# THE RÔLE OF INTENSITY, FREQUENCY AND AMOUNT OF IRRADIATION IN JOSHI-EFFECT

BY DR. N. R. TAWDE, F.A.SC. AND K. GOPALKRISHNAN

*(From the Department of Physics, Spectroscopic Laboratories, Royal Institute of Science, Bombay)*

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## 1. INTRODUCTION

IN the year 1937 Joshi[1-3] reported a significant observation that when a gas is subjected to ionisation by collision by alternating electric fields its conductivity diminished immediately on exposure to light. On the removal of light the conductivity restored to the original value without any sensible lag. This negative photo-effect on conductivity was first noticed in chlorine and a few other gases by Joshi. Later Joshi and co-workers confirmed this effect in many other gases under a range of conditions. This phenomenon first termed by Joshi as 'New Light-effect' has since been worked out in subsequent literature on the subject and has now received the familiar name 'Joshi-Effect' in scientific periodicals.

The conductivity of a gas in a Siemen's tube being obtainable from the measure of the discharge current, this decrease in conductivity will obviously mean a decrease of the discharge current. Thus under the influence of radiation the discharge current in a Siemen's tube containing a gas will be less than when the tube is in the dark. It is this decrease in the discharge current that is measured by Joshi to obtain a quantitative estimate of the effect of radiation on the conductivity of gases contained in Siemen's ozoniser. The technique used in such investigations has been well described in several papers by Joshi and co-workers.[2, 3]

Numerous factors are known to influence the Joshi-effect. Among these, the nature and pressure of the gas in the ozoniser tube, the intensity and frequency of the incident radiation and the resistance in the external measuring circuit are found to have a marked effect.[2, 3] The nature and extent of the ozoniser walls receiving the radiation also affect the magnitude of the current decrease. As the effect is a function of several such parameters, it is worthwhile to investigate the exact relation connecting the current decrease with one or several of the parameters cited above. It is with this objective that the experiments outlined below have been undertaken.

## 2. Experimental

The gases selected for investigation are chlorine and air. The discharge tube is of the form of Siemen's ozoniser. It consists of three co-axial tubes forming three independent space compartments. For investigations on chlorine, the inner and outer spaces are filled with dilute hydrochloric acid (Fig. 1). The middle space is joined to a pump with a tube for

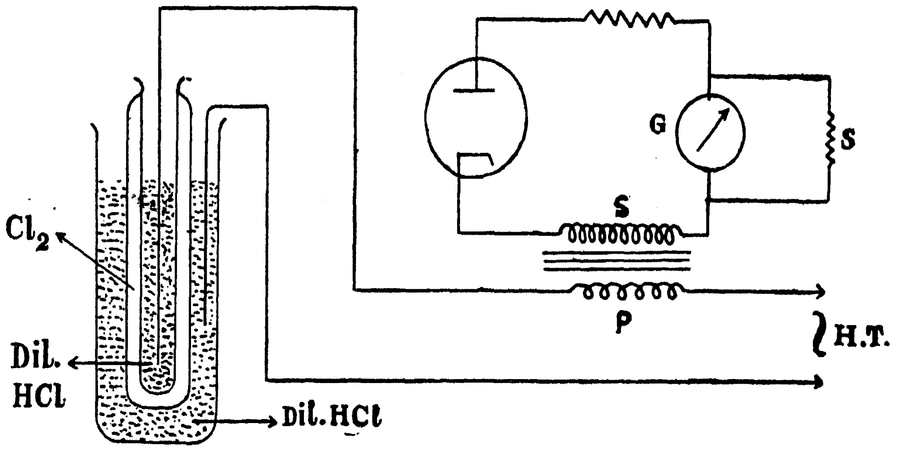



Fig. 1. Experimental arrangement for the study of the effect of intensity and frequency of radiation on discharge in chlorine

exhausting it and to an inlet tube for filling it with chlorine gas at any desired pressure. The columns of hydrochloric acid in the inner and outer tubes serve as the two electrodes of the ozoniser. They are connected to the secondary of a 15 kilovolt, 450 watts, 50 cycles transformer to excite the discharge.

The experimental technique involves the observation of the initial steady galvanometer deflection corresponding to the discharge current $i$ in the ozoniser under dark illumination and the diminution $d\theta$ in the original deflection $\theta$ when the ozoniser is irradiated under precisely known conditions. These two values of $\theta$ and $d\theta$ of the deflection enable us to obtain a measure of the quantity $-d\theta/\theta \times 100$ which is equivalent to $-\Delta i/i \times 100$. The latter is stated to be the percentage decrease in the current or $\% \Delta i$. This needs to be calculated for the reason that the actual magnitude of net Joshi-effect $\Delta i$ measured, is a function of the initial current $i$.

It is proposed first of all to investigate the variation of the discharge current with the intensity and frequency of radiation falling on the ozoniser.

### (a) *Effect of Intensity and Frequency of Radiation on Discharge in Chlorine*

For these experiments the following arrangement shown in Fig. 1 is adopted, where the ozoniser along with the electrical excitation system is sketched.

The ozoniser with its electrodes of dilute hydrochloric acid and chlorine gas in between is indicated diagrammatically to the left. This is fed by the secondary of the high tension transformer mentioned above. In order to measure the discharge current the primary $p$ of another transformer is included in the discharge circuit. When a current is established in the discharge circuit, a small potential difference is developed across the primary $p$. The resulting potential difference in the secondary $s$ of the transformer is then applied to the plate of a diode. The plate current is measured by a sensitive mirror galvanometer $G$ having a suitable shunt $S$. The deflection $\theta$ of the galvanometer gives a measure of the discharge current $i$.

As chlorine is found to give a very large magnitude of Joshi-Effect, it is particularly chosen for these experiments, aiming at the exploration of the quantitative data relating to both intensity and frequency of light.

Since change of frequency of radiation affects simultaneously the intensity, it is difficult to adopt a direct method in which the frequency can be changed keeping the intensity constant. For this purpose, radiation of a narrow selected waveband is isolated at a time from a continuous source of light. Filters used for this purpose were four kinds of coloured glasses. In practice it is found that large intensities are generally desirable to obtain an appreciable measure of current change. With the coloured glasses there is large absorption and hence a continuous source of large intensity is necessary in order to allow a good amount of light intensity to filter out in a given band. Except the sodium discharge lamp, no other truly monochromatic light was available. This is used only at one stage as will be shown later, to obtain confirmation of certain results. For the main part of the experiments, a 250 watt clear tungsten lamp served as the irradiating source.

(1) *Isolation of Wavelength Bands.*—Red, yellow, green and blue glass filters used in conjunction with the above tungsten lamp give bands at effective mean frequencies 15294, 16880, 17737 and 18877 $cm.^{-1}$ determined by standard optical methods. The possible dispersion of the wavelength was of the order of about 200 A.U. on either side of the mean wavelength, but the effective intense band is expected to be much narrower than this spread.

(2) *Intensity Standardisation.*—In a given wavelength band isolated as above, the intensity variation was caused by altering the position of the lamp with respect to a fixed vertical position of the ozoniser. The lamp was kept successively at distances of 40, 50, 60, 70 and 80 cm. from the ozoniser. For expressing the intensities in lumens per sq. metre, the following process of standardisation was adopted.

The intensities of radiation of the above frequencies falling on the ozoniser with the source kept at the above mentioned distances from it were measured by a thermopile which was independently calibrated in terms of a standard G.E.C. photometric lamp. It was necessary to eliminate the heat radiations which were appreciable due to the large wattage of the source. They were cut off by using a glass cell containing a layer of hydrochloric acid uniform with the one that surrounded chlorine in the ozoniser forming the electrodes.

To arrive at the required thickness of the layer to eliminate all heat radiations and obtain only the light radiations, the following procedure was adopted. Using the standard lamp and the abovementioned glass cell, the deflection in the galvanometer used in conjunction with the thermopile is noted when the thermopile is kept at a known distance from the lamp. The thermopile is then replaced by a Weston Light-meter and the deflection produced in it is noted. Another cell is brought in series with the first and with the two together, the observations of the galvanometer deflections and the Weston Light-meter readings are repeated. If all the heat radiations are not cut off by the first cell, the diminution produced in the galvanometer deflection by interposing the second cell should be greater than in the case of the Weston Light-meter, since the latter is not sensitive to infra-red radiations, while the thermopile is affected by both light and infra-red radiations. That limiting thickness of the layer is adjusted which brings about the same diminution of deflection in the galvanometer and the light-meter by adding a fresh layer, showing the elimination of heat effect. When this limiting thickness is arrived at, it is seen that the outer layer of dilute hydrochloric acid acting as one electrode surrounding the ozoniser is not less than this thickness. This ensured the incidence of only light radiations on the discharge column.

By correlating the galvanometer deflections of the thermopile (with the layer of hydrochloric acid in front of it) with the known flux of the standard photometric lamp on the one hand and with the unknown flux of the given source at the abovementioned definite distances used in conjunction with the filters on the other hand, the intensities of the radiations falling on the ozoniser were ultimately expressed in terms of lumens per sq. metre in each of the selected wavelength bands and for the stated distances, *viz.*, 40, 50, 60, 70 and 80 cm.

Observations have been taken for two pressures of chlorine ($P_1$ and $P_2$, $P_1$ being greater than $P_2$) in the ozoniser tube. These pressures were taken of the order of tens of cm. of mercury ($\sim$ 20 to 30 cm.) as the light-effect was noticed to be appreciable for higher pressures.

## 3. RESULTS

Table I below records the results of observations to show the intensity effect of light on current decrease. The effective mean frequency is noted in column one. Intensity of the radiation falling on the ozoniser in lumens per sq. metre is noted in column two and the decrease in current in column three in terms of the percentage decrease in current ($\%\Delta i$) for pressures $P_1$ and $P_2$. In order to see the proportionality of the effect, if any, for the two pressures the ratio of $\%\Delta i$ at $P_1$ and $P_2$ has also been calculated for corresponding values of frequency and intensity.

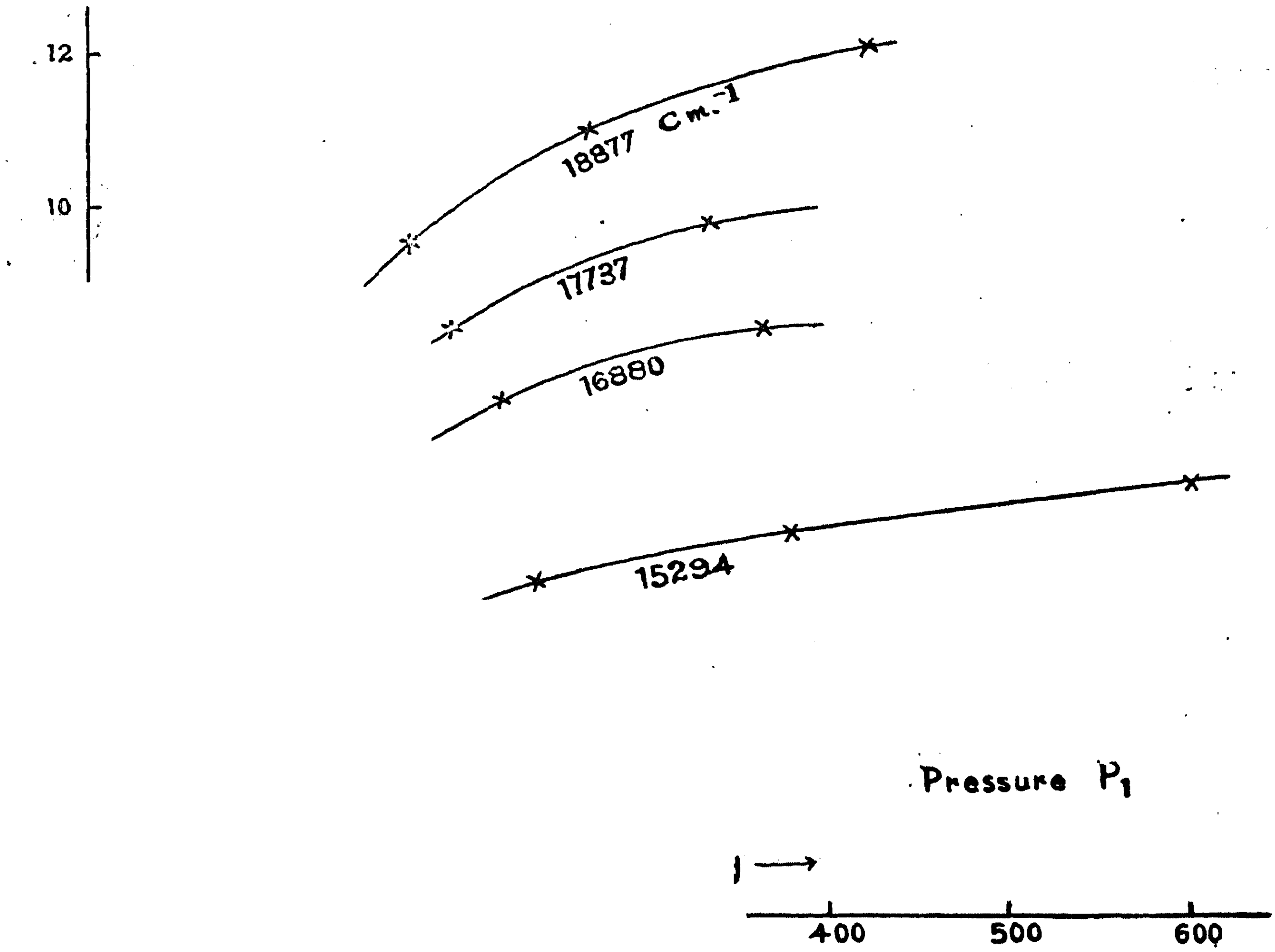
TABLE I

*Joshi-effect as a function of intensity*

($P_1$ greater than $P_2$)

| Frequency cm.$^{-1}$ | Intensity I in lumens per sq. m. | $\%\Delta i$ | | Ratio of $\%\Delta i$ between $P_1$ an8 $P_2$ |
|---|---|---|---|---|
| | | $P_1$ | $P_2$ | |
| 15294 | 590·9 | 6·3 | 4·5 | 1·40 |
| | 378·7 | 5·5 | 4·0 | 1·38 |
| | 261·5 | 4·7 | 3·5 | 1·34 |
| | 204·5 | 4·2 | 3·1 | 1·36 |
| | 147·4 | 3·6 | 2·6 | 1·39 |
| | | | | Mean = 1·37 |
| 16880 | 360·6 | 8·1 | 6·4 | 1·27 |
| | 230·3 | 7·2 | 5·4 | 1·33 |
| | 160·3 | 6·3 | 4·7 | 1·34 |
| | 116·2 | 5·2 | 3·9 | 1·33 |
| | 90·4 | 4·7 | 3·3 | 1·42 |
| | | | | Mean = 1·34 |
| 17737 | 322·8 | 9·4 | 7·1 | 1·32 |
| | 215·2 | 8·2 | 6·2 | 1·32 |
| | 147·4 | 6·8 | 5·3 | 1·28 |
| | 105·4 | 6·3 | 4·7 | 1·34 |
| | 80·7 | 5·7 | 4·2 | 1·36 |
| | | | | Mean = 1·32 |
| 18877 | 421·9 | 12·2 | 9·2 | 1·33 |
| | 269·2 | 10·9 | 7·8 | 1·39 |
| | 186·2 | 9·6 | 7·1 | 1·35 |
| | 137·7 | 8·3 | 6·1 | 1·36 |
| | 106·5 | 7·3 | 5·2 | 1·40 |
| | | | | Mean = 1·37 |

These results have been plotted graphically in Figs. 2 and 3. The values of $\%\Delta i$ as a function of light intensity I in lumens per sq. metre at pressure $P_1$ is shown in Fig. 2 and the same relation at pressure $P_2$ in Fig. 3, for all the wavelength bands.

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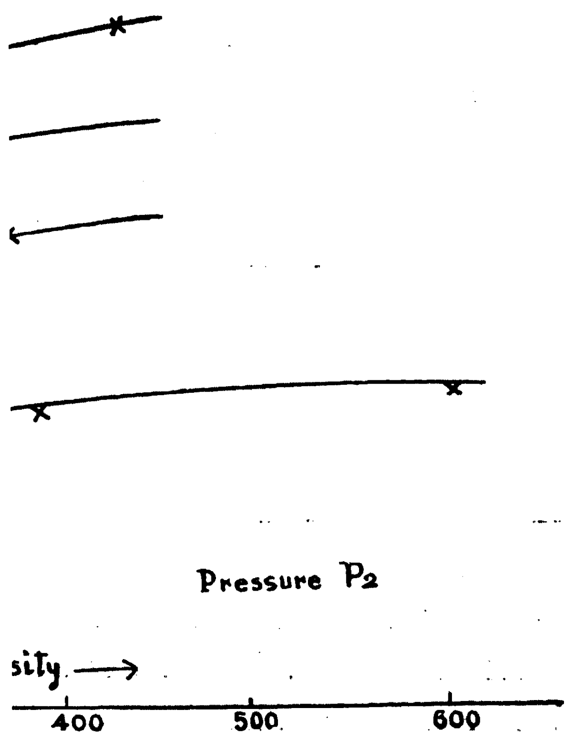


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The relation of $\%\Delta i$ with frequency at constant intensity has been derived from the graphs of Fig. 2 and Fig. 3 in the following manner. Four points of constant intensity 100, 200, 300, and 400 lumens per sq. metre have been chosen on the X-axis of these graphs and the values of $\%\Delta i$ corresponding to these against each of the four observed frequencies are noted down. These derived observations are recorded in Table II below.

TABLE II

*Joshi-effect as a function of frequency*

(Derived from Figs. 2 & 3)

| Intensity I in lumens per sq. m. | Frequency $\nu$ cm.$^{-1}$ | $\%\Delta i$ | | Ratio of $\%\Delta i$ between $P_1$ and $P_2$ |
|---|---|---|---|---|
| | | $P_1$ | $P_2$ | |
| 100 | 15294 | 2·9 | 2·0 | 1·45 |
| | 16880 | 4·7 | 3·7 | 1·27 |
| | 17737 | 5·9 | 4·5 | 1·31 |
| | 18877 | 7·2 | 5·2 | 1·38 |
| | | | | Mean = 1·35 |
| 200 | 15294 | 4·4 | 3·3 | 1·33 |
| | 16880 | 6·9 | 5·4 | 1·27 |
| | 17737 | 8·2 | 6·4 | 1·30 |
| | 18877 | 9·9 | 7·5 | 1·29 |
| | | | | Mean = 1·30 |
| 300 | 15294 | 5·0 | 3·9 | 1·28 |
| | 16880 | 7·9 | 6·2 | 1·27 |
| | 17737 | 9·5 | 7·3 | 1·30 |
| | 18877 | 11·4 | 8·8 | 1·29 |
| | | | | Mean = 1·29 |
| 400 | 15294 | 5·3 | 4·1 | 1·29 |
| | 16880 | 8·2 | 6·5 | 1·26 |
| | 17737 | 9·9 | 7·4 | 1·33 |
| | 18877 | 12·1 | 9·3 | 1·30 |
| | | | | Mean = 1·29 |

The above results are plotted graphically in Figs. 4 and 5.

Here we have frequency $\nu$ in cm.$^{-1}$ along X-axis and $\%\Delta i$ along Y-axis. All the four curves corresponding to constant intensities 100, 200, 300 and 400 lumens per sq. metre are drawn in the same graph, Fig. 4 for pressure $P_1$ and Fig. 5 for pressure $P_2$.

To check the validity of the results obtained, the values of $\%\Delta i$ that are obtainable as a result of incident light of frequency $\nu = 16970$ cm.$^{-1}$ corresponding to monochromatic sodium light are read from graphs of Figs. 4 and 5 by choosing the particular frequency on the X-axis and noting the

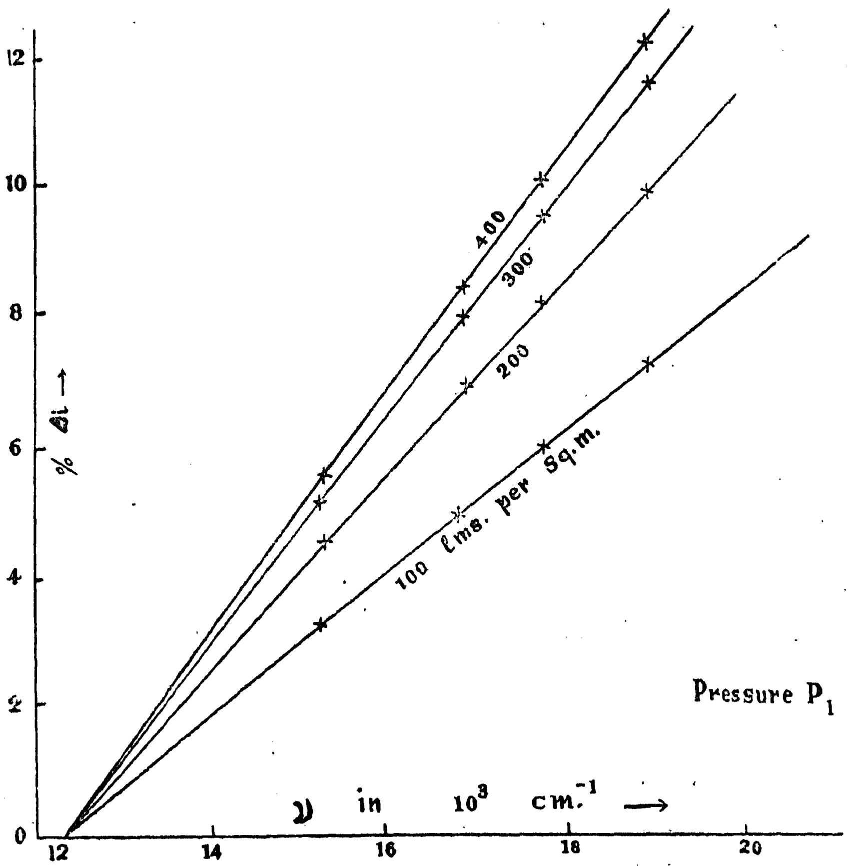


FIG. 4. The Joshi-effect as a function of frequency of radiation
Pressure of chlorine = $P_1$

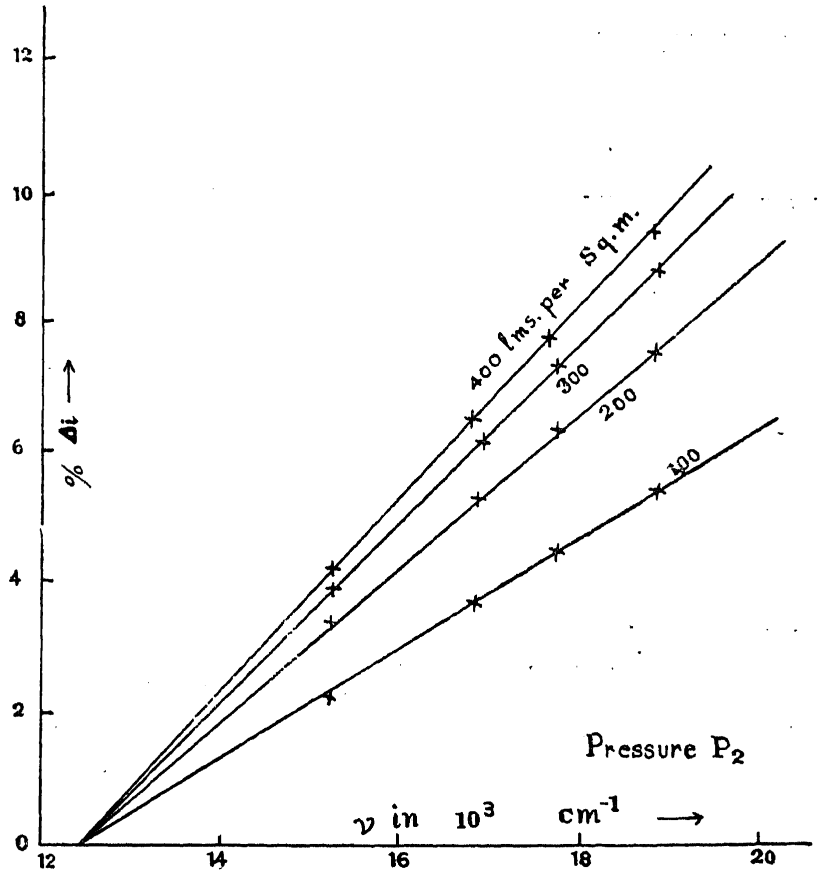


FIG. 5. The Joshi-effect as a function of the frequency of radiation
Pressure of chlorine = $P_2$

$\%\Delta i$ for intensities 100, 200, 300 and 400 lumens per sq. metre. These derived readings are entered in Table III (*b*).

To see whether these graphically derived values of Table III (*b*) confirm the experimental results, observations were taken with sodium light. A Philips Philora sodium vapour lamp (230 volts, 65 watts) was chosen as the source causing truly monochromatic light to fall upon the ozoniser discharge at the five fixed distances mentioned above. The intensities in lumens per sq. metre corresponding to these distances are measured in the manner indicated in the above experiments and the decrease in the ozoniser current observed. These observations are entered in Table III (*a*).

TABLE III (*a*)

*Diminution in discharge current for sodium light*

(Experimental values)

| Intensity I in lumens per sq. m. | $\%\Delta i$ | | Ratio of $\%\Delta i$ between $P_1$ and $P_2$ |
|---|---|---|---|
| | $P_1$ | $P_2$ | |
| 283·1 | 8·5 | 6·8 | 1·25 |
| 245·3 | 7·3 | 5·7 | 1·28 |
| 171·1 | 6·5 | 4·8 | 1·35 |
| 125·9 | 5·5 | 4·0 | 1·37 |
| 96·9 | 5·0 | 3·5 | 1·42 |
| | | | Mean = 1·33 |

TABLE III (*b*)

*Diminution in discharge current for sodium light*

(Graphical values derived from Figs. 4 & 5)

| Intensity I in lumens per sq. m. | $\%\Delta i$ | | Ratio of $\%\Delta i$ between $P_1$ and $P_2$ |
|---|---|---|---|
| | $P_1$ | $P_2$ | |
| 100 | 5·0 | 3·6 | 1·39 |
| 200 | 7·1 | 5·2 | 1·36 |
| 300 | 8·1 | 6·3 | 1·29 |
| 400 | 8·5 | 6·6 | 1·29 |
| | | | Mean = 1·33 |

Results of Tables III (*a*) and III (*b*) are graphically shown in Fig. 6 where the graphically derived values are shown by crosses (×) and the experimental values by circles (⊙). The agreement is seen to be very close in both the curves corresponding to pressures $P_1$ and $P_2$.

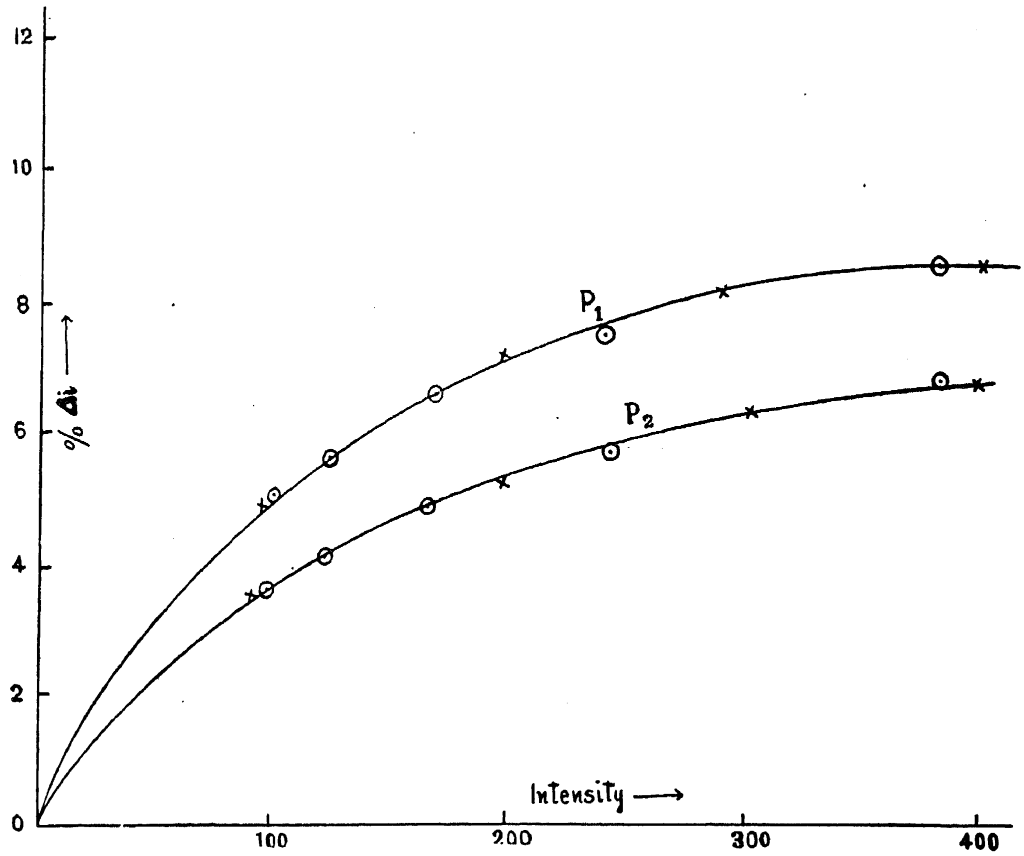


FIG. 6. Experimental and the graphically derived values of the Joshi-effect in chlorine $\nu = 16970$ cm.$^{-1}$

No readings are taken here with air as the Joshi-effect is generally small within the available limits of frequency and intensity variations.

(*b*) *Effect of Amount of Irradiation*

To investigate the effect of amount of irradiation on the ozoniser current, slightly different procedure and technique from those in Section (*a*) above had to be adopted. Fig. 7 shows the diagrammatic sketch of the assembly of the apparatus.

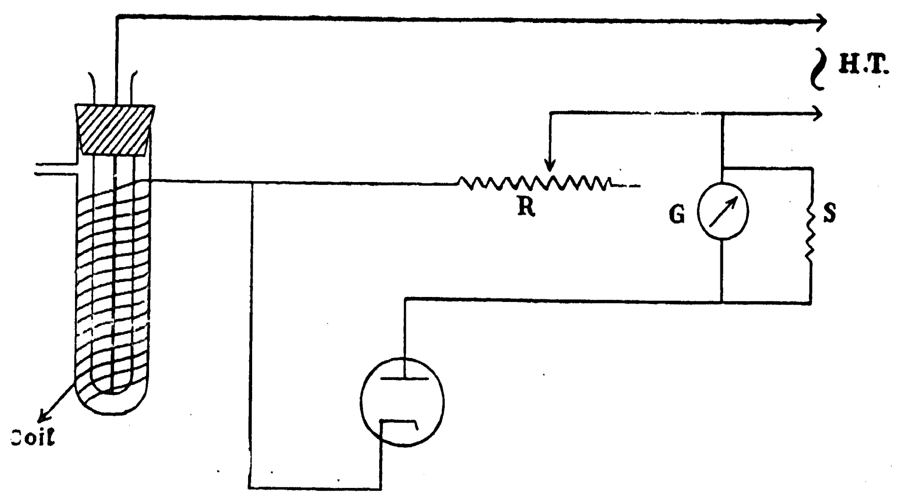


FIG. 7. Experimental arrangement for the study of the variation of the Joshi-effect with the amount of radiation

The ozoniser in this case consists of an ordinary test-tube to the side of which is sealed a small tube for being connected to a vacuum pump. The mouth of the test-tube is closed by a rubber stopper through which another smaller tube is made to pass co-axially with the first. The enclosed gas is air and its pressure is measured by Edward's vacustat. A copper coil wound uniformly round the outer tube served as one of the electrodes, the other being a copper rod inserted in the innermost co-axial tube. The electrodes are connected to the secondary of a 10 kilovolt, 250 watt, 50 cycles transformer. A variable resistance R is included in series with the discharge circuit. The potential difference developed across R is applied to the plate of a diode and the discharge current measured as described already.

The tube is kept vertical and enclosed in a box provided with a shutter to expose it to a given radiation as desired. Opposite to the shutter is a 100 watts clear bulb without any coloured filter at a distance of 50 cm. from it. A water cell of sufficient thickness is used to cut off all the heat radiations. The amount of irradiation falling on the ozoniser is altered in two ways:—(1) by changing the length L of the electrode coil surrounding the ozoniser tube and (2) by using a black paper to block any desired portion of the discharge from the incident light. In the first case the outer electrode coil of given length L allows radiation to pass to the discharge column only *via* open spaces between its turns. With the length of the coil doubled the open spaces between the turns are reduced to half and consequently light reaches the ozoniser column over half the first portion. In the second case the same object is achieved by using an opaque screen in the form of a black paper to intercept as desired the light falling on the ozoniser at any selected spot.

The results of $\%\Delta i$ observed in these experiments are recorded in Tables IV (*a*) and IV (*b*). Table IV (*a*) shows how the percentage decrease

TABLE IV (*a*)

*Effect of the ozoniser surface area*

| Resistance R in ohms | $\%\Delta i$ Electrode coil length L | | $\%\Delta i$ Electrode coil length 2L | | Ratio of $\%\Delta i$ between L and 2L | |
|---|---|---|---|---|---|---|
| | $p_1$ | $p_2$ | $p_1$ | $p_2$ | $p_1$ | $p_2$ |
| 1000 | 2·50 | 3·54 | 1·30 | 1·73 | 1·93 | 2·05 |
| 2000 | 1·95 | 2·69 | 0·97 | 1·37 | 2·00 | 1·96 |
| 5000 | 1·68 | 2·56 | 0·88 | 1·30 | 1·91 | 1·97 |
| | | | | | Mean = 1·95 | Mean = 1·99 |

TABLE IV (*b*)

*Effect of ozoniser surface area (controlled by opaque screen)*

(Length of the electrode coil = L Constant)

| Resistance R in ohms | %$\Delta i$ Without opaque screen | | %$\Delta i$ With opaque screen | | Ratio of %$\Delta i$ | |
|---|---|---|---|---|---|---|
| | $p_1$ | $p_2$ | $p_1$ | $p_2$ | $p_1$ | $p_2$ |
| 1000 | 2·50 | 3·54 | 1·75 | 2·45 | 1·43 | 1·44 |
| 2000 | 1·95 | 2·69 | 1·37 | 1·90 | 1·42 | 1·42 |
| 5000 | 1·68 | 2·56 | 1·18 | 1·75 | 1·42 | 1·46 |
| | | | | | Mean = 1·42 | Mean = 1·44 |

in current changes with change of electrode coil length and Table IV (*b*) shows how variation occurs in it as a result of the interposition of the opaque screen in front of the ozoniser walls. The readings are recorded for different values of the resistance R and for two different pressures of air, $p_1$ and $p_2$, $p_2$ being greater than $p_1$ (pressure being about 10 mm. of mercury).

(*c*) *Effect of the Inclination of the Ozoniser Tube*

It occurred to us from the experiments performed under Section (*b*) and the results obtained thereon to see whether the inclination of the tube to the incident beam will affect the current decrease. With the same set up of experimental arrangement as in Section (*b*) above, the ozoniser tube is rotated in a plane containing the direction of the incident light so as to make it co-axial with the cone of the incident beam. This happens when it makes an angle of 90° with the original vertical position. In this position it is end-on so that the portion now lying exposed to the incident light is the bottom cross-sectional area of the ozoniser tube. This area is practically negligible in comparison to the total surface area of the walls. Curiously enough it is found that the light-effect entirely vanishes in this case. Observations are also taken for two intermediate positions of the tube between 0° and 90°. Some systematic variation is %$\Delta i$ is noted. These values are given in Tables V (*a*) and V (*b*).

Readings are repeated with the tube inclinations in a plane perpendicular to the direction of the incident light. The current decrease in this case remained constant and no variation in %$\Delta i$ takes place,

TABLE V (*a*)

*Volume and surface effect*

Pressure of air = $p_1$

| Resistance R in ohms | $\%(\Delta i)_\phi$ | | | $\%(\Delta i)_\phi/\%(\Delta i)_0$ | |
|---|---|---|---|---|---|
| | Vertical $\%(\Delta i)_0$ | 45° $\%(\Delta i)_{45°}$ | 60° $\%(\Delta i)_{60°}$ | 45° | 60° |
| 1000 | 2·50 | 2·00 | 1·50 | 0·80 | 0·60 |
| 2000 | 1·95 | 1·56 | 1·17 | 0·80 | 0·60 |
| 5000 | 1·68 | 1·34 | 1·01 | 0·80 | 0·60 |
| | | | | Mean = 0·80 | Mean = 0·60 |

TABLE V (*b*)

*Volume and surface effect*

Pressure of air = $p_2$

| Resistace R in ohms | $\%(\Delta i)_\phi$ | | | $\%(\Delta i)_\phi/\%(\Delta i)_0$ | |
|---|---|---|---|---|---|
| | Vertical $\%(\Delta i)_0$ | 45° $\%(\Delta i)_{45°}$ | 60° $\%(\Delta i)_{60°}$ | 45° | 60° |
| 1000 | 3·54 | 2·84 | 2·10 | 0·80 | 0·59 |
| 2000 | 2·69 | 2·18 | 1·66 | 0·81 | 0·62 |
| 5000 | 2·56 | 2·00 | 1·50 | 0·78 | 0·59 |
| | | | | Mean = 0·80 | Mean = 0·60 |

## 4. Precision of Measurements

It should be noted, particularly for the results obtained in the experiments with air in sections (*b*) and (*c*), that the percentage decrease of current is of small order. To see that this measure is not spurious the whole system is tested for steadiness and reproducibility and the decrease of current, though small, is found to be definite and consistent when observations are taken at different times. At the same time, the change in deflection is not allowed to reach below a certain limit ($d\theta$ being always greater than 4 mm.), so as to ensure an accuracy of not less than 12 to 13% in the measurement of current.

In the case of experiments with chlorine in Section (*a*) on intensity and frequency effect, the accuracy in current measurement is much higher, *i.e.*, not less than 6 to 7%.

## 5. Conclusions and Discussion

From the experiments described and the results arrived at in this paper, it is evident that the diminution $\Delta i$ in the ozoniser current is determined by:

(1) the original current under dark illumination,
(2) the pressure of chlorine or air in the ozoniser tube,
(3) the resistance in the external measuring circuit,
(4) the intensity and
(5) the frequency of the incident light.

The higher the values of the initial current $i$ the greater is the magnitude of the change $\Delta i$ for a given light flux. In fact it is by adjusting the original current that the change $d\theta$ is brought within the limits of precision stated above.

The effect of pressure is brought out by the constancy of the ratio in column 5 of Tables I, II and III (*b*). It is evident from these that, other conditions remaining constant, an increase of pressure causes a corresponding increase in the magnitude of the light-effect.

Coming to the influence of frequency and intensity of radiation on the current decrease, we note some very significant conclusions. The graphs of Figs. 4 and 5 make it very clear that the percentage decrease in $i$ bears a straight line relation with the frequency and there is a characteristic frequency $\nu_0$ at which the light effect begins to be apparent on the discharge current, irrespective of all other factors, as the observed curves take their origin in this frequency $\nu_0$. As regards the relation of current decrease with intensity, the nature of the graph connecting the two is well brought out in Figs. 2 and 3. It is significant that the validity of these relations is confirmed as is shown by Fig. 6, where experimental results with sodium light follow those expected on the basis of the recorded observations with other wave-length bands. The derivation of the characteristic frequency and the empirical relation connecting the current decrease with the several parameters is proposed to be taken up after the discussion of the results of experiments of Sections (*b*) and (*c*).

In Section (*b*), Tables IV (*a*) and IV (*b*) reveal some interesting features regarding the quantity of irradiation. As mentioned before, doubling of the electrode coil obviously exposes half the original column to the radiation. With this variation, the amount of the percentage decrease of current is seen to fall to nearly half the original value as evident from the average ratio entered in the last column of Table IV (*a*). Similar conclusions follow from the results of Table IV (*b*). According to the discharge column blocked by the movement of the opaque screen over it the light-effect changes by a constant amount for a constant area of the screen (*vide* constancy of ratio in the last column of Table IV (*b*). In this case, the outer electrode coil of length L is stationary over the ozoniser. Thus we conclude that the greater the extent of the discharge column exposed to light the greater is the current decrease. We are not, however, certain whether it is merely the walls or the column of the gas alone detached from the walls that contribute to the light-effect, or whether there is a contribution due to both.

Experiments performed in Section (*c*) and the results obtained from them and recorded in Tables V (*a*) and V (*b*) provide us with some information on these points. When the ozoniser position is 90° to the vertical practically no surface of the wall is exposed perpendicular to the direction of light. But the entire volume of discharge column of air inside receives the illumination. Even so, no diminution of current is noticed, *i.e.*, the light-effect practically vanishes showing thereby that only the wall surfaces standing perpendicular to the incident cone of light to be the contributory causes for the decrease in the discharge current. If we assume the light-effect $(\Delta i)_\phi$ for the intermediate position $\phi$ to be satisfied by the general relation $(\Delta i)_\phi = (\Delta i)_0 \cos \phi$, where $\phi$ is the angle made by the given position of the ozoniser with the position of maximum light-effect, *i.e.*, the vertical position and $(\Delta i)_0$ the maximum light-effect, then we get the observed values at 45° and 60° roughly satisfied. In the case of 45° we get the calculated value of $\cos \phi$ to be $0{\cdot}7_1$ as against 0·80 experimental, while for 60° it is 0·50 against experimental 0·60. Looking at the average error of measurement, *i.e.*, 12 to 13% discussed in a previous paragraph, these departures are within reasonable limits.

Thus the variation of light-effect with $\phi$ in the intermediate positions may be interpreted as a surface effect, the effective surface according to the above reasoning being the component of the ozoniser wall in a plane perpendicular to the direction of light. Also the absence of any variation in light-effect in a plane perpendicular to the direction of light supports the above assumption, for by the movement of the ozoniser in this plane we have, at any time, the total surface of the walls of the discharge perpendicular to the axis of the light cone.

Lastly the light-effect seems to be influenced by the resistance in the external measuring circuit. The results of Tables IV and V suggest that the greater the resistance R the smaller is the light-effect, a fact confirmed by the earlier observations of Joshi.

The above conclusions taken along with those of Section (*b*) lead us to suggest that the decrease of discharge current on irradiation is more a surface effect than a volume one. It is thought that the nature and extent of the surface and the nature of the gaseous medium inside play a great part in influencing it. It is necessary to have more quantitative data[4] of the above type on several gases, especially those which give intensive effect, and several types of discharge tube surface walls to see if our view is correct.

Returning now to the form of the empirical relation that should follow from results of Section (*a*) and the graphs of Figs. 2 and 3 and of Figs. 4 and 5 we see that it must involve the characteristic or threshold frequency $\nu_0$. Graphical derivation gives the value of $\nu_0$ as 12467 ± 50 cm.$^{-1}$ This corresponds to the mean wavelength 8021 A.U. Working out the observed $\Delta i$ in terms of both intensity and frequency we get

$$\Delta i = i.\, A.\, (I)^{2/5}.\, (\nu - \nu_0), \text{ where}$$

$\Delta i$ = the change observed in the original current $i$.
I = intensity in lumens per sq. metre.
$\nu$ = frequency of the incident light.
$\nu_0$ = the characteristic threshold frequency for negative photo-effect.
A = a constant depending on the surfa e and on the pressure and nature of the gaseous medium.

The linearity of the graphs has been verified by the method of least squares and the test of the above relation is obtained by reference to the following Table VI where values of the constant A for different readings of Tables I and III (*a*) have been calculated. The mean values of A are recorded below:

At pressure $P_1$, $A = 179{\cdot}4 \times 10^{-8}$
" $P_2$, $A = 132{\cdot}9 \times 10^{-8}$

Except in one or two readings, the departures of A from the mean value are within the limits of experimental errors. Any large change from the mean value is to be attributed to random fluctuations beyond control.

Hence, at least for the range of frequencies observed, we should expect the photoeffect in chlorine discharge to disappear in the region of wavelength 8021 A.U. ($\nu = \nu_0$). This happens to coincide almost with the limit of visible red. In the region of wavelengths below this ($\nu > \nu_0$) the negative photoeffect should predominate while for wavelengths higher than this ($\nu < \nu_0$), *viz.*, for infra-red radiations, the equation predicts the conductivity of the discharge to increase (positive photo-effect). The truth of these predictions beyond the limits of wavelengths used in these experiments is a matter for further investigation.

One fact which clearly emerges from these data is the association of the light-effect with the wall influences which is a confirmation of the conclusions of Joshi and co-workers[4, 5] and of Deb and Ghosh.[6]

TABLE VI

*Value of the constant A*

| Frequency $\nu$ cm.$^{-1}$ | Value of A | |
|---|---|---|
| | For press sure $P_1$ | For pressure $P_2$ |
| 15294 | 173·7 $\times 10^{-8}$ | 124·2 $\times 10^{-8}$ |
| | 180·9 ,, | 131·1 ,, |
| | 179·4 ,, | 133·8 ,, |
| | 177·0 ,, | 130·2 ,, |
| | 171·0 ,, | 124·2 ,, |
| 16880 | 174·0 $\times 10^{-8}$ | 137·1 $\times 10^{-8}$ |
| | 185·1 ,, | 139·2 ,, |
| | 187·2 ,, | 139·8 ,, |
| | 175·8 ,, | 132·3 ,, |
| | 175·8 ,, | 123·9 ,, |
| 16970 | 174·9 $\times 10^{-8}$ | 140·1 $\times 10^{-8}$ |
| | 179·4 ,, | 140·1 ,, |
| | 184·5 ,, | 136·8 ,, |
| | 176·4 ,, | 128·7 ,, |
| | 178·2 ,, | 125·4 ,, |
| 17737 | 177·0 $\times 10^{-8}$ | 134·1 $\times 10^{-8}$ |
| | 195·0 ,, | 137·4 ,, |
| | 174·0 ,, | 136·8 ,, |
| | 185·4 ,, | 138·3 ,, |
| | 186·6 ,, | 137·1 ,, |
| 18877 | 169·0 $\times 10^{-8}$ | 127·5 $\times 10^{-8}$ |
| | 181·2 ,, | 130·5 ,, |
| | 185·1 ,, | 137·1 ,, |
| | 180·6 ,, | 132·0 ,, |
| | 175·8 ,, | 125·7 ,, |

Among the various explanations put forward by Joshi,[7] Deb and Ghosh[6, 8] and Prasad[9] and others, we are inclined to tentatively support the view that the effect may be due to some kind of recombination of ions as a result of collisions at the walls induced by the incident light. It is, however, difficult to assess the phenomenon clearly in the absence of a definite picture of the mechanism of ozoniser discharge, especially since such factors as the resistance in the external measuring circuit are found to influence the light-effect.

On comparing the present relation obtained from these experiments, *viz.*,

$$\Delta i = i.A. \, (I)^{2/5} . \, (\nu - \nu_0)$$

with Einstein's equation for photo-electric emission, *viz.*,

$$W_e = \tfrac{1}{2} m v_m^2 = h \, (\nu - \nu_0)$$

and Richardson's equation for thermionic emission, *viz.*,

$$i = AT^2 e^{b_0/T}$$

one is tempted to inquire if the present phenomenon is not allied to the other two.

## 6. Summary

An attempt is made to study quantitatively the variation of the decrease in the discharge current in the Joshi-effect, with the intensity, frequency and the amount of irradiation. The results obtained are represented graphically and an empirical relation is found which satisfies the experimental results fairly well.

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## References

1. Joshi and Narasimham .. *Curr. Sci.*, 1940, **9**, 536.
2. Joshi .. *Presidential Address, Chemistry Section, Indian Science Congress*, 1943.
3. ——— and Deshmukh .. *Nature*, 1941, **147**, 806.
   ——————— .. *Curr. Sci.*, 1945, **14**, 67.
   Prasad .. *Proc. Ind. Acad. Sci.*, 1946, **24**, 514.
4. Joshi .. *Ibid.*, 1945, **22**, 225.
   ——————— .. *Curr. Sci.*, 1945, **14**, 317 ; 1946, **15**, 281.
5. ——————— .. *Proc. Ind. Acad. Sci.*, 1945, **22**, 389.
6. Deb and Ghosh .. *Sci. and Culture*, 1946, **22**, 12.
7. Joshi .. *Ibid.*, 1945, **11**, 318.
8. Deb and Ghosh .. *Ibid.*, 1948, **14**, 39.
9. R. Prasad .. *Nature*, 1945, **155**, 362.