THE SCHOTTKY ANALOGUE IN THE PRODUCTION OF THE POSITIVE JOSHI EFFECT IN HYDROGEN

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ABSTRACT. A lowering of the surface work function of a thermionic emitter in proportion to the square root of the intensity of the applied field, as suggested by Schottky, leads to a linear relation between $\log I$ and $\sqrt{X}$ or $\sqrt{V}$, where I is the thermionic current under the field X due to the potential V. This Schottky relation being known to be valid for both thermionic and photoelectric emission, the present work was carried out to understand its applicability in the production of the positive Joshi effect. Results for the positive Joshi effect $(+\Delta i)$ in hydrogen for 5 different gas pressures show that $\log(+\Delta i)$ varies linearly as $\sqrt{V}$, thus substantiating Joshi's theory of the photoelectric origin of Δi. Results also suggest the co-occurrence of positive and negative Joshi effects $(+\Delta i$ and $-\Delta i)$ above a limiting potential V_l

INTRODUCTION

The Schottky effect refers to a continuous increase of the thermionic current I with the strength of the applied field X without reaching saturation. This was attributed by Schottky (1923) to a lowering of the surface work function in proportion to $\sqrt{X}$. On this consideration, the Richardson equation for I becomes,

$$I = A\epsilon^{-(\phi - c\sqrt{X})e/kT} \quad \ldots \quad (1)$$

where c is the constant of proportionality and $c\sqrt{X}$ is the lowering in the work function ϕ. Representing by I_0 the current in the absence of external field, the above equation may be written as,

$$I = I_0\epsilon^{ec\sqrt{X}/kT} \quad \ldots \quad (2)$$

whence it follows that $\log I$ will be linearly related to $\sqrt{X}$ or to $\sqrt{V}$, if V be the potential causing the field. The validity of this was verified experimentally by Pförte (1928) for thermionic emission for field strengths "as high as 1000 KV/cm." Later, Lawrence and Linford (1930) showed that the Schottky relation (Eqn. 2) holds for photoelectric emission as well under field strengths "up to 63 KV/cm."

In his theory of the above effect, Joshi (1946, 1947*a*, and 1947*b*), postulated: (*a*) the formation of an adsorption-like electrode layer consisting of ionised and excited particles and characterized by a low work function, as a primary reaction; (*b*) light releases electrons from (*a*); and (*c*) these lead to a reduction of the discharge current to give the negative Joshi effect as a space-charge effect due to negative ion formation by the capture of the photoelectrons by the gas particles owing to their enhanced electron affinity under excitation. Within limits, the space charge effect is favoured by increased X. The positive Joshi effect should therefore occur at low voltages associated with the photoelectric emission as in (b). It was of interest, therefore, to investigate its production from the standpoint of the Schottky relation (2).

EXPERIMENTAL ARRANGEMENT

Hydrogen prepared by the electrolysis of N/15 barium hydroxide solution was freed from traces of oxygen and stored in a Töpler evacuated reservoir after drying it over phosphorus pentoxide. The gas was admitted into the annular space of a large size Siemens' ozonizer with a total electrode surface of about 1300 sq. cm., and its pressure was read by a mercury manometer. All the joints in the apparatus were of fused glass. The gas was subjected to a 50 c/s A.C. ozonizer discharge, the details of the electric circuit and current measurement being same as in earlier works on the Joshi effect, (Prasad, 1946, and Rao and Sarma, 1949). For each applied potential V, the values of the discharge current i_{Dark} and i_{Light}, were measured in the dark and under irradiation respectively, by light from a 200-watt incandescent bulb run at a constant potential. A centimetre thick column of dilute sulphuric acid solution surrounding the ozonizer served both as the L.T. electrode and as a filter to cut off the heat radiation. The results for 5 different gas pressures in the range 7—30 mm Hg and for potentials varing in the range 0.23 to 0.60 KV (r.m.s.), are entered in Table I, and the variation of log $(+\Delta i)$ with $\sqrt{V}$ is plotted in figure 1, following Schottky.

DISCUSSION

The dark current values (i_D) in Table I indicate the potential range for the occurrence of the positive Joshi effect is the narrow region near the beginning of the intermittent corona, the current just beginning to rise but not rapidly as at the threshold V_m. This region is highly photo-sensitive even in the visible range, as revealed by the large (several hundred per cent) positive Joshi effect. In other words, the current under irradiation (i_L) rises precipitously over this potential range. The lowering of V_m under light, thus implied, is an expected consequence of postulates (a) and (b) of Joshi's theory of the origin of Δi, described earlier.

The system can thus be considered as a phototube with amplification both in the gas phase, mainly due to the Townsend (α) factor, and at the electrode surface due to the lowering of the work function as a Schottky consequence. Under conditions of the positive Joshi effect $(+\Delta i)$, *viz.*, potentials near V_m, the gas amplification factor is assumed to be less important on account of low V-i_D slope, and the following expression for $+\Delta i$ is suggested analogous to the Schottky relation (2) in thermionics and extended to photoelectric phenomena by Lawrence and Linford (1930):

$$(+\Delta i) = (+\Delta i_0) B e^{\sqrt{V}/kT} \tag{3}$$

where B is a constant, and $+\Delta i_0$ is the hypothetical positive Joshi effect due to the primary photoelectric current with zero field, *i.e.*, in the absence of Schottky lowering of the surface work function.

The straight lines obtaining for the plots of log $(+\Delta i)$ *versus* $\sqrt{V}$ (figure 1), for 5 different gas pressures are in accord with the above deduction. The curves in figure 1, it may be noted, are not only linear, but sensibly parallel to one another, indicating a constant slope independent of gas pressure, as expected on the Schottky equation (2). Further, a limiting potential (V_l) can be discerned in each case where linearity abruptly ceases. It is suggested

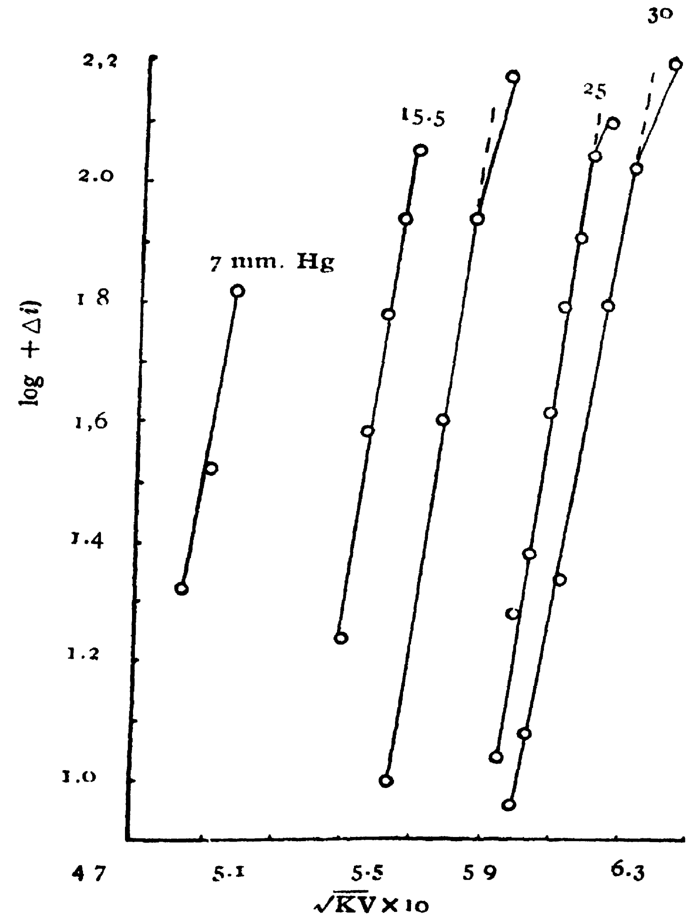

FIG. 1

Potential variation of the positive Joshi effect in hydrogen : The Schottky analogue

that V_l marks the incipience of the co-occurrence of the positive and negative Joshi effects, with the positive predominating. Evidence for such a co-occurrence has been independently established in these laboratories by the oscillographic study of the phenomenon, (Jatar, 1950). As the potential is

TABLE I

Potential variation of the Joshi effect in hydrogen

EV	$\sqrt{KV}$	i_D	i_L	Δi	$\% \Delta i$	$\log(+\Delta i)$
(*i*) pH_2=7 mm Hg						
0.23	0.4796	3	24	+21	+700	1.3222
0.24	0.4899	3	36	+33	+1100	1.5185
0.245	0.4950	3	69	+66	+2200	1.8195
0.255	0.5050	5	44	+39	+780	1.5910
0.27	0.5200	30	48	+18	+60	1.2550
0.30	0.5477	82	78	−4	−4	
0.34	0.5831	132	112	−20	−15	
0.38	0.6164	140	56	−84	−60	
0.40	0.6325	110	1	−109	−99	
0.49	0.7000	60	18	−42	−70	
(*ii*) pH_2=15.5 mm Hg						
0.28	0.5291	12	28	+16	+130	1.2041
0.285	0.5338	13	52	+39	+300	1.5911
0.29	0.5385	13	74	+61	+470	1.7853
0.295	0.5431	14	103	+89	+640	1.9494
0.30	0.5477	14	129	+115	+820	2.0607
0.305	0.5523	224	167	−57	−25	
0.33	0.5745	727	260	−467	−64	
0.375	0.6124	862	175	−687	−80	
0.40	0.6325	625	215	−410	−66	
(*iii*) pH_2=20 mm Hg						
0.295	0.5431	21	31	+10	−50	1.0000
0.31	0.5568	21	62	+41	+200	1.6128
0.32	0.5657	22	110	+88	+400	1.9445
0.33	0.5745	25	178	+153	+610	2.1847
0.34	0.5831	170	230	+60	+40	
0.35	0.5916	555	335	−220	−40	
0.425	0.6519	1280	645	−635	−50	
0.525	0.7426	1400	880	−520	−37	
(*iv*) pH_2=26 mm Hg						
0.33	0.5745	15	26	+11	+70	1.0414
0.335	0.5788	16	34	+19	+120	1.2788
0.34	0.5831	17	41	+24	+140	1.3802
0.345	0.5873	18	60	+42	+230	1.6232
0.35	0.5916	18	81	+63	+350	1.7993
0.355	0.5958	20	102	+82	+410	1.9138
0.36	0.6000	23	136	+113	+490	2.0531
0.365	0.6041	26	156	+130	+500	2.1139
0.375	0.6124	410	235	−185	−45	
0.425	0.6519	1170	585	−585	−50	
0.575	0.7583	1620	1020	−600	−37	
(*v*) pH_2=30 mm Hg						
0.335	0.5788	17	26	+9	+50	0.9542
0.34	0.5831	18	30	+12	+60	1.0792
0.35	0.5916	20	42	+22	+110	1.3424
0.365	0.6041	21	84	+63	+300	1.7993
0.375	0.6124	24	131	+107	+450	2.0294
0.39	0.6245	24	186	+162	+680	2.2095
0.405	0.6364	320	260	−60	−19	
0.425	0.6519	690	440	−250	−36	
0.45	0.6708	1150	650	−500	−43	
0.505	0.7106	1560	930	−630	−40	
0.605	0.7778	1680	1280	−400	−24	

further raised beyond V_t, the negative Joshi effect, anticipated on postulate (*c*) of Joshi's theory, increases rapidly in magnitude finally reverses the sign of net Δi observable.

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REFERENCES

Jatar, D. P, 1950, *J. Sci. Ind. Research*, **9B**, 283
Joshi, S. S., 1946, *Proc. Ind. Sci. Congress, Part* III, *Phys. Sect., Abs. No.* 26,
Joshi, S. S., 1947*a*, *Proc. Ind. Sci. Congress, Part* III, *Phys. Sect., Abs. No.* 25.
Joshi, S. S., 1947*b*, *Curr. Sci.*, **16**, 19.
Lawrence, E. O., and Linford, L. B., 1930, *Phys. Rev.* **36**, 482.
Pförte, W S., 1928, *Z. f. Phys.*, **49**, 46.
Prasad, B. N., 1946, *Ind. J. Phys.*, **20**, 187.
Rao, D.V R. and Sarma, B. K., 1949, *J. Phys. and Colloidal Chem.*, **53**, 753.
Schottky, W., 1923, *Z. f. Phys.*, **14**, 63.