EXPO\`NENTIAL YIELD OF POSITIVE IONS IN ARGON

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Read before the Academy, November 21, 1928

When an electric discharge is passed through a gas-filled tube it is often a problem to know how much of the current is carried by electrons and how much by positive ions. This paper will describe experiments in which these currents were measured, and will suggest a mechanism to account for the observed relationships.

The tube used in the experiments had a pure tungsten filament 0.5 mm. in diameter as hot cathode, a molybdenum disk-shaped anode 6 mm. distant from the cathode, and the tube could be filled with argon at any desired pressure. A side bulb sealed to the tube had a glass surface that was out of the range of any particles sputtered from the cathode, so that it always afforded a clean window through which the filament could be observed with a pyrometer.

Figure 1 shows a plot of 5 volt-ampere characteristics all made with argon in the tube at a pressure of 0.26 mm., but made at a series of different filament temperatures. A short 0.5 mm. filament has a temperature gradient at practically every point along its length so that the temperature marked on each curve refers only to the hottest section near the midpoint. The plot in each case shows only that part of the characteristic which represents the discharge after the arc has struck, that is, after a sufficient number of positive ions are flowing to the cathode to neutralize the electron space charge at the cathode and permit the full saturation electron current to flow to the anode. It is clear from the curves in figure 1 that with this pressure of gas in the tube the current does not reach a limiting value, as it does in a vacuum tube, but on the contrary appears to be rising without limit as the voltage is increased.

The electron current from the filament was calculated for each curve by measuring the temperature of the filament at intervals along its length with a pyrometer, and calculating the saturation electron emission from these temperature data.\(^1\) It was assumed that the emission from a filament in argon can be calculated from the same data that hold for a filament in vacuum. A horizontal line on each curve in figure 1 marks the electron current, determined in this way. Each mark occurs at a voltage between 15 and 19 volts, so that the characteristic in each case passes through the current that corresponds to the electron current at a potential close to the ionization potential of argon (15 volts). A large number of characteristics, taken under widely different conditions of arc current and gas pressure, have all shown this feature. It sometimes happens at
FIGURE 1

Semi-log plot of current-voltage characteristics in argon at 0.26 mm pressure.

FIGURE 2

Ratio of arc current to electron current, plotted against pressure, at three pressures of argon.

FIGURE 3

Ratio of arc current to electron current, plotted against pressure, at 20 cm pressure of argon.
very low currents that the arc will not strike until higher voltages are applied, and cannot be maintained at voltages less than 30 or 50 volts, but in every case in which the arc will run at 15 volts, or less, the current in the neighborhood of 15 volts is found to be the same as the electron current.

The curves in figure 1 have nearly the same slope. This is not the case, however, when the data are taken at currents above 10 milliamps., for then the number of positive ions bombarding the filament at high voltage becomes sufficient to heat the filament. Since the filament-heating current is always held constant while the anode voltage is raised, this additional heating causes the filament to emit a higher electron current, so that the curves bend upward at higher voltages and will eventually rise perpendicularly. With a filament at 2000°K., a change of temperature of only 10° will raise the electron emission 15%, so that even a small input of energy into the filament from positive ion bombardment will seriously affect the slope of the curves. It is necessary, therefore, when exploring the region of currents higher than those in figure 1 to measure the temperature distribution along the filament for each point on the curve, and allow for the changes in electron current when plotting the data. When this correction is applied the resulting curves have the same slope as those in figure 1. For the purpose of comparing data taken at different temperatures it is useful to convert curves of observed current, such as those in figure 1, to curves giving the ratio of the observed current to the electron current. Since the curves in figure 1 are plotted on semi-logarithmic paper, this amounts in effect to displacing these curves vertically in such a way that the lines marking the electron currents all coincide, and when this is done the curves nearly coincide throughout.

Figure 2 shows the ratio of total current to electron current plotted for three different pressures of argon. At the higher pressures the current rises so rapidly with voltage that at 5.0 cm. pressure and 90 volts the total arc current is 13 times the saturation electron emission from the filament. Since this means that the arc current in this case is composed of one part electron current and 12 parts positive ion current, the question arises of how one 90-volt electron can produce 12 positive ions in a gas that has an ionization potential of 15 volts.

In order to see how this rapid multiplication of current may take place, and also why it takes place only at higher pressures, let us consider the course which the electron follows as it leaves the cathode. It is well-known that in a gas tube nearly all the fall of potential takes place close to the cathode, and Langmuir and Mott-Smith have demonstrated that this is because the cathode becomes surrounded by a positive ion sheath, that is, a region from which electrons are repelled by the negative field of the cathode, while at the same time positive ions are attracted in such
numbers that they produce a positive space charge which is able to neutralize the negative field of the filament at a short distance. These authors have shown that the thickness of the sheath can be calculated from space-charge equations of the positive ion current flowing to the cathode, so that in the experiments with this argon tube the sheath thickness was known to be usually of the order of magnitude of the filament diameter. The remainder of the space between the cathode and anode is a region of almost no electric field, that is, a plasma in which there are practically the same number of electrons as of positive ions per unit volume. Consider what will happen when an electron is emitted from a cathode in a gas in which the electron mean free path is sufficiently short compared to the sheath thickness so that the electron can make several ionizing collisions before reaching the boundary of the sheath. The conditions will then be right for the Townsend type of ionization by collision which occurs when an ionizing agent produces electrons in a region of electric field so that the new electrons, being accelerated by the field, become themselves new ionizing agents. If the field is sufficient to allow this process to be repeated \( n \) times, the yield of positive ions will be \((2^n - 1)\). Thus if an electron, in traversing a sheath across which there is a 90-volt potential drop, is able to make 6 ionizing collisions, the theoretical yield of positive ions may be as high as 63. Consider on the other hand what will happen if the sheath is thin compared to the mean free path, so that the electron reaches the sheath edge, or even passes beyond it, before making its first ionizing collision. In this case the new electrons produced by collision will be in a region of no field so that they will not acquire the energy that they must have to ionize, and the only positive ions formed will be those due to the original electron which, after falling through 90 volts, will carry with it into this region sufficient energy to produce, at the most, 6 positive ions.

The dotted line (a) in figure 3 represents the maximum theoretical ratio of total current to electron current in the first case when ionization takes place inside the sheath, and the dotted line (b) represents the case when the electron ionizes beyond the sheath. The data for the three current-voltage curves in figure 3 were all taken at 2.0 cm. pressure of argon. The positive ion currents for the curve at 2088°K. were 10 times those at 1922°, and the currents at 2232° were 5 times those at 2088°. Now at any given voltage the sheath thickness varies inversely with the square root of the positive ion current. Consequently the curve at 1922° corresponds to the thickest sheath, which would give the greatest opportunity for collisions within the sheath, and it is seen that this curve has the steepest slope, whereas the curve at 50 times higher current has so far departed from this steep slope that in the upper region it is approaching the slope of line (b) for ionization beyond the sheath. These data, therefore, bear out the theory that the relation of the sheath thickness to the distance which an
electron must travel from the cathode before it ionizes is a factor of fundamental importance in fixing the magnitude of the positive ion current.  


**ON THE RAMAN EFFECT IN DIATOMIC GASES**

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Communicated February 17, 1929

The only observation on Raman effect in gases, as far as I know, is due to Ramdas. The substance investigated was ethyl ether vapor, and the Raman spectrum was found to be identical with that of the liquid. The aim of the present paper is to give some information about the Raman spectra of molecules of simple and well-known structure. It would have been perhaps more interesting to observe the effect in atoms, but it seems hard to get appropriate metallic vapors of sufficient density, and the rare gases, on the other hand, have no energy levels above the normal state low enough to give a Raman effect in the optical region. But, in the last years, our knowledge of molecular spectra has progressed far enough to enable us to verify if the Raman spectrum of a given molecule is connected with its band spectrum as is to be expected from the theory.

The theory of the Raman effect was given, long before the experimental discovery of the phenomenon, in Kramers and Heisenberg's treatment of dispersion from the point of view of the correspondence principle. In this theory some of the fundamental assumptions of the later-developed matrix mechanics were already implied, so that the formula given by Kramers and Heisenberg for the electric moment of a system perturbed by the field of a light wave is exactly the same as it is when derived with the methods of wave mechanics.

It has been shown that if we take an atom in the quantum state distinguished by the index $k$ (and which we will assume to be the normal state), the perturbation due to a light wave of frequency $\nu$ gives rise to harmonic components in the electric moment of the system having frequencies given by

$$\nu^*_l = \nu - \nu_1 = \nu - \left[ \frac{E_l - E_k}{\hbar} \right],$$

where $l$ represents any other state of the system satisfying only the condition that the expression above must be positive.