On the Radioactive and the Non-radioactive Isotopes.

By

Takeo Hori.

(Received Octber 2, 1925)

Starting on the assumption that the radioactive series could continue below the so-called end-products. I tried to connect the common isotopes by curves similar to those characteristic of radioactive disintegration.

As is generally accepted, the ultimate constituents of the nucleus of an atom may be helium nuclei; hydrogen nuclei, or protons; and electrons, the number of protons being never greater than three. It seems therefore natural to suppose (1) that an atom of greater mass, if it disintegrated, might lose either an α-particle or an electron, the protons being held in the innermost protion of the nucleus too firmly to come into play; and (2) that the disintegration series above imagined are limited to four in number, the members belonging to which are the atoms the nuclei of which contain 0, 1, 2, and 3 protons respectively. In support of the first supposition we have also the behaviour of "C-bodies" in the radioactive region, which show great similarity in their mode of disintegration irrespective of the number of surplus protons and electrons contained in their nuclei.[1]

Now, according to Meitner's theory, which is intended to explain certain features of the radioactive transformation, there are four possible types of disintegration, namely:

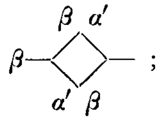
(I) a successive emission of α-particles: α-α-α-. . . . . . . ;

(II) an α'-emission, followed by two β-ray transformations: α'-β-β (α' represents the α-particle associated with two β-particles, forming a sub-group within the nucleus.);

---

1 J. Frank. Inst., **198**, 725 (1924).

(III) a β-emission, which leads to the occurrence of a branching and a re-uniting as is shown by



(IV) a branching of the form $<^{\alpha}_{\alpha'}$ or $<^{\alpha}_{\beta}$ that gives rise to two independent series.

In connecting the isotopes (those of the elements below Cu being for a while left out of account), hitherto known by virtue of the experiments of Aston and others, the atomic masses of which are given by 4n and 4n+2, it is found (1) that the possible mode of "disintegration" is of the type α-α-α . . . , α'-β-β, and β-β-α', making allowance also for the possible branching of the form $<^{\alpha}_{\beta}$; (2) that the first "β-rayer" is unstable (Non-occurrence is assumed to be an indication of instability); and (3) that there may occur an "α-rayer" that is unstable (See Fig. 2). In accordance with these results is the transformation in the radioactive U- and Th- series.

If in the other two series 4n+1 and 4n+3 the characteristic successive changes are assumed to be α-α-α . . . . and $\beta\alpha'\beta\alpha$, where the "β-rayers" are unstable, then every known isotope of odd atomic mass assumes a position in such series of transformation as an "α-rayer," the only exception being Cd (48, 113) if the Aston's result is true. We see here that in the change $\beta\alpha'\beta\alpha$ either α or α' may be unstable (See Fig. 1). These characteristics are now found in the radioactive Ac-series, but the experimental evidence concerning this series is not yet enough advanced to settle its position relative to U- and Th-series.

Now take a step farther and attempt to find the "disintegration curves" passing through the unknown isotopes. It may then be not unreasonble to make the following assumptions, all concordant with the results in the region of known isotopes.

(1) An element of odd atomic number, whose atomic weight is equal to or a little less than an odd integer is simple.

(2) An element of odd atomic number, whose atomic weight exceeds an odd integer by a fraction or a unit, consists of two isotopes of odd atomic masses differing by two units, the atomic weight of the element intervening between them.

The following table shows the odd elements (Cl, K, and all odd elements above V), thier atomic weights, and their isotopes. Those marked with an asterisk are the assumed mass numbers.)

Table.

Elements.	Atomic weight	Isotopes
Cl (17)	35·46	35,37
K (19)	39·10	39,41
V (23)	51·0	51
Mn (25)	54·93	55
Co (27)	58·97	59
Cu (29)	63·57	63,65
Ga (31)	70·1	69,71
As (33)	74·96	75
Br (35)	79·92	79,81
Rb (37)	85·44	85,87
Y (39)	88·7	89
Nb (41)	93·5	93,95
Rh (45)	102·9	103
Ag (47)	107·88	107,109
In (49)	114·8	115
Sb (51)	121·77	121,123
J (53)	126·92	127
Cs (55)	132·81	133
La (57)	139·0	139
Pr (59)	140·9	141
Eu (63)	152·0	151,153
Tb (65)	159·2	159,161
Ho (67)	163·5	163,165
Tu (69)	169·4	169,171
Lu (71)	175·0	175
Ta (73)	181·5	181,183
Ir (77)	193·1	193,195
Au (79)	179·2	197,199
Tl (81)	204·0	203,205
Bi (83)	209·00	209

(3) Bi (209) and Tl (203) are taken as the first "α-rayers" in the series $4n+1$ and $4n+3$ respectively. The type of "disintegration" is confined to α-α-α- . . . . and $\beta\alpha'\beta\alpha$, where the β-rayers are unstable.

Under these three conditions the chains of "transformation" connecting the predicted isotopes of odd atomic masses can be constructed, and these shown in Fig. 1. There occur alternatives at (75,191)∼(73,183), (75,189) ∼(73,181), and (71,177)∼(69,169) and three possible ways at (45,105)∼ (41,93), but in other places the path is uniquely determined. The possible odd isotopes of even atomic number are marked at the position corresponding to the "α-rayer."

(4) The series 4n and 4n+2 can be obtained by the continuation of the Th- and U-series, whose end-products Pb (208) and Pb (206) are taken as "α-rayers." The second "β-rayers" are unstable.

(5) Every horizontal line representing the "β-β change" in one of the even series is intersected by the oblique line denoting the "α- (or α'-) change" in the other series.

(6) The isotopes of the elements of odd atomic number fall within the space bounded by the two curves of the series 4n and 4n+2.

(7) The odd isotope of an even element—if it has two odd isotopes, the interest is confined to the heavier one—also lies between these two curves.

These conditions enable us to complete the series 4n and 4n+2 through the radioactive and the common elements (Fig. 2). The only ambiguity exists between (76,192) and (74,184). A branching is anticipated to occur at (78,198) and (166,164), in order that the last two conditions may be fulfilled.

In the following are given some noteworthy remarks.

(1) Solely from the foregoing arguments, it cannot of course be asserted that the common isotopes are the disintegration products from the elements of higher atomic weight, but I hope they may contain something suggestive as to the genesis of the elements.

(2) From Aston's results we may expect there can exist no "odd isobares." If, however, the atomic masses 197 and 100 are assigned to Au (79) and credit can be given to Aston's result* for Hg isotopes, we shall have the only example that contradicts this expectation. The peculiarity of Hg isotopes may, on the other hand, confrom with Soddy's interpretation on the reported transmutation of mercury into gold, that the diminution of atomic number by one is affected by the capture of an electron by an atomic nucleus (Nature, Aug. 16, 1924). It is a kind of atomic evolution, but not devolution.

(3) The present arguments do not hold good in their entirety for the elements below Cu. Why such should be the case is somewhat made clear by the following three considerations.

In the first place, the number of possible isotopes or the complexity

* He says that "*a strong group 197–200 cannot be resolved on the present instrument, but in all probability contains all the four integers in that range.*"

of an element may well be expected to diminish with the atomic weight, for, as the number of α-particles and electrons in the nucleus decreases, the influence upon the stability of the nucleus exerted by a single addition or removal of its constituent will become greater. It way be here noticed that in the nucleus of an atom in the series $4n+3$, which runs fairly continuously below the limit Cu, the number of the so-called cementing electrons $(\beta+e)$ relative to that of α-particles is always greater than in the nucleus of its isotope belonging to the other odd series.

Secondly, the number of protons in the nuclei of lighter and simpler atoms becomes comparable with that of α-particles, whence the mode of "disintegration" may well be different from that of heavier atoms. For example Si (30), Mg (26), and Ne (22) are not so much the decendants from Fe (54) after the successive or simultaneous emission of α-particles, as the disintegration products of P (31), Al (27), and Na (23) respectively resulting from the ejection of a proton. Rutherford's experiment is in favour of this view. That the series $4n$, the isotopes belonging to which contain no surplus protons in the nucleus, runs continuously below the limit of Cu down to C (12) or possibly to He, is also significant from this point of view.

Thirdly, the deviation of the mass of an atom from a whole number is usually attributed to the so-called "packing-effect." If the atomic weight of a "pure" element exceeds the number given by $4p+1{\cdot}008q$, where p and q are integers and the latter is confined to 0, 1, 2, or 3, then it seems necessary to suppose that some or all of the supposed He-nuclei contained in the nucleus are not really He-nuclei but a group of more or less loosely packed protons. It is a peculiar fact that the deviation from a whole number occurring in the pure elements is positive for those below Mn and negative for heavier ones. The following shows this:

Element	Atomic Weight	Deviation from a whole number
Be	9·02	+0·02
C	12·001	+0·001
N	14·008	+0·008
Al	27·1	+0·1
P	31·04	+0·04
S	32·07	+0·07
Sc	45·10	+0·10
Ti	48·1	+0·1
Mn	54·93	−0·07
Co	58·97	−0·03
As	74·96	−0·04

Y	88·7	−0·3
Rh	102·9	−0·1
In	114·8	−0·2
J	126·92	−0·08
Cs	132·81	−0·19
Pr	140·9	−0·1

Thus the incompleteness of the series continuation down to lighter elements seems to be also suggested by their atomic weights.

I wish to express my cordial thanks to Professor M. Kimura for the interest he has taken in the work and for his suggestive criticism.

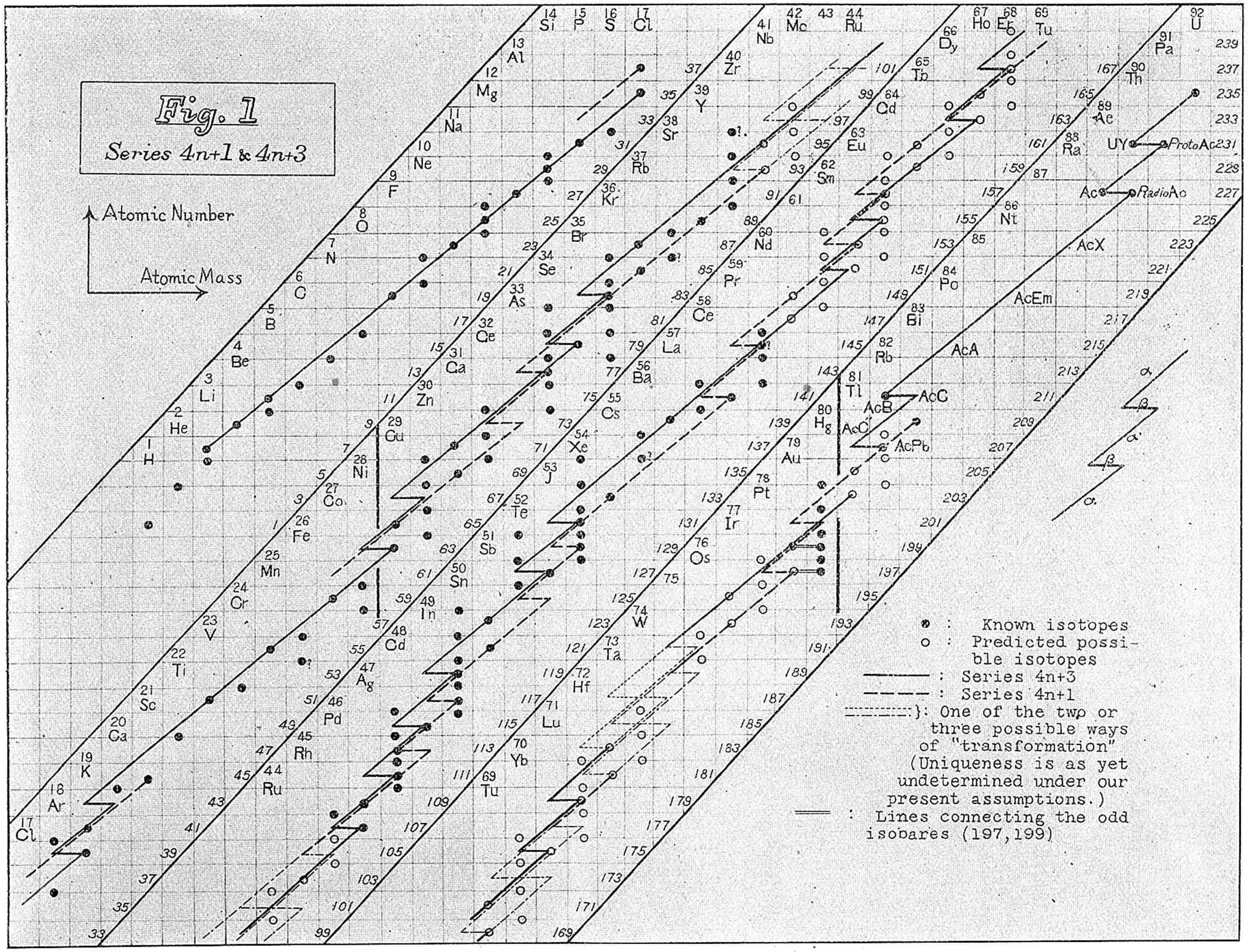


Fig. 1
Series 4n+1 & 4n+3
Atomic Number
Atomic Mass
● : Known isotopes
○ : Predicted possible isotopes
——— : Series 4n+3
– – – : Series 4n+1
} : One of the two or three possible ways of "transformation" (Uniqueness is as yet undetermined under our present assumptions.)
══ : Lines connecting the odd isobares (197,199)

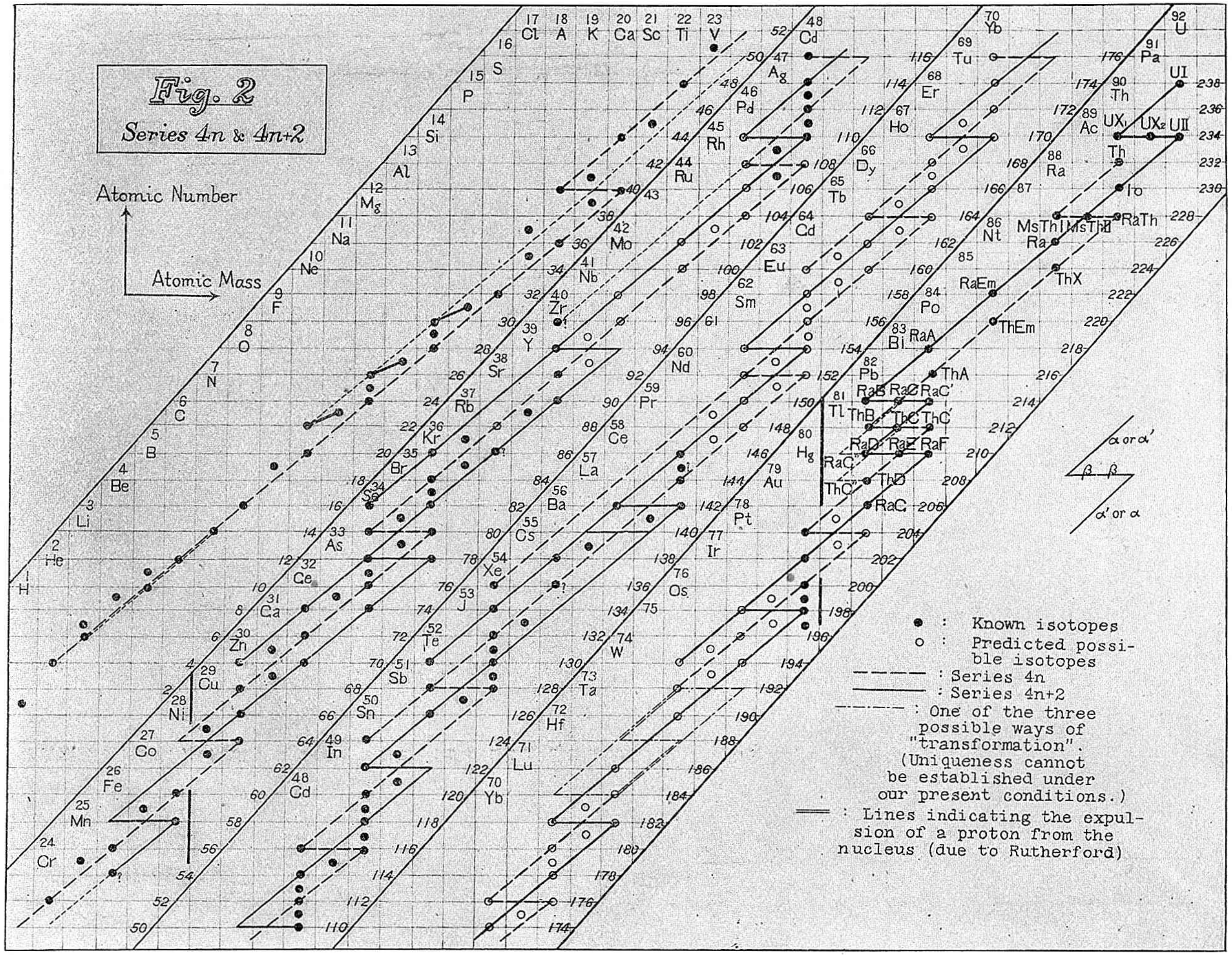


Fig. 2
Series 4n & 4n+2
Atomic Number
Atomic Mass
● : Known isotopes
○ : Predicted possible isotopes
: Series 4n
: Series 4n+2
: One of the three possible ways of "transformation". (Uniqueness cannot be established under our present conditions.)
: Lines indicating the expulsion of a proton from the nucleus (due to Rutherford)
α or α'
β β
α' or α