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Studies of Joshi Effect in Mercury Vapour with a Triode under Various Modes of Detection Mechanism

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Production of Joshi effect ± Δi in mercury vapour excited by a transformer discharge in the range 0.48 kV to 1.00 kV, 50 Hz has been studied with triode 30 coupled resistively with L.T. line using it as anode bend (α) and grid leak (β) detectors. The observations of $i_{D,L}$ are taken in plate as well as in grid currents. For the observations in grid currents, at a given applied potential, i_D and −Δi are in the order $\beta > \alpha$ at lower values of the resistance R; at its higher values, they are in the order $\alpha > \beta$. The corresponding −%Δi is, however, in the order $\alpha > \beta$ for lower values of R, and in the order $\beta > \alpha$ for the higher values of R. For the observations in grid current, at a given applied potential, i_D is in the order $\alpha > \beta$; the corresponding −Δi and −%Δi are in the order $\beta > \alpha$.

Remarkably enough no positive effect +Δi has been observed in grid leak detection when the observations are taken in plate current, whereas for higher values of R— for and above 1 megohm, positive effect upto the magnitude of +44% is observed under anode bend detection. For the observations in grid current, grid leak detection gives +11500%Δi at V_m, while in the case of anode bend detection, a slight positive effect only 1% maximum, is given at 0.92 kV and onwards, and at high values of R. The results have been explained on the basis of Joshi theory for the phenomenon ±Δi.

Key Words: Joshi effect, Mecury vapour, Triode.

INTRODUCTION

In chlorine-ozonizer using triode [1]30 as lower bend (α), push-pull lower anode bend (β), grid leak (γ) and grid (δ) detectors, Prasad[1] has shown that at a given applied potential V, i_D and −Δi were in the order $\alpha > \beta > \gamma > \delta$; the corresponding −%Δi was, however, in the order $\beta > \alpha > \gamma > \delta$. Similar results were reported in iodine vapour by Tiwari[2]. So, it was thought to extend this work also to mercury vapour at low pressure and room temperature.

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EXPERIMENTAL

A Siemens type (glass) full-ozonizer A (*cf.* Fig. 1) and a semi-ozonizer B (*cf.* Fig. 2) were used in the present study. The ozonizer A (24.2 × 0.7 cm wide annular space) containing about 2 g of redistilled mercury metal at the bottom of the tube was evacuated on toepler but for mercury vapour at room temperature (30°C). The mode of excitation of A and the measurement of the discharge current $i_{D,L}$ have been similar to these reported earlier[3]

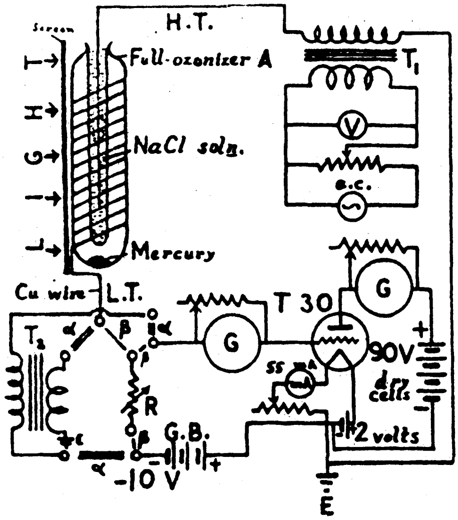

Fig. 1. Study of the Joshi effect in mercury vapour under triode detection (anode band detection)

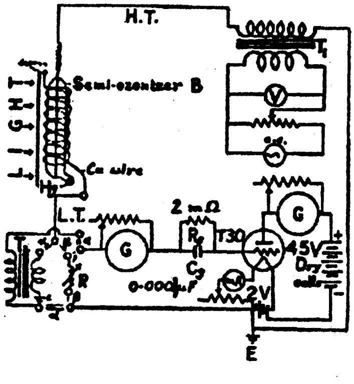

Fig. 2. Study of the Joshi effect in mercury vapour under triode detection (grid leak detection)

In the case of the semi-ozonizer B, the inner electrode was a platinum wire (10.5 × 0.01 cm diameter) fused with the glass. The outer electrode was a helical of bright copper wire wound tightly over the glass wall.

The secondaries of the Bell transformer T_2 were connected to the grid and the negative terminal of the filament battery *via* grid bias battery. The positive terminal of a high tension battery consisting of a number of dry cells in series (90 volts for one set of observations—anode bend detection and 45 volts for the other set—grid leak detection) is connected to the plate, the negative terminal being connected to the positive of the grid bias. The following fourteen series of observations of the discharge current in dark i_D and under light i_L of a 200 watt, 220 volt incandescent (glass) bulb were made by the plate and the grid currents using the triode in various ways as a detector.

When the low tension (L.T.) of the ozonizer is coupled inductively:

(i) **Using full-ozonizer A:** Anode bend detection: The plate voltage V_p was 90 volts d.c., corresponding to which the grid was given −10 volts, V_g (Fig. 1).

(ii) **Using semi-ozonizer B:** In grid leak-detection: V_p and grid voltage were 45 and +2 volts respectively. A mica condenser of 0.0001 μF shunted with a non-inductive and non-capacitative resistance of 2 megohm—called the grid leak, was connected in between the grid and the secondary of the Bell transformer T_2. This has been shown by α and α in Fig. 2.

(iii) The grid leak rectification: V_p, V_g and the grid condenser remained the same as in (ii); the grid leak was varied from 1 to 10 megohms.

(iv) The grid rectification: V_p and V_g remained the same as in (ii), the grid leak and the grid condenser were removed from the grid circuit.

Similar four sets of observations were taken for resistive coupling, *i.e.*, replacing the Bell transformer T_2 by dubilier resistances varying from 1 k-ohm to 10 megohm.

(ix) As in (ii), grid leak rectification, the grid condenser was removed from the circuit, everything else remaining the same.

(x) As in (ii), the grid leak was removed from the circuit, the rest remaining the same.

(xi) As in (ii), both the grid leak as well as the grid condenser were removed from the circuit. The two terminals are joined by a flexible electric wire.

Similar three sets of observations were recorded in the case of observations in grid current.

RESULTS AND DISCUSSION

The results have shown that $-\Delta i$ does not occur well below V_m. At V_m ionisation by collision sets in and consequently the current increases repidly. For the present system with 50 Hz frequency, it (Vm) is 0.48 kV for the full-ozonizer A and 0.56 kV for the semi-ozonizer B, irrespective of the detective methods employed. In agreement with earlier results[4, 5] observed in a number of gases and vapours with various detectors, $-\%\Delta i$ is maximum near Vm in both the types of detection, *viz.*, anode bend (α) and grid leak (β) detections. Furthermore, the applied potential at which the maximum $-\%\Delta i$ occurs is not the same. It changes slightly with the mode of coupling, *viz.*, inductive or resistive and type of ozonizer, *viz.*, full-ozonizer A or the semi-ozonizer B. For the observations in plate current, at a given potential, i_D and $-\Delta i$ are in the order $\beta > \alpha$ at lower values of the dubilier resistance; at its higher values, however, they are in the order $\alpha > \beta$.

Remarkably enough no positive effect $+\Delta i$ is observed in grid leak detection when the observations are taken in plate current, whereas for higher values of R, *viz.*, for and above 1 megohm, positive effect up to the magnitude of +44% is observed for observations in plate current under anode bend detection. The corresponding $-\%\Delta i$ is, however, in the order $\alpha > \beta$ for lower values of R, and in the order $\beta > \alpha$ for the higher values of R. For the observations in grid current, at a given potential, i_D is in the order $\beta > \alpha$; the corresponding $-\Delta i$ and $-\%\Delta i$ are, however, in the order $\beta > \alpha$. For the observations in grid current, grid leak detection gives at V_m a positive effect of large magnitude, *viz.*, +11500%. while in the case of anode bend detection, a slight positive effect, only 1% maximum, is given at high applied potentials, *viz.*, 0.92 kV and onwards and high values of R, *viz.*, 5.1 and 10 megohms. Furthermore, in β for both the observations, *viz.*, in plate current as well as in grid current and in α only for the observations in grid current, as the applied potential is increased i_D increases progressively; however, for observations in plate current in α, i_D first decreases with the applied potential for lower values of R and inductive coupling too and then for and above $R = 1$ megohm, i_D increases progressively as the applied potential is increased. In the range of $R = 5.1$ and 10 megohms, and at applied potentials of 0.92, 0.96 and 1.00 kV, the sign of Δi is changed from negative to positive in accordance with the anticipation[6] that at higher values of the applied potential and R, $+\Delta i$ is observed.

In α, for the observations in plate current, the behaviour of Δi is similar to that of i_D.

In β, for the observations in grid current, $-\%\Delta i$ decreases as the applied potential is increased from 0.56 1.00 kV; however, for the observations in plate current, $-\%\Delta i$ first decreases, attains a minima and then increases reaching a value greater than that at V_m. In α, for both the observations in plate current as well as the grid current, $-\%\Delta i$ is maximum at V_m and then decreases progressively as the applied potential is increased. This is in conformity with the results reported by Joshi.[7]

The necessary grid current flowing in the circuit which is an essential condition for grid detection, reduces the effective parallel resistance of the grid filament path from almost infinity, when no grid current flows, to some much lower finite value under working conditions. This reduces a damping effect, being equivalent to the introduction of a series resistance (R_s). R is approximately given by:

$$R_s = L/C\, r_g \tag{1}$$

where L and C are the inductance and capacitance of the transformer secondary and r_g represents the effective resistance of grid filament path. Mathematically the equation (1) is derived by finding the effective impedance (Z) represented by the circuit[1]. This is given by

$$\frac{1}{Z} = \frac{1}{\frac{-j}{\omega C}} + \frac{1}{r_g} = \omega C + \frac{1}{r_g}$$

$$= (jr_g\omega C + 1)/r_g$$

or
$$Z = r_g/(jr_g\omega C + 1)$$
$$= r_g(1 - jr_g\omega C)/(1 - r_g^2\omega^2C^2)$$

$$\therefore \quad Z = r_g/(1 - r_g^2\omega^2C^2) - jr_g^2\omega C/(1 - r_g^2\omega^2C^2) \qquad (2)$$

The resistance term in (2) gives the equivalent series resistance; hence

$$R_s = r_g/(1 + r_g\omega^2C^2) = 1/(1/r_g + r_g\omega^2C^2)$$

r_g is sufficiently large, hence $1/r_g$ may be neglected.

$$\therefore \quad R_s = 1/r_g\omega^2C^2 \qquad (3)$$

Alternatively, using $\omega^2 = 1/LC$,

$$R_s = 1/r_g \cdot 1/LC \times C^2 = L/Cr_g \qquad (3a)$$

Including the grid leak (R_g), the total effective parallel load or input resistance (r_g) may be shown to be approximately half the value of grid leak, *i.e.*, $R_g/2$. An equation indicating approximately the order of magnitude of the total equivalent series resistance is, therefore,

$$R_s = 2L/CR_g \qquad (4)$$

At a given applied potential, the discharge current i is a vectorial sum of various frequency currents.[4, 8, 9] For simplicity i can be expressed by

$$i = i_{h.f.} + i_{l.f} + i_{s.f.}$$

where $i_{s.f.}$ represents the supply frequency and its harmonics. By oscillographic studies[8] of this phenomenon and especially with l.f. and h.f. filters,[4, 5] the author[10] has established that, in general, $i_{h.f.}$ is the chief seat of $-\Delta i$. It is a well known fact that electrical oscillations especially the h.f.s are damped markedly by an ohmic resistance. Furthermore, this damping is larger, greater the value of the resistance. For the equation $R_s = L/Cr_g$, it is seen that R_s would be greater in β than in α, because in β due to large grid current, r_g is much smaller than in α. It is, therefore, anticipated that in β, i_D, $-\Delta i$ and $-\%\Delta i$ would be smaller than those in α. This is in agreement with the experimental results for high values of R and the applied potential. Furthermore, as the applied potential is increased, the grid current increases progressively over the applied potential range employed in this work, *viz.*, 0.56 to 1.00 kV. This increases R_s by reducing r_g. This explains easily why $-\%\Delta i$ should be maximum near V_m and there should be a marked decrease in it, *viz.*, from +1233, +1100, +2700, +3600 and +11500 to −27, −42, −36 and −33 respectively at R = 1, 2, 3, 5.1 and 10 megohms by the reduction in its magnitude in α.

Results obtained in the present case have shown that when the input to the triode is tapped across 1 to 51 k-ohms for observations in plate current and 1 to 10 megohms for observations in grid current (except for higher values of R at high applied potentials) there occurs a decrease on irradiation of the discharge tube at exciting potentials 0.48 to 1.00 kV employed in this work. Thus, *e.g.*, in grid circuit, as the applied potential was increased from 0.48 to 1.00 kV, a current decrease of about 100.0 to 0.2% was observed with but ordinary light. When input to the triode is taken across R = 1 megohm at 0.48 kV, the plate current has shown a current decrease as high as 100% under light; at 0.52 kV, however, on irradiation first a negative kick (*viz*., a decrease in plate current) is observed but slowly the current becomes more than that in dark. With greater applied potential, *viz*., 0.56 to 1.00 kV, the negative kick becomes inappreciable and a gradual small increase in current is observed. This apparently positive effect is never comparable with the corresponding negative effect observed with other a.c. detectors such as vacuo-junction, using the same ozonizer circuit. At a given R, at or above 1 megohm, as the potential applied to the mercury vapour tube is increased, i_D observed in the plate-circuit increases progressively; the corresponding $+\Delta i$, however, increases up to a certain potential, attains a maximum and thereafter becomes almost constant at this maximum; and the associated $+\%\Delta i$ increases with the applied potential, attains a maximum and thereafter it decreases as the applied potential is increased. Thus, *e.g.*, at $R = 2$ megohm, as the applied potential was increased from 0.52 to 1.00 kV, i_D increased from 6 to 43; the corresponding $-\Delta i$ increased from 1 to 2 as the exciting potential was raised from, 0.52 to 0.60 kV, a further increase in the applied potential up to 1.00 kV produced a slight decrease in $-\Delta i$, $-\%\Delta i$, however, increased from 12 to 14 as the applied potential was increased from 0.52 to 0.56 kV; on increasing the latter further to 0.96 kV, the former decreased to 1. At a given lower value of the applied potential as R increases i_D and $-\Delta i$ increase; the corresponding $-\%\Delta i$, however, increases up to some value of R and then decreases at large values of R.

The slow building up of the positive effect suggests a probable grid shift and secondary emission, if any.

As R increases, the grid current and plate current increase (because of input being larger), the corresponding $-\%\Delta i$, however, decreases. This is in agreement with the results observed by the author[6]. It must be emphasised here that in all the cases observed, the Joshi effect was negative in the grid circuit.

The production of large $-\%\Delta i$ in grid circuit may be accounted for as follows: The grid current will only flow when the peak of the signal applied to the grid is sufficiently large to make the grid momentarily positive. From the characteristics of triode 30 it is found that at plate voltage of 90 volts (d.c.) and filament current of 55 mA (d.c.), grid current begins to flow at 1.5 volts (d.c.) positive. Since the voltage applied to the grid is −10 volts (d.c.) even at 0.48 kV applied to the ozonizer, the least peak value of the signal applied to the grid is not less than −10.5 volts, undoubtedly a very strong signal. The oscillographic studies of this phenomenon would show that input across a resistance of a low amplitude of l.f. component has been superimposed with large h.f. amplitudes. Increasing the applied potential, the h.f. streaks increase in amplitude much more than those of l.f.s on oscilloscope without any gain showed that even at 0.48 kV, the threshold potential V_m of this mercury vapour tube where negative Joshi effect is observed simultaneously in plate and grid circuits, input to the triode being across 1 k-ohm, the input was of the order of 15 to 20 volts. This shows that even at low applied potential at which $-\Delta i$ occurs, the l.f. component of discharge current will not be effective in producing the grid current; in other words, grid current is chiefly due to h.f.s. As h.f.s are the chief seat of $-\Delta i$, a large $-\%\Delta i$ in grid circuit even in resistively coupling of the triode 30 with L.T. is expected. The present experimental results are in accord with this.

During the studies of this phenomenon in various systems under various conditions a positive effect $+\Delta i$ has been observed.[10] This suggests that $+\Delta i$ corresponds to a distinctive photo-reaction under discharge. The author[11] has found that V_m decreases under irradiation corresponding to the production of the positive effect. Since the discharge current i depends upon $V - V_m$, where V is the applied potential to the ozonizer, it is to be anticipated that a decrease in V_m would increase i under light. In this theory of Δi, Joshi[7] has postulated the formation of an activated layer on the annular walls, constituting the electrons, ions and excited atoms and molecules primary to Δi. The limited conditions within which only $+\Delta i$ is observed corresponds perhaps to the comparative rarity of the positive ion emission. A positive effect is, however, to be anticipated from the greater probability of the photo-ionisation of the pre-excited particles under the electrical discharge.

The production of $+\Delta i$ at large applied potential sufficiently above V_m as in the present case does not originate from a distinctive physical change under the discharge but is largely associated with the external detector circuit in grid control detectors. It is instructive to consider the following factors in regard to the production of $+\Delta i$ at large resistive inputs to the triode. The plate current depends on the grid voltage at a constant plate voltage and filament current; ordinarily in a triode such as Triode 30 (RCA) biased for the 'lower anode bend detection', as here, the plate current varies correspondingly with the grid voltage. This holds strictly only in the case of very low inputs. When, however, a high resistive impedance is present in the grid circuit and the input is heavy (as in the inputs studied in this work) a flow of grid current causes an amplitude distortion. Characteristics of Triode 30 (RCA) show that saturation in plate current begins at grid voltage equal to 6 volts (d.c.) positive. Very small decrease in grid currents by shift in the grid bias towards negative by –6 volts reveals that the inputs at large applied potentials are such as to produce saturation in plate current momentarily. This input impressed upon the grid consists of l.f.s and h.f.s produced under discharge; its amplitude (as shown by the cro used without gain) is so large that even the amplitudes of l.f.s are not effective in the production of plate current. Due to the flow of a large grid current and the presence of a large resistance (*viz*., 1 megohm and more), the grid bias is shifted towards negative by a small amount. On irradiation of the discharge tube, the input, predominantly h.f. part of it, is reduced. Assuming on plausible grounds that h.f.s are still far above the saturation point of the plate current, it follows that an inappreciable decrease or no decrease in plate current should occur. Contrary to this, as grid current is chiefly due to h.f.s, on irradiation a large decrease in it is observed. This results in reducing the negative grid potential developed in dark. In other words, grid shifts slightly towards positive. Due to this shift in grid bias an increase in plate current is in accord with this. The absence of, or decrease in, –Δi by decreasing the inputs at various applied potentials using electrical filters and by-passing capacity C confirm the validity of the explanation of +Δi given above.

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REFERENCES

1. B.N. Prasad, Ph.D. Thesis, Banaras Hindu University (1949).
2. S.N. Tiwari, Unpublished results.
3. J. Prashad, *Acta Cienc. Indica*, **1**, 13 (1974) and *Islamabad J. Sci.*, **5**, 32 (1978).
4. S.S. Joshi, *Curr. Sci. (India)*, **14**, 67 (1945).
5. B.N. Prasad, *Indian J. Phys.*, **20**, 187 (1946).
6. J. Prashad, *Bol. Soc. Quim.*, **53**, 48 (1987).
7. S.S. Joshi, Proc. Indian Sci. Cong., Presid. Address, Chem. Sec., p. 51 (1943).
8. ———, *J. Sci. Res. B.H.U.*, **8**, 99 (1943).
9. ———, *Curr. Sci. (India)*, **15**, 281 (1946).
10. J. Prashad, *Res. J. Hindi Sci. Acad.*, **42**, 145 (1999).
11. ———, *Rev. Roumaine Chim.*, **18**, 1865 (1972).

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