The Emission of Positive Ions from Heated Metals

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The positive ion emission from iron, nickel, copper, rhodium, columbium, platinum, uranium and thorium has been studied. In addition to the emission of singly charged atoms of the alkalies, reported by others, it is found that iron, nickel, copper, rhodium and columbium emit singly charged atoms of their own metals. The results from rhodium and columbium are in agreement with those already reported by H. B.Wahlin.

INTRODUCTION

FOR many years it has been known that positive electricity will leak away from a metal when the metal is heated to a visible red. This leakage has been found, in some cases at least, to be due to two types of ion emission (1) to positive ions of impurities[1,2,3] in the metal (2) to positive ions of the metal[4,5] itself. Mass-spectrographic studies indicate that the first type of emission, from a given sample of metal, can be reduced to zero by sufficient heating and aging of the sample. In this paper we shall be primarily interested in the second type of positive ion emission.

That a well-aged tungsten filament emitted positive ions when heated to a high temperature, was first discovered by Jenkins[6] and independently by L. P. Smith.[7]

By means of a Dempster type mass-spectrograph, Smith[4] made an analysis of the positive ion emission from both tungsten and molybdenum. In addition to the ions of the alkalies, which were emitted at relatively low temperatures, he found that, when the temperatures of the respective metals were sufficiently high to produce fairly rapid vaporization, ions corresponding to singly charged atoms of the metals were emitted.

While Smith's work was in progress, H. B. Wahlin[8] was making similar investigations and reported that tungsten, molybdenum, tantalum and rhodium each emitted singly charged atoms of its own metal. Later Wahlin[5] reported similar results for chromium, columbium and ruthenium.

The author has made a mass-spectrographic examination of the positive ion emission from iron, nickel, copper, rhodium, columbium, platinum,

[1] O. W. Richardson, *Emission of Electricity from Hot Bodies.*
[2] J. J. Thomson, *Conduction of Electricity through Gases.*
[3] Barton, Harnwell and Kunsman, Phys. Rev. **27,** 739 (1926).
[4] L. P. Smith, Phys. Rev. **35,** 381 (1930).
[5] H. B. Wahlin, Phys. Rev. **37,** 467 (1931).
[6] Jenkins, Phil. Mag. **47,** 1025 (1924).
[7] Smith, Phys. Rev. **33,** 279 (1929).
[8] Wahlin, Phys. Rev. **34,** 164 (1929).

uranium and thorium. The mass-spectrograph used was essentially the same as that used by Smith.[4] The positive ion currents from the mass-spectrograph were measured by means of an FP-54 Pliotron and a high sensitivity galvanometer, the maximum current sensitivity being of the order of 10^{-16} amperes.

Experimental Work and Results

In addition to the sodium and potassium emission observed by others,[1,2,3,4,5] the author has found that when platinum is first heated to a dull red, a relatively weak emission of rubidium and caesium ions is obtained. The purpose of the investigation, however, was to find out, in the case of each metal tried, whether or not positively charged atoms of the metal itself would be emitted when the metal was heated.

Iron and Nickel

Filaments of iron and nickel, when heated to temperatures just below their respective melting points, were found to emit singly charged atoms of these metals, but the filaments lasted only a few seconds because of the high temperature required to get the emission. This made it impossible to obtain data on the positive ion currents. In order to obtain an emission which would last long enough to make possible a more accurate recording of the location of the ions on the mass scale, a source of the following type was tried.

A wire of the metal to be investigated, was rolled out into a uniform strip from two to three thousandths of an inch thick. One end of the strip was then made pointed so that it could enter a small wire die. A piece of nickel wire about 0.02 inch in diameter was placed in contact with the strip and the two were drawn through the die. This left the strip in the shape of a trough and

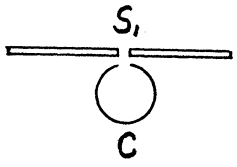

Fig. 1.

with continued drawing of the trough alone, through successively smaller dies, it took on the shape of a cylindrical shell with a slit down the side. The ends of this cylindrical shell were then spot welded to the filament leads of the mass-spectrograph and it was placed in front of the slit S_1 as shown in Fig. 1. Fig. 1 is an end view of the slit S_1 (the first slit of the mass-spectrograph) and the cylindrical shell C. The shell was heated by means of an electric current.

Because of radiation the outside of such a source is cooler than the inside. Thus the shell may be cool enough on the outside to support its own weight, while on the inside it is hot enough to vaporize quite rapidly and give a measurable emission of positive ions.

From one nickel source of this type an emission of positive ions of nickel was maintained for more than an hour before the cylinder melted. Data taken

with this source are shown by the first curve in Fig. 2. The currents were very small, of the order of 10^{-16} to 10^{-15} amperes, and in this case not very steady, as is shown by the roughness of the curve. The mass scale was checked by the potassium peak from the same source, and as is shown the two peaks fall quite close to atomic weights 58 and 60, the mass numbers of the two isotopes of nickel.

A large number of iron sources, of the type described above, were tried but the emission of positive ions of iron was never maintained for more than three or four minutes before the cylinder melted. This did not allow sufficient

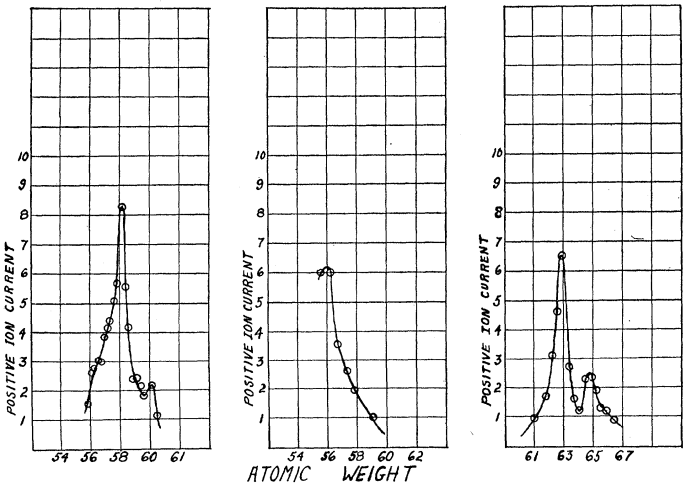

Fig. 2.

time for data to be taken on a complete peak. The second curve of Fig. 2 shows that part of the curve due to iron ions which it was possible to obtain before the cylinder melted.

It may be of interest to note that the melting point of iron is nearly 100° higher than that of nickel and that the rate of vaporization[9] of iron, just below its melting point, is a little higher than for nickel just below its melting point. The above results show, however, that nickel gives the stronger ion emission. The ionization potentials for iron and nickel[10] are 7.83 volts and 7.63 volts respectively. One might raise the question whether or not the difference in the emission in the two cases could be due to this small difference in ionization potentials.

Copper

The author has previously reported[11] that positive ions of copper were obtained when the copper was supported and heated by a tungsten filament. In that case, due precaution was not taken to avoid the possibility of obtain-

[9] Jones, Langmuir and MacKay, Phys. Rev. **30,** 201 (1927).
[10] Ruark and Urey, *Atoms, Molecules and Quanta.*
[11] L. L. Barnes, Phys. Rev. **37,** 218 (1931).

ing copper ions produced by thermal ionization of the copper vapor striking the hot tungsten filament. The production of copper ions by this method has been described by Kingdon.[12]

To make certain that no mistake had been made in saying that the copper ions were emitted by the copper itself, a thin strip of copper was bent into the shape of a trough and placed over the straight tungsten filament and then closed on the under side of the filament. This source was placed at right angles to the slit of the mass-spectrograph so that no part of the tungsten was exposed to the slit. With such an arrangement all ions entering the slit must come from the copper surface. With this source the third curve in Fig. 2 was obtained, showing the two isotopes of copper at atomic weights 63 and 65.

Wahlin[13] has recently reported that he has obtained positive ions of copper at a temperature just below and at the melting point of the metal.

Rhodium

The two peaks shown in Fig. 3 were obtained from a rhodium filament at a temperature of about 1800°C. The smaller peak falling at atomic weight 103 corresponds to singly charged atoms of rhodium and the larger peak at 137 to singly charged atoms of barium. A recent communication from the company from which the rhodium was purchased, states that they have detected,

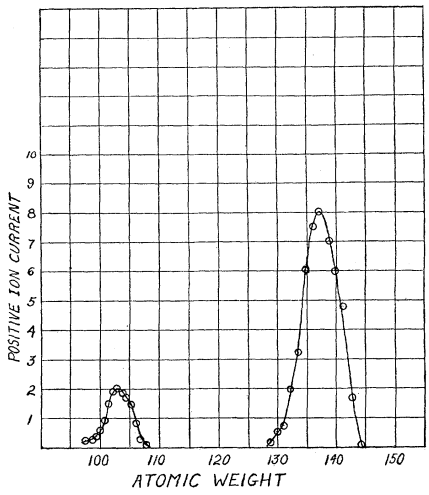

Fig. 3.

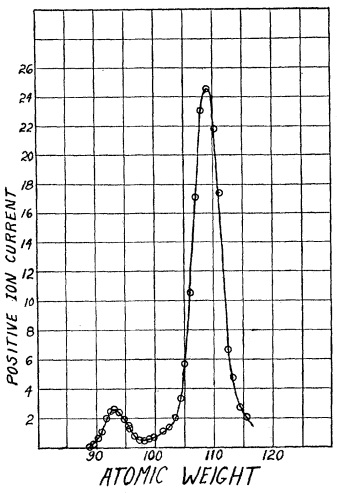

Fig. 4.

by spectroscopic analysis, a trace of barium in all of the samples of rhodium which they have tested. The fact that the barium ion current is larger than the rhodium ion current may be explained by the fact that the ionization potential for barium is so much lower than that for rhodium. One would expect that with both metals at the same temperature, a much greater percentage of the vaporized barium would be ionized than of the vaporized rhodium.

[12] Kingdon, Phys. Rev. **23,** 778 (1924).
[13] Wahlin, Phys. Rev. **38,** 1074 (1931).

The peak due to rhodium ions is a confirmation of results already reported by Wahlin.[5]

Columbium or Niobium

Fig. 4 shows two peaks due to positive ions from a columbium filament at a temperature of about 1800°C. The smaller peak at atomic weight 93 corresponds to singly charged atoms of columbium (also reported by Wahlin).[5] The larger peak at 109 is just 16 mass units greater than that due to columbium ions. It has been demonstrated by Wahlin[14] that uranium oxide ions and thorium oxide ions may be obtained from heated tungsten filaments containing these oxides. It would not be surprising if the columbium used here contained some of its own oxide, near the surface at least, and, in view of Wahlin's results, that some of the evaporating oxide comes off as CbO^+ (mass 109).

Platinum

Several attempts to obtain positive ions of platinum have resulted in nothing more than a rush of current at the time that the filament burned out. This rush of current accompanying the burning out of the filament came only if the accelerating potential, for the ions in the mass-spectrograph, happened to be set at approximately the correct value for platinum ions to be recorded. To be sure that it was not due to an electrical disturbance accompanying the burning out of the filament, a platinum filament was burned out with the accelerating potential set well off the value for platinum ions and no rush of ion current was observed. Both filaments and cylindrical shells, of the type used in the case of iron and nickel, were tried in an attempt to get an emission of platinum ions which could be recorded, but none was obtained.

Both Smith and Wahlin were unsuccessful in obtaining platinum ions by this method. Murawkin[15] reports that from a heated platinum foil alone he obtained no platinum ions but with an electrolytic layer of copper on a platinum foil he obtained a surprisingly large emission of platinum ions. The positive ion currents which he has recorded for platinum ions are some 10,000 times larger than the smallest current detectable in the author's experiments. If the ions which he obtains in this way are positive ions of platinum, it is, indeed, an interesting fact in view of its analogy to the enhanced electron emission from tungsten when covered with a layer of thorium.

Uranium and Thorium

Strips of uranium and thorium, very kindly provided by Professor Wahlin, were heated in the mass-spectrograph and a careful search for positive ions of these metals was made but none were found. This is in agreement with Wahlin's report.[5]

The author wishes to express his appreciation to Dr. L. P. Smith who was responsible for his first acquaintance with this field of research, and to Professors R. C. Gibbs and C. C. Murdock for their helpful suggestions and criticisms during the course of the work reported here.

[14] Wahlin, Phys. Rev. **39**, 183 (1932).
[15] Murawkin, Ann. d. Physik **8**, 385 (1931).