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THE DEVELOPMENT OF THE CARBON ARC SOURCE OF HIGH INTENSITY RADIATION

by

D. I. Lawson, R. W. Pickard and D. L. Simms

Summary

A carbon arc searchlight has been modified for use as a source of high intensity radiation. Instruments have been designed to measure and monitor its output: the position of the area of maximum intensity can be observed and held constant. An electronic switch has been designed so that specimens can be exposed to the radiation for set periods.

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Boreham Wood,
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1. Introduction

The amount of radiation necessary to ignite combustible materials is dependent upon the absorptivity of the surface and this varies with the wavelength of the radiation used. In studying the ignition of materials by radiation from an atomic explosion, the quality of the radiation used in the experiments should be characteristic of such a source, otherwise corrections have to be made which are difficult if not impossible to apply, particularly as the absorptivity of the surface surface varies continuously during charring (1). These corrections can be obviated by using a carbon arc source since its radiation has about the same spectral quality as that of an atomic explosion (2, 3). In this paper, the development of such a source is described together with the auxiliary equipment.

2. Apparatus

2.1. Power supply

The power supply for the carbon arc was a standard type Lister 22 KW generator set but a more convenient method has been developed using a three phase rectifier system (4).

2.2. Carbon arc

The carbon arc source was a standard HCD 90 cm Mark V searchlight system operating at 75 volts and 150 amperes, burning 16 mm diameter cored carbons. The carbons were fed at approximately their burning rates by a motor, but since these did not remain constant, uniform feeding by the motor resulted in the arc position wandering. For this reason some tests were carried out on a Mark III lamp. This had a rotating positive carbon which ensured even burning and the burning rate of both carbons were automatically controlled by probes. The feed was not continuous, however, but intermittent and it was found to be unsatisfactory. Further tests using this system showed that the output radiant intensity varied in phase with the rotation of the positive carbon. With the development of the monitoring system described in section 2.6., the Mark V lamp was restored. The position of the focal spot was located by means of a scribed metal plate mounted horizontally on the central axis of the convergent beam. Any movement of the focus was corrected by manual adjustment of the carbon positions.

2.3. Optical system

The standard 90 cm parabolic searchlight mirror with a rhodium surface was supplied. A second parabolic mirror with an aluminium surface was used to condense the radiation (Figure 1, Plate 1). The optical quality of the two mirrors was not high but it was sufficiently good for the present purpose.

2.4. Timing device

With the highest intensities of radiation available, the time taken by a specimen to ignite was short and some form of automatically timed shutter was necessary to make the exposure. A signalling device in the form of a venetian blind operated by a solenoid was supplied with the searchlight and this has been adapted to control the exposure time. Its operation which was made independent of the generator supply, was controlled by an electronically timed switch. The circuit diagram is shown in Figure 2; the method of calibration is described in Appendix A, and the calibration is shown in Figure 3. It has remained stable for several months. A correction for the finite opening and closing times of the shutter is discussed in Appendix B. A typical variation in output intensity during the operation of the shutter is shown in Plate 2.

2.5. Intensity measurements

No means were available in this country for measuring the intensities of radiation available. Water-cooled thermopiles developed for this purpose (5) have proved adequate up to 30 watts cm^{-2} (7.5 cal cm^{-2} $sec.^{-1}$). Owing to the high temperature reached by the junctions at higher intensities of radiation, the absorbing coating on the junctions was rapidly removed. A photo-electric method has been adopted to extend the range of measurements, and it has not been found necessary to develop thermal instruments to measure higher intensities. This method is described in section 2.6. below.

2.6. Monitoring system

Owing to the instability of the position of the carbon arc there were considerable variations in the intensity of radiation received at the focus of the system, making it essential to monitor the radiation during the actual exposure of the specimen.

An attempt was made to do this by passing the radiation through a wire grid and observing the change in resistance of the wires to measure the radiation flux. This apparatus was found to be too sensitive to draughts. Finally a split beam technique was adopted similar to that in use at the University of Rochester (6). A sheet of mica 9 in. x 9 in. x $^{10}/1000$ in. was placed in the path of the beam between the second mirror and the focus (Figure 4). Some of the radiation was reflected to form an image of the focus on a sheet of frosted glass. A condensing lens placed behind the frosted glass directed a beam of nearly uniform light upon a photocell, the output from which was recorded automatically. This method had the disadvantage that it reduced the intensity of radiation at the focus by about 25 per cent.

2.7. Methods of varying the intensity of radiation

The form of optical system used did not permit interposing a rotating sector disc in the beam to reduce the intensity of radiation. Instead stops were inserted in the shutter movement so that its angle of opening could be reduced (Figure 5a) and also a foraminated screen was made which could be placed in the main beam and which allowed only a part of the radiation to pass through (Figure 5b). In this way a wide range of intensities of radiation could be obtained.

2.8. Distribution of intensity of radiation

In order to determine the intensity distribution near the focus a table was built which could be adjusted in three mutually perpendicular directions (Plate 3.

3. Determination of radiation intensity

3.1. Intensity of radiation at the focus

The thermopile was fixed in position on the movable table and adjusted until the maximum output was obtained. At the same time the output from the photocell corresponding to this was recorded. A series of readings were made using the stops and screen; the results are shown in Figure 6. As the photocell has an output proportional to the intensity of light falling on it the curve of Figure 6 has been extrapolated to the highest reading recorded on it. The maximum intensity of radiation is about 180 watts cm^{-2} (40 cal cm^{-2} $sec.^{-1}$). Repeated calibrations have agreed to within 10 per cent, a sufficiently high degree of accuracy. The position of maximum intensity of radiation coincides with the position of the focal spot found by the method of 2.2.

3.2. Variation of intensity in the focal plane

Plate 4 shows the size of the focal spot when a photographic paper is exposed for various periods of time, from which some idea of the uniformity can be obtained. Radiometric measurements of the variation in intensity with distance across the focal plane for an intensity of about 3 watt cm^{-2} (0·75 cal cm^{-2} $sec.^{-1}$) and are shown in Figure (7a, b). The area of uniform radiation, defined as the area over which the intensity does not vary by more than 10 per cent, is less than 0·1 sq. cm and the area over which the variation does not exceed 20 per cent, is less than 0·2 sq. cm.

3.3. Variation of intensity along axis of system

This is shown plotted in Figure 8.

3.4. Intensity distribution away from focus

As Figure 8 showed no pronounced focus existed, the areas $\frac{1}{2}$ in. and 1 in. in front of the focus were explored. The results are shown in Figures 9a, b, 10a, b. Although an increased area of irradiation is obtained the loss in intensity is high (Figure 11a, b).

4. The ignition of materials

Samples of oven dried oak and fibre insulating board were exposed to various intensities of radiation from the arc source. The curves, shown in Figure 12, of intensity plotted as a function of the time to ignite follow the usual pattern, the ignition time increasing as the intensity is lowered. Below a certain level of intensity ignition does not take place whatever the time of irradiation. For the specimens tested this intensity level was about 50 watts/cm^2 and the corresponding ignition times were 2·5 and 1·0 seconds for oak and fibre insulating board respectively.

These curves could be extended using as a radiation source a tungsten filament lamp and ellipsoidal mirror. This irradiated a larger area of the specimen and so ignition took place at a lower intensity. In spite of the fact that the tungsten lamp operates at a much lower temperature than that of the arc, the two sets of results lie on a smooth curve.

The experiments were repeated with blackened samples of oak and fibre insulating board and curves having the same general form were obtained. For ignition times of less than 1·0 sec. the effect of blackening the oak was small.

A curious anomaly occurred with the fibre insulating board. At intensitities above about 70 watts/cm^2 the ignition time became long and another curve was obtained. This appeared to be due to a blister being formed over the irradiated area, owing no doubt to the laminar form of fibre insulating board, which shielded the subcutaneous layers from radiation while itself being denuded of volatiles.

5. Conclusions

The carbon arc radiation source developed is capable of giving very high radiation intensities over a small area. The output can be monitored adequately and the position of the focus held constant. Specimens can be exposed to radiation for known periods by means of an electronic switch operating a venetian blind shutter. The intensity of radiation to which specimens are exposed can be varied by inserting stops in the shutter movement which alters the angle of opening, and by placing perforated screens in the path of the beam.

Tests on the spontaneous ignition of oak and fibre insulating board both blackened and unblackened have shown that this apparatus rates woods in the same order for ease of ignition as other methods using sources of lower temperature. This may however not be true for other materials.

References

(1) Simms, D. L., Pickard, R. W. and Law, M. Factors influencing the ignition of materials (to be published).
(2) The effects of atomic weapons. McGraw-Hill & Co., P. 183.
(3) Fiat Final Report 1052, The high current carbon arc. P. 72.
(4) Pickard, R. W. A proposed power supply for a high current carbon arc. F.R. No. 114/1954.
(5) Simms, D. L. and Pickard, R. W. Thermopiles for measuring high intensity radiation. F.R. No. 83/1954.
(6) Davis, T. P., Krolak, L. J. and Blakney, R. M. Studies of flash burns: the carbon arc source, University of Rochester atomic energy project, project report No. UR-226 (1952).
(7) Lawson, D. I. and Simms, D. L. The ignition of wood by radiation. Brit. J. App. Phys. 3, pp. 288-292.
(8) Carslaw, H. S. and Jaeger, J. C. Conduction of heat in solids. P. 57, Section 25, Equation 9, Chap. II.
(9) Ibid. P. 56, Section 25, Equation 8, Chap. II.

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APPENDIX A

Design and calibration of electronic shutter switch

The solenoid operating the shutter was energised by means of an 80 volt D.C. supply independent of the searchlight supply. The time interval for which the shutter was held open was controlled by a flip-flop trigger circuit (Figure 2). The time interval between the making and breaking of the operating relay contacts was varied by means of the 2·2 MΩ potentiometer (Figure 2). The relation between the time interval and the potentiometer scale reading is shown in Figure 3.

Since short exposure times were used it was necessary to correct for the time taken by the shutter to open and close. The light from a 40 watt bulb placed behind the shutter was allowed to fall on a photocell. The shutter was operated by the trigger circuit and the output from the photocell recorded on a cathode ray oscillograph. The resulting trace was photographed and a typical curve is shown in Plate I. In addition to the finite time the shutter took to open and shut there was a delay between the operation and the movement of the shutter due to the inertia of the system.

From a series of experiments the mean value of the opening and closing times were determined together with the delay times mentioned above. The results are given in the table below.

Delay time on opening (sec)	Opening time (sec)	Delay time on closing (sec)	Closing time (sec)
0·12	0·13	0·22	0·17

These results show that the time t for which the shutter is fully open is given by

$$t = \mathcal{T} - 0{\cdot}03$$

where $\mathcal{T}$ is the time interval of the operating relay. The effect of the finite opening and closing times is dealt with in Appendix B.

APPENDIX B

Correction due to finite opening and closing time of shutter

Figure 4 shows that the radiation is received by the specimen in the form of a trapezoidal pulse. For short time intervals the heat losses from the surface may be neglected and the specimen assumed to be infinitely thick.

If the time taken by the shutter to open is t_1 then the surface temperature of the specimen is given by

$$\theta = \frac{k^{1/2}}{K\pi^{1/2}} \int_0^t f(t_1 - \tau)\frac{d\tau}{\tau^{1/2}}$$

where $f(t_1 - \tau)$ relates the variation in intensity of radiation with time
k is the thermal diffusivity of the material
K is the thermal conductivity of the material

Since the intensity rises linearly with time

$$f(t_1-\tau) = \frac{I}{t_1}(t_1-\tau)$$

where I is the maximum intensity of radiation

Hence

$$\theta = \frac{4Ik^{1/2}}{3K\pi^{1/2}}t_1^{1/2}$$

If the radiation is of constant intensity I from $t = o$ until $t = t_c$

then

$$\theta_c = \frac{2Ik^{1/2}}{K\pi^{1/2}}t_c^{1/2}$$

Thus if $\theta = \theta_c$ then

$$\frac{t_c}{t_1} = \frac{4}{9}$$

Hence a linearly increasing intensity of radiation for time t_1 reaching a maximum value of I is equivalent to a constant intensity of radiation I for a period $\frac{4}{9}t_1$.

It is unlikely that ignition of a specimen will take place during the closing of the shutter and the correction for the time taken for this has not been calculated.

Using the result of Appendix A the time for which the specimen is effectively exposed to the maximum intensity of radiation is given by

$$t = \tau - 0{\cdot}03 + \frac{4}{9} \times 0{\cdot}12$$

$$= \tau + 0{\cdot}02$$

where τ is the time interval of the operating relay. This result shows that the time interval of the operating relay may be taken as the exposure time.

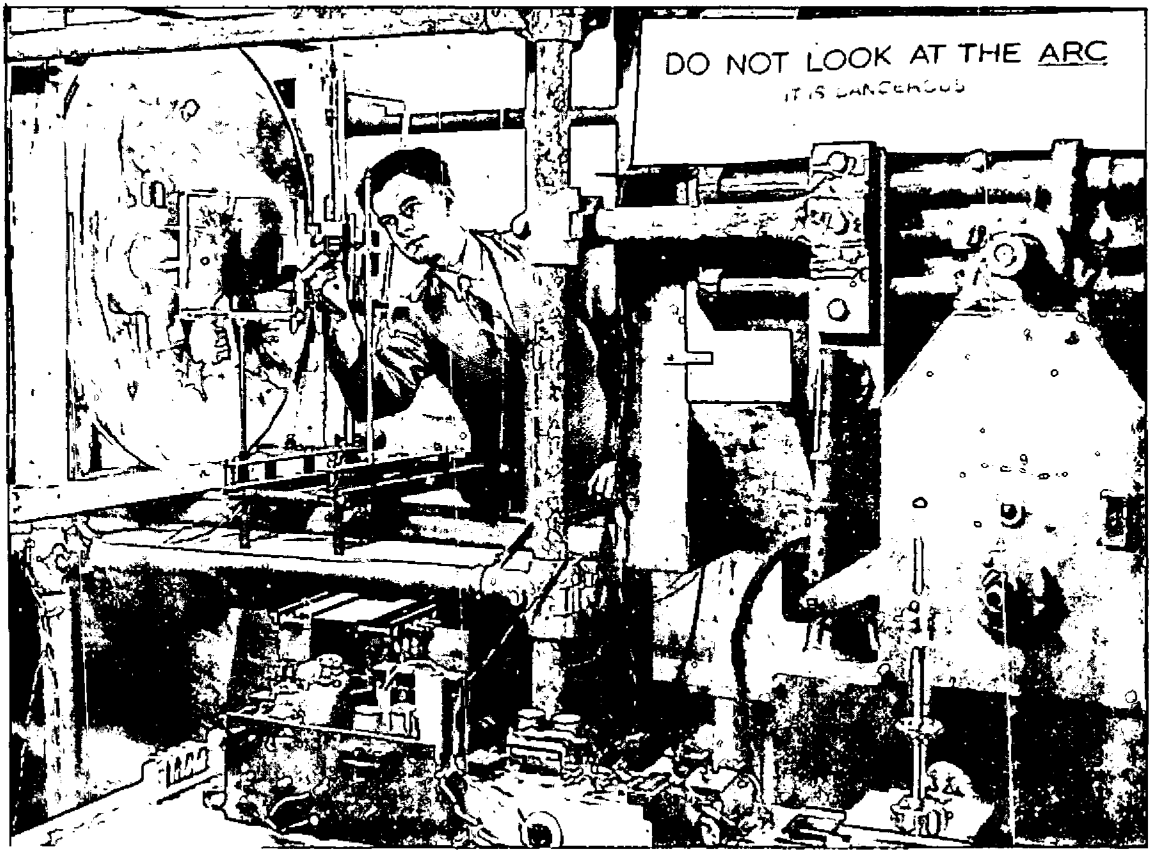


PLATE. I. GENERAL VIEW OF THE APPARATUS

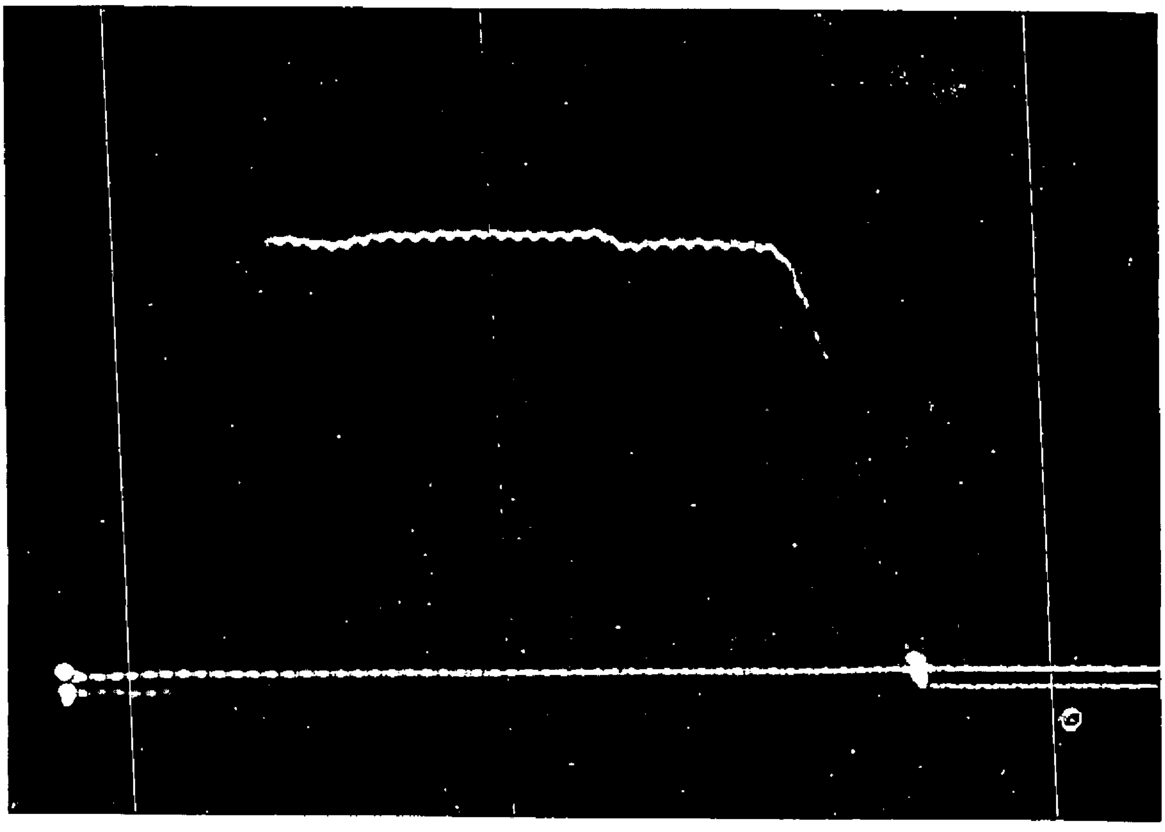


PLATE. 2. TYPICAL INTENSITY TIME CURVE
TIME INTERVAL — I SECOND

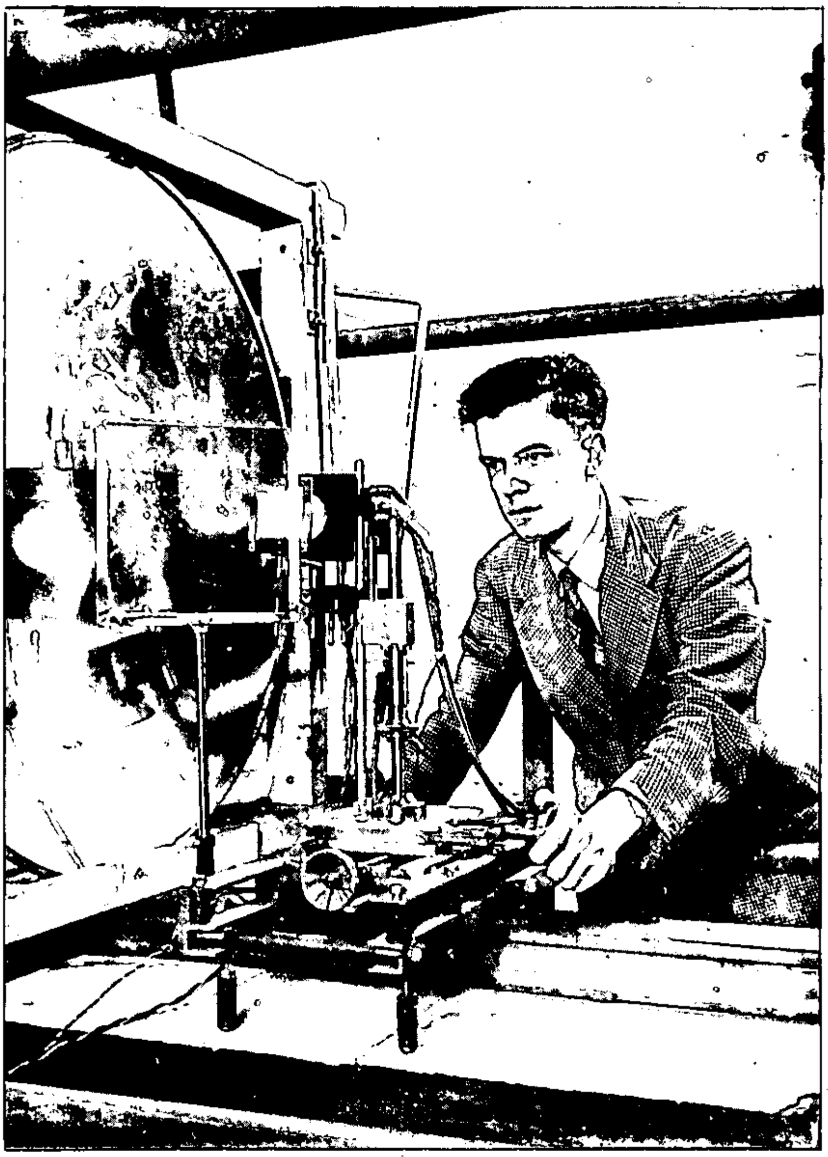
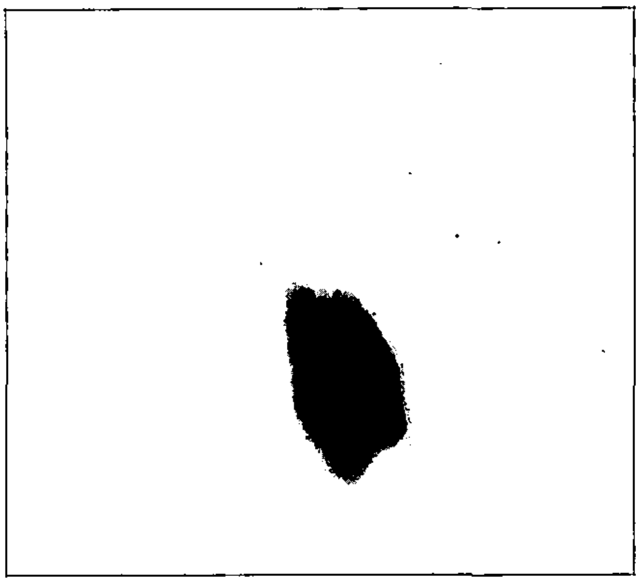
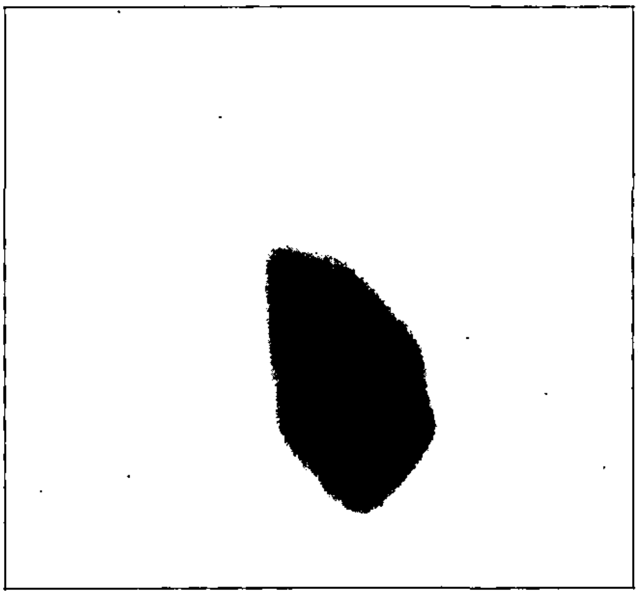


PLATE.3. ADJUSTABLE TABLE

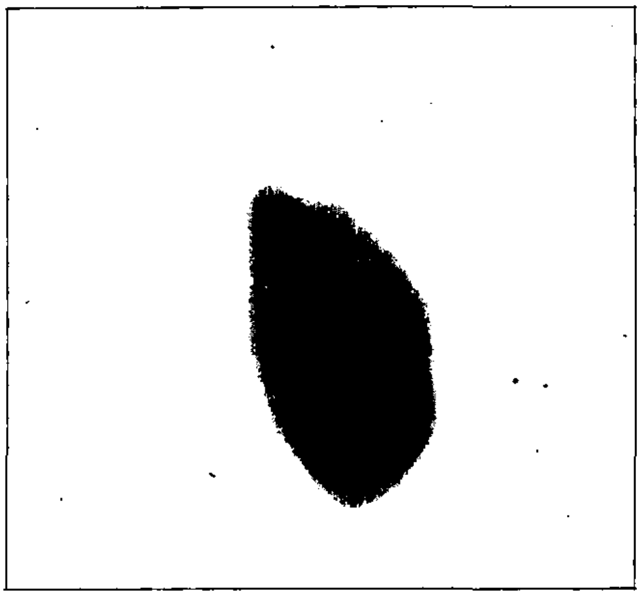
DS 23854/1/148 60 10/54 CL



EXPOSURE — $\frac{1}{4}$ sec



EXPOSURE — $\frac{1}{2}$ sec



EXPOSURE — 1 sec

PLATE. 4. VARIATION IN SIZE OF FOCAL SPOT

DS82657/1/114 60 11/54CL

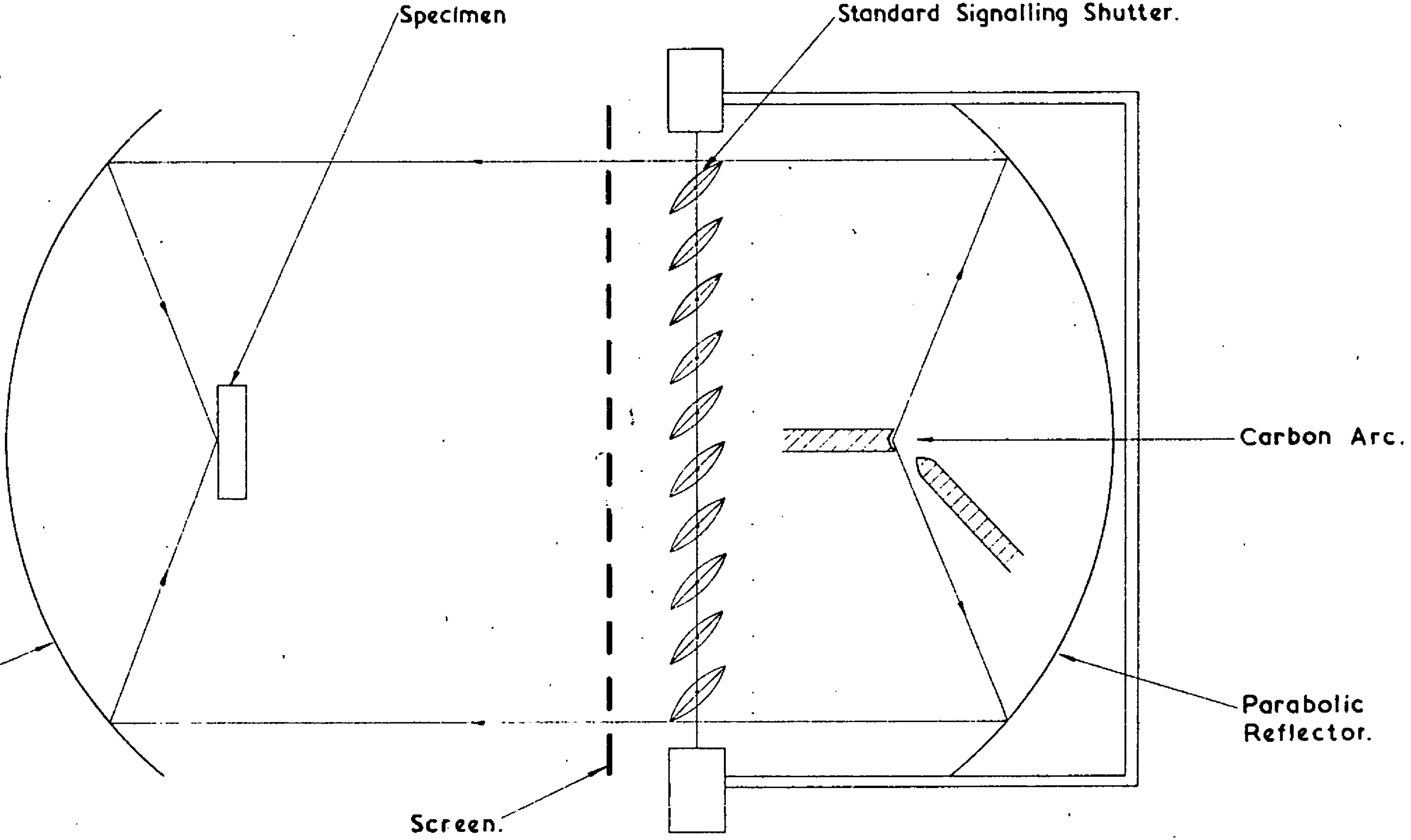
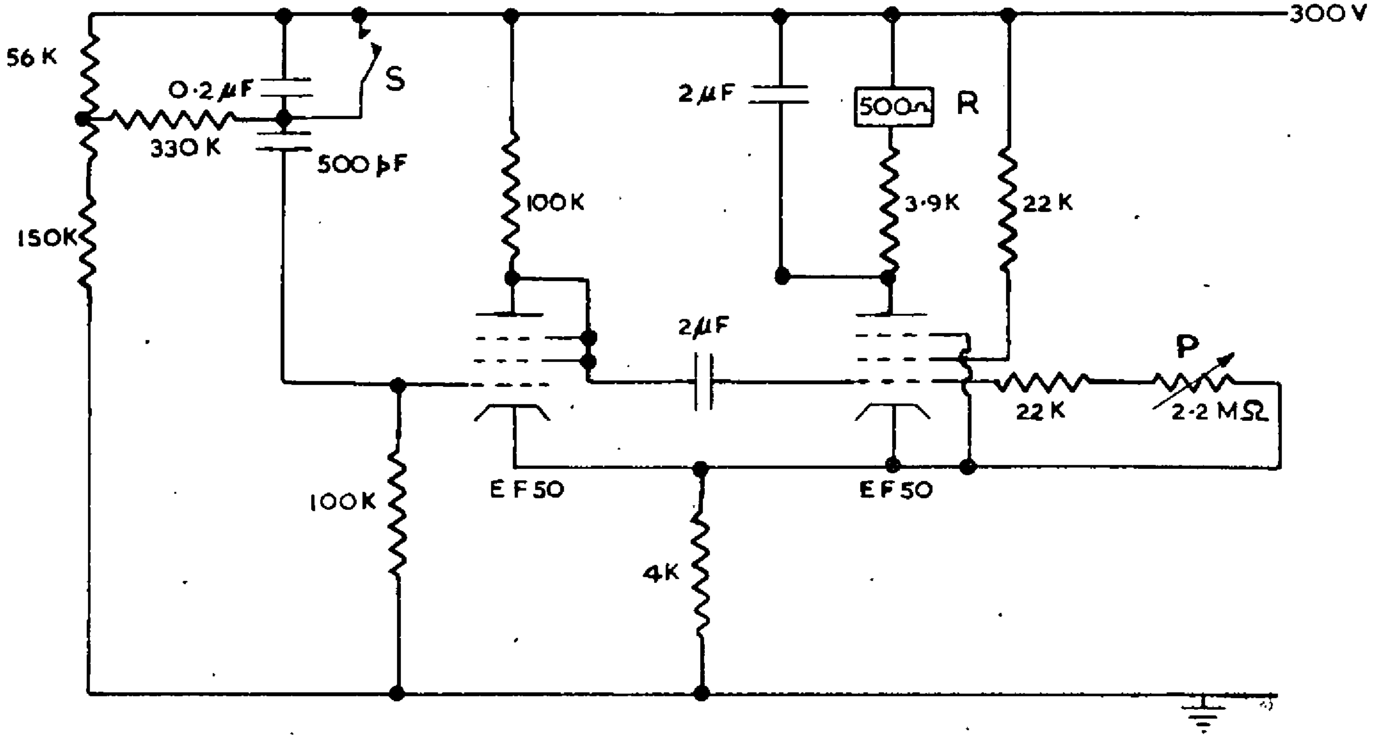


FIG. I. OPTICAL SYSTEM EMPLOYED, TOGETHER WITH RADIATION REDUCING DEVICES.



S	Operating switch
R	Relay operating shutter
P	Potentiometer to vary time of operation

FIG. 2. CIRCUIT DIAGRAM OF TIMING DEVICE

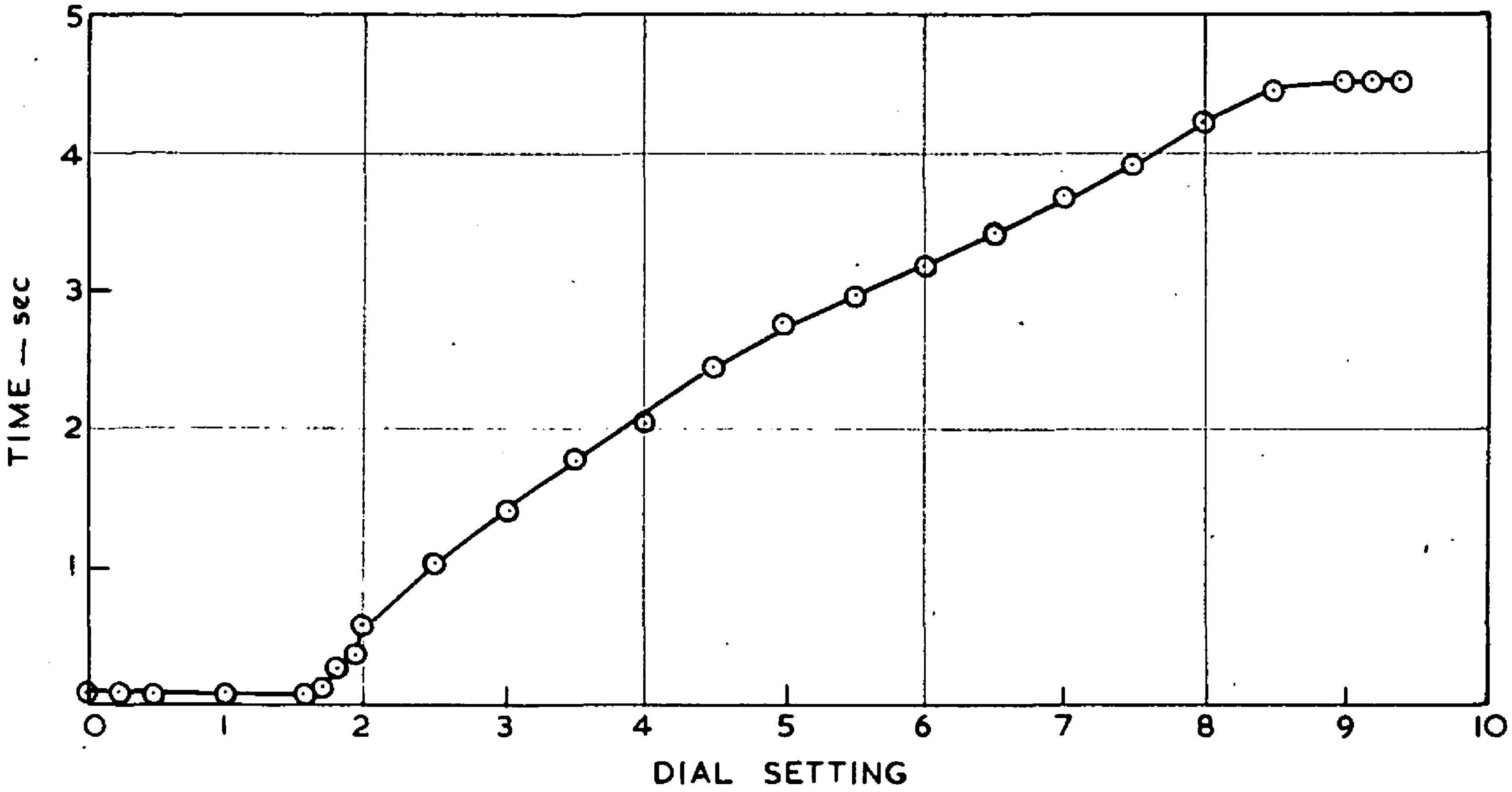


FIG. 3. CALIBRATION OF TIMING DEVICE

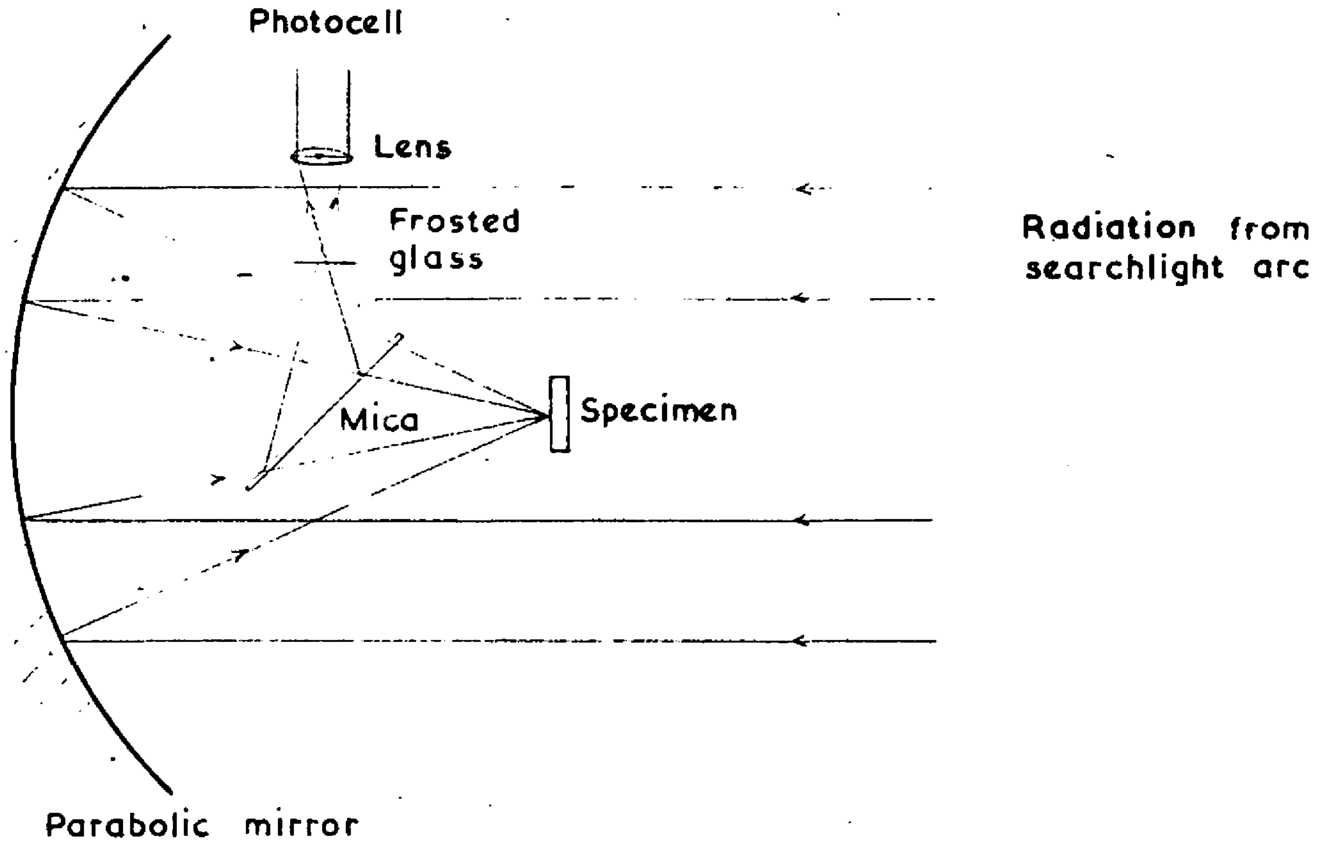


FIG. 4. RADIATION MONITORING SYSTEM

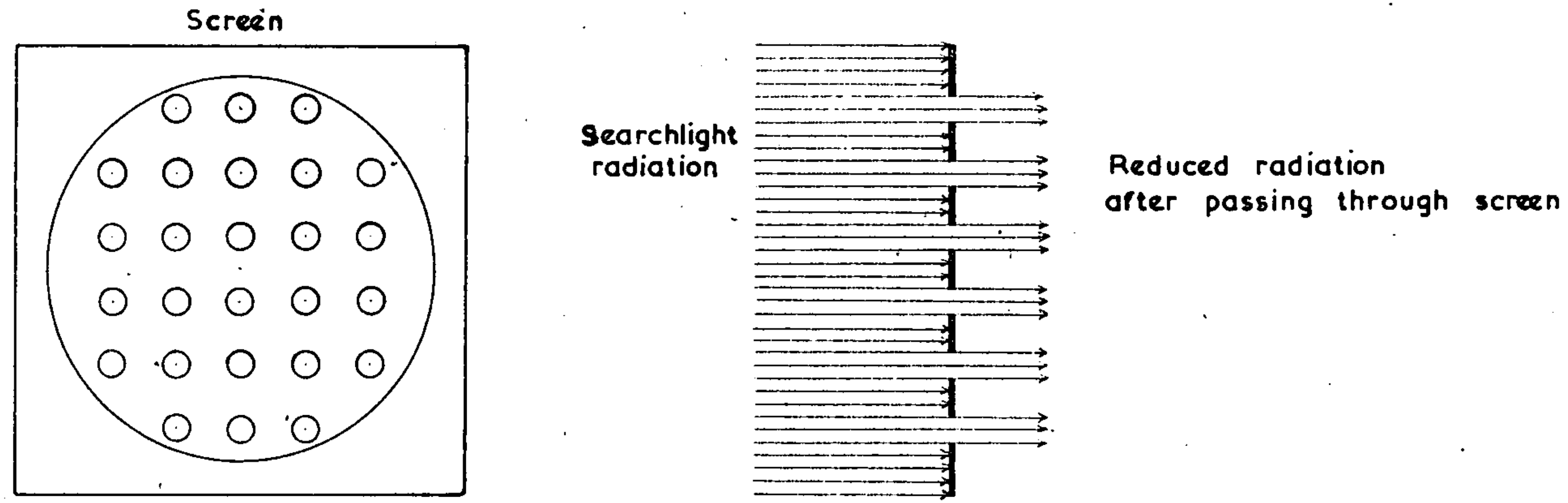
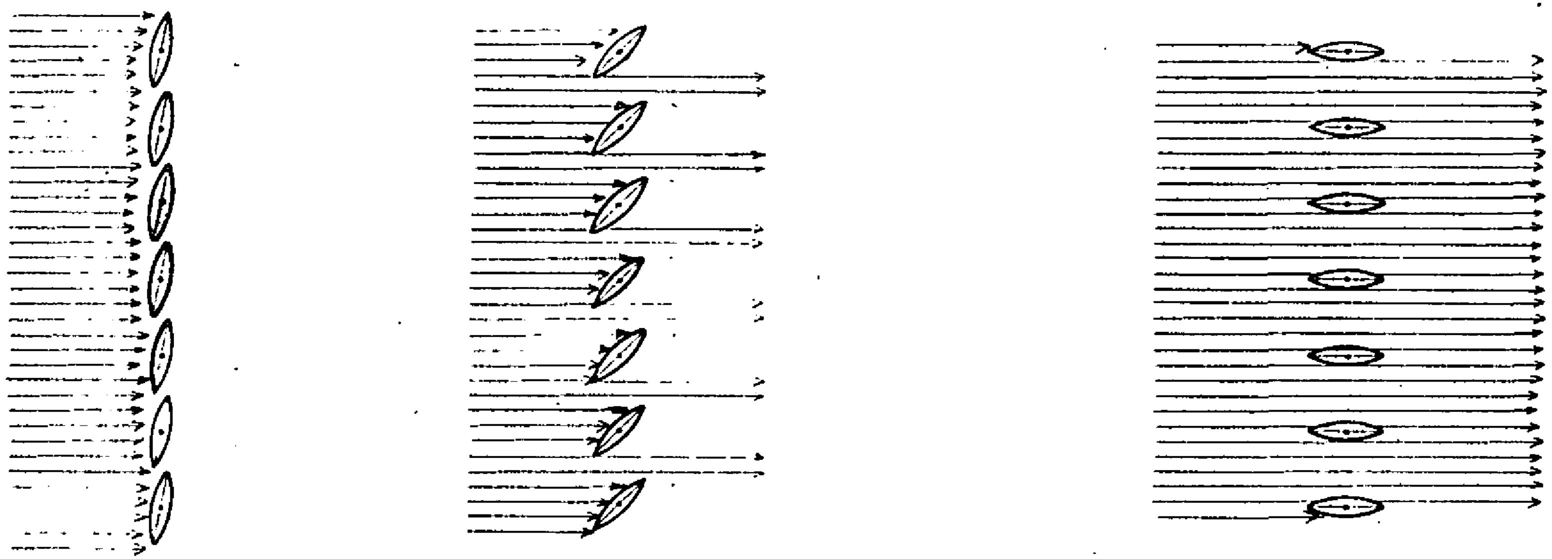


FIG.5b. DIAGRAM TO ILLUSTRATE EFFECT OF SCREEN



SHUTTER CLOSED

SHUTTER PARTIALLY OPEN

SHUTTER FULLY OPEN

FIG. 5a. DIAGRAM TO ILLUSTRATE EFFECT OF STOPS

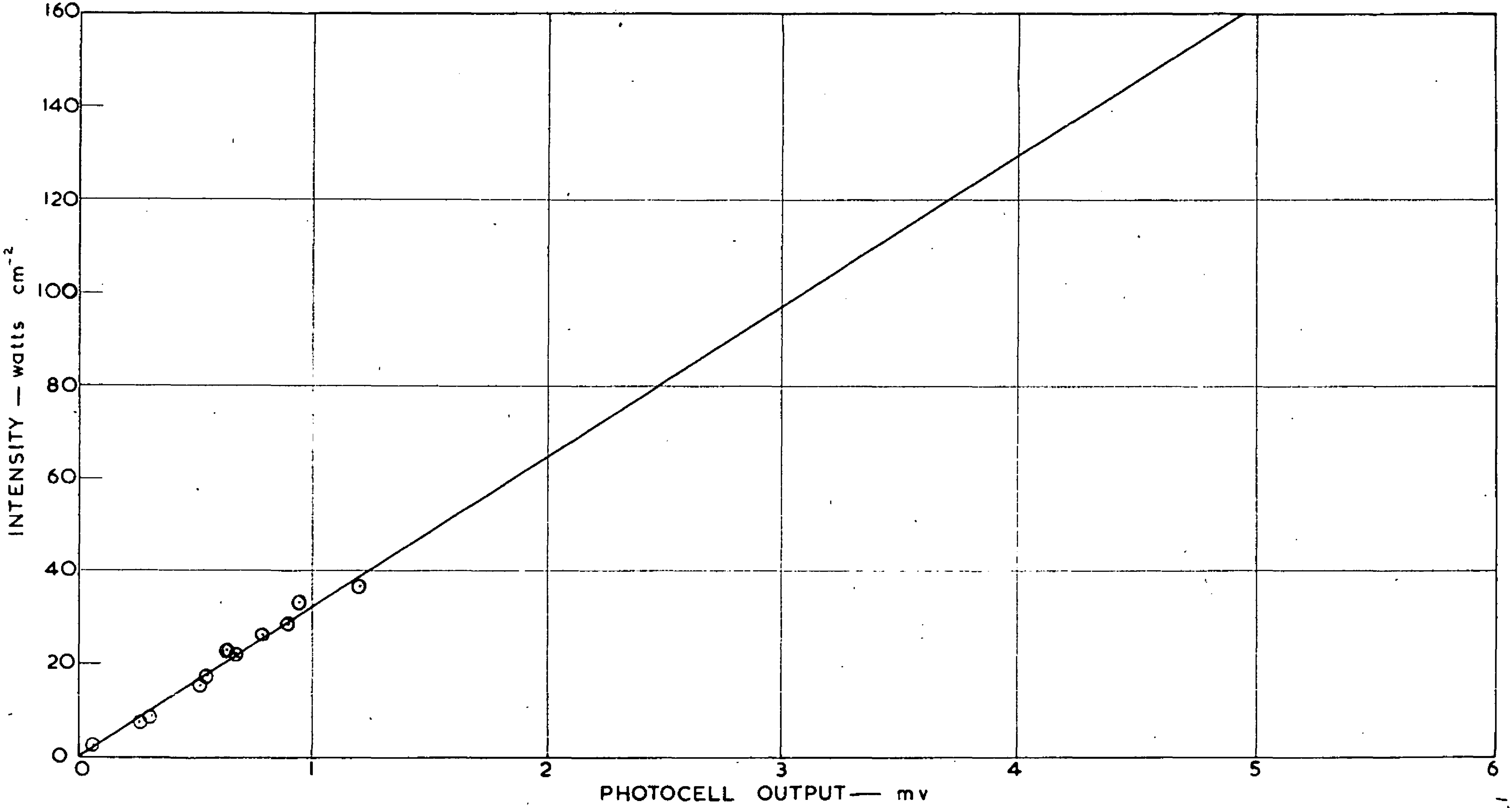


FIG. 6. INTENSITY OF RADIATION AT THE FOCUS AS A FUNCTION OF PHOTOCELL OUTPUT

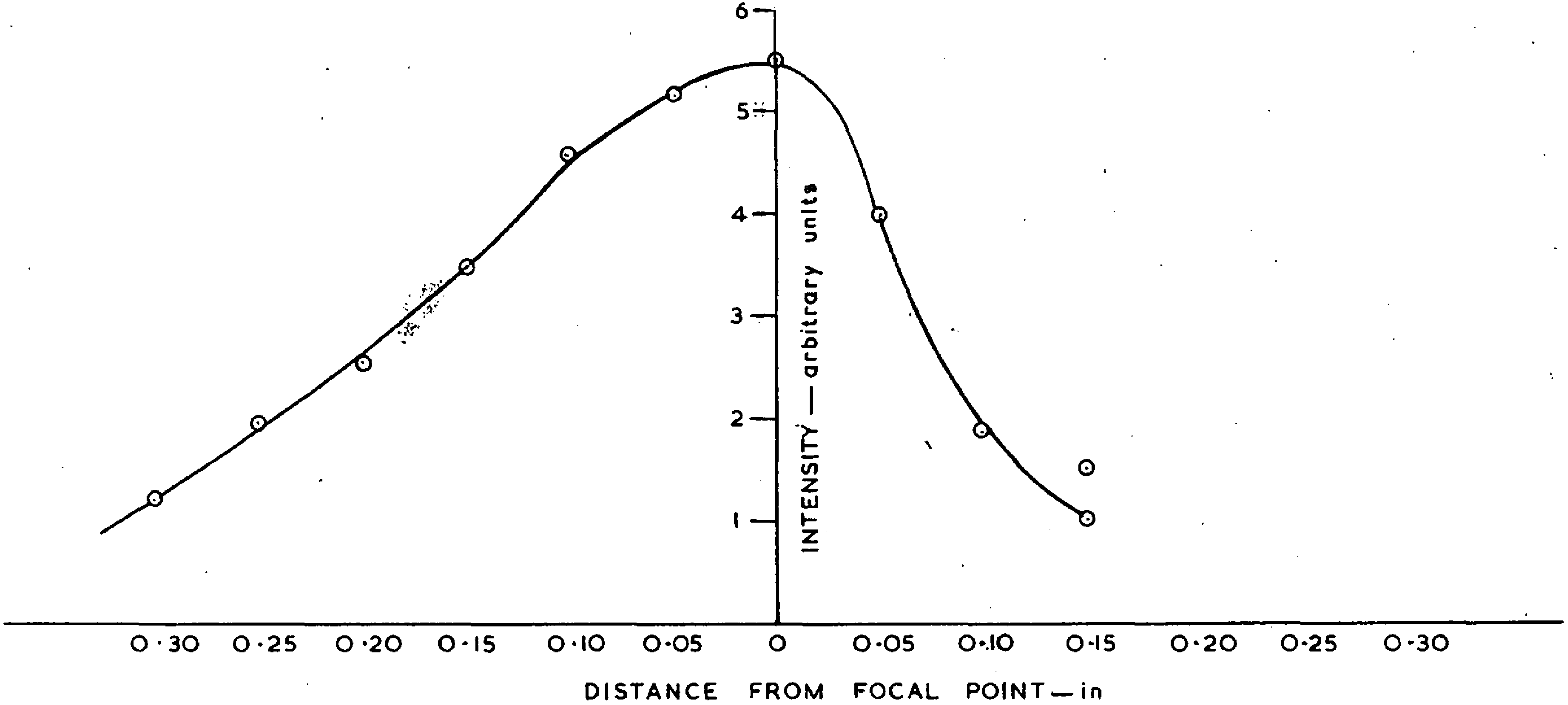


FIG.7b. INTENSITY DISTRIBUTION IN FOCAL PLANE (VERTICAL)

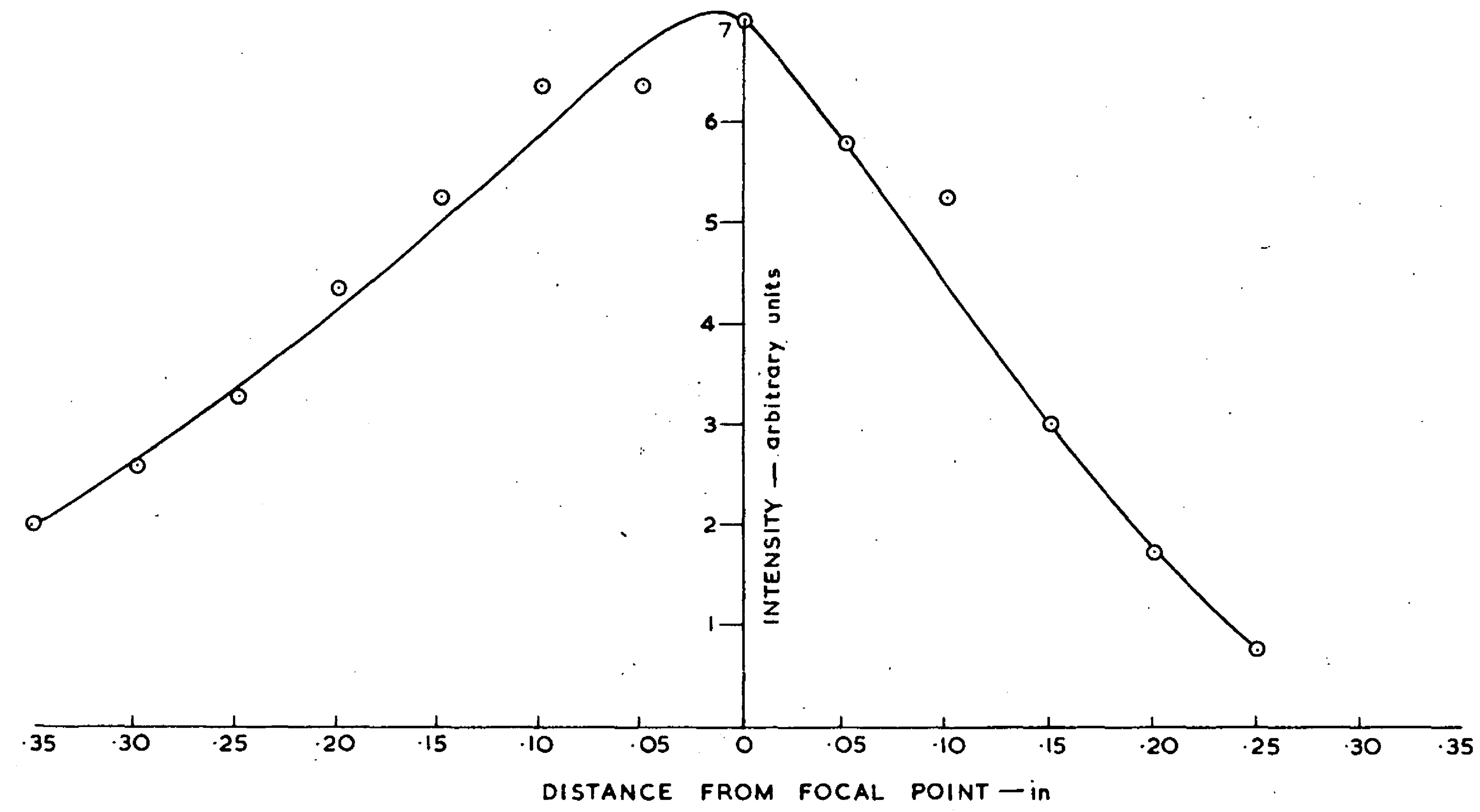


FIG. 7a. INTENSITY DISTRIBUTION IN FOCAL PLANE (HORIZONTAL)

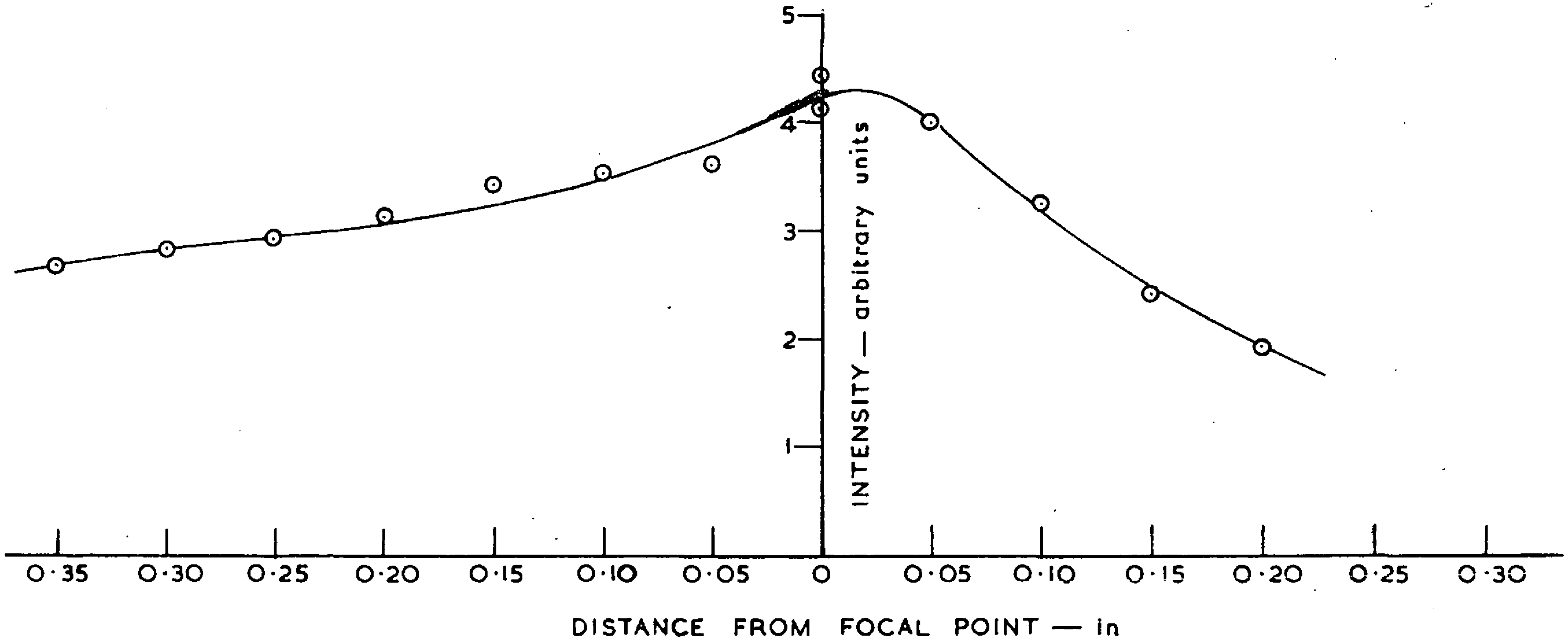


FIG. 8. INTENSITY DISTRIBUTION ALONG AXIS OF SYSTEM

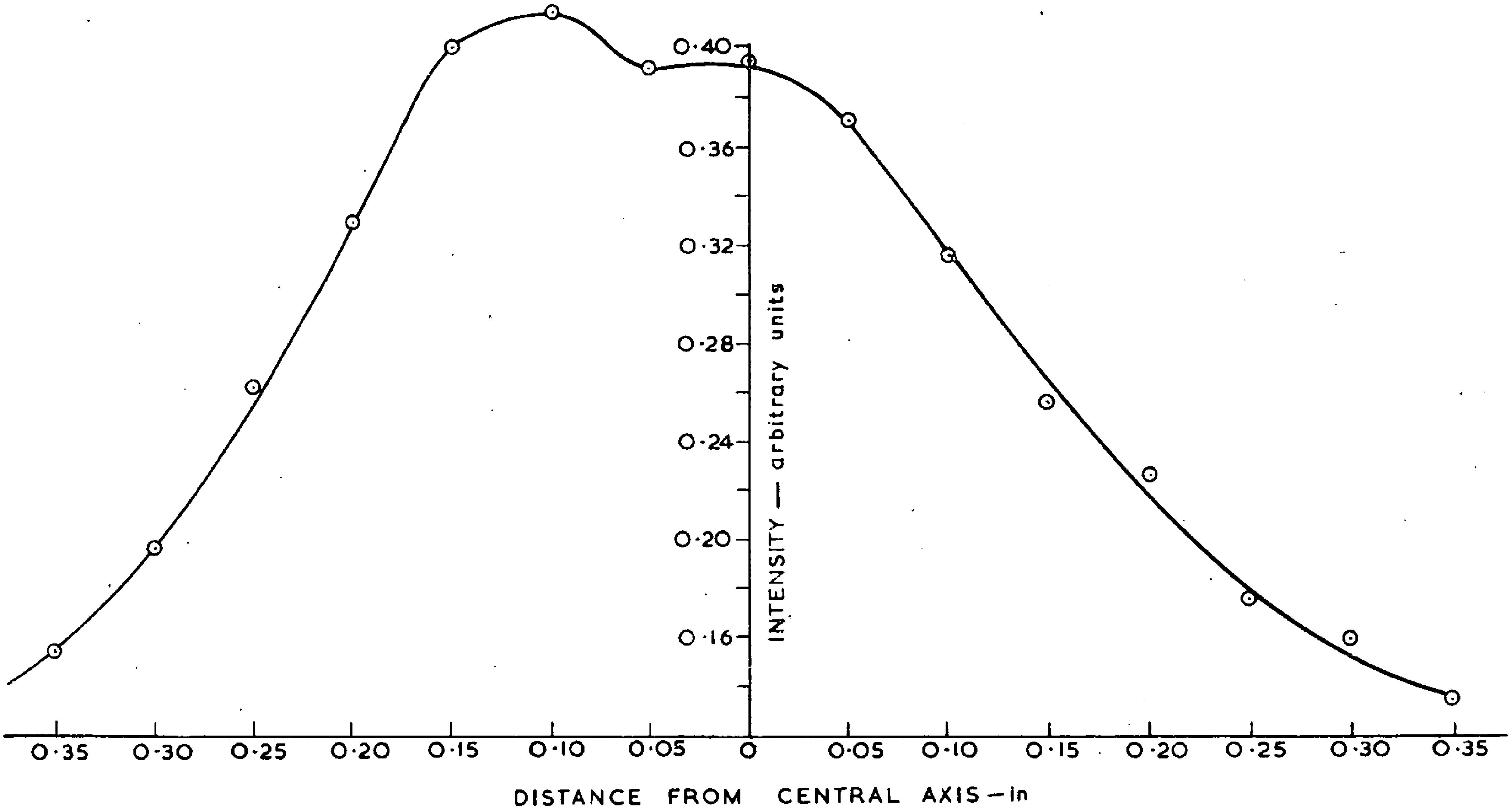


FIG.9b. INTENSITY DISTRIBUTION IN PLANE $\frac{1}{2}''$ IN FRONT OF FOCAL PLANE (VERTICAL)

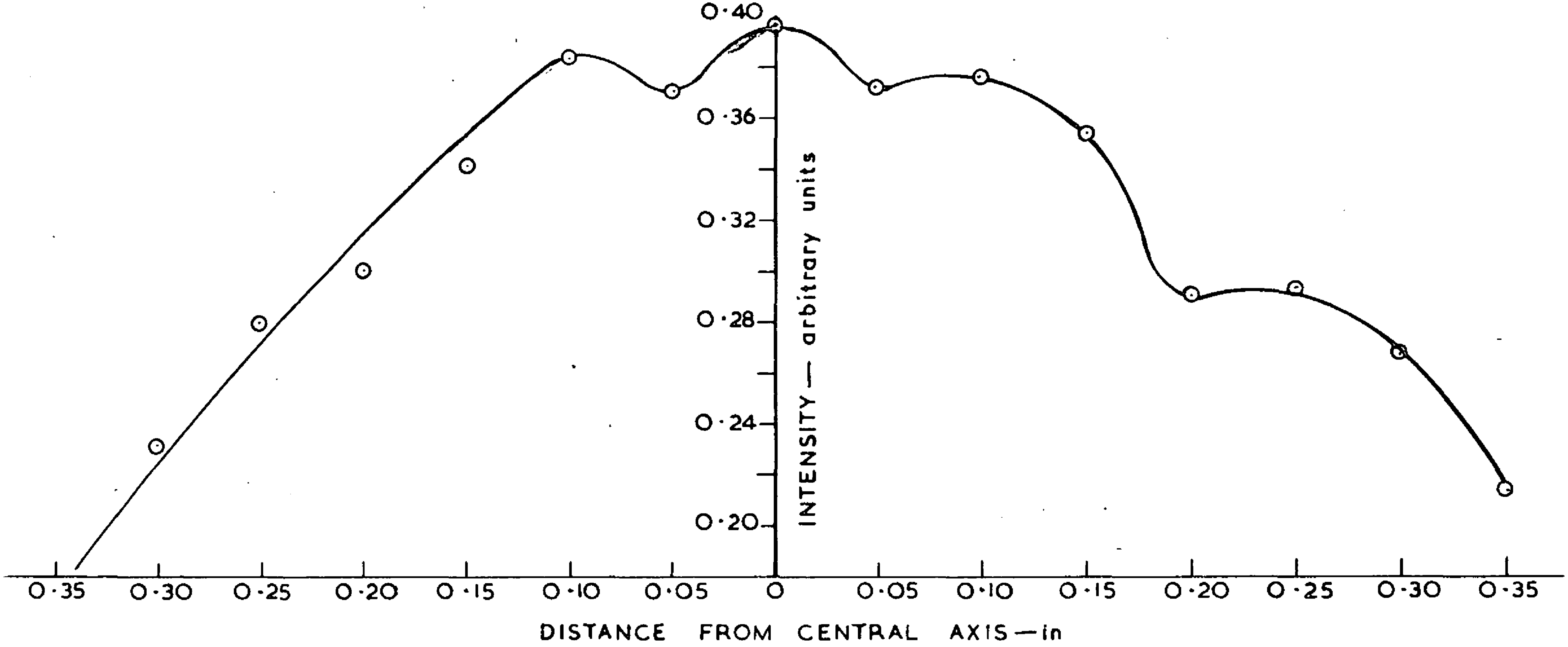


FIG. 9a. INTENSITY DISTRIBUTION IN PLANE $\frac{1}{2}$" IN FRONT OF FOCAL PLANE (HORIZONTAL)

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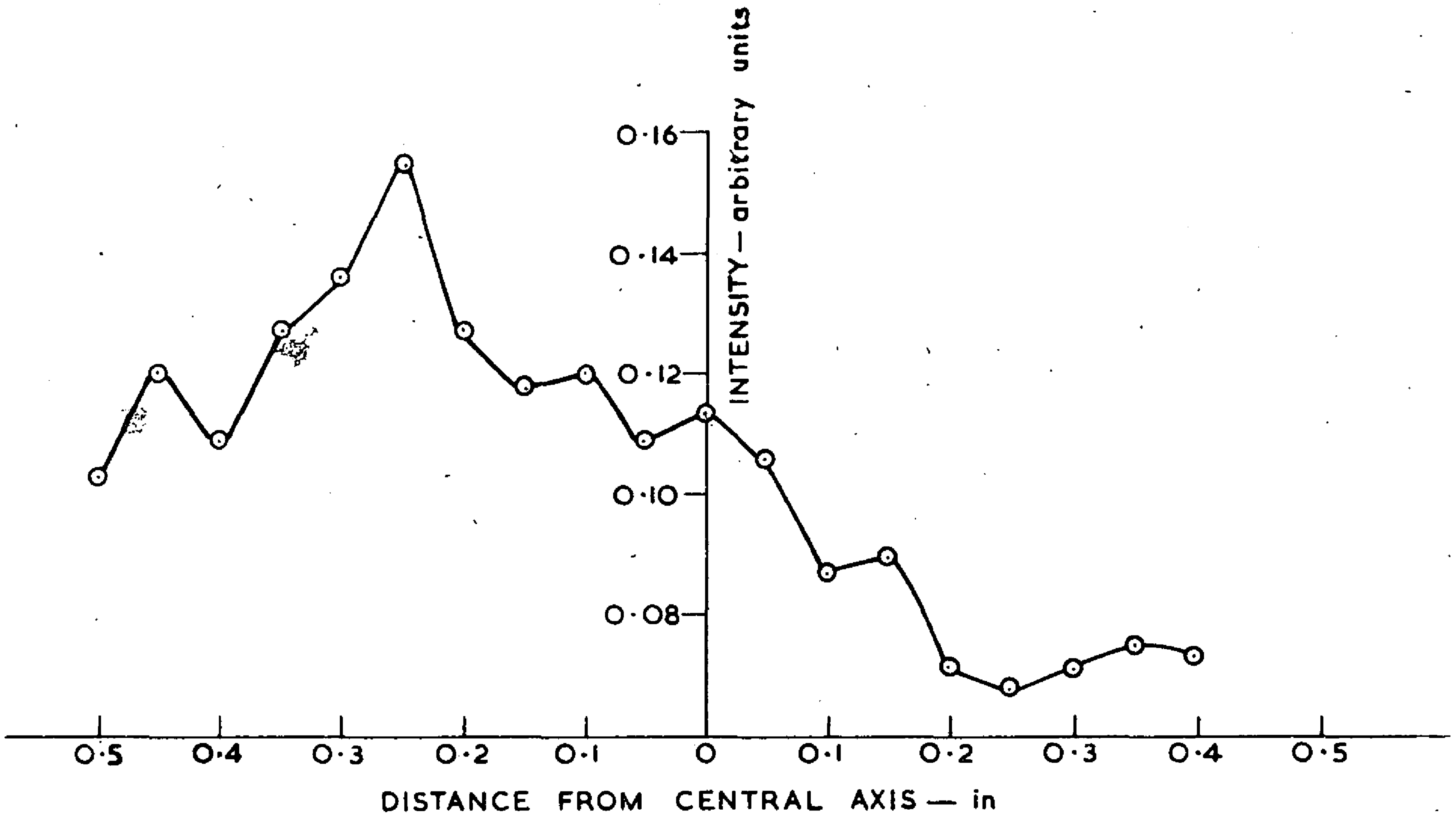

FIG. 10b. INTENSITY DISTRIBUTION IN PLANE 1" IN FRONT OF FOCAL PLANE (VERTICAL)

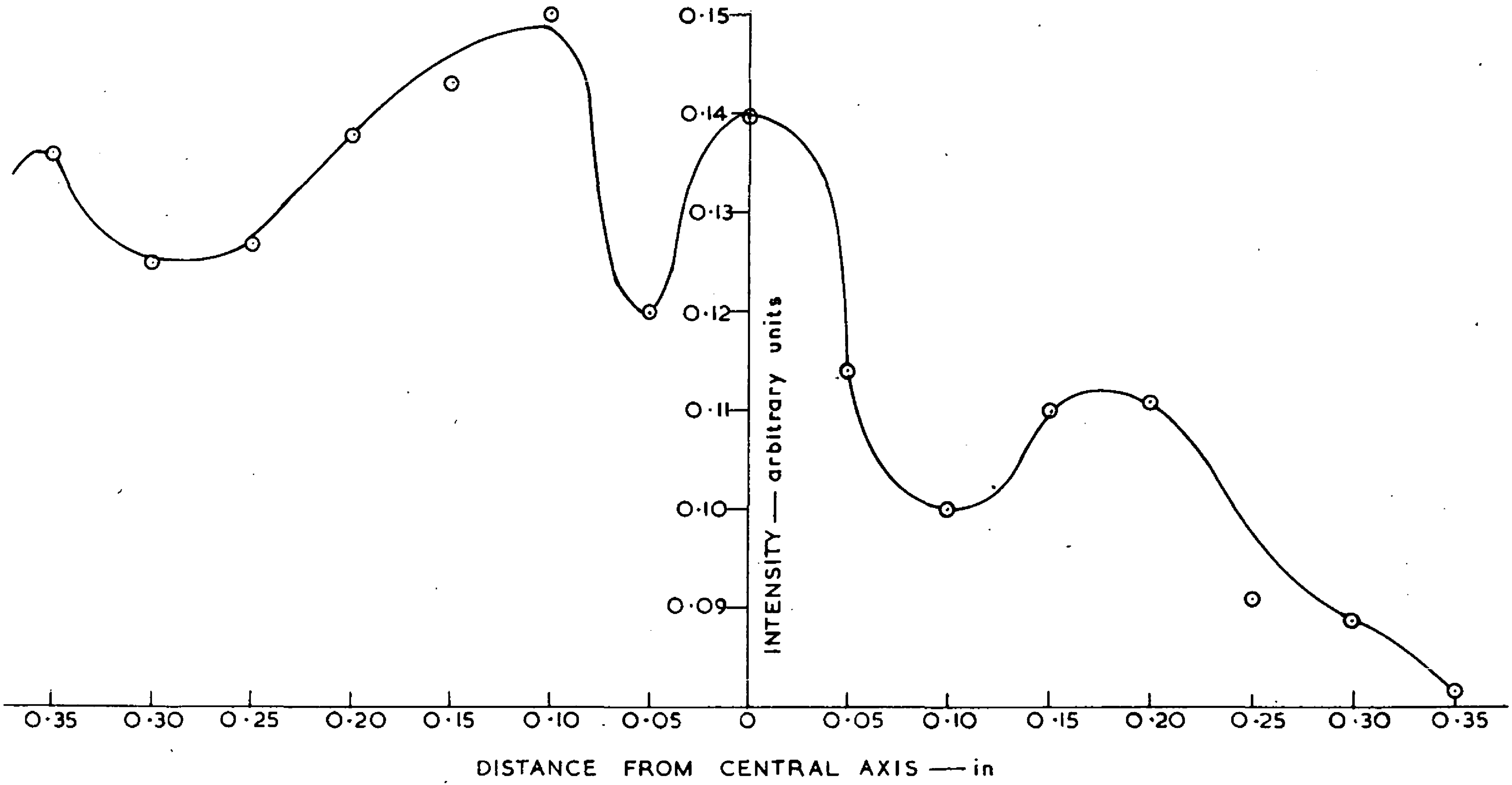

FIG. 10a. INTENSITY DISTRIBUTION IN PLANE 1" IN FRONT OF FOCAL PLANE (HORIZONTAL)

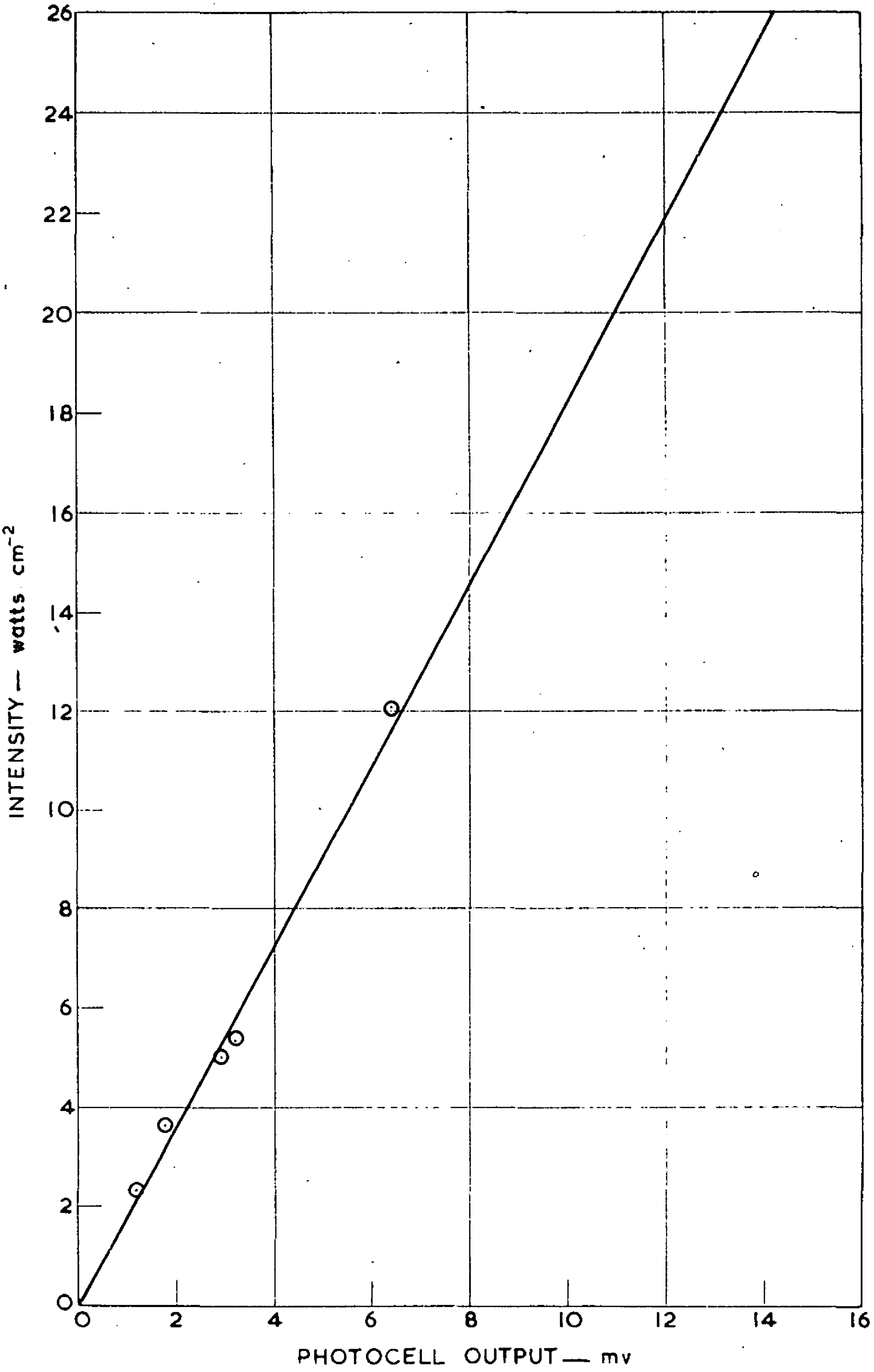

FIG. 11a. INTENSITY IN PLANE $\frac{1}{2}''$ IN FRONT OF FOCAL PLANE

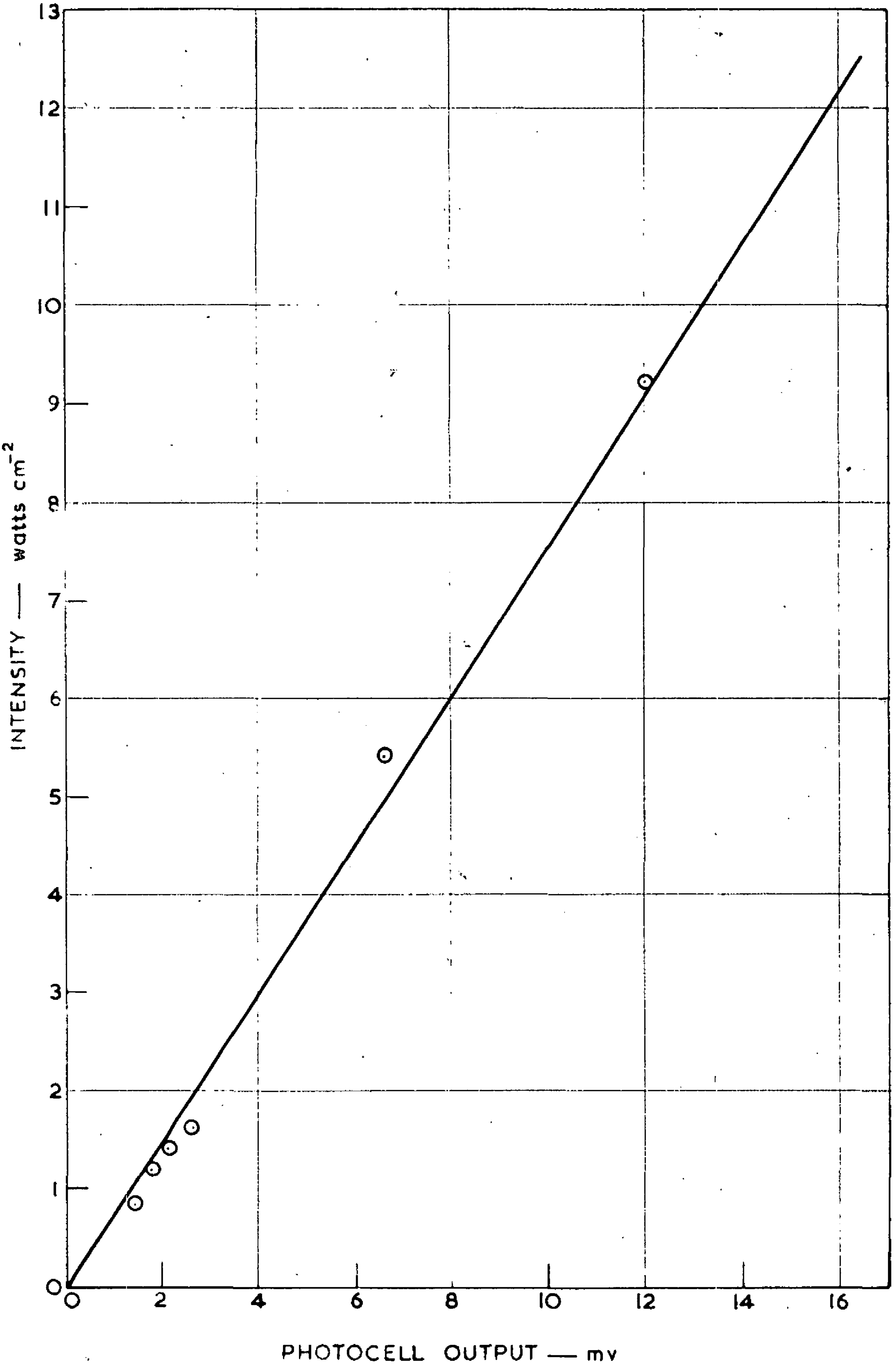

FIG. 11b. INTENSITY IN PLANE 1" IN FRONT OF FOCAL PLANE

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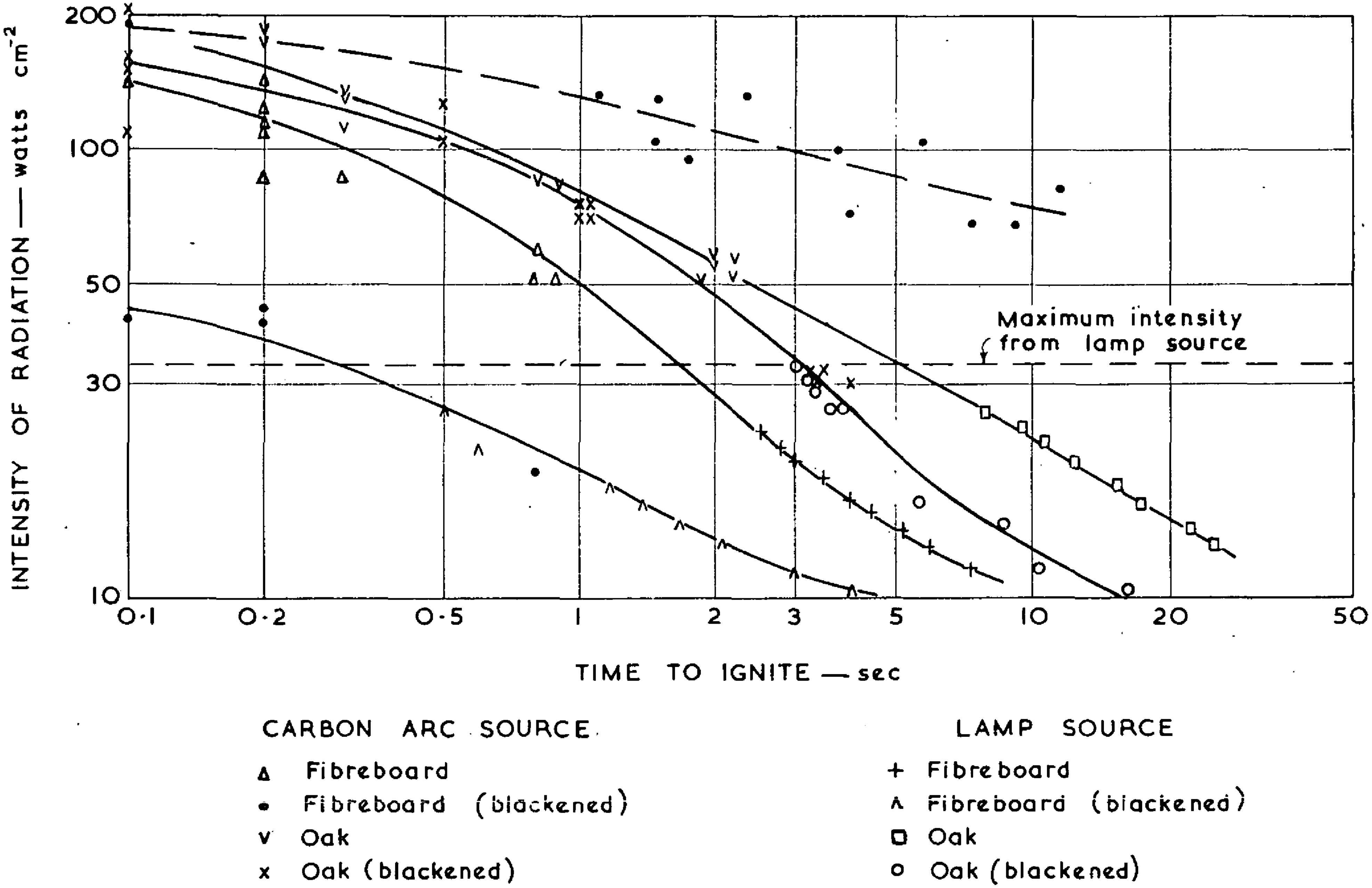

FIG. 12. SPONTANEOUS IGNITION OF OAK AND FIBREBOARD