PART II

SECTION IV

GENERAL CONSIDERATIONS OF THE JOSHI-EFFECT
The influence of irradiation on the starting potential for electrical discharge in gases has been a subject for study since the time of Hertz\textsuperscript{75}. Most of these investigations were carried out with metal electrodes, employing illumination by short wave radiation, or exposure to rays from a radioactive substance, and refer to a change, (generally a lowering), of the minimum potential for a self-sustaining discharge.

This change is ascribed to the release of additional electrons from the cathode, as a photo-electric effect, and from the gas due to photo-ionization (where possible). Of these and similar experiments, only the more recent ones are described below on account of some similarity they appear to have with the Joshi Effect.

(a) Salzwedel\textsuperscript{76} observed both an increase and a decrease of the discharge current when the cathode was illuminated by ultra violet light. The effect was found to be independent of the gas and the material of the electrodes, its magnitude depending on the intensity of illumination. The changes in current were connected with changes in the
distribution of potential in the path of the discharge and in the outer portions of the current region. He concludes, "Ascertaining the quantitative relation of the parameters, necessary for a theoretical treatment of the subject, is impossible with the methods now available for potential measurements".

(b) That the striking potential can both be raised or lowered, depending on the pressure of the gas and the field distribution, was shown by Fucks and his collaborators. For nitrogen and hydrogen, using ultraviolet light, they found that the change in the striking potential,

\[ \Delta U = U_{\text{light}} - U_{\text{dark}}, \]

obeyed the Rogowski-Fucks Law viz.

\[ \frac{\Delta U}{U_{\text{dark}}} = K_i \],

where \( K \) is a constant and \( i \) is the photo current. According to them, ' 30 to 40 % decrease of \( U \) by irradiation can be attributed to change of field strength by space charge of photo-current and corresponding change of positive ionization at the cathode'. These studies have also been extended to air at atmospheric pressure.

(c) Schade found that for the Townsend current, the lowering of the spark potential due to irradiation and the striking current density are proportional to the
square root of the primary (or photo) current density. Similar results were also reported by White\textsuperscript{79} and Rągowski and Walraff\textsuperscript{80}.

(d) The Penning\textsuperscript{81} effect: Small quantities of argon or mercury vapour (foreign gas) were shown, by Penning to lower the striking potential of Neon (main gas). The ionization potential of the foreign gas in this case is lower than the excitation potential corresponding to the metastable state (\textup{S}_3 and \textup{S}_5) of the main gas. Metastable neon atoms are therefore able to ionize the atoms of the foreign gas and thus lower the spark potential. On irradiation by neon light, the metastable Ne are destroyed. Ionization of the argon atoms by neon is thereby prevented and the sparking potential rises. The effect was observed by Penning in both, the Townsend and wire-in-cylinder type corona discharges. Helium with traces of argon was found to give similar results. Identical results were obtained by Glotov\textsuperscript{82} who assumed the same mechanism as given above.

(e) Zonckermann's experiments on electrodeless discharge showed a maximum of 15% variation of the striking potential, the effect being independent of the source of light, provided its intensity be high enough. No effect
was obtained with yellow, orange or red light and it was suggested that the effect is connected with photoelectric action on the walls of the tube.

(f) Thomson observed a lowering of the breakdown potential for an electrodeless ring discharge in various gases using different sources of illumination. By interposing thin films of glass, mica etc, he showed that the effect was due to ultraviolet light of short wave length. It was maximum at an optimum pressure depending on the nature of the gas but did not show much evidence of selective absorption.

(g) Irradiation of air by rays from radioactive substances was shown by Trichel to lead to disappearance of pulses (or stabs) in the positive point to plate corona at atmospheric pressure. On the other hand, the recent studies of Craggs and Meek showed an appreciable increase in the number of pulses in freon with radium gamma rays. In other gases, (H₂, N₂, A, O₂ and CH₄), such irradiation had a negligible effect. An increase in the pre-breakdown current, by ultraviolet illumination, was however, observed by Ehrenkranz in her studies of the spark breakdown potentials in A, N₂ and H₂.
Similar other phenomena, to wit, the auxiliary photo electric effect in metals under simultaneous illumination and electron bombardment, the marked photo sensivity of Geiger-Müller counters especially after a continuous discharge, and the enhanced thermionic emission from composite surfaces on illumination, are also reported. It is, however, to be noted that the Joshi Effect, viz., a change in the conductivity of gases on irradiation by but visible light (upto $\lambda = 3000 \text{ Å}$) is a new phenomenon to be reported. Its occurrence in a number of gases, both elemental and compound using a wide variety of discharge tubes of the Siemens, Crooks, Geissler and G.M. Counter type and the mode of its variation with the various determinants distinguishes it from all other effects of light reported earlier. Various authors have attempted to explain this phenomenon from time to time. Their hypotheses together with the limitations are discussed below.

2. **THE MECHANISM OF THE JOSHI EFFECT**

(a) The Quantum-Mechanical Hypothesis of Parshad

Parshad has attempted an explanation of the Joshi Effect, $\Delta i$, from the standpoint of Kramers quantum mechanical theory of light dispersion. He argues
that, "In an excited gas, the refractive index, \( n \), should be less than that for the normal unexcited gas due to the negative terms in the (Kramers dispersion) formula for excited states." Now \( n^2 - K \), according to Maxwell's relation, where \( K \) is the dielectric constant. "Hence, when radiation falls in the gas, exciting it to higher vibrational and electronic states, the dielectric constant decreases and so does the dielectric current in the electrical circuit. According to this theory, (i) the magnitude of \( i \) should depend only on the displacement part as distinct from the conduction or ohmic part of the current; and (ii) the maximum value of \( i \) may be about 20% due to a change in the dielectric constant, (as shown by Parshad). (i) Experimental data in these laboratories clearly indicate that the Joshi Effect is not observed (a) in any case below the threshold potential where the current is chiefly capacitative, and (b) even under high frequency excitation (5 to 10 Mc/Sec.) when the displacement current is increased several fold. (ii) The magnitude of the Joshi Effect in most of the systems studied so far is well above 90% under optimum conditions. These together with (iii) the non-dependence of the Joshi Effect on selective light absorption
and (iv) the occurrence of a large positive Joshi Effect under certain conditions are not in accord with Parshad's theory.

(b) The hypothesis of Sahay and Garg

The underlying idea of the hypothesis proposed by Sahay is the increase in recombination between electrons and positive ions. On irradiation there is an increase in the diameter of gas particles which are excited to higher electronic states. This leads to an increase in the collisions between the expanded particles and the electrons, thereby causing a decrease in the velocity of the latter. Since slow moving electrons recombine more easily, a decrease in current follows. Garg with essentially the same assumptions has calculated recently the decrease in the ionic mobility which is shown to be inversely proportional to the fourth power of the quantum number of the orbit the outermost electron occupies. Thus if the electron goes from first orbit to second orbit, the current due to the ion will be reduced in the ratio of 16:1. To explain the positive Joshi Effect, the destruction of metastables is envisaged. Irradiation, in this case, excites
the metastables to higher states from which transitions to lower states are allowed.

The above hypotheses lead evidently to the following conclusions: (i) the Joshi Effect should be entirely a consequence of selective light absorption, (ii) it should be a volume effect, in no way dependent on the nature of the electrodes, and (iii) destruction of the metastables, on account of light absorption and subsequent radiation, should increase the current. (1) A large $\Delta i$, with frequencies well outside the absorption bands of the gas under investigation, has been reported in a number of systems studied to date in these laboratories. Moreover, in all the systems studied, the Joshi Effect is found to be frequency-wise, irrespective of selective light absorption. (2) The development of $\Delta i$ with the initial ageing of the tube, the marked change in its magnitude, and in some cases even its sign, with wall coatings, and its rare occurrence in all systems using metal electrodes strongly suggest the Joshi Effect to be predominantly a wall effect. This is further borne out by the marked influence of temperature and the mode of irradiation (transverse or longitudinal) on $\Delta i$. (3) Metastables are known to be
one of the agents promoting secondary emission in a discharge. Contrary to what has been assumed by Garg, destruction of the metastables, at least in one case, viz., the Penning Effect is known to cause a decrease of in the discharge current. Furthermore, the dependence of the Joshi Effect on the magnitude and the frequency of the applied field and its distribution in the different components of the discharge current go contrary to the Sahay-Garg hypothesis.

(c) The 'Wall-Complex' hypothesis of Ahmed and Murti:

These authors suggest (i) the formation of a single bounded polarised wall complex, \( W^{\frac{1}{2}} (XY)^{\frac{1}{2}} \), where \( W \) denotes a wall molecule and \( XY \) a gas molecule from the discharge space; (ii) the ionization of the complex, under operating fields (< \( V_m \)), into \( (W,XY)^{+} + e^- \), these electrons being responsible for the discharge, and (iii) the dissociation of the complex, under light, into neutral particles (a) \( W+XY \), (b) \( WX + Y \), or / and positive and negative ions (c) \( W+k XY^- \), (d) \( WX^+ + Y^- \). 'The light action therefore introduces negative ions and/or neutral particles in lieu of electrons, causing a current decrease'. Positive Joshi Effect at low potentials near \( V_m \) is explained by assuming (ii) to be negligible, while (iii) still operates.
It is seen that on such a hypothesis the magnitude of $\Delta i$ will depend markedly on the tendency of the gas to form the wall complex and its dissociation under light. The order quoted by the authors in Chlorine > Bromine > Iodine > Oxygen > Nitrogen > Hydrogen > Neon. However, detailed studies, under a wider range of operative conditions with improved technique, have shown the occurrence of a very large $\% \Delta i$, (> 95%) in gases like Nitrogen, Hydrogen and even Neon. Under conditions productive of a positive Joshi Effect, where the ionization listed in (ii) above is negligible according to the authors, an increase in the intensity of irradiation should enhance (iii) leading to an increase in the magnitude of $\Delta i$. Experimental data with chlorine, air, Iodine and water vapours, however, show that increased intensity (in the visible range) favours the negative Joshi Effect. Moreover, according to the above hypothesis, negative ions, liberated due to the dissociation of wall complex are responsible for the positive Joshi Effect. The liberation of the negative ions in such large numbers as to give a current of a few microamperes does not seem to be likely. The difficulty becomes more acute in the case of systems like iodine, where the concentration of the wall complex is bound to be low on
account of its low vapour pressure, but which shows a marked and large positive Joshi Effect. The ionization by negative ions in the gas phase due to the applied fields, as an alternative is still less probable. Lastly, the recent observations of an appreciable $\Delta i$ in Nitrogen, Hydrogen and Neon with metal electrodes, under a very limited range of conditions, and considerations regarding the formation of negative ions and their stability under the high fields (vide infra) go contrary to the above hypothesis.

(d) The hypothesis of Rais Ahmed and Gill\textsuperscript{103}

In a recent note Rais Ahmed and Gill have proposed another explanation for the Joshi Effect depending on additional ionization by low energy visible light. They postulate that (i) the major portion of gas amplification takes place near the anode, and (ii) on irradiation a strong ion sheath is created near the cathode, which decreases the potential gradient in the region of the anode, thus diminishing the gas amplification. Admittedly, the mechanism of such volume ionization in the gas phase (which leads to the formation of the ion sheath in (ii) above) is not clear.
The ionization potential of most gases and vapours, used for the study of Joshi effect, is above 10 electron volts, while the maximum energy in the lowest frequency band used (6100 to 7100 Å) is of the order of 2 electron volts. Hence ionization of the gas by but visible light does not appear to be likely. Moreover, on the above hypothesis, the effect should depend on the volume of the gas ionized, should increase with an increase in ionization and hence should be less in the halogens and other electronegative gases due to the formation of negative ions which give a larger anode fall of potential. Results in these laboratories and elsewhere, however, clearly indicate that the phenomenon is of surface origin, is appreciably more under visible than under X-rays and is obtained with greater ease and over a large range in the halogens than in the other gases. Lastly it may be pointed out that both photo-ionization of the gas and a rise of the potential gradient in the cathode region due to the enhanced positive ion space charge, as postulated by the authors, should cause a current increase. Numerous examples of such an increase due to
radiation that can ionize the gas are available in literature.

(e) The hypothesis of Deb and Ghosh :-

Deb and Ghosh have proposed a hypothesis based on the hypothesis of Klemenc et al for the ozonizer discharge. This has already been discussed earlier (Part II Section III).

(f) The 'Activated Layer' hypothesis of Joshi:-

To explain the phenomenon, now known after him, Joshi contemplates the following three distinct stages (i) It is assumed that under discharge in dark, an adsorption-like boundary layer is formed on the electrodes of the discharge tube. This 'activated layer' being formed on a dielectric surface, contains ions, electrons and excited and neutral particles derived from the gas under discharge and is in dynamic equilibrium with the gas phase. (ii) The characteristic work function of the electrode layer is assumed to be low so that even with visible light, photo-electrons are released from it. If no secondary changes (vide infra (iii) take place, these photo-electrons lead to an increase in current i.e. the positive effect. (iii) These photo-electrons are captured by the gas particles forming slow moving negative ions, which, as in space charge effect, reduce the current i.e. the negative effect.
The theory has been widely applied by subsequent workers to explain not only the observations of Joshi Effect but also a number of allied phenomena. In a few cases it has been modified to incorporate the influence of certain other parameters not originally included in the original hypothesis. It is apparently in accord with the earlier observations on the influence of various parameters such as ageing, the intensity and frequency of light etc. These earlier results showed the following order of magnitude of $\Delta i$ :

Chlorine $>$ Bromide $>$ Iodine $>$ HCl $>$ Oxygen $>$ Air $>$ Nitrogen $>$ Hydrogen $>$ Neon $>$ Metallic vapours. This is also approximately the order of their electron affinity. From this Joshi anticipated $\Delta i$ in metallic vapours from the findings of Frank and Coworkers that excitation of even metallic and rare gas atoms increases their electron affinity appreciably. This prediction has since been verified experimentally in a number of metallic vapours viz. Mercury, Sodium, Potassium, Se, Te, and Zinc. Subsequent work on $\Delta i$ has, however, shown that while a few of the broader concepts and conclusions of Joshi's theory are in general applicable, some generalization are found unsatisfactory when studied in details and the theory is found to be inadequate in certain other points.
Thus the observations of (i) a very large
( > 90%) Joshi Effect in systems generally know to have a
very low electron affinity eg. Mercury vapour, Hydrogen,
Nitrogen and even Sodium, (ii) the decrease of \[ \% \Delta I \]
in certain systems with the pressure of the gas at constant \( X \)
(iii) the increase of \[ \% \Delta I \] especially at high \( p \) with
increase in \( X \), and (iv) a large \[ \% \Delta I \] ( ~70%) in very
low pressure systems e.g. Mercury, Iodine, Sodium, Potassium,
Se, Te, Zinc vapours, are not in accord with the hypothesis.
Moreover, the theory is based on the inherent assumption of
a preferential formation of negative ions under light, and
near the cathode which do not appear likely.

(g) The new hypothesis of photo-denudation.\(^{27}\)

The assumptions.

It is assumed that (a) an adsorbed layer of
the gas is formed on the walls of the discharge tube. This
layer, under discharge in dark, anchor electrons and ions
which are not neutralized completely due to the dielectric
nature of the glass. (b) Some of these anchored electrons
and ions are liberated on irradiation even by visible light,
owing to their low binding energy to the walls. (c) The
emission of electrons from the electrode and the electrode layer is inherently limited due to the dielectric nature of the glass. This emission may be due to one or more of the secondary processes at the cathode and/or an external source of irradiation, and (d) especially in the high field regime, the positive ion space charge is one of the chief determinants of the conductivity and also of the Joshi Effect.

**MECHANISM OF THE DISCHARGE**

A complete mechanism of the silent electric discharge and the Joshi Effect under A.C. excitation may now be postulated from the foregoing as follows:

When the applied potential is very low so that ionization in the gas phase is not possible, the current through the discharge tube is capacitive. Irradiation at this stage does not cause any discharge. As potential is increased, at a critical value the discharge sets in. As the potential during the A.C. cycle is constantly changing with time, ionization is restricted to that part when the instantaneous applied potential is greater than $V_m$. During the first half of the first potential cycle, the discharge is initiated by some stray electrons. The electrons and ions
produced in the gas under discharge move towards the respective electrodes and deposit there. The electrode surface being dielectric these are not neutralized. Depending on their momentum and hence the penetration in the electrode(layer), these electrons have different energies of binding to the walls. Now when the applied potential during the A.C. cycle becomes zero and changes sign, some of the very loosely bound electrons leave the electrode (now cathode) and neutralize some of the positive ions in space or on the anode. This is responsible for the aerial current.

However, most of the electrons deposited during the preceding half cycle, still remain on the electrode. When the potential during this half cycle is high enough, the discharge takes place in the form of discreet pulses as seen on the oscillograph, each pulse corresponding to a discharge from a limited region (active spot) on the cathode. The ionization increases very rapidly (rising part of the pulse) as a number of electrons from the active spot feed into a single initial Townsend avalanche (due to field emission or photon action at the cathode) as the supply of electrons from the spot is exhausted and the positive ions
are collected. The next pulse starts (due to this ionized bombardment) from another spot on the cathode. The total amount of ionization produced in one such discharge corresponds to the amplitude of the pulse and depends on the number of electrons starting from the cathode and the effective field. Such discharges (high frequency pulses) would continue till the peak value of the potential is reached or the supply of electrons from the cathode is exhausted. The effective field is the vector resultant, \( X + X_1 \), of the applied field \( X \) and the (positive ion) space charge field \( X_1 \). The latter is negligible for low pressure and at potentials near \( V_m \), and becomes important at higher gas pressures and large potentials.

**MECHANISM OF THE JOSH EFFECT**

On this view most of the electrons from the cathode start in the ionizing part of the potential cycle and initiate Townsend avalanches constituting the discharge current. When the discharge tube is irradiated even with visible light, some of these anchored electrons are released in the non-ionizing part of the potential cycle. This 'photo-denudation' of the cathode diminishes the number of electrons starting from the cathode and hence the discharge
current. Another (secondary) change arises from this
(primary) photo-denudation. Under conditions where space
charges are active, these photo-denuded electrons virtually
neutralize the positive ion space charge, which diminishes
the effective field \( X + X_1 \) and hence the discharge current.
The negative Joshi Effect is thus a consequence of the
'photo-denudation' of the cathode and 'virtual neutralization'
of the positive ion space charge and should have a more vide
and common occurrence than the positive Joshi Effect. This
last is possible under certain restricted conditions
especially those favourable for an additional electron
supply under irradiation. Thus when the secondary mechanisms
at the cathode are not efficient and well established, when
there are marked irregularities, specks or foreign particles
on the cathode, when regions other than the cathode (say
walls) allow appreciable accumulation of surface charges
which are liberated, or when positive ions are liberated
from the anode, irradiation of the tube may lead to the
positive Joshi Effect.

LIMITATIONS

While this mechanism is found to explain
satisfactorily the influence of various parameters on the
Joshi Effect, it does not envisage any effect in metal
electrode systems or under D.C. excitation. With metal
electrodes, however, if some insulating layers could be
formed, the effect would be observed over a restricted range and would disappear on heating, degassing or long heavy ageing. Experimental results are in accord with this. The exact mechanism of virtual neutralization, moreover, has not been specified here. This may be direct electron-ion recombination in low fields, recombination through a three body collision at the walls or in the gas by the formation of a negative ions, or merely the neutralization in effect by virtue of coexistence in space as in a discharge plasma.
SUMMARY

PART II

Studies of Joshi Effect in air were made over the low pressure range (\( p < 100 \text{ mm. Hg.} \)) using Siemen's type all glass ozonizers, wire-in-cylinder type semi-ozonizers and tubes excited by external sleeves. The current potential characteristics showed three distinct regions. In the case of an all glass ozonizer, these corresponded closely with those in the \( \Delta i \sim V \) characteristics. Under optimum conditions a practically 100% negative Joshi Effect was observed. In a semi-ozonizer, the magnitude of \( \Delta i \) and the potential range over which it was observed were appreciably smaller. Under sleeve excitation also a large negative Joshi Effect was observed. Wave patterns of the discharge current were examined by a cathode ray oscillograph both in dark and in light. This revealed the occurrence of a very large number of pulses in addition to the sine wave due to the supply frequency. Joshi Effect was found to be associated with a change in the number and the amplitude of these pulses. The irreversible negative Joshi Effect and the co-occurrence of the positive and negative Joshi Effect under certain conditions are the two
important findings.

The various hypotheses proposed for the Joshi effect are critically discussed. A consistent explanation of the results is attempted according to the new mechanism for $\Delta i$. 
REFERENCES

   Thomson, J.J. and G.P.

   Loeb, L.B. and Meek, J.M.
   The Mechanism of the Electric Spark, Stanford University Press, 1941.

   Whitehead, S.


17. Arnkar.

18. Bhide, M.R.

19. Joshi, S.S.


Joshi, S.S.


Tiwari and Prasad.


22. Joshi, S.S.

Prasad, B.N.


23. Schade.


Ibid. 21, 295, 1947.

24. Loeb, L.B. and Meek, J.M.

Reference 2.

25. Penning.

Penning and Addink.

Physica. 13, 209, 1933.


27. Jatar, D.P.

28. Weissler and Mohr.
Mohr. and Weissler.
Fisher and Weissler.

29. Bradbury.


31. Jatar, D.P.

32. Joshi, S.S.

33. Mc Bain.

34. Jones.

Ibid. B64, 397, 1951.
Ibid. B64, 560, 1951.

Saugar University Journ.

Phys. Rev. 66, 95, 1944.


Physica. 4, 434, 1936.


Curr. Sci. 8, 543, 1939.
Ibid. 14, 67, 175, 1945.
Ibid. 15, 281, 1946.
Ibid. 16, 19, 1947.


Jones. Reference 34.


Zeits. f. Phys. 31, 605, 1925.


Medicus.


49. Loeb, L.B. Reference 2.

Thomson, J.J. Phil. Mag. 8, 393, 1929.

Also Reference 1.


51. Reference 1 and 2.

52. Reference 1 and 2.


" " " 5, 165, 1924.

" " " 6, 625, 1925.


Nature. 154, 147, 1944.


57. Bhide.

58. Loeb, L.B.

59. Harris and Von Engel.

60. Khastgir.

61. Ramaiah.

62. Warburg.

63. Muller.

64. Craggs and Meek.

65. Cady.
Plesse.
Kaiser and Wollroff.

66. Loeb, L.B. et al.

67. Loeb, Kip, Hudson and Bennett.
Fitzsi.

68. Morton.
Johnson.

69. Korff.

70. Loeb, L.B.

Ph.D. Thesis, Nagpur University,


Reference 56.

Reference 56.

Reference 56.

p. 382, 1903.


60, 327, 1948.


Phys. Rev. 69, 714, 1944.

Ibid. 61, 175, 1942.

Ibid. 70, 353, 1946.

Ibid. 73, 284, 1948.

Electron and Nuclear Counters.
D. Van Nostrand Co. Inc. 1946.

Reference 2.
71. Loh and Dieke.  

72. Marathe.  

73. Jatar, D.P.  
Sauger University Journ. Vol. 1, 5,  
Part II, 1955-56.

74. Green Wood, A. 

75. Hertz.  
Ann. d. Phys. 31, 983, 1887.

76. Salzwedel. 

77. Fucks. 
Zeits. f. Phys. 103, 709, 1936. 
Fucks and Collaborators.  
& & 120, 468, 1943.  

78. Shade.  
Zeits. f. Phys. Bull. 38,(68), 17,  
1937.  
Naturwiss. 24, 813, 1936.  

79. White.  

80. Walraff.  
Reukama.  

81. Penning.  
Phil. Mag. 11, 361, 1931.
82. Glotoo.  
  " " " 13, 84, 1938.

83. Zonckermann's  
  Comptes Rendus. 206, 331, 1938.

84. Craggs and Meek.  

85. Miss Ehrenkranz.  

86. Dember.  
  Zeits. f. Phys. 33, 529, 1925.
  Frey.  

87. Kohl.  
  Pollock and Cooper.  

88. Hughes and Du Bridge.  
  Photoelectric Phenomena,  

89. Parshad.  

90. Van Vleck.  
  Electric and Magnetic Susceptibilities,  
  Oxford University Press 1944.

91. Joshi, S.S.  

92. Das Gupta.  
  Sci. and Cult. 11, 318, 1945.

93. Tiwari and Prasad.  

98. Deo. Sci. and Cult. 9, 252, 1943.
See also reference 94.


104. Jatar, D.P. Sci. and Cult. (Communicated.)


108. Trichel. Ibid. 54, 1078, 1938; 55, 582, 1939.
