out above. The two curves which result from this strip theory are thus seen to be in definite disagreement with experiment. Again it is not difficult to see that with the narrow regions (order of 10^{-5} cm) of low work function surface separated by wide regions (order of 5×10^{-4} cm) of high work function area, the effect of the strips on the retarding potential side would be greatly reduced and at the same time they would serve to give the large deviations from the Schottky theory which have been known to exist, especially with composite surfaces. If it is reasonable to suppose that such a theory of strips or patches might give a satisfactory explanation for the poor saturation effects for accelerating fields without appreciably influencing the currents predicted as a function of retarding potentials, then we must abandon hope of explaining the observed reflection effects by patches and must look to some "atomic explanation" for the excluded areas or the variable transmission coefficient.

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Negative Atomic Hydrogen Ions

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Negative atomic hydrogen ions have been directly observed to exist at the heads of striations in discharges in water vapor. The ions appear to form surprisingly readily in these regions of high density of slow electrons, but they are lost very easily by collision.

NEGATIVE ions are supposed to exist in discharges through gases, as necessary for the explanation of the existence of striations[1] as well as for other reasons. They have not been observed there directly, but have been detected and studied in the past at extremely low currents differing greatly from those of the usual kinds of discharge through gases.

In work begun recently at this laboratory, negative atomic hydrogen ions have been observed directly at relatively high densities in the heads of striations in discharges through water vapor, and some information about their properties and behavior in a discharge obtained. The results establish that the ions exist at the heads of striations at high enough densities to play the role assigned them.

METHOD OF OBSERVATION

Various forms of discharge in water vapor were used as sources. In order to analyze the beams obtained through an aperture in the anode of the discharge, an electric lens system was used, shown in Fig. 1. The products from the source came through a sharp-edged aperture in A, 1 mm in diameter, and were accelerated by about 1200 volts into B. Approaching C, which had an accelerating potential of about 16,000 volts, the particles were focused, and going from C into D they were defocused less, thus producing a real image of the source aperture on the willemite-covered copper screen, F. The spot was observed through a screened narrow slot, E, and focused by adjustment of the middle electrode on the xylene-alcohol 10-megohm potential divider. A magnetic field from the Helmholtz coils HH deflected the particles through a hole in the screen on a collecting electrode, G, for measurement. The hole in F should be out from the plane of the figure when the coils HH are oriented as shown.

A great advantage of the electric lens system used was that when the potential divider was set for focus of the slowest electrons emerging

[1] See Thomson, *Conduction of Electricity Through Gases* (1933), vol. 2, pp. 387ff.

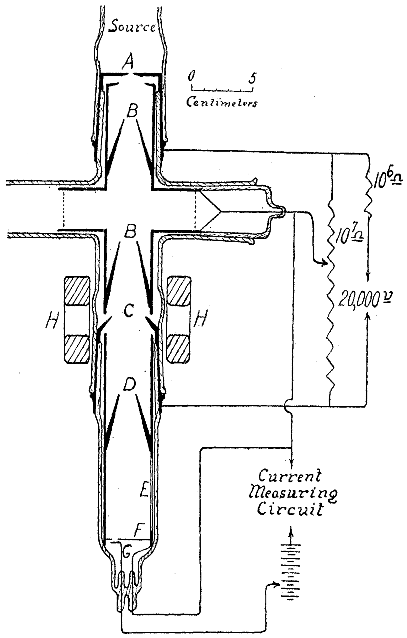


FIG. 1. Section of electric lens system.

through A, the same adjustment focused all singly charged particles in the plane of F, regardless of mass, and variations of potential drop across the potential divider were without effect on the focus.[2]

Whenever question arose as to whether the gas pressure in the tube below A had risen to too high a value through use of too high a water-vapor pressure in the arc chamber above A, liquid air could be put on the lower end of the tube, freezing out water vapor and greatly increasing the pumping speed. This question has seldom arisen, but the greatly increased pumping speeds so easily available have occasionally been very convenient in testing this point. Water vapor was admitted to the discharge chamber from a reservoir containing water cooled to any temperature desired from $-20°C$ to $-45°C$ at will.

Arc in Water Vapor

An arc of the shape shown in Fig. 2 was used with all water-vapor pressures from 1 mm down.

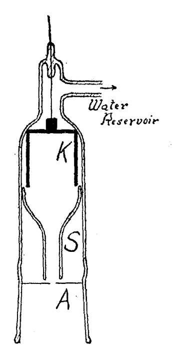
[2] For a discussion of electron optics, see Bruche and Scherzer, *Electronenoptik.*

The cathode, K, was cup-shaped to concentrate the discharge towards the axis. The glass funnel, S, served further to concentrate the discharge on the aperture. Omitting S gave similar results but weaker beams of negative ions. A potential of 2000 volts was applied through a variable resistance limiting the arc current to 10–50 ma while at lower pressures the current fell to less than 1 ma before being extinguished.

Beginning with a high pressure and slowly reducing the pressure, it was found that no H^- spot appeared until the discharge had become of the "abnormal" type and well-defined striations had appeared in S. As the pressure fell, successive striations disappeared at the anode, and just as each striation disappeared at the anode the H^- spot faded out and then reappeared, becoming most intense just as the next striation had become a well-defined positive column in front of the anode. The most intense H^- spot was obtained when the last striation had become the positive column. At this point the pressure was roughly 5.10^{-2} mm, the current in the arc was 10 ma, the voltage on the arc 1800 volts and the current in the H^- beam was 2.10^{-8} ampere.

With further reduction of the pressure, the positive column faded out and the H^- beam decreased proportionally with the arc current.

Various shapes and smaller sizes of electrodes and tubes were tried, but these all gave smaller H^- currents. In all cases, the beam was strongest when there was a well-defined positive column above the anode without any striations.



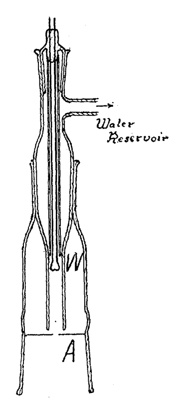


FIG. 2. (left) Water vapor arc.
FIG. 3. (right) Form of arc with oxide-coated filament.

Discharge with Filament Cathode

An oxide-coated platinum filament, *W* (see Fig. 3), conditioned in vacuum was used as cathode. If enough water vapor was admitted to give several striations, the filament was poisoned and had to be reconditioned in vacuum. At lower vapor pressures, a dense discharge was easily obtained at as low a potential as 88 volts with the positive column extending nearly to the cathode. The current was 50 ma and a more intense H^- beam was obtained than with the high voltage arc. The gas pressures used here were about the same as those used before with the arc.

In this discharge, when the dense discharge was first obtained a second ion spot appeared as strong as the H^- spot. The mass of this second spot was tested for and found to be about 16 or 18. The resolution of the tube was not sufficient to distinguish between masses 16, 17, and 18, although quite adequate to identify the H^- ions by comparison with electrons. This heavy ion beam soon disappeared with operation of the tube and could be reproduced only by giving the tube a long rest. At no point in the experiments has a spot with mass 2 been seen although such a spot could easily have been detected.

Discussion

Negative atomic hydrogen ions were detected in Thomson's early experiments[3] in which he used a canal-ray tube with the applied field in the wrong direction to eject negative ions. That they were observed at all suggests that they may be remarkably easy to form because they had to be formed from high velocity positive hydrogen ions by the capture of two electrons in the canal. No other process would give the negatives the velocity observed, except head-on collisions of H^+ on molecules containing hydrogen and simultaneous retention of an extra electron by the recoil hydrogen atom. Hylleraas[4] has calculated the dissociation potential for the negative hydrogens as 0.715 volt. Lozier[5] has reported some measurements giving the result that H_2O vapor can acquire an electron at 6.6 or 8.8 volts and the resulting H_2O^- breaks up to give neutral OH and H^- with the recoil of the H^- having an energy of 1.5 or 3.2 for the two association energies, respectively. He found further that H^- currents could not be obtained as readily in purified hydrogen gas as in the water vapor.

The hypothesis made by Lozier to explain the formation of negative hydrogen ions in water vapor is supported by several points in our observations. The head of the positive column and the heads of striations are regions of slowly moving electrons necessary for attachment to water molecules. Heavy ions (presumably negative water ions, although not yet definitely identified) appeared sometimes with the negative hydrogen ions. The observed ion currents were much larger when the luminous part of a striation was close to the aperture. The rapidity with which the negative ions were otherwise lost by collisions necessitates the assumption of a high density for their formation.

It would seem that a negative hydrogen would be much more apt to be dissociated by a collision with a positive ion than with electrons or neutrals, because the attractive force would draw the colliding particles nearer to each other during a collision when they are oppositely charged than when they are not. Thus the use of the filament cathode has the advantage of a lower positive ion density since the discharge does not depend on ionization for the supply of electrons.

The writers wish to express appreciation to Professor L. H. Thomas for helpful discussions of the problem.

[3] Reviewed in Thomson's *Conduction of Electricity Through Gases*, vol. 1, Chap. 5.

[4] Hylleraas, Zeits. f. Physik **63**, 291 (1930).

[5] Lozier, Phys. Rev. **36**, 1417 (1930).