Ion Concentrations in Shock-type Spark Discharge Tubes

R. G. FOWLER and H. C. ROSE, University of Oklahoma, Norman

Ion concentration measurements using the Stark broadening of hydrogen have been made by many workers, here and abroad, including ourselves. The most detailed of these have been reported by Olsen and Huxford (2) who find, upon applying them to the low pressure spark discharge (confined to a definite volume), that the ion concentration appears to increase in time to a maximum which is a respectable fraction of the initial gas particle concentration. The remarkable thing about this maximum is that it occurs at a considerable time interval (5 microseconds) after the maximum of the discharge current, suggesting that the action which builds up the ion concentration is not primarily that of the discharge current.

A similar phenomenon was observed by Fowler, Atkinson and Marks (1) in low pressure sparks which are allowed an avenue of expansion. Here, using an avenue at right angles to the main discharge, it was found that the ion concentration reached a maximum in *position* which when divided by the velocity of advance of the expanding gas gives a time lag roughly the same as that observed by Olsen and Huxford. Because of the uncertainty introduced by the geometry of the expansion tube, it was felt that one could not say with certainty that the maximum was not an artifact produced by compression and expansions of the ionized gas. The same experiment has therefore been repeated in a tube which possessed a symmetry for which the flow patterns are reasonably well known, the shock tube.

This tube was made by placing a snug-fitting plane electrode in one end of a straight tube, and another electrode in the side, separated by 12 cm. from the other, and ground to conform to the curvature of the tube wall. Expansion would then be expected to take place according to the laws of one dimensional supersonic flow. Examination of the radiation emitted by hydrogen by focussing the image of the discharge tube upon the slit of a quartz Littrow spectrograph showed Stark broadenings very similar to those found in the previous tube. When these broadenings were interpreted to give average ion concentrations according to the Holtsmark equation, the usual maximum in the expansion chamber was again obtained, together with a minimum exactly at the side electrode. Whereas the position of the maximum was sensitive to the initial energy supplied to the discharge and the initial gas pressure, the minimum was invariably located at the side electrode. The entire concentration curve was completely insensitive to the direction of charge flow in the main tube.

In earlier work we have also shown that the total intensity of these broadened Balmer lines is accurately proportional to the square of the ion concentrations indicated by the Holtsmark theory, which would be expected if radiative recombination contributed heavily to the production of quantized light. A point by point plot of the square of the ion concentration against the total H_β intensity shows a remarkable agreement everywhere except in the main discharge tube where electric and magnetic fields may persist for some time and limit recombination.

It is our conclusion that the evidence favors the relative correctness of ion concentrations as calculated by the Holtsmark theory. The chief objection to using this theory is that it assumes a distribution of the surrounding ion cloud which should be static over intervals of the order of the relaxation time of the atom, an assumption which is not completely justified by the facts. It has been customary to ignore the *electron* cloud which is present in the discharge plasma when making ion concentration estimates on the assumption that it is not static, but rather averages to zero because of its rapid fluctuations. An estimate of the distance that a positive ion moves during atomic relaxation shows that it is not negligible, and casts doubt on this use of theory. In addition, failure of the Holtsmark theory would give an elegant explanation of the belated rise to a maximum in time and space shown by the ion concentration curves. On the contrary, however, it seems hardly credible that both the recombination coefficient and the Stark broadening should depend in the same fashion upon electron and ion temperature as would then be required to explain the agreement between the total intensity and squared ion concentration curves.

We therefore believe tentatively that the passage of the discharge current stores energy in the gas in the main discharge section by imparting much energy to a few ions which then gradually share their energy with neutral atoms so that many ions are formed having little energy. Thus, the belated maxima arise from an ionization process which continues after the current subsides, essentially a thermal process.

LITERATURE CITED

1. Fowler, R. G., W. R. Atkinson and W. Marks. 1952. Ion concentrations and recombination in expanding low pressure sparks. Phys. Rev. 87, 966.

2. Olsen, H. N. and W. S. Huxford. 1952. Dynamic characteristics of the plasma discharges through rare gases. Phys. Rev. 87, 922.