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Electron Emission from a Carbon Surface

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Electron Emission from a Carbon Surface[1]

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The determination of the electron affinity of an element can be made through measurement of the equilibrium constant for electron attachment reactions. The equilibrium constant, K, for the reaction

$$X(g) + e^-(g) = X^-(g)$$

occuring at or near a surface S at temperature T is

$$K = P_{x-}/P_x \cdot P_{e-}$$

where P_j represents the pressure of the j th species. When equilibrium is established, K can be shown to be

$$K = (i_{x-}/i_{e-})\ (1/P_x)\ (m_{x-}/m_{e-})^{1/2}$$

where i_j is the electrical current carried by the j th species and m_j is the mass of the j th species. This in turn can be related to the electron affinity, $-\Delta E^\circ$, as follows:

$$-\Delta E^\circ = RT \ln [(i_{x-}/i_{e-})\ (1/P_x)\ (m_{x-}/m_{e-})^{1/2}] + \int_0^T C_p dT - T\Delta S$$

Whereby the determination of the electron affinity is dependent on the ratio of the ion current to the electron current, the pressure of the gas and the temperature of the surface. The current ratio can be obtained by using a magnetic field to separate the electron current from the ion current and measure each separately; the pressure of the gas from the heat of sublimation of carbon at the specified temperature; and the temperature by means of an optical pyrometer.

In a study of the electron affinity of carbon by Glockler and Sausville[4] it was found that the presence of positive carbon ions was responsible for a temperature trend in the ion-current ratio observed. The positive ions resulted from a high potential drop across the filament. The purpose of this investigation was to determine whether a surface could be produced which would eliminate the high potential drop, and hence the positive carbon ions, while operating in a temperature range of 1850° K to 2250° K. It can be said that a filament was constructed which permitted the attainment of these temperatures. However, further development along the

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[4]G. Glockler and J. W. Sausville, J. ELECTROCHEM. SOC., 95, 282 (1949).

lines of cooling the filament leads will be necessary before the tube will be completely satisfactory for operation.

The most obvious construction was an equipotential surface. If this did not produce the desired results, the next most obvious method would be a surface having a very low potential drop. The following assemblies were tried:

A. Equipotential surface
   1. Indirectly heated, double-wound heaters
   2. Indirectly heated, hair pin heaters
   3. Indirectly heated, internal cylinder heater
   4. Indirectly heated, paper cylinder

B. Straight surface with mechanical interrupter

C. Straight surface with low potential drop.

To determine whether a carbon surface could be made having the desired characteristics it was necessary to build a vacuum system by which the glass tube containing the carbon surface and other tube elements could be exhausted to 10^{-6} to 10^{-5} mm Hg. Auxiliary apparatus consisting of proper electrical heating and measuring circuits were also constructed. Temperature measurements were made with an optical pyrometer.

The first type of equipotential surface tried was made by forming a cylinder from spectrographic graphite with the following dimensions: diameter, 0.25 inch; length, 1.00 inch; wall thickness, 0.02 inch. The cylinder was heated by a double-wound tungsten heater 10 mil in diameter which touched the graphite cylinder at one point. By this method a temperature of 1750° K was achieved. A smaller cylinder was constructed (diameter, 0.125 inch; length, 1.00 inch; wall, 0.020 inch) and heated with a double-wound coil of 2 mil tungsten. A temperature of 1670° K was obtained. In each case the heaters burned through at the temperature indicated.

Hairpin heaters were used with 0.25 inch (diameter) graphite cylinders. Various heaters of 20 and 30 mil tungsten were used. The maximum temperature recorded was 1650° K.

Hoping to provide a method whereby higher temperatures could be obtained, the surface was constructed in the following manner: the carbon surface to be indirectly heated was a cylinder made from spectographic graphite 0.25 inch (diameter), 1.00 inch (length), 0.02 inch (wall). The heater was constructed by using a graphite cylinder 0.125 inch (diameter), 1.125 inch (length), 0.020 inch (wall) and either carbon or tungsten wire 20 to 30 mil in diameter. All three units were mounted coaxially, thus producing an indirectly heated, non-inductive, equipotential surface. The maximum temperature recorded before a burning out of the center wire was 1548° K.

To determine whether the wall thickness played a part in the maximum temperature obtainable, a surface similar in structure to the previous one but having cylinders made of two thicknesses of onion skin paper coated with carbon clamping paste (General Electric 15C-2-10) were used. This surface was placed in the vacuum system and the paper charred by passing an electric current through it, driving off tar products. Upon removal of the tar products a carbon surface remained. After cleaning the tar products from the envelope of the tube, observations were made to determine the maximum temperature obtainable. The maximum was 1473° K.

It was thought that a rotating commutator or interrupter might be successfully employed to produce a condition whereby electron and ion current measurements might be made when there was no current flowing through the filament and hence no potential drop. A commutator was constructed and placed in the circuit so that the circuit to the carbon surface (5 mil in diameter and 3 inches long) was closed through two brushes contacting a brass strip on the rotor for slightly less than one-fourth a revolution, then this circuit was broken and the circuit to the plate was closed through the next one-fourth revolution in a similar manner, but through a different set of brushes and brass strip. The speed of the rotor could be adjusted from 10 rpm to 1200 rpm.

In the work with indirect heaters it was found necessary to adjust for the expansion of the filament on heating. Two methods were devised for the filaments used with the commutator. One of these made use of a Kovar glass terminal (type H) centered at the base of the all glass envelope with respect to the tube elements. A Sylphon bellows (total stroke movement of 0.118 inch) was soft soldered to the Kovar portion and a brass rod was mounted at the lower portion of the Sylphon bellows. One end of the filament was attached to the brass rod and the tension adjusted mechanically as the filament elongated. The other type used the force of gravity, by having a brass weight on the lower end of the filament, to keep it taut. This made electrical contact through a copper coil to the leads.

The surface was operated with the mechanical interrupter using a DC supply and having the commutator rotating at 1200 rpm to keep as even a temperature as possible. A flickering effect was apparent to the eye but was not observable as a temperature variation with the pyrometer. The maximum temperature obtained was 1909° K. It was limited by the high resistance offered by the interrupter when in motion.

A study was made of the plate current with the filament at 1709° K and 1784° K. The plate voltage was varied and the plate current measured with a Leeds and Northrup highsensitivity (HS) galvanometer. No accurate readings could be made as the plate current fluctuated widely and in an irregular fashion.

Since the previous methods did not produce the desired characteristics it was thought that a filament having a low potential drop might produce the desired temperature with the available source of DC. If the potential drop could be maintained below eleven volts the production of positive carbon ions should be avoided and the difficulty explained by Sausville on the basis of such ions circumvented. A carbon surface made from spectrographic graphite was prepared, having a diameter of one-sixteenth inch and a length of two centimeters. To provide free expansion of the surface it was mounted in quarter inch copper rods which made electrical contact with the leads through a flexible copper coil containing approximately 225 copper wires 5 mil in diameter. The copper wires were silver soldered to copper caps which made a press fit with the holding rods. The surface was heated to a temperature of 2060° K with a potential drop of 5.3 volts. At this temperature the holding rods became red (800-900° K) and the zinc in the silver solder distilled to the inner wall of the envelope. The copper holding rods also melted to some extent. Carbon holding rods were used in place of the copper and a mechanical contact was made to the copper coil in place of the silver solder contact. By this means a temperature of 2020° K was achieved with a potential drop of 6.2 volts. At this temperature the fine copper wire melted due to the conduction of heat from the filament.

These observations have shown that it is possible to obtain the required temperature with a voltage drop less than the ionization potential of carbon. The problem remains of building a cooled lead which is flexible enough to provide for the expansion of the filament. Providing for this it should be possible to make electron affinity measurements without hinderance of positive carbon ions.