

The Discoverers of the Osmium Isotopes

THE THIRTY-FOUR KNOWN OSMIUM ISOTOPES FOUND BETWEEN 1931 AND 1989

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This is the third in a series of reviews of circumstances surrounding the discoveries of the isotopes of the six platinum group elements; it concerns the discovery of the thirty-four isotopes of osmium. The first review on platinum isotopes was published in this Journal in October 2000, and the second review on iridium isotopes was published in October 2003 (1).

Of the thirty-four isotopes of osmium that we know today, seven occur naturally with the following authorised isotopic abundances (2) (Table I):

Table I The Naturally Occurring Isotopes of Osmium	
Mass number	Isotopic abundance, %
¹⁸⁴ Os	0.02
¹⁸⁶ Os	1.59
¹⁸⁷ Os	1.96
¹⁸⁸ Os	13.24
¹⁸⁹ Os	16.15
¹⁹⁰ Os	26.26
¹⁹² Os	40.78

The discovery of the six major isotopes of osmium was reported by F. W. Aston (Figure 1) in 1931 (3) after being detected mass spectrographically at the Cavendish Laboratory, Cambridge University, England. The rare isotope, ¹⁸⁴Os, was discovered by A. O. C. Nier (Figure 2) in 1937 (4) using a new type of high resolution mass spectrometer at Harvard University, in Cambridge, Massachusetts, U.S.A., where he was carrying out a redetermination of the isotopic abundances of osmium. Nier's abundance measurements became the definitive values for osmium for over half a century, only being superseded in 1990 by the measurements of Völkening, Walczyk and Heumann (5). These latter results were immediately incorporated into the 1991 atomic weight table (6).

Of the naturally occurring isotopes, Viola, Roche and Minor suggested in 1974 (7) that ¹⁸⁶Os was radioactive with a half-life of 2.0×10^{15} years,

and this remains the presently accepted value (8). Mattauch's Rule (9) states that if two adjacent elements have nuclides of the same mass then at least one of them must be radioactive. In the case of the naturally occurring pair ¹⁸⁷Re-¹⁸⁷Os, the ¹⁸⁷Re is radioactive with a half-life of 4.12×10^{10} years (8). Since ¹⁸⁷Re undergoes beta decay to ¹⁸⁷Os, then in a mixture of rhenium-platinum element ores, the over-abundance of ¹⁸⁷Os with respect to that expected for the primordial abundance (the actual measurements are ¹⁸⁷Re/¹⁸⁶Os and ¹⁸⁷Os/¹⁸⁶Os) leads to an estimate of the excess ¹⁸⁷Os, and from this is obtained a direct assessment of the age of the ores. The half-life of ¹⁸⁶Os is so long that it can be considered to be "stable" for these measurements.

The use of this cosmochronometer was first suggested by Clayton in 1963 (10).

Artificial Osmium Isotopes

Prior to 1940 there appears to have been mention of only one radioactive osmium isotope: by Kurchatov *et al.* in 1935 (11) with a half-life of 40 hours. This now seems likely to have been ¹⁹³Os.

In 1940 Zingg (12) correctly identified both ¹⁹¹Os with a 10 day half-life (modern value 15.4 days) and ¹⁹³Os with a 30 hour half-life (the presently accepted value is 30.11 hours). However, immediately afterwards Seaborg and Friedlander (13) switched these around and there then followed a bizarre period of seven years in which all of the property measurements on ¹⁹¹Os were ascribed to ¹⁹³Os, and *vice versa*, until the mistake was finally corrected in the 1948 edition of the "Table of Isotopes" (14).

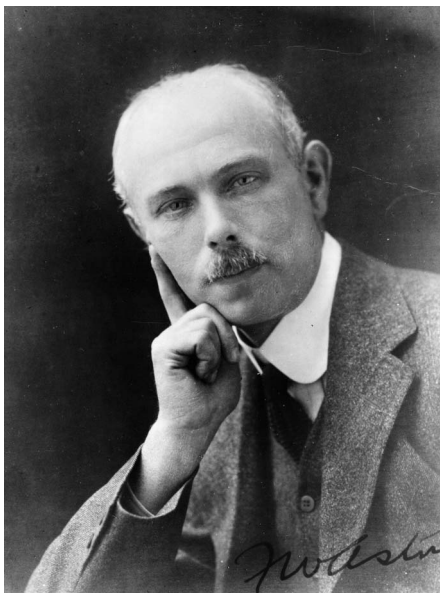


Fig. 1 **Francis William Aston**
1875–1945

F. W. Aston was born in Harbourne, Birmingham, England, and educated at Birmingham University. In 1909 he joined J. J. Thompson at the Cavendish Laboratory, Cambridge, as his assistant. At that time Thompson was working with positive rays from which he could determine the atomic weights of elements. Thompson noted that for the element neon, in addition to the mass 20, there was always a ghost at mass 22. This suggested the extremely controversial idea that naturally occurring stable elements also had isotopes in addition to those being found for the heavy radioactive elements.

After serving in World War I, Aston eventually returned to the Cavendish Laboratory and in 1919 built the first mass spectrograph. He was immediately able to prove that neon contained at least two isotopes of masses 20 and 22 in the ratio 9:1, and thus explained the odd atomic weight of 20.2. In 1920 Aston analysed chlorine and found that it contained two isotopes of masses 35 and 37 in the ratio 3:1. This explained the unusual atomic weight of chlorine which is 35.5.

Between 1919 and 1935, and through three generations of mass spectrographs, Aston personally discovered 212 of the 287 naturally occurring nuclides of primordial origin. His determination of nuclide masses showed that they were all very close to whole numbers, and usual differed by a small amount known as the "packing fraction". By direct measurement or

interpolation of the packing fraction it was possible to obtain atomic weights, especially for mononuclidic elements, and these were vastly superior to those being determined by chemical methods.

Aston was awarded the 1922 Nobel Prize for Chemistry for the invention of the mass spectrograph

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Fig. 2 **Alfred Otto Carl Nier**
1911–1994

A. O. C. Nier was born in Saint Paul, Minnesota, U.S.A. and studied at the University of Minnesota where he remained for most of his academic career. After graduating, Nier's first important contribution was the development of the double focusing mass spectrograph in which, by accelerating a beam of ions through an electrical field at an angle of ninety degrees and then through a magnetic field at an angle of sixty degrees, he was able to increase considerably the resolution of ions of similar atomic mass.

This instrument allowed him, in 1935, to discover the rare potassium isotope ^{40}K . From 1936 to 1938 he was at Harvard University, and between 1937 and 1938, he discovered five more rare naturally occurring nuclides: ^{36}S , ^{46}Ca , ^{48}Ca , ^{184}Os and ^{234}U . His accurate measurements of the ratio of uranium isotopes: ^{235}U to ^{238}U in many minerals led to the development of the uranium/lead cosmochronometer. In 1940 he separated ^{235}U from ^{238}U : the first isotope separation, and experiments on ^{235}U proved that it was the fission isotope of uranium, and not the more abundant ^{238}U .

This research led to the Manhattan Project, on which he worked from 1943 to 1945. Mass spectrographs, designed by Nier, were used extensively during this time for monitoring ^{235}U to ^{238}U separations. In the early 1950s Nier developed the mass spectrometer which differs from the mass spectrograph in that ion detection is electrical rather than by photographic plate.

Between 1956 and 1979 Nier spectrometers were used to measure the masses of nearly all the stable nuclides, while his isotopic abundance measurements for nitrogen, oxygen, the heavy inert gases and the alkaline earth elements became the definitive values for a long time. Nier also developed the miniature mass spectrometers which were used on the Viking Landers sent to Mars to sample the atmosphere

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Table II

The Discoverers of the Osmium Isotopes

Mass number	Half-life	Decay modes	Year of discovery*	Discoverers	Ref.	Notes
162	1.87 ms	α	1989	Hofmann <i>et al.</i>	17	
163	5.5 ms	α , EC + β^+ ?	1981	Hofmann <i>et al.</i>	18, 19	A
164	21 ms	α , EC + β^+	1981	Hofmann <i>et al.</i>	18, 19	
165	71 ms	α , EC + β^+	1978	Cabot <i>et al.</i>	16	B
166	216 ms	α , EC + β^+	1977	Cabot <i>et al.</i>	15	
167	810 ms	α , EC + β^+	1977	Cabot <i>et al.</i>	15	
168	2.06 s	EC + β^+ , α	1977	Cabot <i>et al.</i>	15	
169	3.46 s	EC + β^+ , α	1972	Toth <i>et al.</i>	21	
170	7.46 s	EC + β^+ , α	1972	Toth <i>et al.</i>	22	
171	8.3 s	EC + β^+ , α	1972	Toth <i>et al.</i>	22	
172	19.2 s	EC + β^+ , α	1970	Borgreen and Hyde	23	
173	22.4 s	EC + β^+ , α	1970	Borgreen and Hyde	23	
174	44 s	EC + β^+ , α	1970	Borgreen and Hyde	23	
175	1.4 min	EC + β^+	1972	Berlovich <i>et al.</i>	24	
176	3.6 min	EC + β^+	1970	1: Arlt <i>et al.</i>	25	
				2: de Boer <i>et al.</i>	26	
177	3.0 min	EC + β^+	1970	Arlt	25	
178	5.0 min	EC + β^+	1968	Belyaev <i>et al.</i>	27	
179	6.5 min	EC + β^+	1968	Belyaev <i>et al.</i>	27	
180	21.5 min	EC + β^+	1965	1: Belyaev <i>et al.</i>	28, 29	C
				2: Hofstetter and Daly	30, 31	
181	1.75 h	EC + β^+	1966	Hofstetter and Daly	30	D
181m	2.7 min	EC + β^+	1966	Hofstetter and Daly	30	E
182	22.10 h	EC	1950	Stover	37	
183	13.0 h	EC + β^+	1950	Stover	37	
183m	9.9 h	EC + β^+ , IT	1957	Foster, Hilborn and Yaffe	32	
184	Stable	–	1937	Nier	4	
185	93.6 d	EC	1946	Goodman and Pool	38	
186	2.0×10^{15} y	α	1931	Aston	3	F
187	Stable	–	1931	Aston	3	G
188	Stable	–	1931	Aston	3	H
189	Stable	–	1931	Aston	3	
189m	5.8 h	IT	1958	Scharff-Goldhaber <i>et al.</i>	43	I
190	Stable	–	1931	Aston	3	
190m	9.9 min	IT	1955	Aten <i>et al.</i>	44	
191	15.4 d	β^-	1940	Zingg	12	
191m	13.10 h	IT	1952	Swan and Hill	45	
192	Stable	–	1931	Aston	3	J
192m	5.9 s	IT, β^-	1973	Pakkenen and Heikkinen	48	K
193	30.11 h	β^- ?	1940	Zingg	12	L
194	6.0 y	β^-	1951	Lindner	52	
195	–	β^- ?				M
196	34.9 min	β^-	1976	Katcoff <i>et al.</i>	58, 59	

* The year of discovery is taken as available manuscript and conference dates. Where these are not available then the year of discovery is the publishing date

Table III		
Notes to Table II		
A	¹⁶³ Os	Alpha energy only. The half-life was determined by Page <i>et al.</i> in 1995 (20).
B	¹⁶⁵ Os	Alpha energy only. The half-life was determined by Hofmann <i>et al.</i> (18, 19).
C	¹⁸⁰ Os	In 1957 Foster, Holborn and Yaffe (32) assigned a 23 min half-life activity to ¹⁸¹ Os but according to Hofstetter and Daly (30) this now appears to have more likely been ¹⁸⁰ Os. In 1965 Bedrosyan <i>et al.</i> (33) identified a 23 min half-life activity but did not assign a mass number.
D	¹⁸¹ Os	A 2.7 h half-life activity described by Surkov <i>et al.</i> in 1960 (34) and apparently associated with ¹⁸¹ Os was not observed by Hofstetter and Daly (30). Balyaev <i>et al.</i> (29) observed a 2.5 h half-life activity which appeared to confirm the observations of Surkov <i>et al.</i>
E	^{181m} Os	Hofstetter and Daly's claim to have identified this isomeric state was only tentative but was confirmed by Goudsmit in 1967 (35). Shortly before the observations of Hofstetter and Daly, Aten and Kapteyn (36) also identified a 2.8 min half-life activity but gave no mass assignment.
F	¹⁸⁶ Os	The half-life was measured by Viola, Roche and Minor in 1974 (7).
G	¹⁸⁷ Os	Chu in 1950 (39) and Greenlees and Kuo in 1956 (40) observed activities with half-lives of 35 h and 39 h, respectively, which they suggested could be an isomer of ¹⁸⁷ Os. However such an activity was not observed by either Newton (41) or Merz (42).
H	¹⁸⁸ Os	A 26 d half-life activity suggested by Greenlees and Kuo (40) as being an isomer of ¹⁸⁸ Os was not observed by Merz (42).
I	^{189m} Os	A 6 h half-life activity observed by Chu in 1950 (39) and a 7.2 h half-life activity observed by Greenlees and Kuo in 1950 (40) were both likely to have been ^{189m} Os.
J	¹⁹² Os	Fremlin and Walters (46) suggested that the isotope, although described as being "stable", could be radioactive with a half-life exceeding 2.3×10^{14} y. Tretyak and Zdesenko (47) reassessed the data and suggested a revised value of greater than 9.8×10^{12} y which indicates that the suggestion of radioactivity is inconclusive.
K	^{192m} Os	A 6 s half-life activity assigned to ¹⁹² Re by Blachot, Monnard and Moussa in 1965 (49) was reassigned to ^{192m} Os by Pakkenen and Heikkinen (48). Hermann <i>et al.</i> (50) almost certainly discovered ^{192m} Os in 1970 but could not decide as to whether it was ¹⁹² Re or ^{192m} Os.
L	¹⁹³ Os	A 40 h half-life activity described by Kurchatov <i>et al.</i> in 1935 (11) was assigned to ¹⁹³ Os by the "Table of Isotopes" (51).
M	¹⁹⁵ Os	In 1957 Baró and Rey (53) and Rey and Baró (54) identified a 6.5 min half-life activity which they assigned to ¹⁹⁵ Os, but in 1974 Colle <i>et al.</i> (55) showed that this was the rubidium isotope ⁸¹ Rb, so ¹⁹⁵ Os remains undiscovered. Takahashi, Yamada and Kondoh (57) estimated the half-life to be about 9 min.

The most prolific period for the discovery of radioactive osmium isotopes was the 1970s with fourteen ground states and one isomeric state being identified. The most discovered by any one person or group was four by Cabot *et al.* in 1977 (15) and 1978 (16).

The lightest osmium isotope, ¹⁶²Os, still only appears to be an alpha emitter with no evidence of proton decay, so the drip line for osmium has not been reached, in contrast to ¹⁶⁷Ir for iridium. The most likely reason for this is that with an even

atomic number, osmium nuclides are likely to be more tightly bound than those for iridium, which has an odd atomic number, so it is not surprising that proton decay has not yet been seen from osmium isotopes.

In Table II, the same criteria for discovery are used as in the prior reviews on platinum and iridium (1). Notes to Table II, Some of the terms used for this review, and the decay modes are given in Tables III, IV and V. The half-lives given in the tables are from the revised NUBASE database (8).

Table IV Some of the Terms Used for this Review	
Atomic number	the number of protons in the nucleus
Mass number	the combined number of protons and neutrons in the nucleus
Nuclide and isotope	A nuclide is an entity characterised by the number of protons and neutrons in the nucleus. For nuclides of the same element the number of protons remains the same but the number of neutrons may vary. Such nuclides are known collectively as the isotopes of the element. Although the term isotope implies plurality it is sometimes used loosely in place of nuclide.
Half-life	the time taken for the activity of a radioactive nuclide to fall to half its previous value
Electron volt (eV)	The energy acquired by any charged particle carrying a unit (electronic) charge when it falls through a potential of one volt, equivalent to 1.602×10^{-19} J. The more useful unit is the mega (million) electron volt, MeV.

Table V Decay Modes	
α	Alpha decay is the emittance of alpha particles which are ${}^4\text{He}$ nuclei. Thus the atomic number of the daughter nuclide is lower by two and the mass number is lower by four.
β^-	Beta or electron decay for neutron-rich nuclides is the emittance of an electron (and an anti-neutrino) as a neutron decays to a proton. The mass number of the daughter nucleus remains the same but the atomic number increases by one.
β^+	Beta or positron decay for neutron-deficient nuclides is the emittance of a positron (and a neutrino) as a proton decays to a neutron. The mass number of the daughter nucleus remains the same but the atomic number decreases by one. However, this decay mode cannot occur unless the decay energy exceeds 1.022 MeV (twice the electron mass in energy units). Positron decay is always associated with orbital electron capture (EC).
EC	Orbital electron capture. The nucleus captures an extranuclear (orbital) electron which reacts with a proton to form a neutron and a neutrino, so that, as with positron decay, the mass number of the daughter nucleus remains the same but the atomic number decreases by one.
IT	Isomeric transition, in which a high energy state of a nuclide (isomeric state or isomer) usually decays by cascade emission of γ (gamma) rays (the highest energy form of electromagnetic radiation) to lower energy levels until the ground state is reached. However, certain low level states may also decay independently to other nuclides.

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