for counting of alpha particles and there are no cumulative space charge effects.

In 1949 Goldsmith and Lark-Horovitz (30) reported that synthetic cadmium sulfide, which is obtained by the method of Frerichs (8), could be used as a crystal counter of alpha particles, beta particles and gamma rays. Frerichs' method for growing cadmium sulfide crystals was as follows: Cadmium metal in a small porcelain boat was heated in a quartz

tube to about 800°C to 1000°C. The cadmium vapour was driven by a slow stream of hydrogen from the boat to the zone of the tube where it could react with a slow stream of hydrogen sulphide which entered there through a second quartz tube. By slow cooling down, with hydrogen sulphide still flowing, crystals of very pure cadmium sulphide are obtained.

The synthetic cadmium sulphide crystal, because of its high amplification and absorption, for some time has appeared to be an ideal device for use as an x-ray detector (31,32,33,34,35). However, some defects of the crystal, namely, too long a time being needed to reach a stable value of output current and space charge effects following irradiation, have been the principal problem in applying a detector of this type in practical use.

PURPOSE

Cadmium sulphide crystals are found in nature as a rare mineral known as "greenockite." This mineral crystallizes in the hexagonal system with axial lengths equal to 4.14A and 6.72A (29).

It is the purpose of this work to investigate photoconductivity, conduction amplifier, and the effects of space charge in a sample greenockite, as compared to some known crystal counters. An attempt will be made to present a working theoretical model which will explain the observed facts of photoconductivity, conduction amplifier and the space charge effects. Additional experiments to verify the theory will be performed. Also experiments will be suggested which might be used in using greenockite as a detector of radiation.

THEORY

(A) MECHANISM OF THE CRYSTAL COUNTER

In order to understand some of the factors governing the behavior of a crystal counter, it is necessary to describe its mechanism. The process by which electrons are released in a crystal may be thought of in a simple manner suggested by the present energy band theory of solid state. Such a description is analogous to the quantitative theory of photoconduction in crystals (24,25,26). A simplified model or energy band diagram (Fig. I) will aid in the explanation. In the unexcited state, the electrons occupy the states of the uppermost filled band A. Situated above this band there are the states of conduction band C in which the electrons move freely through the whole crystal. If the crystal lattice is indefinitely extended and if it does not contain any impurities or any other type of irregularity (cracks, for example) in the lattice, these two bands represent the only possible states for the electrons of the lattice.

In such a crystal, conductivity may occur if by some means electrons are raised from the highest filled band into the empty band above, where they may be freely accelerated. In addition to the conductivity due to

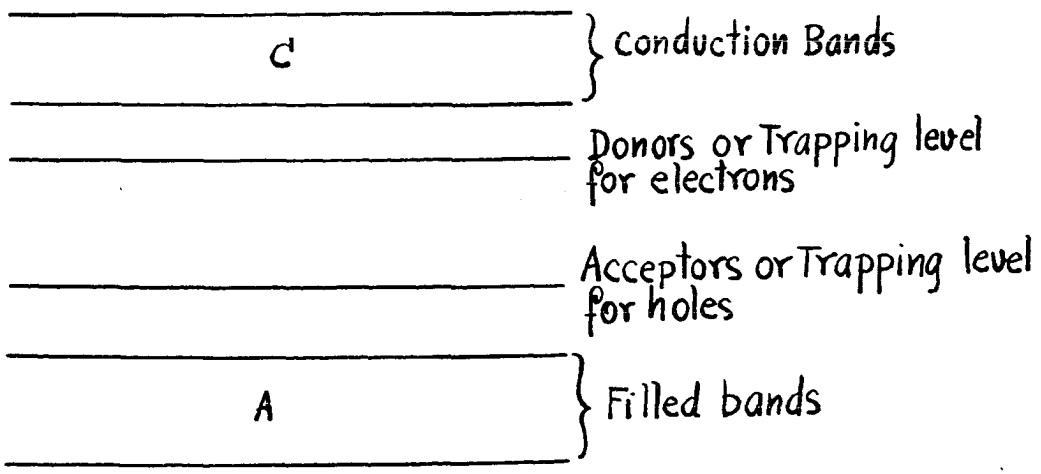


Fig. 1 Energy band diagram.

such electrons raised into the normally empty conduction band, there will be a contribution from the movement of the "holes" left in the originally full band. By virtue of other electrons in the filled band moving into the vacancies, the holes effectively drift through the material (under the applied field) in the opposite direction to the electrons. If the holes do not move, a positive space-charge field will form in the crystal.

Two ways in which electrons may be exited from the filled band into the conduction band are a) by thermal agitation b) by the absorption of radiation quanta. If the width between the filled band and the conduction band is relatively small, then appreciable numbers of electrons will be raised by thermal agitation into the conduction levels at room temperature or above, and consequently such a material will be a partial or semi-conductor. Thus there is no difference in principle between an insulator and a semi-conductor; it is merely a question of the width between the filled band and the conduction band.

In a real crystal with impurities and imperfections, additional states have to be introduced between the filled band and the conduction band. Two kinds of impurity levels are possible, donor levels and acceptor levels. At low

temperature the donor levels are occupied by electrons which may be exited into the conduction band as the temperature is raised or by the absorption of radiation quanta, giving electron conductivity. On the other hand, acceptor levels are empty at low temperature, but electrons may be exited to these levels from the filled band, the positive holes thus created giving "hole" conductivity.

B) HALL EFFECT

Measurement of the Hall effect is a very important source of information about semi-conductors, whether the charge carriers are holes or electrons.

In Fig. 2, if a current I amp. flows uniformly through a crystal, and a magnetic field H gauss is applied perpendicular to the direction of current flow, then a voltage gradient can be detected in the third direction at right angles to the other two. This is because the electrons tend to travel in a curved path in the magnetic field, and a space charge is formed along the sides of the crystal due to the change in the balance of the electron concentration.

This space charge causes the build-up of a transverse electric field until in equilibrium the electrons travel without deflection under the combined influence of the magnetic field and this transverse electric field. The Hall coefficient J is the potential gradient produced by unit-applied magnetic field when unit current density flows through the specimen. The direction of the gradient J depends on the sign of the charge of the carrier of the current. Thus if the carriers are predominantly positive holes, the gradient is in the opposite direction to that when the carriers are predominantly electrons. In semi-

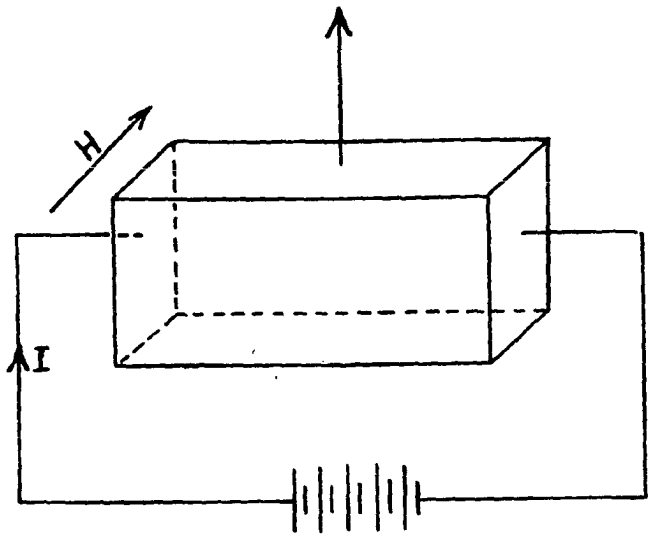


Fig. 2. Hall effect in Solid.

conductor with both donor and acceptor centers, electrons and holes arising from these centers cannot be present at the same time in the same region of a crystal.

If donor and acceptor centers are both present, the number of carriers will always be the difference between the number of electrons and the number of holes which these centers would provide. In an ideal semi-conductor the number of holes is equal to the number of electrons, and if each had the same mobility, the Hall effect would always be zero.

C) ELECTRICAL CONDUCTIVITY OF SEMI-CONDUCTOR

It is supposed that the free electrons move randomly in the solid. When an electric field is applied, there is a drift velocity superposed on the random velocity. The mean free path of an electron is terminated by collision with atom (or ion) or lattice vibration of the crystal, and the drift velocity acquired during the previous flight is assumed lost at the collision. When the drift velocity is u, the current density is neu. n is the number of electrons in the conduction band per unit volume and e is the charge on the electron. The conductivity σ of the crystal is given by

$$\sigma = \frac{neu}{E} = neu_0 \qquad (1)$$

where E is the electric field intensity and u_0 the drift velocity in the unit field, is called the mobility of the electron. For all electrons the mean drift velocity is given by[27]

$$u = \frac{4}{6}\frac{Ee}{m}\delta\left(\frac{3}{2}\frac{m}{h}\left(\frac{8\pi}{3n}\right)^{\frac{1}{3}}\right) \qquad (2)$$

where δ is a mean free path, m is the mass of an electron, h is Plank's constant and the other notations have the same meaning as before.

From (1) and (2) we have

$$\sigma = \frac{8\pi e^2\delta}{3h}\left(\frac{3n}{8\pi}\right)^{3/2} \qquad (3)$$

An ideal semi-conductor at low temperature will have a few electrons in the conduction band, and an equal number of holes in the highest filled band.

If there are no impurity levels (donor or exceptor level), and if the energy gap between the two bands is Q as in Fig. 3, the number of electrons in the conduction band per unit volume is[28]

$$n = (2)\frac{(2\pi mkT)^{3/2}}{h^3} e^{-Q/2kT} \qquad (4)$$

where k is Boltzman's constant, T is absolute temperature.

The first multiplier 2 is placed in the brackets since it occurs only when every level is occupied by two electrons of opposite spin.

Similarly, on introducing donor levels at dept. R below the conduction band (Fig. 3), by any of the mechanisms discussed above, e.g. impurity centers or lattice vacancies, if the density of centers is n_o per unit volume, the number of electrons in the conduction band per unit volume when the temperature is low and when n is small compared with n_o is[28]

$$n = (2)\, n_0^{1/2}\frac{(2\pi mkT)^{3/4}}{h^{3/2}} e^{-R/2kT} \qquad (5)$$

or

$$n = \gamma e^{-Q/2kT} \qquad (6)$$

where $\gamma = (2)\, n_0^{1/2}\frac{(2\pi mkT)^{3/4}}{h^{3/2}}$

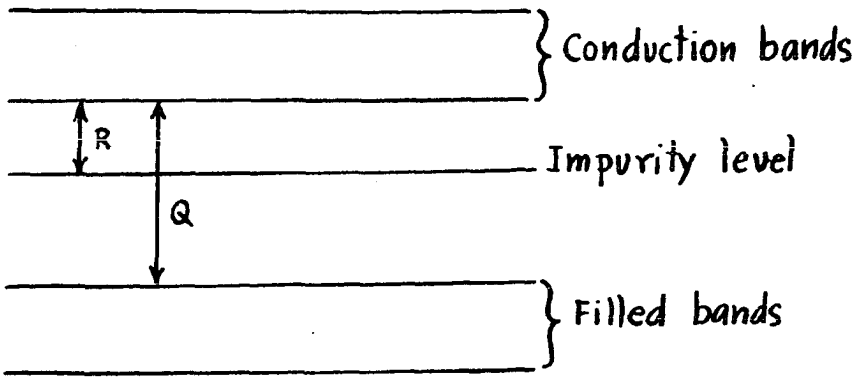


Fig. 3. Energy Levels in semi-conductor.

Since τ is a slowly varying function of T, this variation is normally negligible in comparison with the exponential term. The conductivity σ of the semi-conductor is given by $ne u_0$ where u_0 is the drift velocity of the electrons in unit applied field. u_0 is usually referred to as the "mobility." The mobility in a perfect lattice is large at low temperature, and falls as the temperature rises due to interaction between the electrons and the lattice vibrations. The mobility is known from experiments on metals to be inversely proportional to the absolute temperature.

In a semi-conductor the electron motion is further complicated by the process of trapping referred above, since an electron may be caught and held at any imperfection or impurity center which has an effective positive charge. As temperature rises, the electron caught in such traps will be more readily free again; thus the lifetime of electrons in the traps decreases and the mobility due to this factor increases. The net effect of temperature on mobility is usually supposed to be small compared with the variation in n with temperature. Over the range where it is true, the conductivity will vary with temperature as in equation (3).

$$\text{or} \qquad \ln \sigma \propto -\frac{1}{T} \qquad (7)$$

(D) SPACE CHARGE EFFECTS ON POLARIZATION

Using the energy band diagram (Fig. 1) one can assume the following mechanism for the explanation of space charge produced in the crystal by bombardment with radiation quanta. If a potential is applied at two electrodes put into the crystal, a small current will flow through it. This current is carried by the small number of electrons which are lifted up by thermal agitation from donor centers into the conduction band. The conductivity depends on the temperature according to the law $\ln \sigma \propto -\frac{1}{T}$.

The number of electrons present at each instant in the crystal is determined by the stationary negative space charge of electrons which are held in the donor centers. If one electron leaves the crystal at the anode, another electron enters the crystal at the cathode and the number of electrons in the crystal stays constant. When the radiated quanta are absorbed in the crystal, a number of electrons are lifted up from the highest filled band into the conduction band. The holes in the filled band are then quickly occupied by the electrons of the easily ionizable acceptor centers. The acceptor center which lost electrons thus represents a stationary positive space charge field which is opposite in direction to the applied field

which, as the bombardment proceeds, will glow larger until the resultant field in the crystal reduces to a very low value. The formation of space charge causes a falling off of the electrical conductivity caused by bombarding radiations. The positive space charge can be neutralized only if the electrons recombine with it.

Let N be the numbers of radiation quanta bombarding on the crystal of volume $\mathcal{T}$. Each radiation quantum is assumed to provide, on the average, H/ϵ electron and hole pairs, where H is the energy of bombardment radiation and ϵ is the energy per electron and hole pair. The positive space charge per unit volume is

$$\rho = \frac{NH}{\epsilon \mathcal{T}} e \qquad (8)$$

or

$$n = \frac{NH}{\epsilon \mathcal{T}} e$$

where n is the number of electrons in the conduction band per unit volume of the crystal. For the case of uniform space charge it can be shown that the effective field is [2]

$$E = \frac{2\pi\rho}{K}(2x-d) - \frac{V_0}{d} \qquad (9)$$

where x represents distance from the negative electrode, d is the thickness of the crystal, K is the electrical dielectric constant of the crystal, and V_0 is the applied potential.

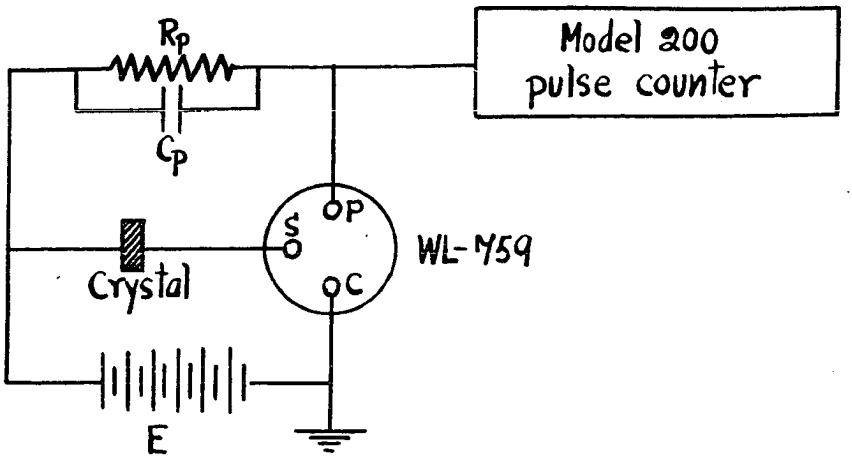


Fig. 4. Experimental arrangement for studying the conduction amplifier of crystal.

EXPERIMENTAL ARRANGEMENT

The basic experimental arrangement is shown in Fig. 4 (p. 18). The main components are as follows:

(a) Model 200 Pulse Counter: The circuit components for the Model 200 Pulse Counter are shown in Fig. 5 to Fig. 9. The counter consists of three principal parts:

1. An amplitude discriminator which is a trigger circuit which produces a pulse of standard size whenever it receives a pulse.
2. A Scaler which employs two 6SN7 units followed by seven 6SL7 units, all directly connected in a chain arrangement. It provides one output pulse for each 2, 4, 8, 16, 32, 64, 128, or 256 pulses which it receives.
3. A Register Circuit which operates the electromechanical recorder each time the scaler produces an output pulse.

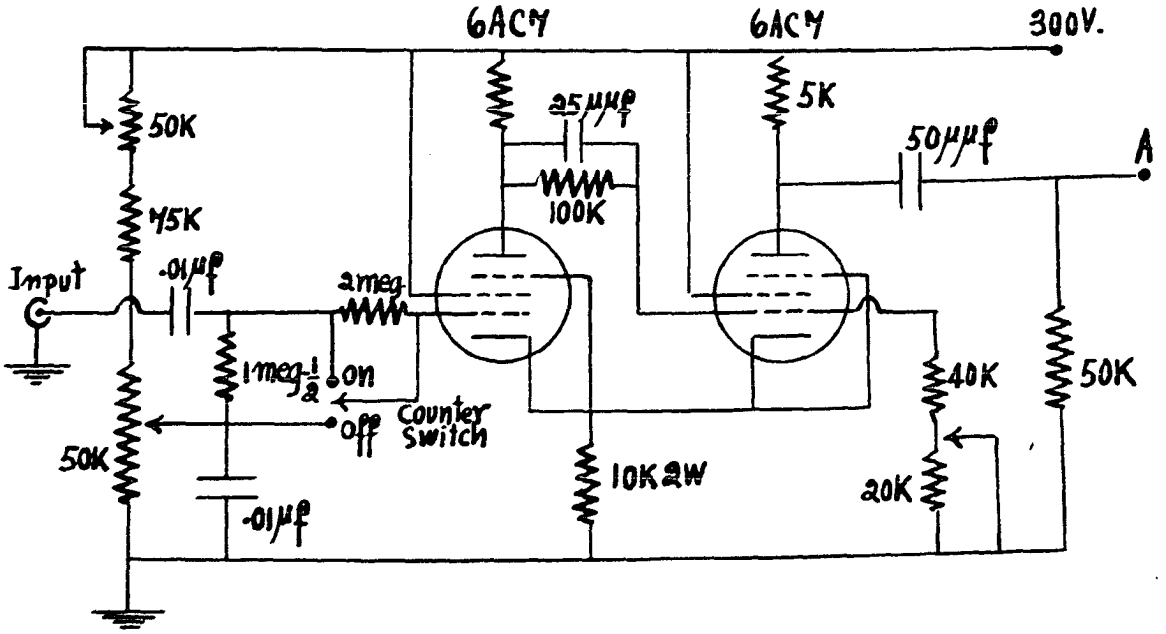


Fig. 5. The amplitude discriminator

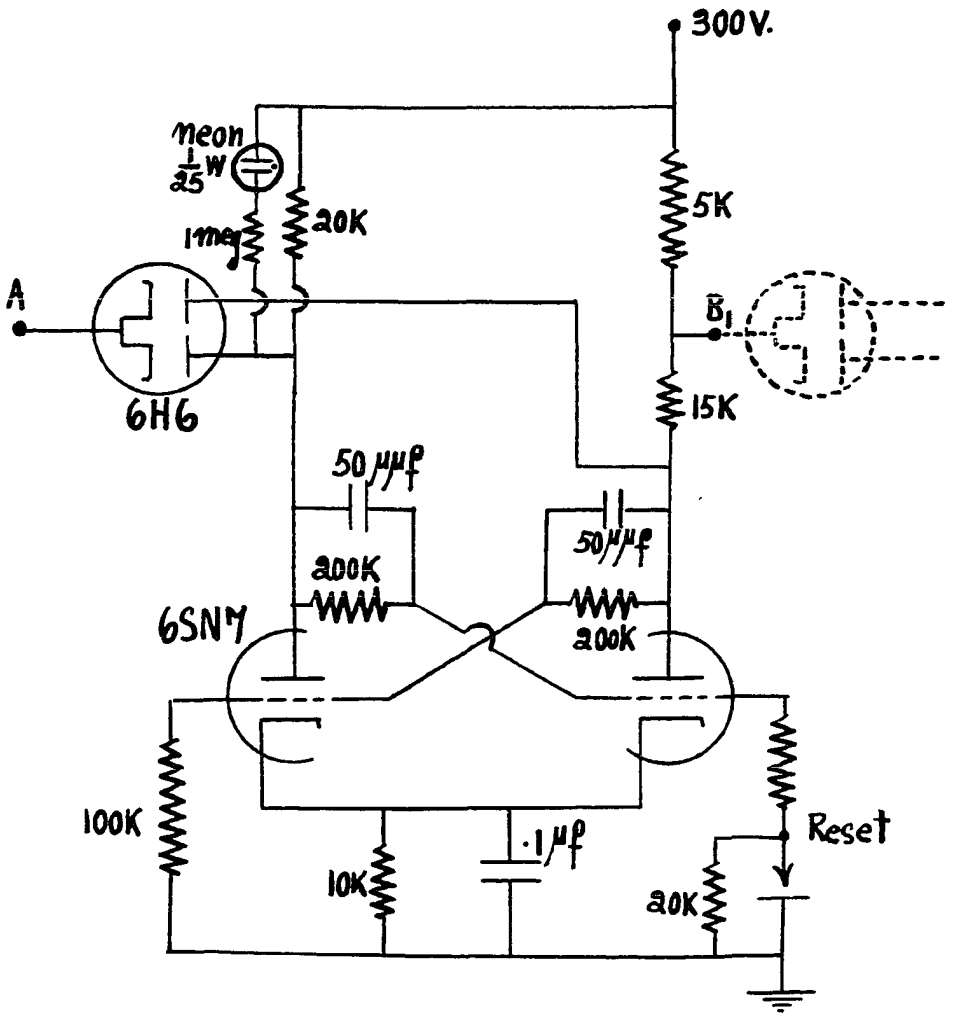


Fig. 6. 6SN7 scaler unit.

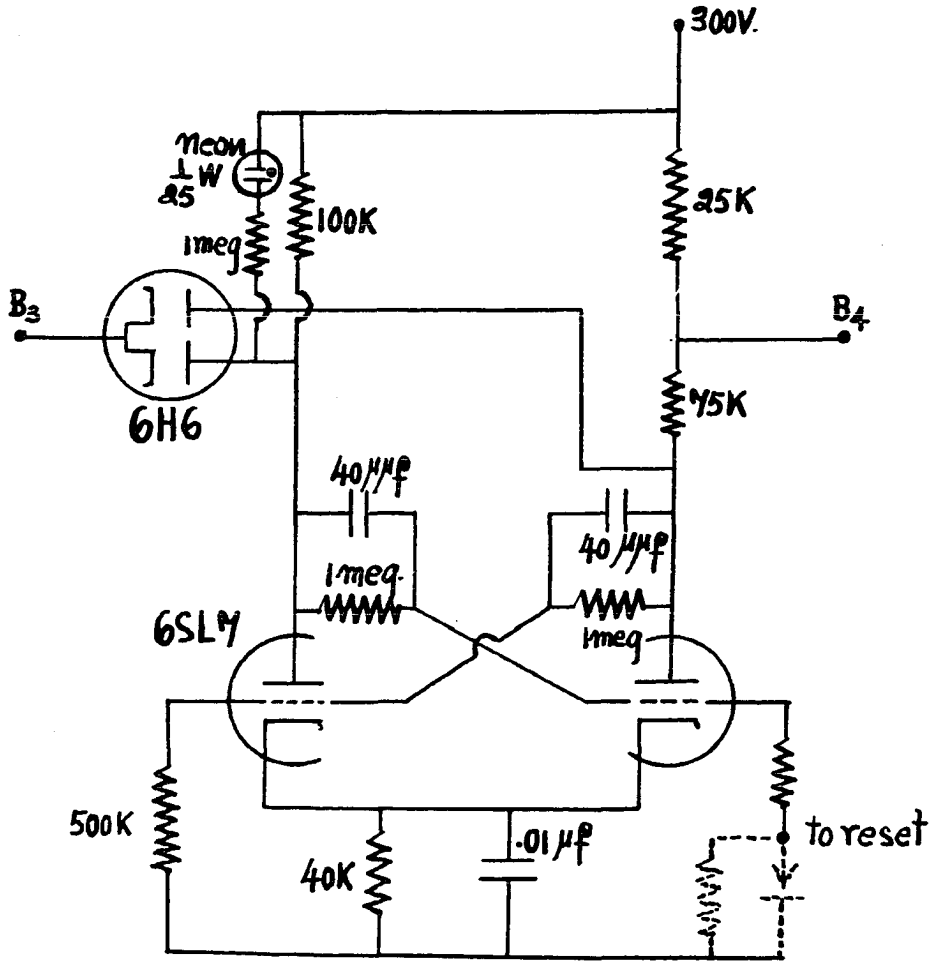


Fig 7. 6SL7 scaler unit.

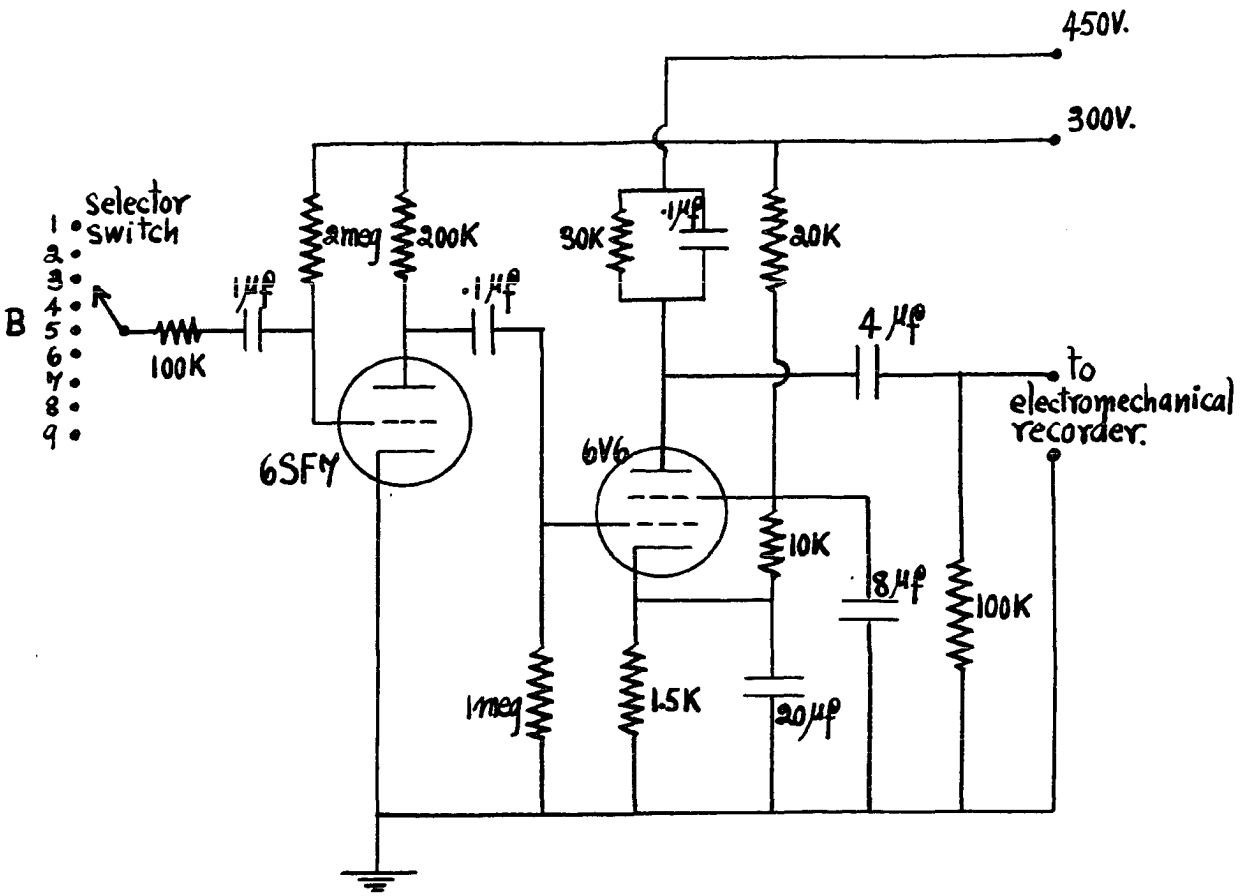


Fig.8 Register circuit.

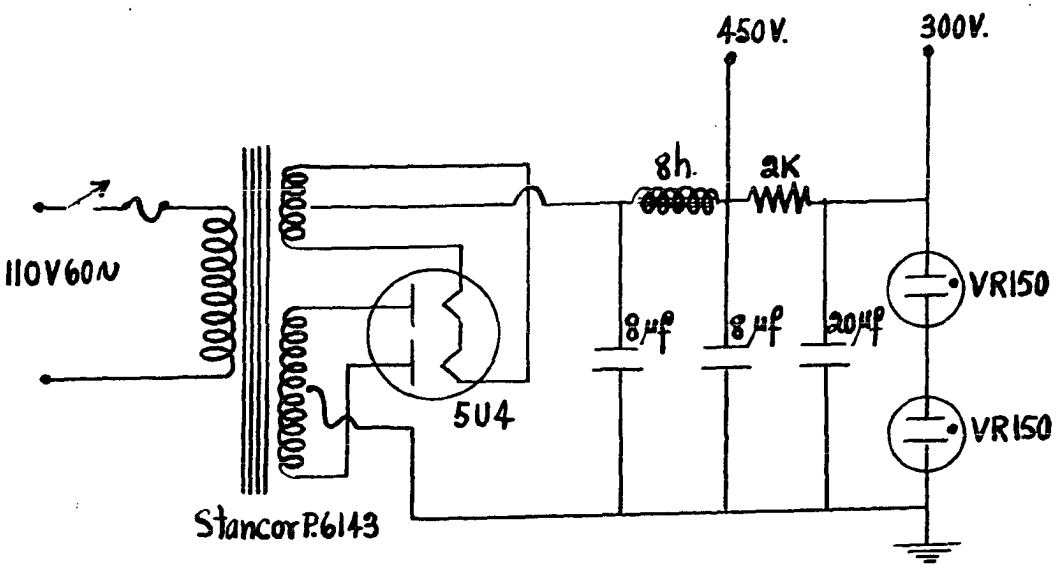


Fig. 9. Power supply for model 200 pulse counter.

(b) Stop Clock: Precision Scientific Co., No. 126, 893

(c) Electromechanical Recorder: Production Instrument Co. Type EC-214

(d) Interval Timer: General Electric, Type T-48

(e) Westinghouse WL-759 "Trigger" Tube: The WL-759 is a cold-cathode glow discharge tube with a well-insulated starting anode S to control the starting of the discharge between a thoriated cathode C and the principal anode P (Fig. 10).

The minimum current which must be furnished by the starting anode circuit is less than 10^{-11} amp. and the maximum rated anode current (average) is 4 milliamperes.[38] With the circuit illustrated by the diagram of Fig. 10, it is possible to measure the current flowing in the starting anode circuit. The principal anode P is connected to a 255 volt power supply through the 1 megohm resistance Rp and a .01 microfarad capacitor Cp. When the current is created in the starting anode circuit, the starting anode charges up to the critical voltage in the neighborhood of 180 volts and the WL-759 tube suddenly becomes conducting and discharges the condenser Cp. The potential difference C to P is about 90 to 100 volts while the tube is conducting; the drop over Cp may go as low as 30 volts.

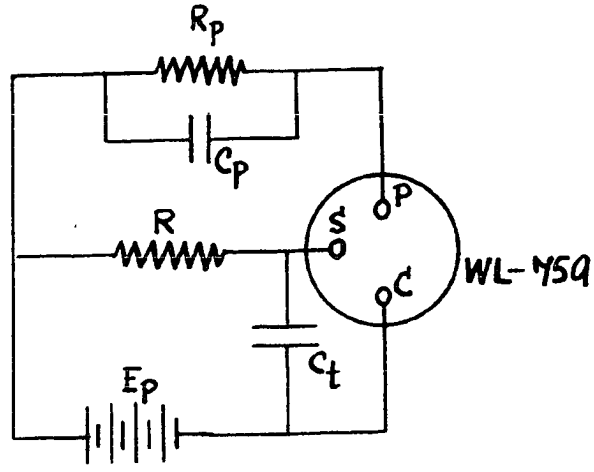


Fig. 10. WL-459 tube circuit.

Under these conditions conduction suddenly stops and the condenser Cp starts to charge up. During the conduction period, the starting anode S drops to the potential between 75 and 80 volts positive with respect to the cathode. As soon as conduction within the tube stops, the starting anode begins to charge up through the condenser Ct. When the starting anode charges up to critical voltage, the tube is conducting again and the process is repeated. Increasing the capacity Ct decreases the counting rate for a given current in the starting anode circuit.

(f) Light Sources

1. Ultraviolet light source: Physics Dept.
2. Sodium light source: General Electric 160-6A11X1
3. Unresolved light: Electric light bulb 100 watts

(g) X-ray Sources: The X-rays are produced by a Machlett AEG-50-T Beryllium window tube (Machlett Laboratories, Inc.) This x-ray tube is capable of operation at any voltage up to 50 kv., and with the currents up to 50 ma. An intensity of 2,330,000 roentgens per minute is obtainable at a distance 2cm. from the outer surface of the window, with 50 ma. at 50 kv. The x-ray tube current is maintained at 10 ma. throughout

the experiment. At 35 kv. and 10 ma., the intensity of the radiation is of the order of 12,000 roentgens per minute as estimated from data on this tube in the paper by T. H. Rogers. (40)

(h) Greenockite Crystals: The author attempted to obtain greenockite crystals from companies known to supply the natural crystal. Only two sources were able to supply the crystal. A sample of greenockite was obtained from Eckert Mineral Research Co., Florence, Colorado. The source of the sample supplied by Mineral Research was Bishopton, Scotland. Its size is about a half cubic centimeter. Being decayed, it was difficult to cut to a suitable size for the experiment.

Another crystal was obtained from Ward's Natural Science Establishment, Inc., which supplied a crystal from Asunta Mine, San Vicente, Bolivia. It is a non-homogeneous crystal which appears to have metallic traces. When the author cut the crystal into smaller pieces, some of them showed as good conductors. Seeking another crystal from Ward's, the author was informed that greenockite is no longer available.

All of the experimental results in this thesis were then obtained from Ward's sample of Greenockite. The crystal, of no definite cleavage, was cut into small pieces about

.3cm. in length and .2cm. in width by .1cm. thick. A crystal was choosen for its lowest dark current. The crystal mounting is shown in Fig. 11.

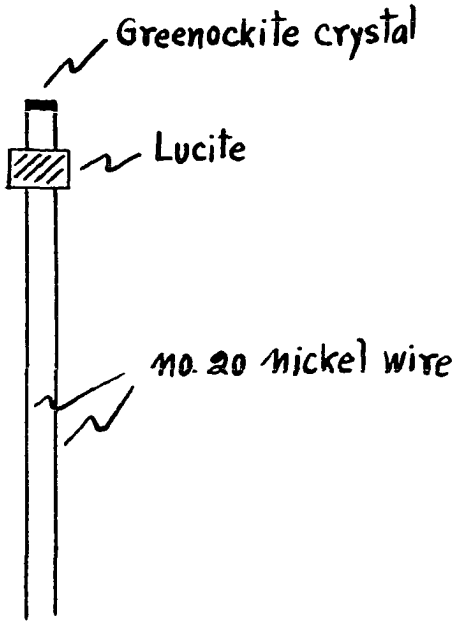


Fig. 11. Crystal mounting.

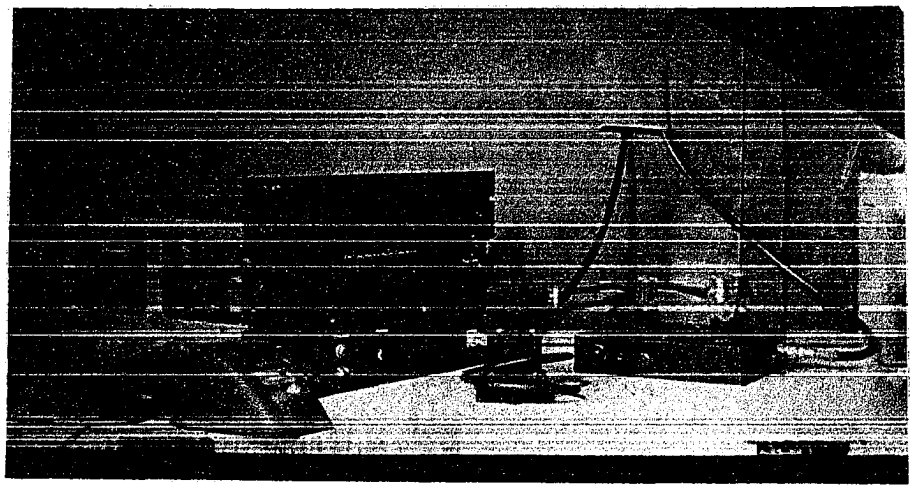


Fig. 12. Experimental arrangement showing model 200 pulse counter, electromagnetic recorder, interval timer, stop clock and applied voltage power supply connection outside x-ray chamber.

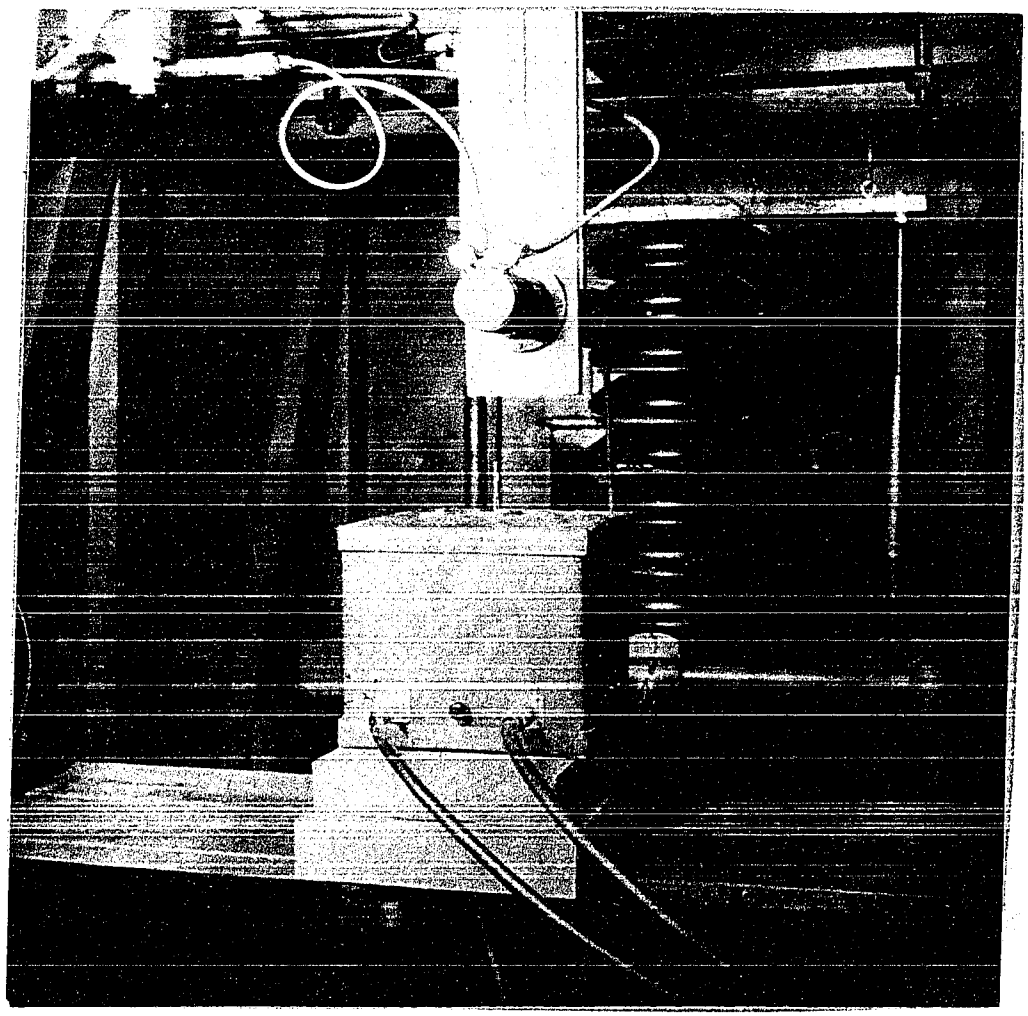


Fig. 13. Experimental arrangement showing x-ray tube and WL-759 circuit shield with lead box.

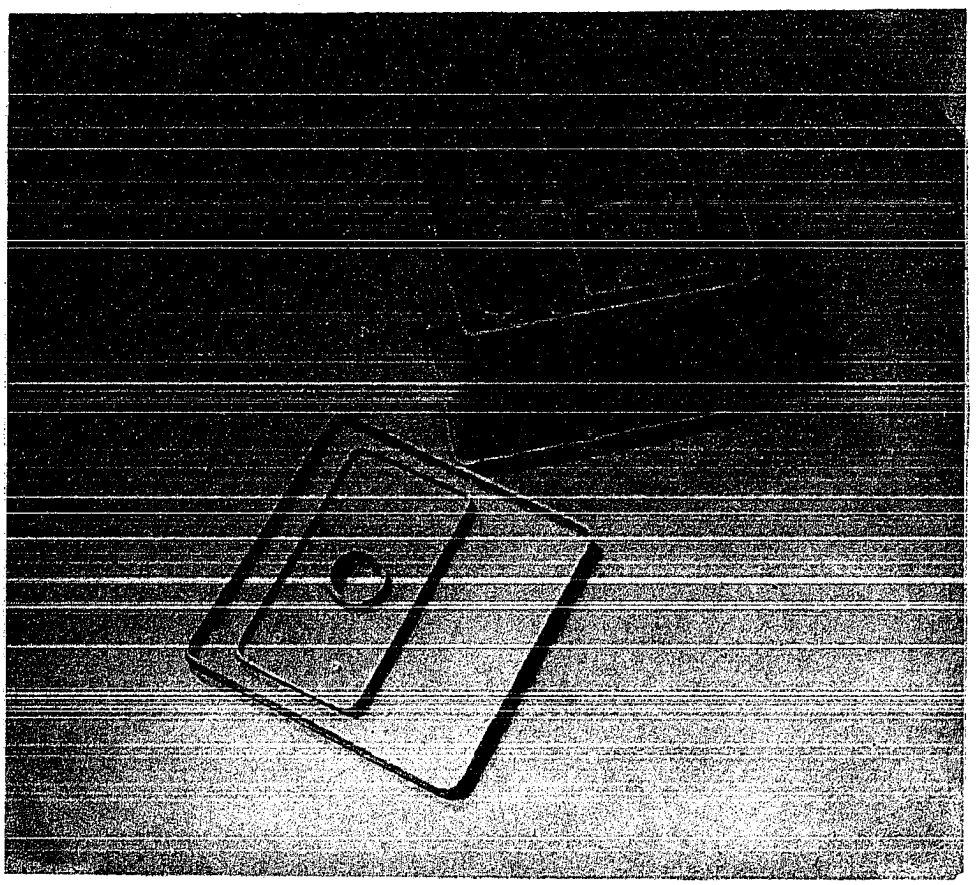


Fig. 14. Experimental arrangement showing WL-759 circuit shielded by the lead box.

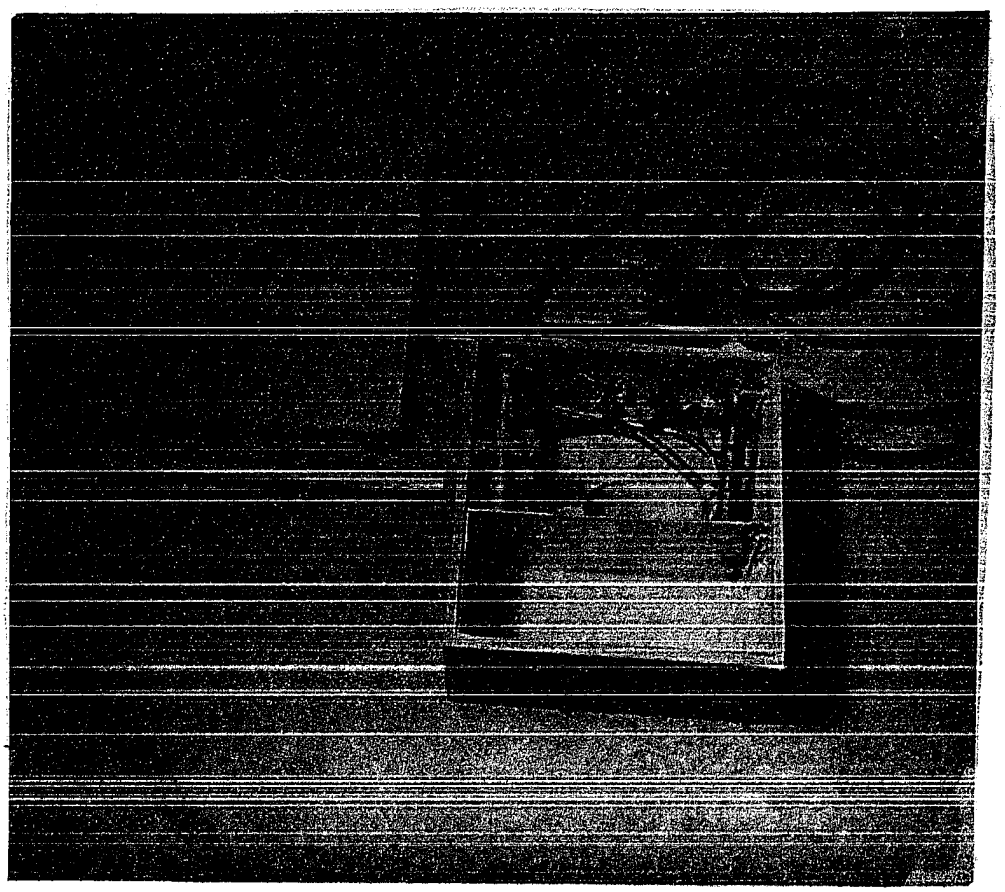


Fig. 15. Experimental arrangement showing temperature control insulating box.

EXPERIMENTAL RESULTS.

Fig. 16. WL-759 characteristic.
Variations of no. of counts/min with applied voltages.

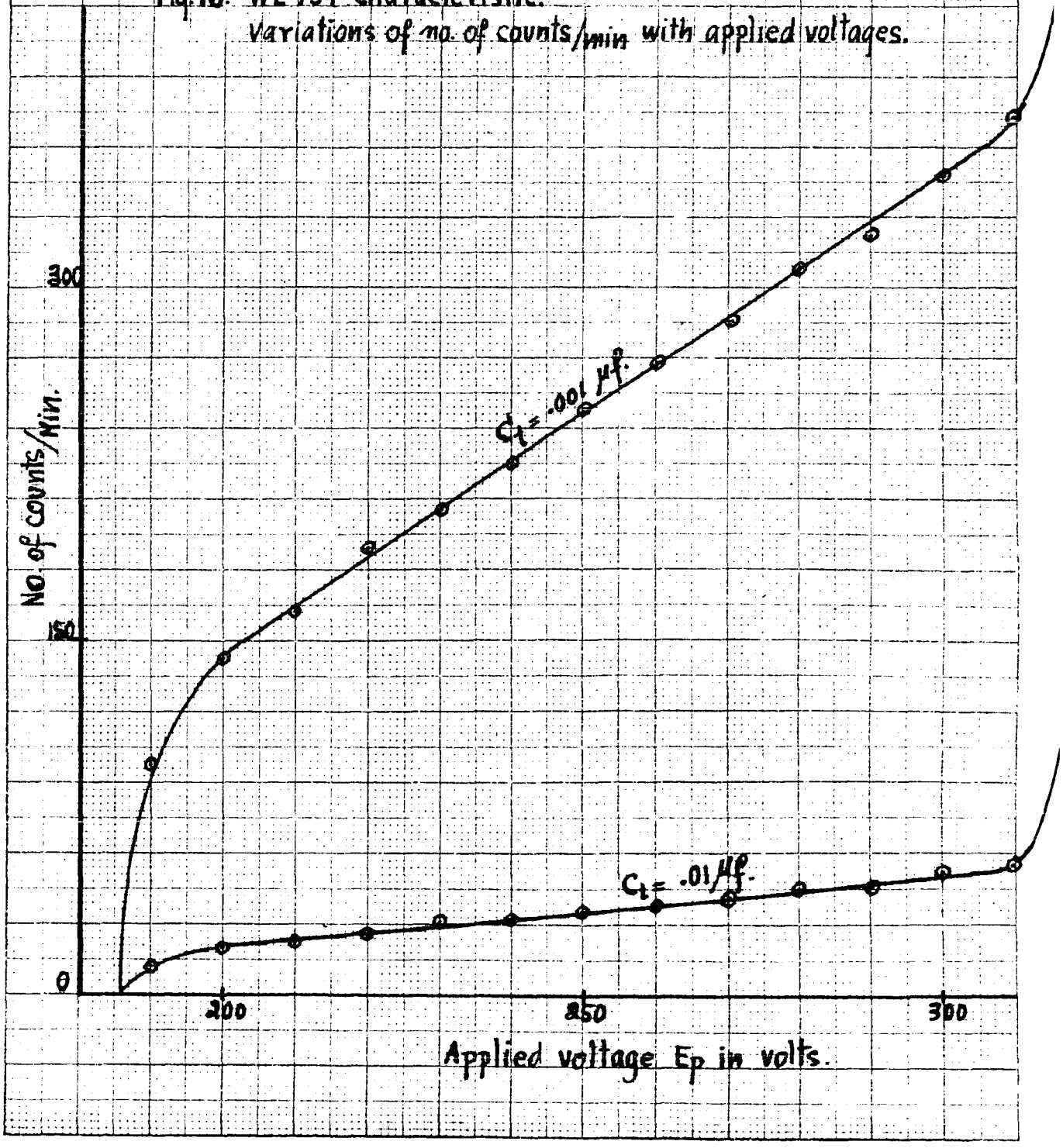


Fig. 17. WL-759 characteristic.
Variations of no. of counts/min with starting anode currents.

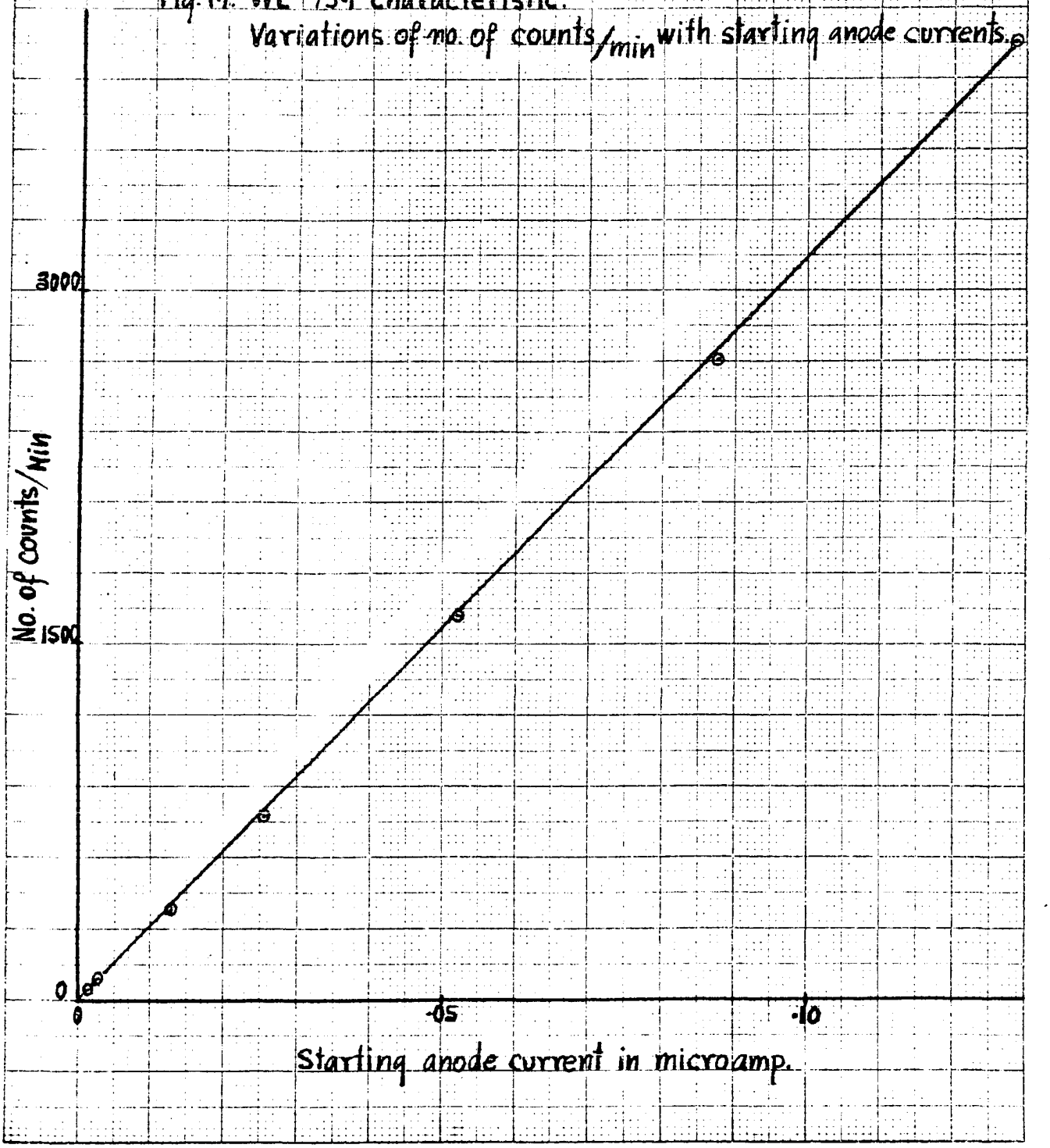


Fig. 18. Effect of x-rays on carbon resistor 2020 meg.

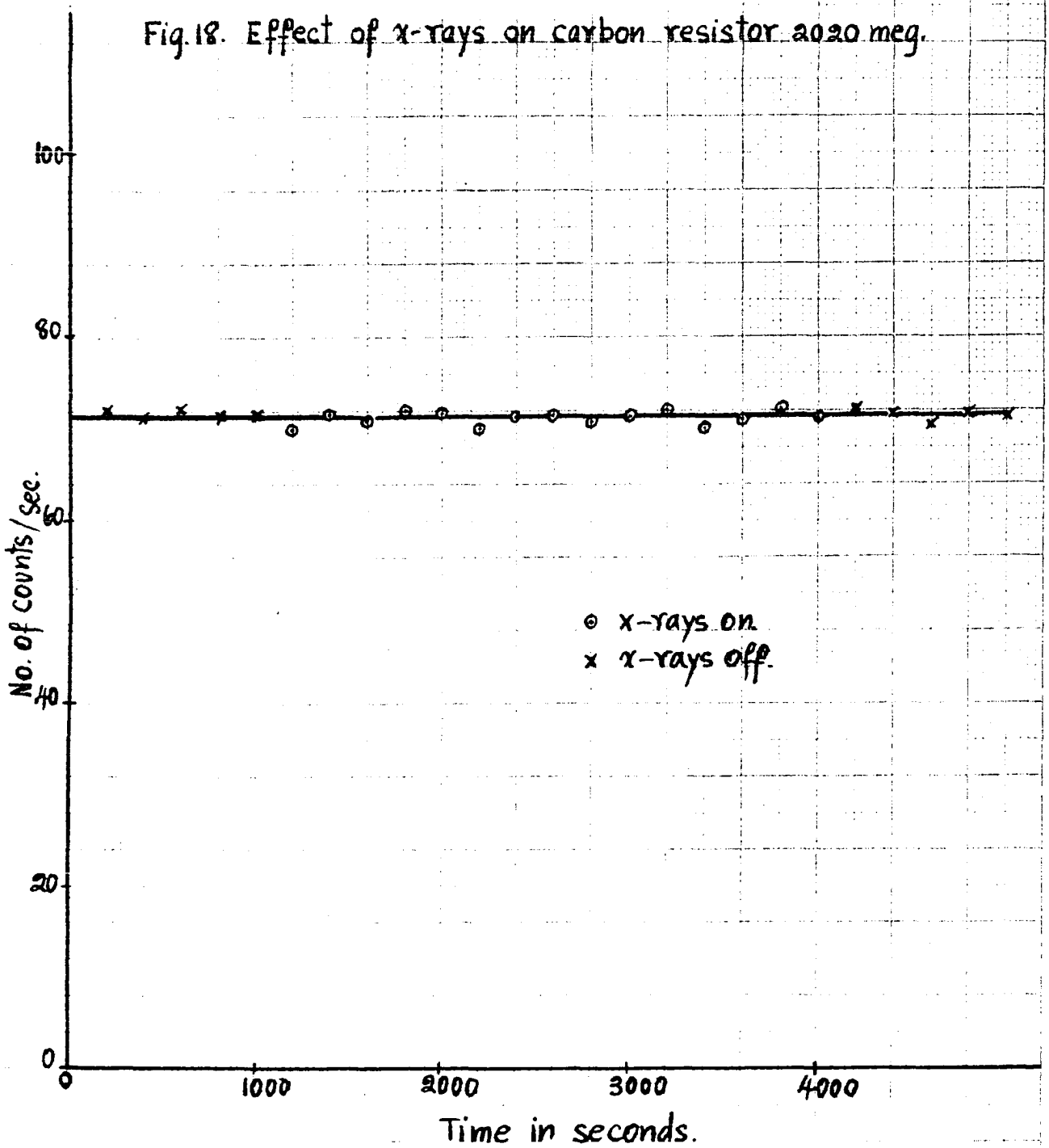


Fig. 19 Effect of temperature on greenockite crystal.

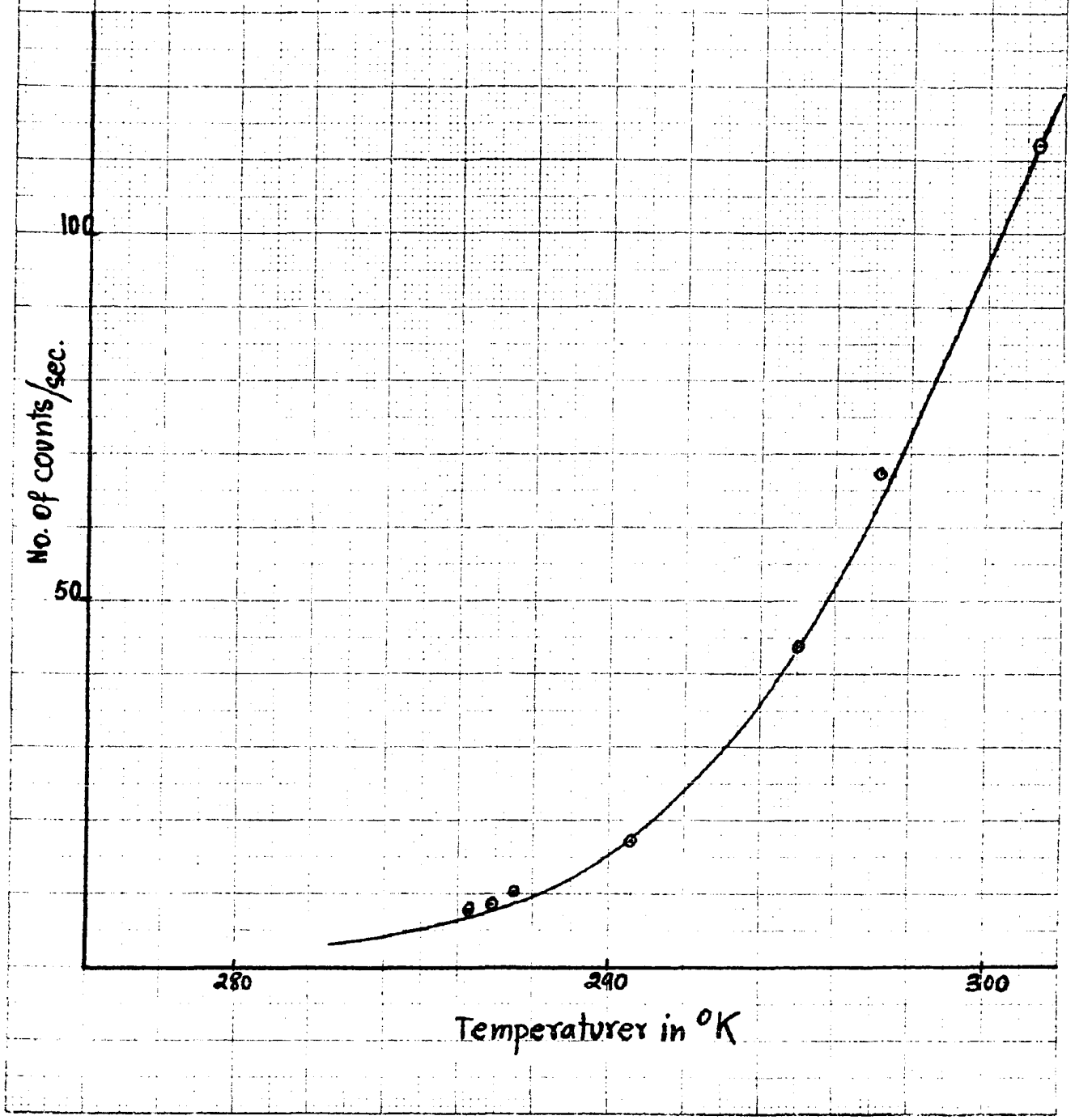


Fig. 20. Graph showing the relation between natural logarithms of no. of counts/sec and 1/Absolute temp.

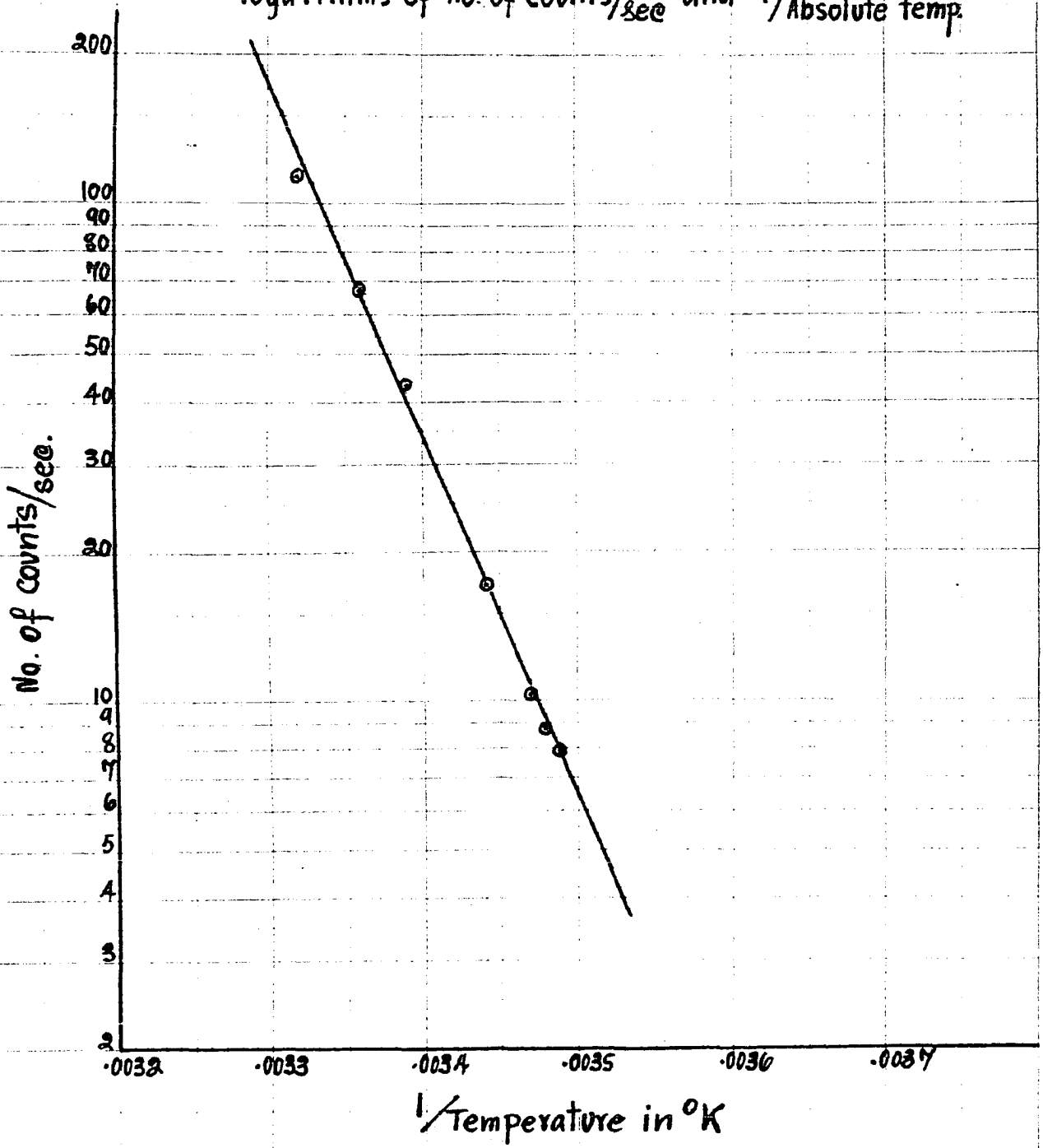


Fig. 21. Effect of ordinary light on greenockite crystal.

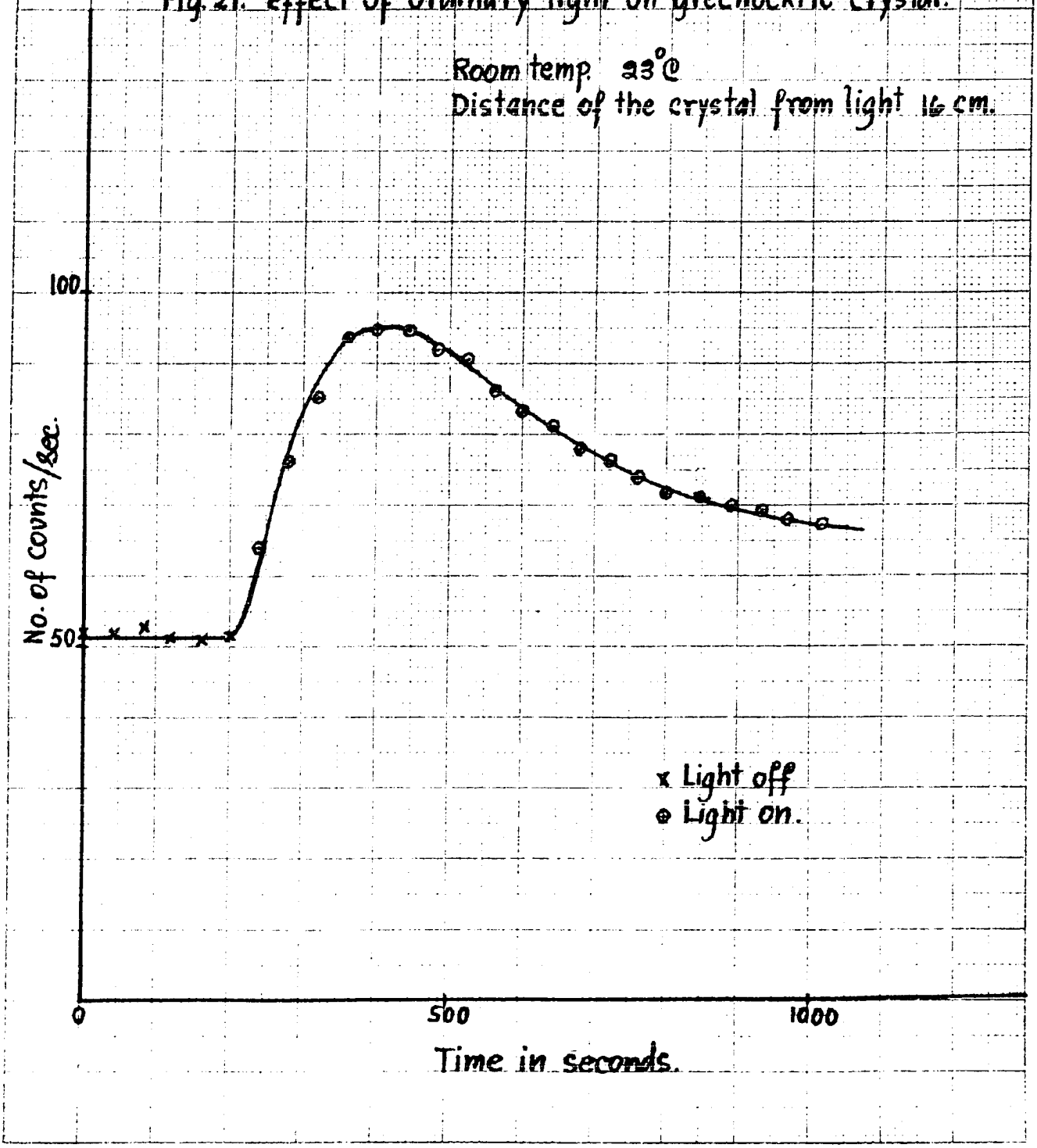


Fig. 22. Effect of Sodium light on greenockite crystal.

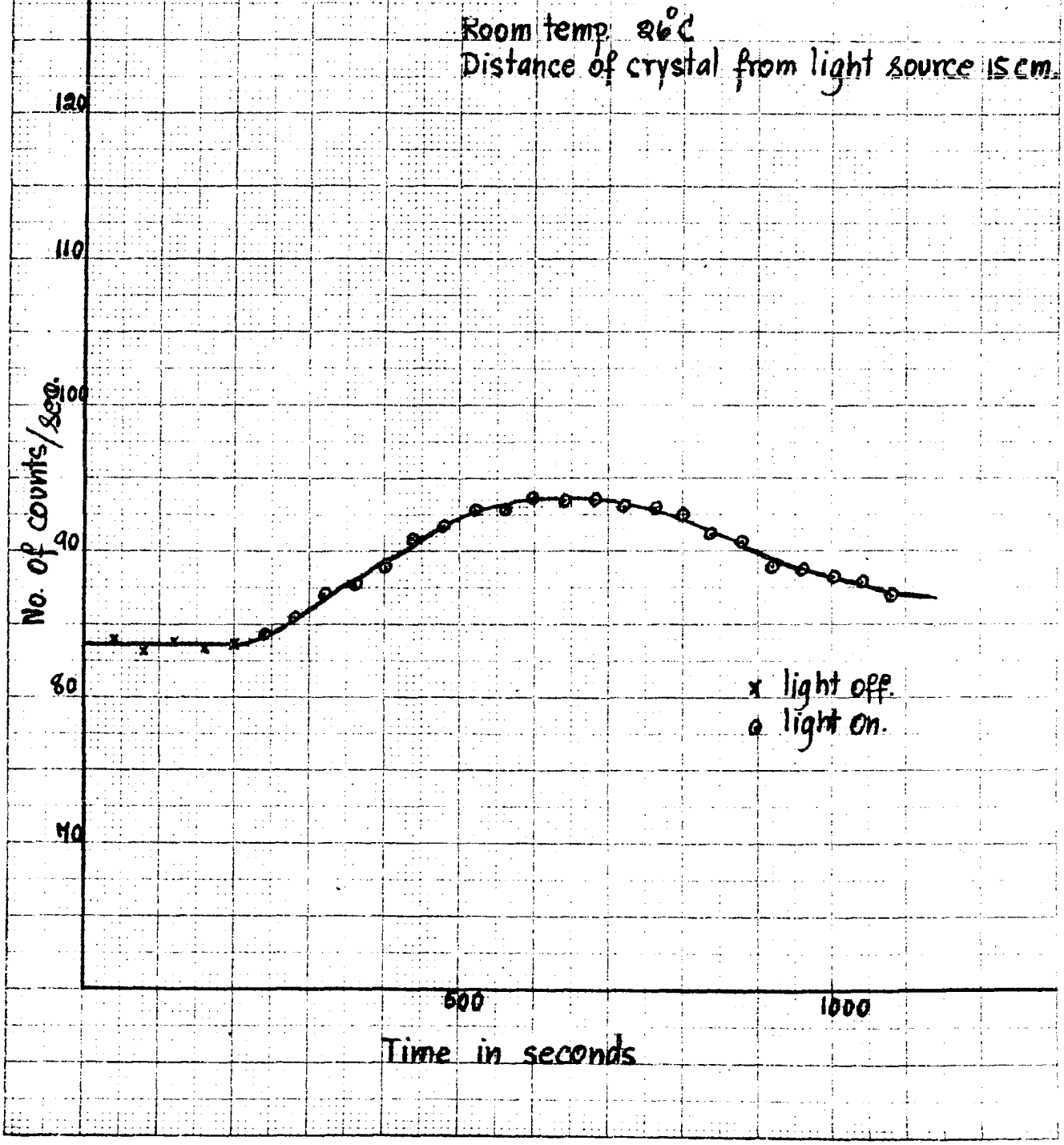


Fig 22. Effect of ultra-violet light on greenockite crystal.

- Room temp. 25°C
- Distance of crystal from light source is cm.

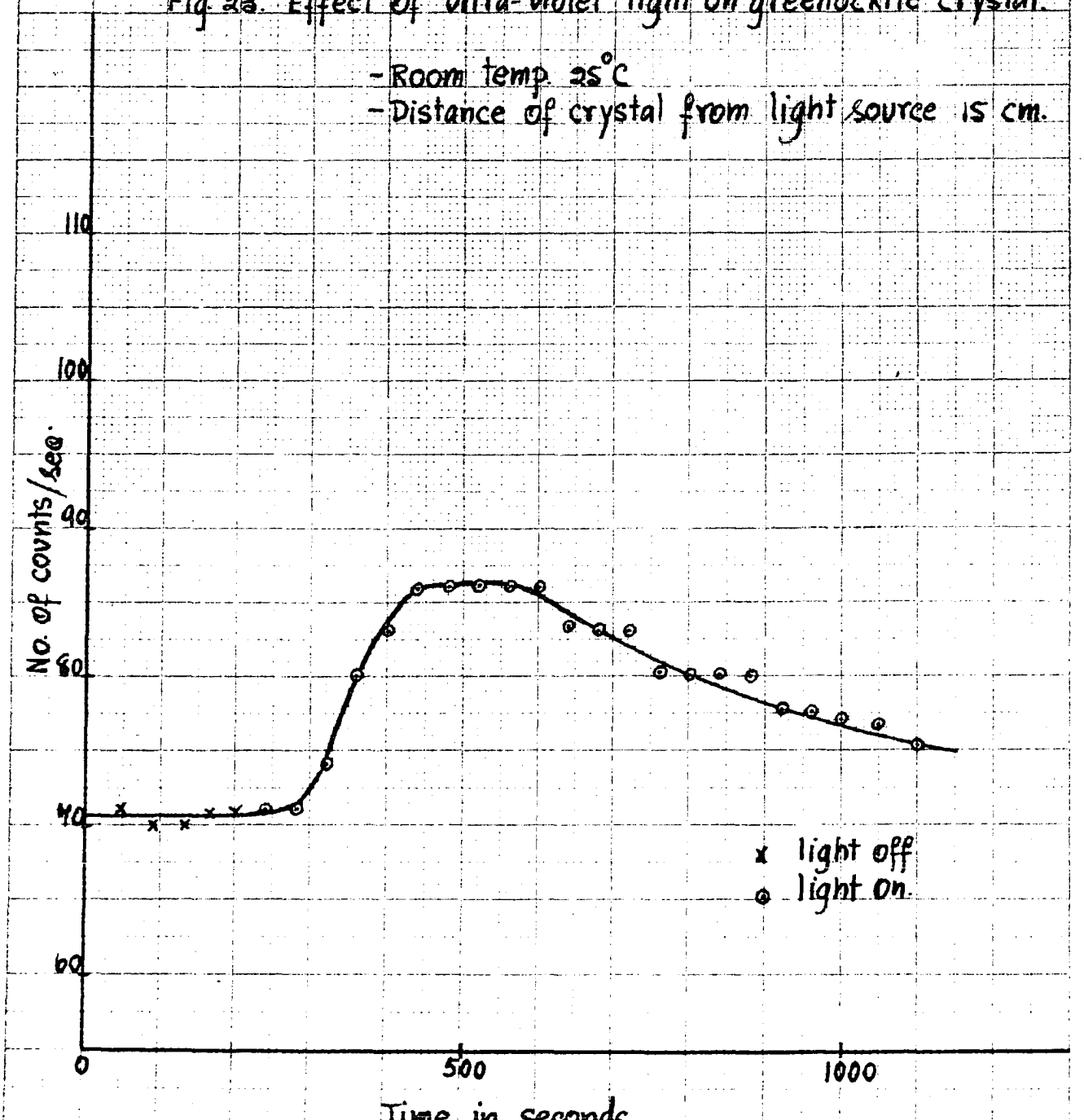
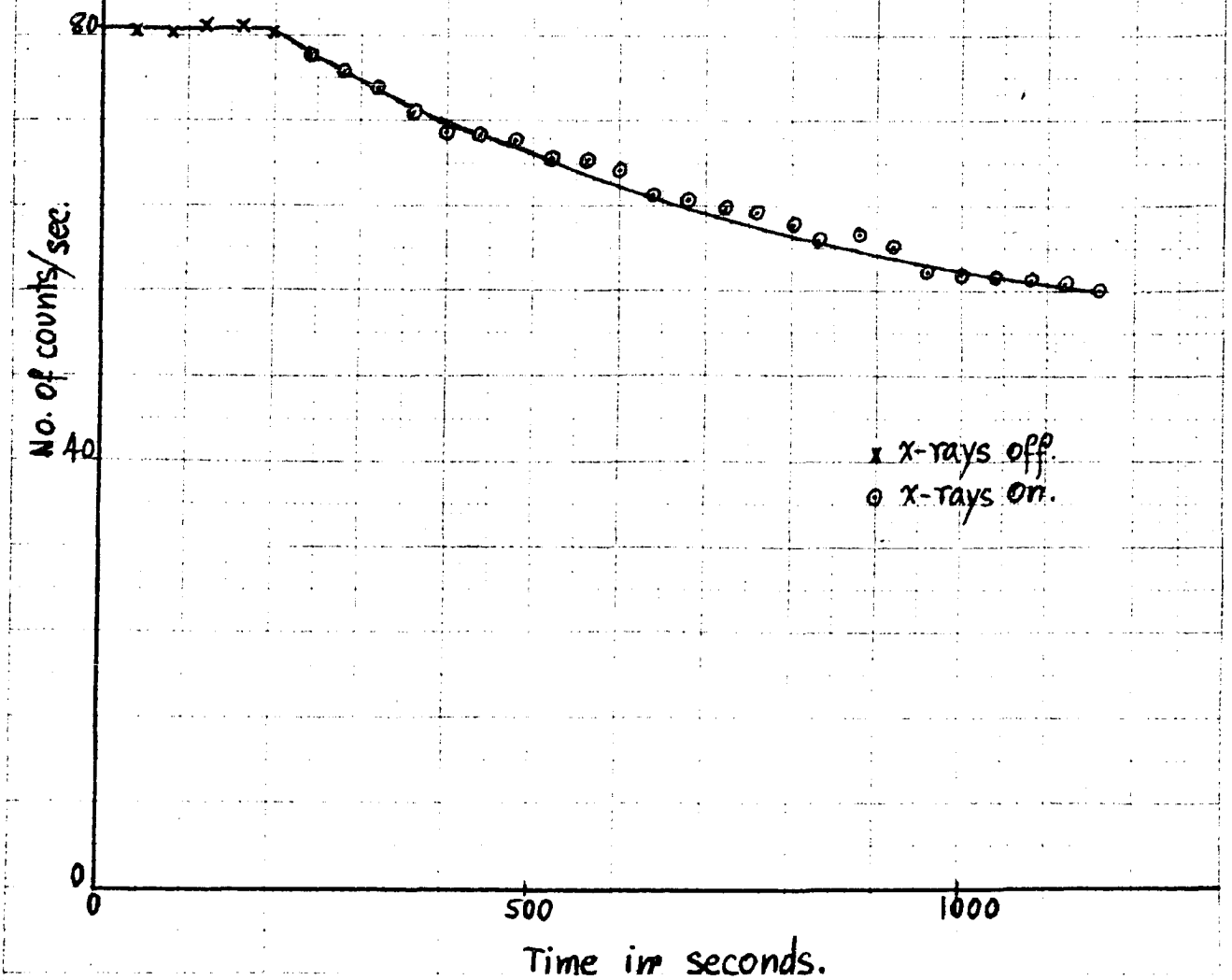


Fig. 24 Effect of x-rays on greenockite crystal.
Variations of no. of counts/sec with time.

- Room temp. 26°C
- Distance of crystal from x-ray tube window 13 cm.
- With x-rays 4 kv. at 10 ma.



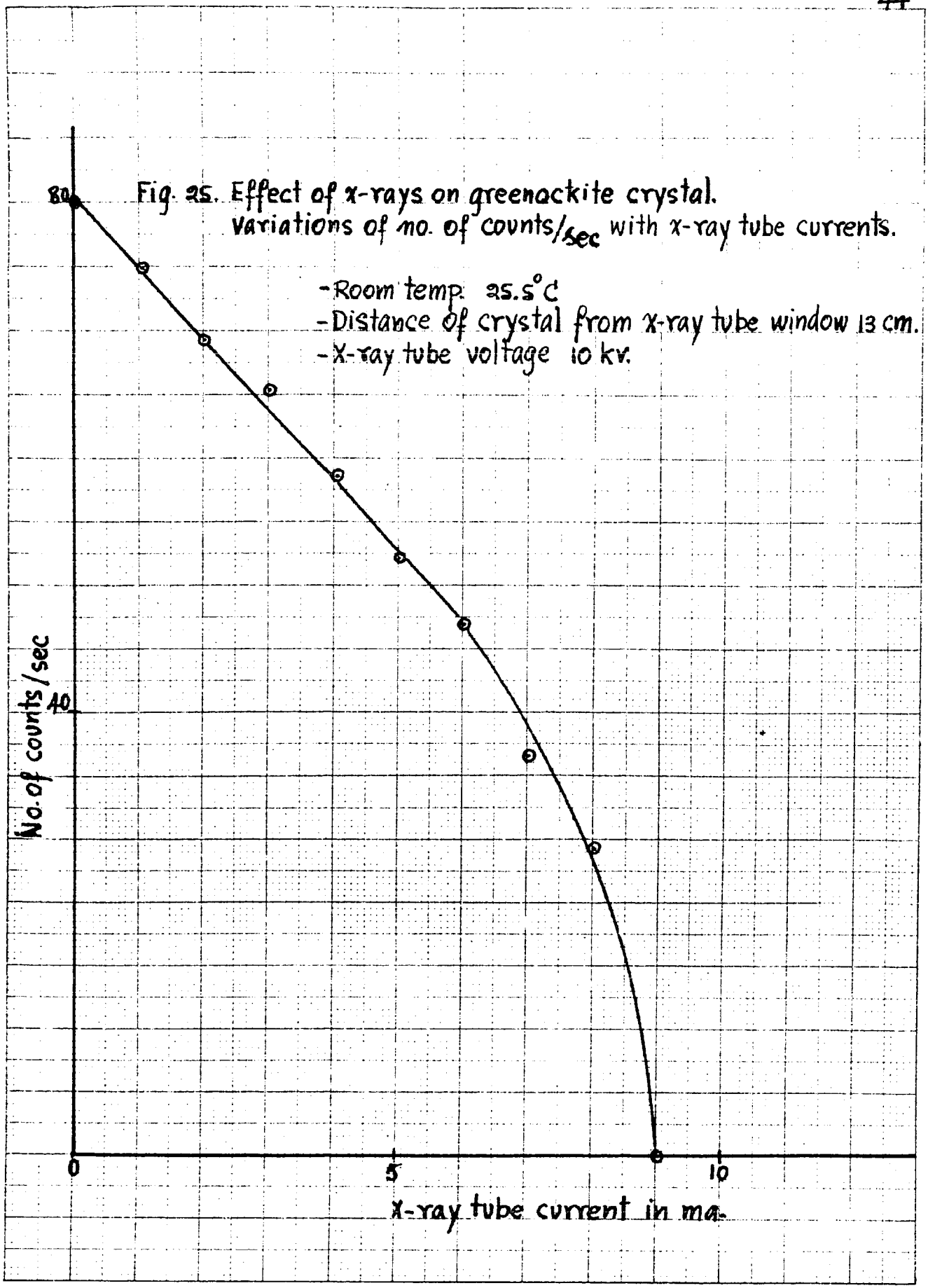


Fig. 25. Effect of x-rays on greenockite crystal.
Variations of no. of counts/sec with x-ray tube currents.

- Room temp. 25.5°C
- Distance of crystal from x-ray tube window 13 cm.
- X-ray tube voltage 10 kv.

Fig. 26. Effect of x-rays on greenockite crystal.
Variation of no. of counts/sec. with x-ray tube voltages.

- Room temp. 26°C
- Distance from x-ray tube window 13 cm.
- X-ray tube current at 10 ma., using aluminum absorber .148 mm. thick.

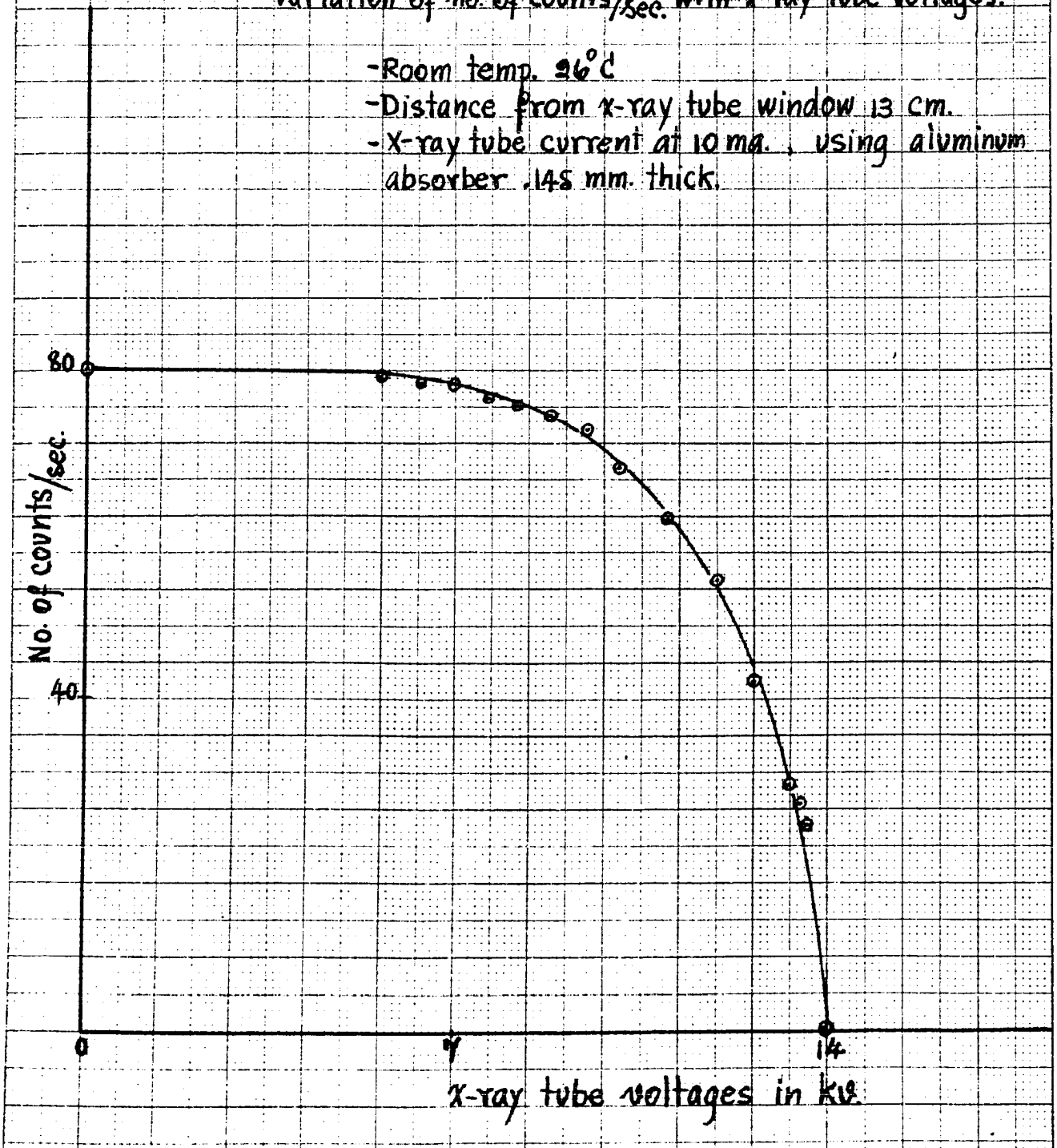


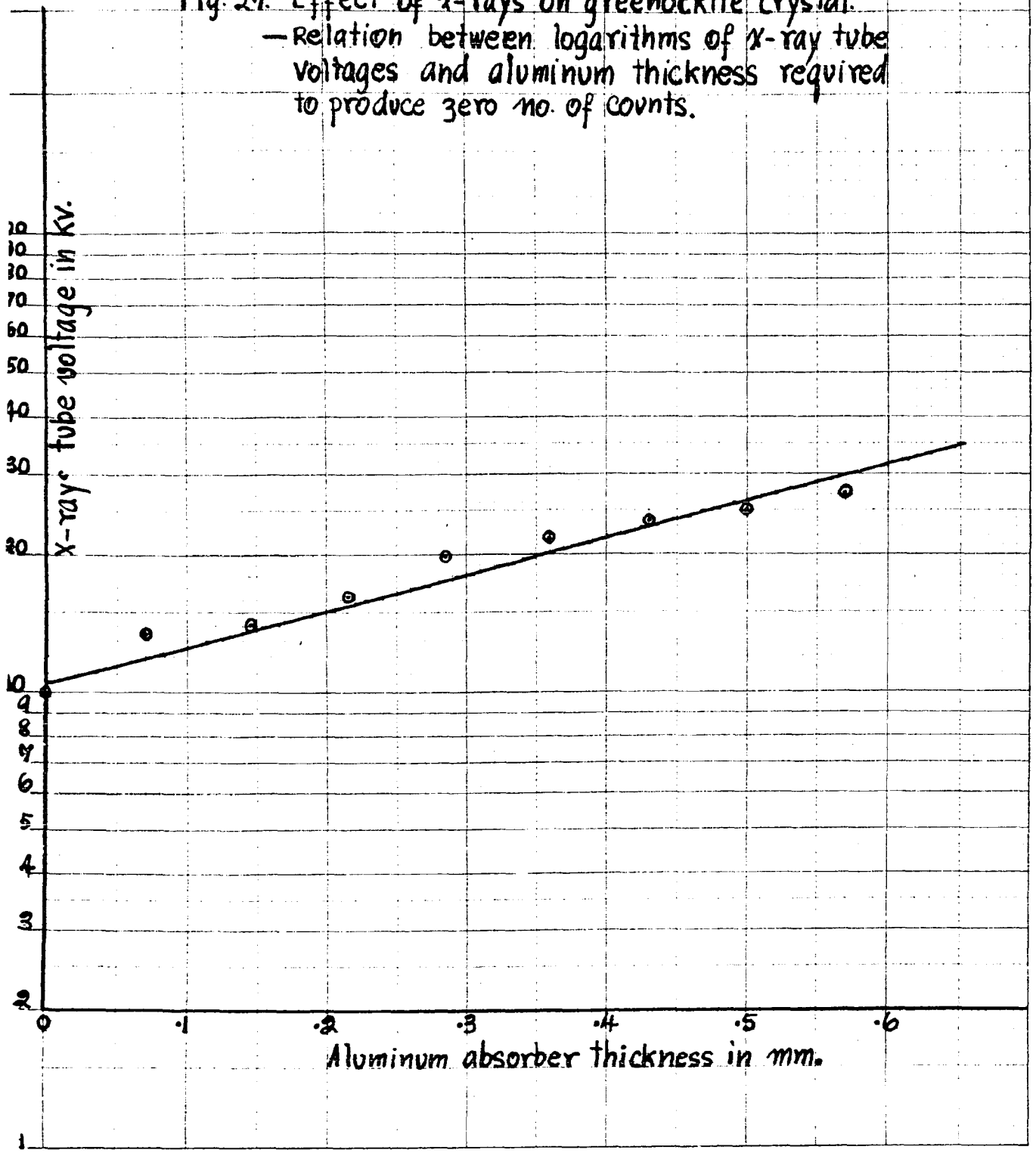
Table 1. Effect of x-rays on greenockite crystal.

- Aluminum absorber thickness for producing zero number of count at different x-ray tube voltages with 10 ma.

- Room temp. 25.6°C

Aluminum absorber thickness in mm.	x-ray tube voltages in kv. at 10 ma. producing zero count.
0	9.9
.040	13.4
.145	14.0
.215	16.2
.285	19.8
.360	21.7
.430	23.6
.500	24.8
.570	26.2

Fig. 24. Effect of x-rays on greenockite crystal.
— Relation between logarithms of x-ray tube voltages and aluminum thickness required to produce zero no. of counts.



DISCUSSION OF EXPERIMENTAL RESULTS

A. WL-759 CHARACTERISTICS

1. As shown in the curve (Fig. 16), the breakdown voltage of WL-759 is 310 volts applied voltage. The number of counts per unit time changing linearly with applied voltages ranges from 200 volts to 310 volts. The operating voltage of WL-759 was chosen between those two voltages, i.e., 255 volts, which was used throughout the entire experiment with WL-759.

2. The number of counts per unit time is proportional to the current flowing in the starting anode circuit, as shown in the curve (Fig. 17).

3. When a carbon resistor in the starting anode circuit is bombarded with x-rays, it shows no effect on the number of counts, as shown in the experimental curve (Fig. 18). The author also irradiated the carbon resistor with sodium light and ultra-violet light. The results again show no effect on the number of counts per unit time.

By the above experimental results, the WL-759 circuit was then used for detecting the variation of conductivity of a greenockite crystal.

B. EFFECTS OF TEMPERATURE ON A GREENOCKITE CRYSTAL

As sone in the curve (Fig. 20), the natural logarithms of the number of counts per unit time is shown to be inversely proportional to the temperature in degrees absolute, which is in good agreement with the law $\ln \sigma \propto -\frac{1}{T}$, equation (7) page 15. Since the conductivity σ of the drystal is proportional to the number of charge carriers in the conduction band or current, this is in turn proportional to the number of counts per unit time.

C. EFFECTS OF LIGHT ON A GREENOCKITE CRYSTAL

The effect of unresolved light on the crystal is shown in the curve (Fig. 21) which shows the variation of conductivity of greenockite. The number of counts per unit time increases to a certain value and then gradually decreases as the time goes on. Similar effects of sodium light and ultra-violet light are shown in Fig. 22 and Fig. 23. In the case of unresolved light, the number of counts increases to the maximum value more rapidly than when sodium light or ultra-violet light is used. This is probably due to the effect of heat from the light bulb. In the other two cases it shows a very slow response. The subsequent decrease in the number of counts, which is due to the space charge effect, appears in all the three cases.

D. EFFECTS OF X-RAYS ON A GREENOCKITE CRYSTAL

The space charge effects created by s-ray bombardment on the greenockite crystal is more severe than in the case of the crystal irradiated by light as shown in the curve (Fig. 24). Instead of increasing, the number of counts starts to decrease immediately, due to the more severe space charge effects. Fig. 25 shows the variation of the number of counts with x-ray tube currents at 10 k.v., and Fig. 26 shows the variation of the number of counts with x-ray tube volrages at 10 ma. In both cases, the number of counts per unit time decreases when the x-ray tube voltages or currents are increased.

In the case of the variation with x-ray tube currents, the number of counts per second is linearly proportional to the x-ray tube current in the range 0-6 ma; but the number of counts fall off rapidly as the x-ray tube current is further increased. At the very end point where the number of the counts is zero, the adjustment of the tube current is very critical and this is also true when the tube voltages are varied.

In order to find the correlation between intensities of x-rays and the space charge effect, aluminum sheets were used to absorb the x-rays, in order to reduce the number of counts to zero with different x-ray tube voltages at 10 ma.

When a beam of x-rays is allowed to pass through an absorbing material of thickness t, it is found that the transmitted intensity, I, is related to the original incident intensity, I_o, by the relation

$$I = I_o e^{-\mu t} \qquad (10)$$

where μ is a constant called the "linear absorption coefficient."

Since the intensity of x-rays is proportional to the square of x-ray tube voltage, or

$$I_o \propto V^2 \qquad (11)$$

V is the x-ray tube voltage. Then from equations (10) and (11) we have

$$V^2 \propto e^{\mu t} \qquad (12)$$

or

$$\ln V \propto t \qquad (13)$$

I, transmitted intensity, is maintained at constant value, so that the intensity of the transmitted x-rays is just enough to produce no number of counts. The curve plot of $\ln V$ vs. t, is shown in Fig. 27 and is in agreement with the theory stated above.

CONCLUSION

The space charge effects, which reduce the number of counts when greenockite is irradiated with light, appear to be less than when greenockite is irradiated with x-rays. This is probably due to a certain surface layer effect of light on the crystal. The difference in shape of the curves (Fig. 40, 41, 42) may also be due to the difference in energy absorbed by the crystal or the difference in the wave length of light used, or both. In case of x-ray bombardment, the space charge effect appears to be more and more severe. As the intensity of the x-rays is increased, having more penetrating power than light, the space charge is created throughout the whole volume of the crystal. This presents a difficulty in using greenockite as a radiation detector unless we can find effective ways to reduce these space charge effects while using the crystal as a detector.

However, as shown in the experimental results (page 47) it is quite possible that the space charge effects which are created in the crystal can be used as the means for detecting the intensity of radiation, especially for more powerfully penetrating radiation such as gamma rays or x-rays. By varying the thickness of the absorbing screen just enough to produce no number of counts while the crystal is irradiated, the intensity of radiation could be measured as compared to the known sources of radiation.

The experiments have shown that the variations of x-ray intensities, in order to produce no number of count (i.e. the current flowing in the crystal becomes very small and it is also below the limit of current which WL-759 could detect), are very critical. By means of using space charge effects created in the crystal, the detection of the intensity of radiation, such as gamma rays or x-rays, should give quite accurate results.

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