MASSES OF Ru^{98}, Ru^{99}, Os^{189}, and Os^{192}.

MASSES OF Ru^{98}, Ru^{99}, Os^{189}, and Os^{192}.

By

EDWIN MCFARLANE PENNINGTON, B. Sc.

A Thesis

Submitted to the Faculty of Arts and Science

in Partial Fulfilment of the Requirements

for the Degree

Master of Science

McMaster University

October 1954

MASTER OF SCIENCE (1954) McMASTER UNIVERSITY
(Physics) Hamilton, Ontario

TITLE: Masses of Ru^{98}, Ru^{99}, Os^{189}, and Os^{192}.

AUTHOR: Edwin McFarlane Pennington, B. Sc. (McMaster University)

SUPERVISOR: Professor H. E. Duckworth

NUMBER OF PAGES: vi, 15.

SCOPE AND CONTENTS: Mass spectrographic masses have been determined for the nuclides Ru^{98}, Ru^{99}, Os^{189}, and Os^{192}. The Ru masses are used in a discussion of the Mo - Ru isobaric mass differences. A packing fraction curve is drawn for the heavy elements from previous mass spectrographic data combined with the Os masses. This curve is used to predict several masses of atoms of odd mass number.

ACKNOWLEDGEMENT

I am indebted to Professor H. E. Duckworth for his assistance during the course of the experimental work and in the preparation of this thesis. I also wish to thank Professor A. B. McLay for reading the original manuscript and suggesting improvements.

It is a pleasure to acknowledge financial assistance in the form of a scholarship from the Research Council of Ontario.

TABLE OF CONTENTS

	Page
Introduction and Experimental	1
Mass Differences	4
Discussion of Measured Doublets	4
Summary of New Mass Values	6
Mo - Ru Isobaric Mass Differences	6
Packing Fraction Curve	8
Prediction of Odd A Masses from Packing Fraction Curve	9
Bibliography	12
Figures	14

LIST OF TABLES

Table		Page
I	List of New Mass Differences	4
II	List of New Mass Values	6
III	Packing Fractions of Heavy Isotopes	8
IV	Masses Predicted from Figure 2	10

LIST OF FIGURES

Figure		Page
1	Mo - Ru Mass Differences	14
2	Packing Fraction Curve	15

INTRODUCTION AND EXPERIMENTAL

There are three main reasons for measuring atomic masses. The first and most obvious one is that as pure scientists we simply want to know how heavy the various atoms are. Secondly, atomic masses can be used to predict the energy available for beta decay of nuclei or to check Q values of decay schemes already studied by beta and gamma spectroscopists. (The Q value of a decay scheme is the total energy difference between the parent and daughter atom). Finally, accurate atomic masses are useful in checking theories of nuclear structure. Thus we can test the predictions of the semi-empirical mass formula of Weizsäcker (20) or the theory of nuclear shell structure (20). The shell structure theory associates greater stability and hence a lower mass with atoms having certain "magic numbers" of protons and neutrons.

The measurements reported below were made by the doublet method using the Dempster-type mass spectrograph at McMaster University (2). The description of this instrument follows. Ions from the source are accelerated in a 1/8" space by about 16,000 volts and, after passing through two collimating slits, enter the electrostatic analyser. This consists of a 90° cylindrical condenser which has a radius of curvature of 7.90" and a plate separation of .200". The voltage across this condenser is maintained by B batteries. After travelling through this condenser, the ions enter a uniform magnetic field and follow a semi-circular path to a photographic plate 10" in length. The position of best focus on the plate corresponds to a radius of curvature of 9.1"

in the magnetic field. A highly stabilized power supply provides the current for the magnet coils and produces a field of the order of 6,000 gauss in the 1/8" gap. The source and analysing regions which are separated by the collimating slits are pumped independently by diffusion and backing pumps.

Ions from two atomic species of almost the same ratio of charge to mass will strike the photographic plate at slightly different places. Hence they produce two closely spaced lines which if resolved are referred to as a doublet. For example, triply-charged Gd^{156} and singly-charged Cr^{52} form a doublet at mass 52. By measuring the positions of the Cr^{52}, Gd^{156} and Cr^{53} lines on the plate with the aid of a microscope, one can calculate the mass difference $1/3\ Gd^{156} - Cr^{52}$, and hence the mass of Gd^{156} if the mass of Cr^{52} is known accurately. The position of the Cr^{53} line has to be measured in order to provide the "mass scale" used in the calculations. Often mass differences are expressed in terms of packing fraction differences. The packing fraction is defined as $f = (M - A) / A$ where M is the mass of the atom in question in atomic mass units (a.m.u.) and A is its mass number. The atomic mass unit is defined by assigning a mass of 16 to O^{16}. Thus the packing fraction of O^{16} is zero. It has been found that very light and very heavy atoms have positive packing fractions while those of intermediate mass have negative ones.

In order to obtain accurate results, it is necessary that the doublets to be measured are matched in intensity. This is partly because of the fact that a line may not be symmetrical about its maximum and partly because of psychological effects involved in

measuring lines of unequal intensity.

For the experiments reported below, ions were produced in the source by a high frequency spark which took place between a nickel tube and a brass or lead diaphragm with a small hole in the centre leading to the accelerating region. The materials to be studied were packed in the nickel tube in powdered form in such a proportion as to yield doublets matched in intensity. Throughout the experiments the pressure in the analysing region, read on an ionisation gauge, was below 10^{-5} mm. Hg. Unfortunately it was necessary in some cases to use exposure times of as long as half an hour in order to obtain lines of reasonable intensity. Slight field variations during these long exposure times led to lines which were wider than desired. Sometimes intensity considerations made it necessary to use rather wide slits which also resulted in wide lines.

MASS DIFFERENCES

Table I tabulates the mass differences measured in this investigation.

TABLE I

List of New Mass Differences

Doublet	Mass Difference (Millimass units)	Previous Measurements
1/2 Pt^{196} - Ru 98	77.03 ± 25	
1/2 Pt^{198} - Ru 99	76.33 ± 20	81.8 ± 20 (1)
		78.4 ± 10 (10)
1/3 Os^{189} - Cu^{63}	56.6 ± 3	
1/3 Os^{192} - Ni^{64}	59.90 ± 24	

DISCUSSION OF MEASURED DOUBLETS

(a) Ruthenium Doublets

(1) Mass 98

Doubly-charged Pt^{196} forms a doublet at mass 98 with Ru^{98}. Measurements were made of six 1/2 Pt^{196} - Ru^{98} doublets with the spacing between Pt^{194} and Pt^{196} being used as the mass scale. The masses used for Pt^{194} and Pt^{196} in these calculations are 194.0241 ± 6 a. m. u. and 196.0267 ± 6 a. m. u. respectively (12). The mass found for Ru^{98} is 97.93632 ± 40 a. m. u. No previously determined values for the mass of Ru^{98} exist with which this value can be compared.

(ii) Mass 99

Measurements of nine 1/2 Pt^{198} - Ru^{99} doublets were made with the Pt^{196} - Pt^{198} spacing serving as the mass scale. The value used for the mass of Pt^{198} is 198.0283 ± 6 a. m. u. (12), (3). (An error in arithmetic leading to the different mass given in reference (12) has been corrected). This leads to a mass of 98.93782 ± 36 a. m. u. for Ru^{99}. Previous measurements of this doublet have been made by Dempster (1) and Graves (10). Their mass differences combined with the above mass value for Pt^{198} yield for Ru^{99} the masses 98.9324 ± 20 a. m. u. and 98.9358 ± 10 a. m. u. respectively. Although the new value does not agree with the previous values within the probable error, it is not felt that the disagreement is great enough to be significant.

(b) Osmium Doublets

(i) Mass 63

The doublet formed by triply-charged Os^{189} and singly-charged Cu^{63} was photographed at mass number 63 with the Cu^{63} - Ni^{64} apparation being used as the mass scale. The Cu^{63} and Ni^{64} masses used in the calculations are 62.94926 ± 6 a. m. u. and 63.94755 ± 7 a. m. u. respectively (11). From measurements of five doublets, the mass of Os^{189} was found to be 189.0177 ± 9 a. m. u. There are no other experimental values with which this mass can be compared.

(ii) Mass 64

The doublet at mass 64 consisting of triply-charged Os^{192} and singly-charged Ni^{64} was photographed with the mass scale being the

Cu^{63} - Ni^{64} spacing. Measurements of nine doublets resulted in a mass of 192.02235 ± 75 a. m. u. for Os^{192} . The mass of Os^{192} has been previously found from the 1/2 Os^{192} - Mo^{96} doublet (9), (11) to be 192.0225 ± 5 a. m. u. It is seen that the two values are in excellent agreement.

SUMMARY OF NEW MASS VALUES

The new mass values obtained in this investigation are listed in Table II.

TABLE II

List of New Mass Values

Ru^{98}	=	97.93632 ± 40 a. m. u.
Ru^{99}	=	98.93782 ± 36 a. m. u.
Os^{189}	=	189.0177 ± 9 a. m. u.
Os^{192}	=	192.02235 ± 75 a. m. u.

Mo - Ru ISOBARIC MASS DIFFERENCES

It is instructive to plot the isobaric Mo - Ru mass differences vs. mass number as is done in Figure 1. An approximately linear plot is predicted by the semi-empirical mass formula. Many plots of this nature have been made by K. Way and M. Wood (14) by using experimental total beta-disintegration energies.

The points used in the plot were obtained as follows. At mass 96 Geiger et al (9) have found mass-spectrographically that the Mo - Ru difference is - 2.8 $\pm$ 0.2 Mev. The value reported above for Ru^{98} is combined with that of Duckworth and Preston (5), (12) for Mo^{98} to give $Mo^{98} - Ru^{98} = - 0.55 \pm 0.53$ Mev. Two values of the Mo - Ru difference are available at mass 99. The mass of Ru^{99} given above can be combined with the mass of Mo^{99} found from a (γ, n) reaction on Mo^{100} (4), (6) to give $Mo^{99} - Ru^{99} = 0.80 \pm 0.54$ Mev. Also the $Mo^{99} - Ru^{99}$ difference can be found from the $Mo^{99} - Tc^{99}$ and $Tc^{99} - Ru^{99}$ decay schemes (13) to be 1.66 Mev. Finally at mass 101 the $Mo^{101} - Tc^{101}$ and $Tc^{101} - Ru^{101}$ decay schemes (17) give $Mo^{101} - Ru^{101} = 4.10$ Mev.

The Mo - Ru differences calculated from the semi-empirical mass formula (8) are also plotted. These values are $Mo^{96} - Ru^{96} = -4.34$ Mev., $Mo^{98} - Ru^{98} = - 1.30$ Mev., $Mo^{99} - Ru^{99} = 0.14$ Mev., $Mo^{101} - Ru^{101} = 2.87$ Mev. It is seen that the curve given by the mass formula is approximately parallel to the experimental one although displaced by about 1 to 1.5 Mev.

The mass spectrographic values at masses 98 and 99 deviate from the experimental curve in Figure 1 by slightly more than the probable error. The graph suggests that either the Ru masses are too high or the Mo masses too low at these two mass numbers.

PACKING FRACTION CURVE

TABLE III

Packing Fractions of Heavy Isotopes (X 10^{-4})

Dy^{160} = -1.55 ± 0.09	Ta^{181} = 0.21 ± 0.04	Pt^{196} = 1.36 ± 0.03
Dy^{162} = -1.36 ± 0.07	W^{182} = 0.23 ± 0.04	Pt^{198} = 1.43 ± 0.03
Dy^{164} = -1.13 ± 0.09	W^{183} = 0.36 ± 0.04	Tl^{203} = 1.72 ± 0.05
Ho^{165} = -1.08 ± 0.05	W^{184} = 0.40 ± 0.04	Tl^{205} = 1.85 ± 0.05
Er^{164} = -1.05 ± 0.07	Os^{188} = 0.84 ± 0.03	Pb^{204} = 1.78 ± 0.05
Er^{168} = -0.90 ± 0.02	Os^{189} = 0.94 ± 0.05	Pb^{206} = 1.88 ± 0.05
Er^{170} = -0.55	Os^{190} = 0.92 ± 0.03	Pb^{207} = 1.96 ± 0.05
Hf^{176} = -0.24 ± 0.04	Os^{192} = 1.17 ± 0.03	Pb^{208} = 2.00 ± 0.05
Hf^{178} = -0.07 ± 0.05	Pt^{194} = 1.24 ± 0.03	Bi^{209} = 2.13 ± 0.05
Hf^{180} = 0.17 ± 0.04	Pt^{195} = 1.36 ± 0.03	

Figure 2 shows the packing fraction of isotopes plotted against mass number for mass numbers from 160 to 210. The values used in this plot are shown in Table III. They were derived chiefly from the table of atomic masses in reference (12). In addition the packing fractions of Os^{189}, Ta^{181}, Tl^{203} and Tl^{205} are plotted. The value for Os^{189} comes from the mass measurements described above while the last three packing fractions were found as follows. A mass of 181.0038 ± 7 a. m. u. for Ta^{181} and hence the listed packing fraction was derived from the mass of W^{182} (12), the known $Ta^{182} - W^{182}$ mass difference of .00224

a. m. u. (7), and the Q's of the Ta^{181} (d,p) Ta^{182} and Ta^{181} (n,γ) Ta^{182} reactions (15). A Tl^{205} mass of 205.0380 $\pm$ 10 a. m. u. was found from the mass of Pb^{206} (12), the Tl^{206} - Pb^{206} beta-decay energy (13), and the Q's of the Tl^{205} (n,γ) Tl^{206} and Tl^{205} (d,p) Tl^{206} reactions (15). Finally the Tl^{205} (γ, n) Tl^{204} threshold was combined with the Tl^{203} (n,γ) Tl^{204} and Tl^{203} (d,p) Tl^{204} reactions to give for Tl^{203} a mass of 203.0350 $\pm$ 10 a. m. u. (15).

PREDICTION OF ODD A MASSES FROM PACKING FRACTION CURVE

On Figure 2 curves were drawn through the even A isotopes of each element. Then the envelope of these curves and a curve parallel to the envelope passing through or close to the odd A isotopes were constructed. From the curve through the odd A isotopes it is possible to predict the masses of some nuclides whose masses have not as yet been determined experimentally. These masses are shown in Table IV.

TABLE IV

Masses Predicted From Figure 2

Nuclide	Packing Fraction ($\times 10^{-4}$)	Mass (a. m. u.)
Tm^{169}	-0.78 ± 0.05	168.9868 ± 8
Re^{185}	0.54 ± 0.05	185.0100 ± 9
Re^{187}	0.70 ± 0.05	187.0131 ± 9
Ir^{191}	1.03 ± 0.05	191.0197 ± 10
Ir^{193}	1.18 ± 0.05	193.0228 ± 10
Au^{197}	1.42 ± 0.05	197.0280 ± 10

From the masses of the Re and Ir isotopes and their relative abundances (19), the chemical atomic weights of Re and Ir can be calculated. (Note that conversions to the chemical scale of masses reported on the physical scale are made by using the divisor 1.000275). These calculations result in values of 186.22 for Re and 192.20 for Ir. The accepted chemical atomic weight of 186.31 for Re agrees fairly well with this calculated value but the hitherto accepted value of 193.1 for Ir is in error by a large amount. However the Committee on Atomic Weights of the American Chemical Society has recently changed the value for Ir to 192.2 (16) in order to make it agree with mass spectrometric data.

It will soon be possible to check the mass of Au^{197} predicted

above since it can be computed from the mass of Hg^{198} which is being measured by J. T. Kerr on the McMaster mass spectrograph.

BIBLIOGRAPHY

1. Dempster, A. J. Phys. Rev. 53 : 64. 1938.
2. Duckworth, H. E. Rev. Sci. Instruments. 21 : 54. 1950.
3. Duckworth, H. E., Johnson, H. A., Preston, R. S., and Woodcock, R. F. Phys. Rev. 78 : 386. 1950.
4. Duckworth, H. E., Preston, R. S., and Woodcock, K. S. Phys. Rev. 79 : 188. 1950.
5. Duckworth, H. E., and Preston, R. S. Phys. Rev. 82 : 468. 1951.
6. Duffield, R. B. Private communication to H. E. Duckworth. April 26, 1951.
7. Engelkemeir, D. W., Freedman, M. S., and May, J. ANL - 4473. June 20, 1950.
8. Fermi, E., Orear, J., Rosenfeld, A. H., and Schluter, R. A. Nuclear Physics. University of Chicago Press. 1951.
9. Geiger, J. S., Hogg, B. G., Duckworth, H. E., and Dewdney, J. W. Phys. Rev. 89 : 621. 1953.
10. Graves, A. C., Phys. Rev. 55 : 863. 1939.
11. Hogg, B. G., and Duckworth, H. E. Can. J. Phys. 31 : 942. 1953.
12. Hogg, B. G., and Duckworth, H. E. Can. J. Phys. 32 : 65. 1954.
13. Hollander, J. M., Perlman, I., and Seaborg, G. T. Table of Isotopes. UCRL - 1928 Revised. December, 1952.
14. Way, K., and Wood, M. Phys. Rev. 94 : 119. 1954.
15. Whaling, W. Table of Nuclear Reaction Q Values. Unpublished. Nov. 17, 1952.

16. Wichers, E. Jour. Am. Chem. Soc. 76 : 2033. 1954.

17. Wiles, D. R. Phys. Rev. 93 : 181. 1954.

GENERAL REFERENCES

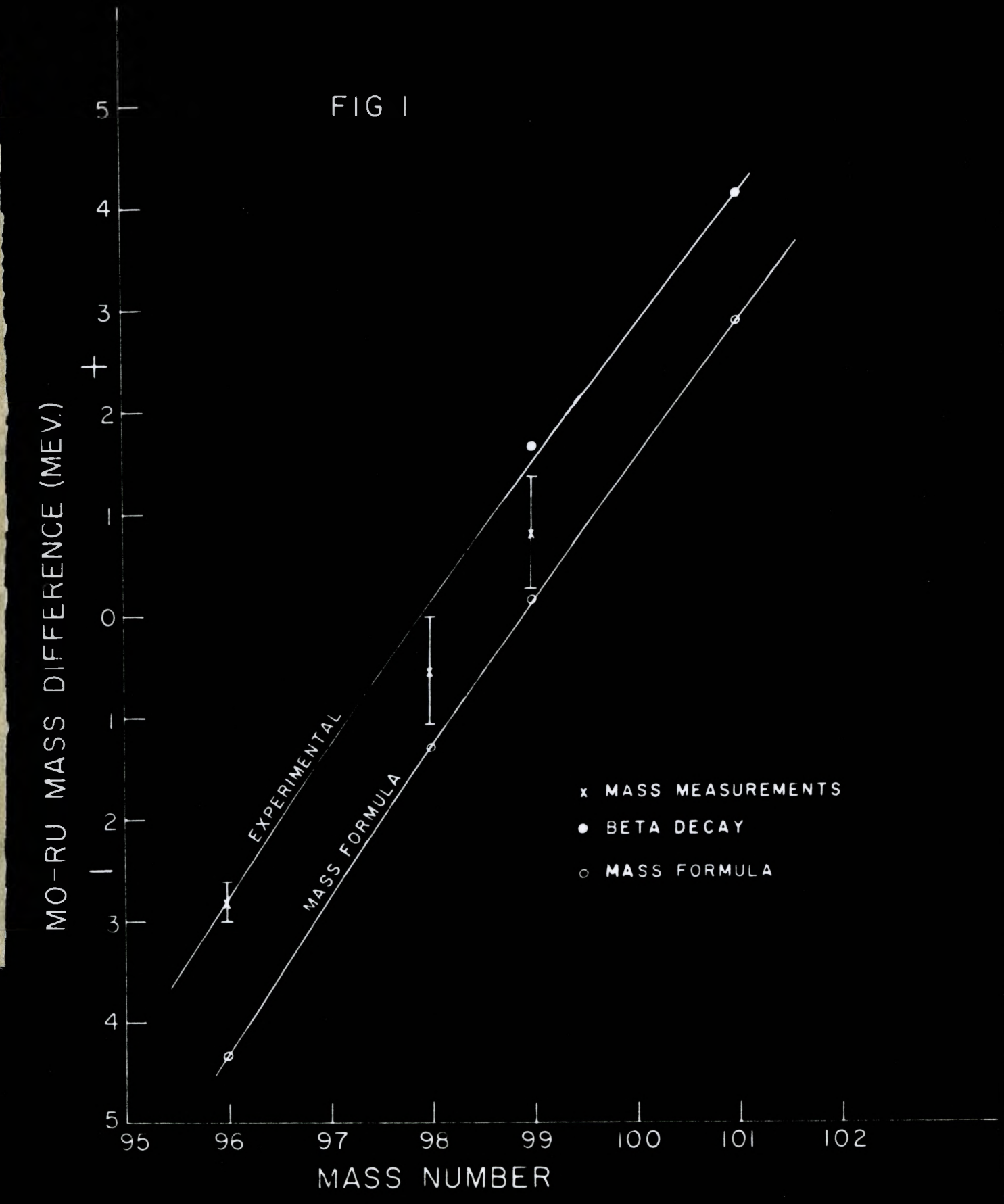
18. Aston, F. W. Mass Spectra and Isotopes. Edward Arnold and Company. London. 1933.

19. Bainbridge, K. T. Experimental Nuclear Physics. Vol. I. Part V. John Wiley and Sons. New York. 1953.

20. Blatt, J. M., and Weisskopf, V. F. Theoretical Nuclear Physics. John Wiley and Sons. New York. 1952.

21. Mass Spectroscopy in Physics Research. National Bureau of Standards. Circular 522. 1953.

FIG 1


MO-RU MASS DIFFERENCE (MEV.)
+
5
4
3
2
1
0
1
2
3
4
5
EXPERIMENTAL
MASS FORMULA
x MASS MEASUREMENTS
● BETA DECAY
○ MASS FORMULA
95
96
97
98
99
100
101
102
MASS NUMBER

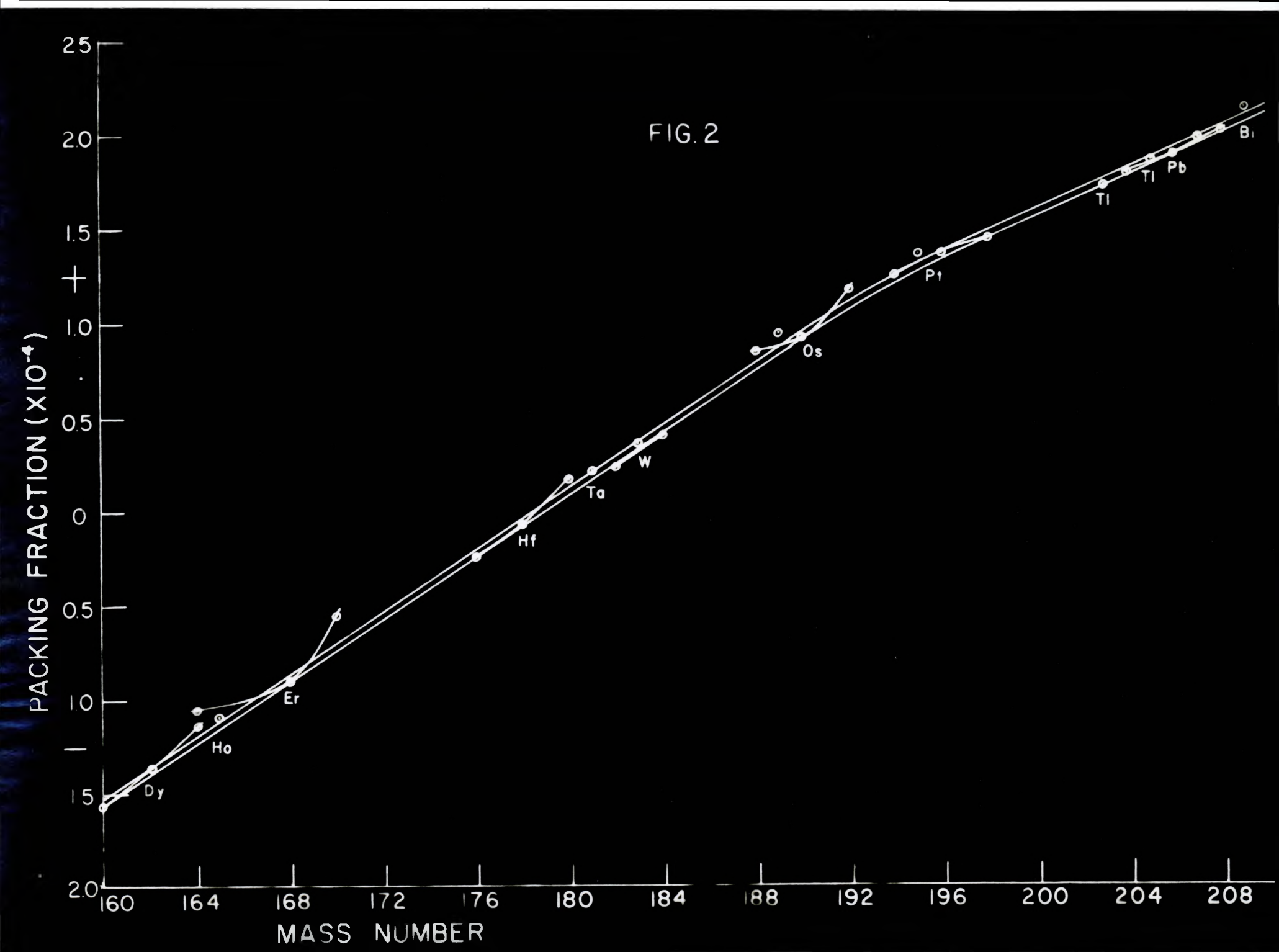


FIG. 2
PACKING FRACTION (X10⁻⁴)
+
−
2.5
2.0
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
Dy
Ho
Er
Hf
Ta
W
Os
Pt
Tl
Tl
Pb
Bi
160
164
168
172
176
180
184
188
192
196
200
204
208
MASS NUMBER