

of sulphur with oxygen, and argon with neon. However, if any significance can be attached to them, it would seem that a satisfactory range-velocity relation must take into consideration the electronic configuration of the recoiling atom, at least in the low energy regions where we cannot consider the recoil particle to be a nucleus stripped of all outer electrons. If this be true, it should lead to a regularity in the forms of the range-velocity curves for the various atoms corresponding to their positions in the periodic

table, as has been suggested by Feather. In any event, the simple empirical formula of Blackett and Lees has been shown definitely to be invalid, not only in this work but also in the earlier work of Feather and of Eaton.

In conclusion, it is a pleasure to thank Professor A. F. Kovarik for his constant advice and encouragement throughout the course of this work, Dr. F. N. D. Kurie for the camera castings and a blue-print of his latest design, and Dr. E. C. Pollard for much helpful advice.

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The Relative Abundance of the Isotopes in Mn, Cb, Pd, Pt, Ir, Rh and Co

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Using a new type of ion source, the abundances of the isotopes of Pd, Ir and Pt were measured and the atomic weights deduced from these values. The atomic weight of Ir was found to be quite different from the chemical value. The analysis of Mn and Cb confirmed the simple nature of these elements to a higher degree than known before. Evidence for the existence of Rh^{101} present to one part in 1300 of Rh^{103} was obtained. Likewise Co^{57} , present to one part in 600 of Co^{59} , was found.

INTRODUCTION

IT is only recently that the isotopic analysis of the last few remaining elements has been determined. Dempster¹ has given some results on Pt, Ir, Rh and Pd but has made no quantitative measurements of abundances. A more thorough search for isotopes of rhodium is of particular interest in view of the fact that it emits β -rays of two periods (44 sec. and 3.9 min., half lives) on irradiation with slow neutrons.² Since a knowledge of the relative abundances of isotopes in many other elements is desirable in view of the intensive study now in vogue of nuclear disintegration by various bombarding particles, it seemed worth while to re-examine some of the elements which may be studied by our method.

Apparatus

The apparatus used was the 180° permanent magnet mass spectrograph described in a previous paper.³ The arrangement was the same

except for the ion source, which is shown in Fig. 1. The substance to be analyzed was vaporized from a furnace of tungsten foil *W*. The ions were produced in the molecular jet by collisions with electrons entering from the opposite side of G_2 . G_2 is made of tantalum, the top and bottom being covered with platinum gauze. A small potential of about 1 volt was applied between G_2 and S_1 to draw the ions out. S_1 is a double slit, the two being placed 5 mm apart to prevent the high field between S_1 and S_2 from reaching into the ionization space and producing a velocity spread of the ion beam. The same system of focusing and deflecting the ion beam onto the entrance slit of the mass spectrograph was again applied. The electrons were emitted from a 7.5-mil tungsten filament *F*. A potential of 45 volts was applied between *F* and G_1 and a variable potential between G_1 and G_2 . For the production of multiply charged ions the total electron accelerating voltage was about 300 volts. The furnace *W* was made of 1-mil tungsten or tantalum foil, folded into a V shape. The ends of the foil were spot welded to heavy nickel leads. *R* is a tantalum radiation

¹ Dempster, Proc. Am. Phil. Soc. **75**, 755 (1935); Nature **136**, 909 (1935).

² Fermi *et al.*, Proc. Roy. Soc. **A146**, 483 (1934).

³ Sampson and Bleakney, Phys. Rev. **50**, 456 (1936).

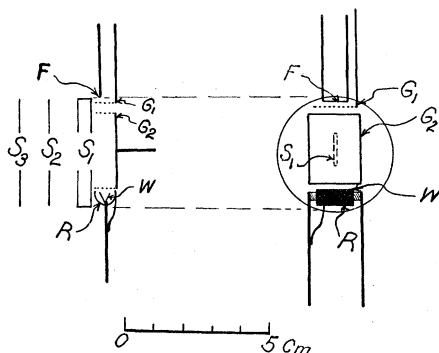


FIG. 1. Ion source. Ions produced by collisions of electrons from filament *F*, with vapor jet from tungsten furnace *W*. Slits *S*₁, *S*₂ and *S*₃ are 1.5 mm by 1 cm.

shield supported by one of the current leads, the whole structure being mounted on a ground glass joint to facilitate renewal of the furnace *W* or its contents. The furnace was heated by a suitably insulated low voltage transformer.

This type of ion source was found to work very well for nearly all the elements tried, giving a reasonably steady source of ions for some time, depending on the rate of vaporization. Multiply charged ions were produced quite effectively with this arrangement, which is particularly advantageous because the isotopes may be examined in several different "orders." The resolution for the higher masses is also greatly improved by using the multiply charged ions.

Palladium

Pure palladium metal was vaporized from the tungsten furnace giving very steady ion beams in several orders. The six isotopes given by Dempster¹ were confirmed and their abundances measured. The ion currents used were not sufficiently great to show any additional isotopes that might have been present in very small amounts. One of the plots taken for palladium is shown in Fig. 2. The mean values for eight measurements on the abundances are given below. The accuracy is believed to be about one part in one hundred.

Mass number	102	104	105	106	108	110
Percent abundance	0.8	9.3	22.6	27.2	26.8	13.5

The atomic weight of palladium, calculated by assuming a packing fraction of -6 and reducing to the chemical scale, is 106.6 from these measurements. The chemical value⁴ is 106.7.

⁴ Baxter, Hönigschmid and Le Beau, *J. Am. Chem. Soc.* **58**, 541 (1936).

Iridium

Dempster⁵ has shown iridium to consist of two isotopes of mass numbers 191 and 193, the latter being somewhat more abundant. Venkatesachar and Sibaiya⁶ have given the ratio of 193 to 191 as roughly 2 : 1 from their work on the hyperfine structure, and deduce an atomic weight of 192.4. Abundance measurements on iridium were made both for the singly and doubly charged ions. A plot of the Ir⁺⁺ ions is shown in Fig. 3. Masses 191 and 193 were found to comprise 38.5 and 61.5 percent respectively of the total ion current. The packing fraction has not been measured but from Aston's curve the masses of iridium must be nearly integral. The atomic

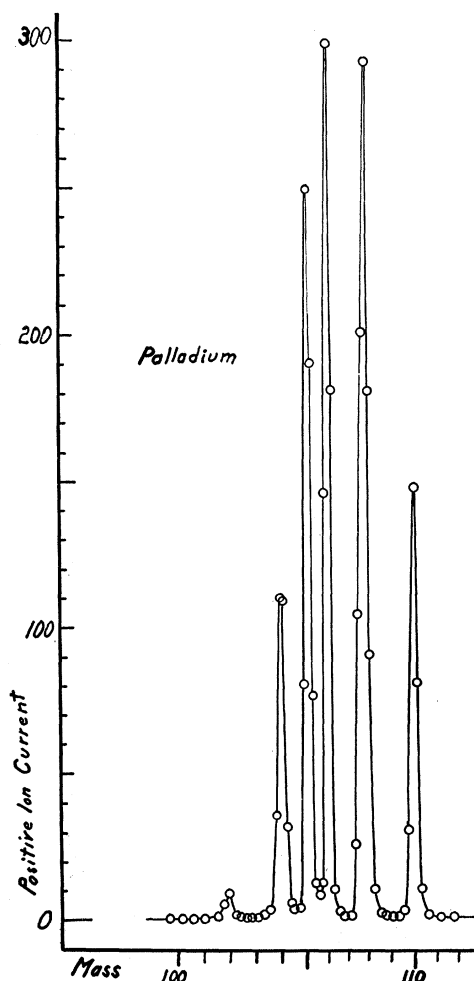


FIG. 2. Plot of singly charged palladium isotopes.

⁵ Dempster, *Nature* **136**, 902 (1935).

⁶ Venkatesachar and Sibaiya, *Proc. Ind. Acad. Sci.* **2**, 203 (1935).

weight of 192.2 thereby deduced is in very poor agreement with the chemical value⁴ of 193.1. It seems fairly certain that the value now in use is too high.

Platinum

Abundance measurements made on the platinum isotopes confirmed the isotopes given by Dempster. Doubly, triply and quadruply charged ions were readily produced. The abundances* given below are the average of four measurements, none of which deviated more than one part in 100 from the mean for the abundance of any one isotope.

Mass number	192	194	195	196	198
Percent abundance	0.8	30.2	35.3	26.6	7.2

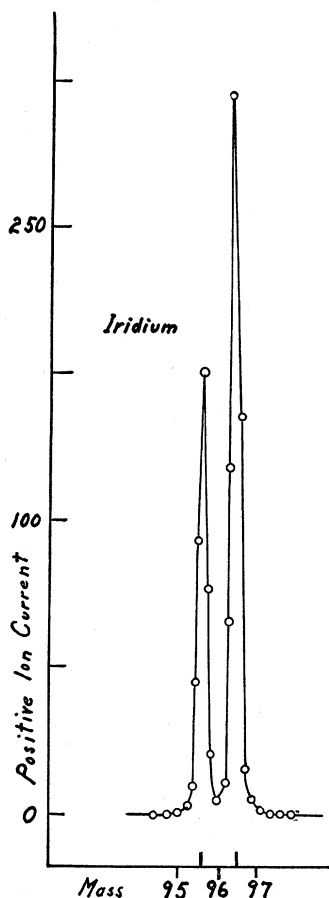


FIG. 3. Mass-spectrum plot of doubly charged iridium isotopes. Peaks at mass numbers 95.5 and 96.5 correspond to masses 191 and 193, respectively.

* Recently Kopfermann and Krebs, *Zeits. f. Physik* **101**, 193 (1936), have found abundances in rough agreement with those presented here.

If we assume a packing fraction of 0.5 from Aston's curve the atomic weight corrected to the chemical scale comes out to be 195.23 which is identical with the chemical value.

Columbium

This element was found to be very difficult to volatilize. A peak of 400 units at mass 93 was obtained however, confirming Aston's observation.⁷ No peaks appeared at mass numbers 91 and 95. No isotope of either of these masses is therefore present to a greater extent than 1 part in 400 of mass 93.

Manganese

Very large ion currents of this element were easily obtained in the three orders Mn^+ , Mn^{++} , Mn^{+++} . No isotope of either mass 53 or 57 was found to as much as one part in 15,000 of Mn^{55} .

Rhodium

Rhodium was tried in the hope of discovering an additional isotope, which would explain the presence of the two periods of artificial radioactive decay observed for this element.

Pure rhodium metal was vaporized from a tungsten furnace. Considerable trouble was experienced with this element because of the high temperatures (*ca.* 2500°C) necessary to vaporize the metal in sufficient quantities. The tungsten foils burned out very readily and results were only obtained after a large number of trials. Large peaks were obtained but were not sufficiently constant to give accurate values of their magnitudes. With a peak of 13,000 units at mass 103 one of 10 units at mass 101 was also observed. No isotope of mass 105 was found although 1 in 1000 of mass 103 would have been observable. The 101 peak maintained a reasonably constant ratio to the 103 peak under all experimental conditions. As no peak was observed at mass 102 the possibility of its being a ruthenium impurity of this mass is eliminated. With doubly charged ions of rhodium, peaks were observed at mass numbers 50.5 and 51.5 bearing the same ratio as for the singly charged ions. The ratio of the 103 to the 101 peak was concluded to be about 1300. The possibility of the 101 peak being due to a multiply charged

⁷ Aston, *Mass Spectra and Isotopes* (Arnold, 1933).

mercury ion is improbable since no peak was observed at this position except when the one due to Rh^{103} was more than 1000 units high and no other mercury isotopes were observed. It seems reasonably sure that these data represent a new isotope of rhodium. If we assume a packing fraction of -6 , the atomic weight of rhodium comes out to be 102.89, in fair agreement with the chemical value of 102.91.

Cobalt

Metallic cobalt was first tried and gave indications of an isotope of cobalt of mass 57 in addition to the one at 59. An impurity peak at mass 57 due to some vapor contamination in the tube was observed, so to get around this difficulty anhydrous cobalt chloride was tried with a tantalum furnace. CoCl^+ ions were found

at masses 92 ($\text{Co}^{57}\text{Cl}^{35}$), 94 ($\text{Co}^{57}\text{Cl}^{37}$, $\text{Co}^{59}\text{Cl}^{35}$) and 96 ($\text{Co}^{59}\text{Cl}^{37}$) in relatively large intensities. An average run gave the following results.

Mass number	92	94	96
Height of peak	4	2400	740 cm

These results agree with the known abundances of the two chlorine isotopes and it is concluded that Co^{57} is present to 1 part in 600 of Co^{59} . Since no peaks were observed due to a mass 56, the possibility of an iron impurity is eliminated. Results on the irradiation of cobalt with slow neutrons lend support to this analysis.⁸

A grant from the Penrose fund of the American Philosophical Society aided us greatly in this research.

⁸ Sampson, Ridenour and Bleakney, *Phys. Rev.* **50**, 382 (1936).

Positive and Negative Thermionic Emission from Tungsten

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The positive and negative thermionic emission and the rate of evaporation of neutral atoms have been studied for well outgassed tungsten. To fix a reliable temperature scale the spectral emissivity for $\lambda=0.669\mu$ has been determined for a cylinder heated in a vacuum. The emissivity has been found to be a constant and equal to 0.46 from 1200°K–2200°K. A determination of the heat of evaporation of neutral atoms gave a value of 8.44 ev. The electron work

function was found to be 4.55 ev with an A of 75 amp./cm²/degree² until the filament was heated to a temperature of 3100°K, after which the work function was 4.63 ev and the value of A was 212. The average positive ion work function was 11.93 ev. This value closes the thermionic cycle if Russell's value of 8.1 for the ionization potential is used.

INTRODUCTION

THE positive ion work function of tungsten has been determined by Smith¹ and by Moon² with results which are far from agreement. Thus Smith found a value of 6.44 ev, and Moon a series of values between 10 and 11 ev. The discrepancy in these results led the writers to undertake the experiments described below in order to determine if, with improved technique, more consistent values could be obtained.

Smith has shown that the following relation should hold:

$$H+I=\varphi_{0-}+\varphi_{0+} \quad (1)$$

where H is the heat of evaporation of neutral atoms, I the ionization potential, φ_{0+} the positive ion work function, and φ_{0-} that of the electrons.

Of these quantities φ_{0-} is the only one which is known with any degree of certainty. Smith assumes a value of 7.1 volts for the ionization potential and Russell³ estimates it to be 8.1 volts. Jones, Langmuir and McKay⁴ calculated the heat of evaporation to be 8.33 ev, but their calculations are based on evaporation data obtained at a time when vacuum conditions had not been developed to the present extent, so this value is somewhat questionable. Further-

¹ L. P. Smith, *Phys. Rev.* **35**, 381 (1930).

² P. B. Moon, *Proc. Camb. Phil. Soc.* **28**, 490 (1932).

³ H. N. Russell, *Astrophys. J.* **70**, 11 (1929).

⁴ Jones, Langmuir and McKay, *Phys. Rev.* **30**, 201 (1927).