

# Chapter 11

## Group 18: The Noble Gases

### 11.1 The Group 18 Elements: The Noble Gases<sup>1</sup>

#### 11.1.1 The elements

The Group 18 elements have a particular name Noble gases. *Noble gas* is translated from the German noun *Edelgas*, first used in 1898 by Hugo Erdmann (1862 - 1910) to indicate their extremely low level of reactivity. The noble gases were often also called the *inert gases*, however, since noble gas compounds are now known this name is no longer used. Table 11.1 lists the derivation of the names of the Noble gases.

Element	Symbol	Name
Helium	He	Greek <i>helios</i> meaning the <i>Sun</i>
Neon	Ne	From the Greek meaning <i>new one</i>
Argon	Ar	From the Greek meaning <i>inactive</i>
Krypton	Kr	From the Greek <i>kryptos</i> meaning <i>the hidden one</i>
Xenon	Xe	From the Greek <i>xenos</i> ], meaning <i>foreigner, stranger, or guest</i>
Radon	Rn	From its <i>radioactive</i> nature

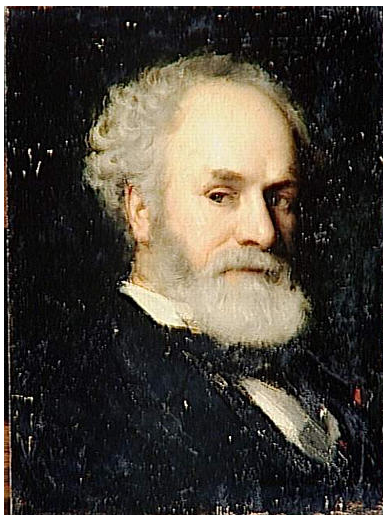
**Table 11.1:** Derivation of the names of each of the Group 18(VIII) elements.

#### 11.1.1.1 Discovery

##### 11.1.1.1.1 Helium

The first evidence of helium was the observation by astronomer Pierre Janssen (Figure 11.1) on August 18, 1868 as a bright yellow line with a wavelength of 587.49 nm in the spectrum of the chromosphere of the Sun. On October 20 of the same year, English astronomer Norman Lockyer (Figure 11.2) observed a yellow line in the solar spectrum, which he named the *D3 Fraunhofer* line because it was near the known *D1* and *D2* lines of sodium. He concluded that it was caused by an element in the Sun unknown on Earth. Lockyer and Edward Frankland (Figure 11.3) named the element with the Greek word for the Sun, *helios*.

<sup>1</sup>This content is available online at <<http://cnx.org/content/m34653/1.1/>>.



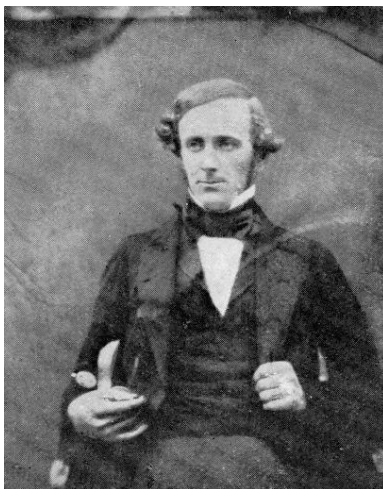
**Figure 11.1:** Portrait of French astronomer Pierre Jules César Janssen (1824 - 1907).

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**Figure 11.2:** English scientist and astronomer Sir Joseph Norman Lockyer, FRS (1836 - 1920).

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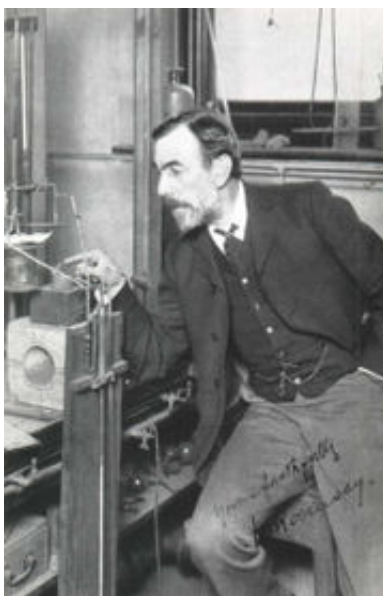


**Figure 11.3:** English chemist Sir Edward Frankland, KCB, FRS (1825 - 1899).

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On March 26, 1895 British chemist Sir William Ramsay (Figure 11.4) isolated helium on Earth by treating the mineral cleveite (a radioactive mineral containing uranium and found in Norway) with mineral acids.

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**Figure 11.4:** Scottish chemist Sir William Ramsay, KCB FRSE (1852 - 1916).

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#### 11.1.1.1.2 Neon

Neon was discovered in 1898 by Sir William Ramsay (Figure 11.4) and Morris Travers (Figure 11.5). When Ramsay chilled a sample of air until it became a liquid, then warmed the liquid and captured the gases as they boiled off. After nitrogen, oxygen, and argon, the three gases that boiled off were krypton, xenon, and neon.



**Figure 11.5:** English chemist and founding director of the Indian Institute of Science, Morris William Travers (1872 - 1961).

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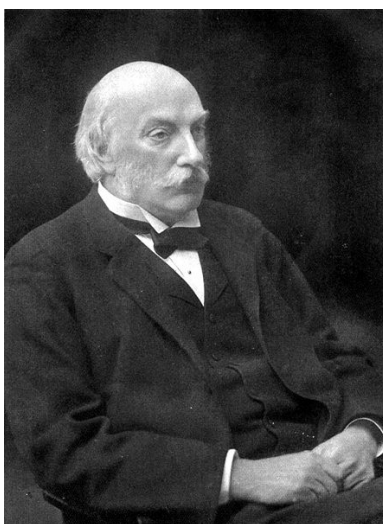
#### 11.1.1.1.3 Argon

In 1785 Henry Cavendish (Figure 11.6) suspected that argon was present in air but it was not isolated until 1894 by Lord Rayleigh (Figure 11.7) and Sir William Ramsay (Figure 11.4) in an experiment in which they removed all of the oxygen, carbon dioxide, water and nitrogen from a sample of clean air.



**Figure 11.6:** British scientist Henry Cavendish FRS (1731 - 1810).

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**Figure 11.7:** English physicist John William Strutt, 3<sup>rd</sup> Baron Rayleigh, OM (1842 - 1919).

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#### 11.1.1.1.4 Krypton

Krypton was discovered in 1898 by Sir William Ramsay (Figure 11.4) and Morris Travers (Figure 11.5) in residue left from evaporating nearly all components of liquid air.

NOTE: In 1960, an international agreement defined the *meter* (m) in terms of wavelength of light emitted by the  $^{86}\text{Kr}$  isotope (wavelength of 605.78 nm). This agreement replaced the standard meter located in Paris, which was a metal bar made of a Pt-Ir alloy, and was itself replaced by a definition based on the speed of light, a fundamental physical constant. In October 1983, the *Bureau International des Poids et Mesures* defined the meter as the distance that light travels in a vacuum during  $1/299,792,458$  s.

#### 11.1.1.1.5 Xenon

Xenon was discovered by William Ramsay (Figure 11.4) and Morris Travers (Figure 11.5) on July 12, 1898, shortly after their discovery of krypton and neon.

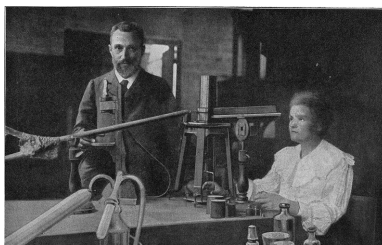
#### 11.1.1.1.6 Radon

Radon was the fifth radioactive element to be discovered after uranium, thorium, radium and polonium. Discovered in 1900 by Friedrich Dorn (Figure 11.8) after he noticed that radium compounds emanate a radioactive gas that he named *Radium Emanation* (*Ra Em*). Prior to these experiments, in 1899, Pierre and Marie Curie (Figure 11.9) observed that the gas emitted by radium remained radioactive for a month. Later that year, Ernest Rutherford (Figure 11.10) noticed variations when trying to measure radiation from thorium oxide. In 1901, he demonstrated that the emanations are radioactive, but credited the Curies for the discovery of the element.



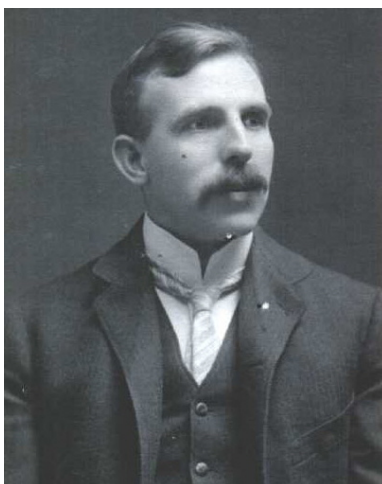
**Figure 11.8:** German physicist Friedrich Ernst Dorn (1848 - 1916).

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**Figure 11.9:** Pierre (1859 - 1906) and Marie Skłodowska-Curie (1867 - 1934) in their Paris laboratory.

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**Figure 11.10:** British-New Zealand chemist and physicist Ernest Rutherford, 1<sup>st</sup> Baron Rutherford of Nelson, OM, FRS (1871 - 1937).

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#### 11.1.1.2 Abundance

The abundance of the Noble gases is given in Table 11.2.

Element	Terrestrial abundance (ppm)
He	$8 \times 10^{-3}$ (Earth's crust), $4 \times 10^6$ (sea water), 5 (atmosphere)
Ne	$70 \times 10^{-3}$ (Earth's crust), 0.2 (sea water), 18 (atmosphere)
Ar	1.2 (Earth's crust), 0.45 (sea water), $0.93 \times 10^4$ (atmosphere)
Kr	$10 \times 10^{-6}$ (Earth's crust), $80 \times 10^{-6}$ (sea water), 1 (atmosphere)
Xe	$2 \times 10^{-6}$ (Earth's crust), $100 \times 10^{-6}$ (sea water), $90 \times 10^{-3}$ (atmosphere)

**Table 11.2:** Abundance of Group 18 elements.**11.1.1.3 Isotopes**

The naturally abundant isotopes of the Group 18 elements are listed in Table 11.3. All of the isotopes of radon are radioactive.

Isotope	Natural abundance (%)
Helium-3	0.000137
Helium-4	99.999863
Neon-20	90.48
Neon-21	0.27
Neon-22	9.25
Argon-36	0.337
Argon-86	0.063
Argon-40	99.600
Krypton-78	0.35
Krypton-80	2.25
Krypton-81	trace
Krypton-82	11.6
Krypton-83	11.5
Krypton-84	57
Krypton-86	17.3
Xenon-124	0.095
Xenon-126	0.089
Xenon-128	1.91
Xenon-129	26.4
Xenon-130	4.07
Xenon-131	21.2
Xenon-132	26.9
Xenon-134	10.4
Xenon-136	8.86
Radon-222	trace

**Table 11.3:** Abundance of the non-synthetic isotopes of the Group 18 elements.

Unlike most elements, helium's isotopic abundance varies greatly by origin, due to the different formation processes. The most common isotope,  $^4\text{He}$ , is produced on Earth by a decay of heavier radioactive elements. It was also formed in enormous quantities during the *Big Bang*.

Naturally occurring  $^{40}\text{K}$  with a half-life of  $1.25 \times 10^9$  years, decays to stable  $^{40}\text{Ar}$  (11.2%) by electron capture and positron emission, and also to stable  $^{40}\text{Ca}$  (88.8%) via beta decay. These properties and ratios are used to determine the age of rocks.



With a half-life of 230,000 years  $^{81}\text{Kr}$  is used for dating 50,000 - 800,000 year old groundwater.  $^{85}\text{Kr}$  is an inert radioactive noble gas with a half-life of 10.76 years. It is produced in nuclear bomb testing and nuclear reactors.  $^{85}\text{Kr}$  is released during the reprocessing of fuel rods from nuclear reactors.

### 11.1.2 Industrial production of the elements

Helium is extracted by fractional distillation from natural gas, which contains up to 7% helium. Since helium has a lower boiling point than any other element, low temperature and high pressure are used to liquefy nearly all the other gases. The resulting helium gas is purified by successive exposures to lowering temperatures. A final purification step with activated charcoal results in 99.995% pure Grade-A helium.

Argon is produced industrially by the fractional distillation of liquid air, a process that separates liquid nitrogen, which boils at 77.3 K, from argon, which boils at 87.3 K and oxygen, which boils at 90.2 K. Xenon is obtained commercially as a byproduct of the separation of air into oxygen and nitrogen.

#### 11.1.2.1 Physical properties

The physical properties of the Group 18 elements are given in Table 11.4.

Element	Mp ( °C)	Bp ( °C)
He	-272.20	-268.93
Ne	-248.59	-246.08
Ar	-189.35	-185.85
Kr	-157.36	-153.22
Xe	-111.7	-108.12
Rn	-71.15	-61.85

**Table 11.4:** Selected physical properties of the Group 18 elements.

All of the Noble gases show characteristic spectral lines (Figure 11.11 – Figure 11.15).



**Figure 11.11:** Spectral lines of helium.

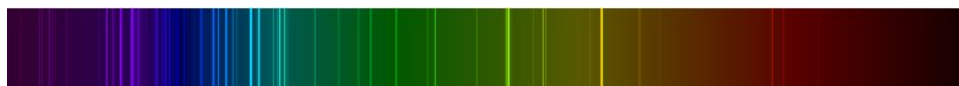


**Figure 11.12:** Spectral lines of neon.



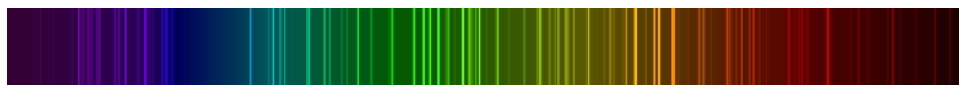
**Figure 11.13:** Spectral lines of argon.

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**Figure 11.14:** Spectral lines of krypton.

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**Figure 11.15:** Spectral lines of xenon.

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### 11.1.3 Compounds of the Group 18 elements.

Only a few hundred noble gas compounds have been formed. Neutral compounds of helium and neon have not been formed, while xenon, krypton, and argon have shown only minor reactivity. The reactivity follows the order:

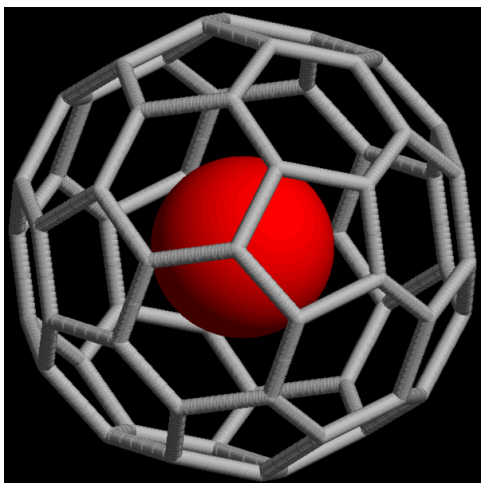


Xenon compounds are the most numerous of the noble gas compounds. Oxidation states of +2, +4, +6, and +8 with electronegative elements, e.g.,  $\text{XeF}_2$ ,  $\text{XeF}_4$ ,  $\text{XeF}_6$ ,  $\text{XeO}_4$ , and  $\text{Na}_4\text{XeO}_6$ . Compounds of xenon bound to boron, hydrogen, bromine, iodine, beryllium, sulphur, titanium, copper, and silver have also been observed but only at low temperatures in noble gas matrices, or in supersonic noble gas jets.

Although radon is more reactive than xenon it should form chemical bonds more easily than xenon, however, due to the high radioactivity and short half-life of radon isotopes, only a few fluorides and oxides of radon have been formed.

Krypton is less reactive than xenon, and oxidation states are generally limited to +2,  $\text{KrF}_2$ . Compounds in which krypton forms a bond to nitrogen and oxygen are only stable below  $-60^\circ\text{C}$  and  $-90^\circ\text{C}$ , respectively. Krypton atoms chemically bound to other nonmetals (hydrogen, chlorine, carbon) as well as some late transition metals (copper, silver, gold), but only at low temperatures in noble gas matrices, or in supersonic noble gas jets. Similar conditions were used to obtain the first compounds of argon.

Noble gases also form non-covalent compounds, for example clathrates that consist of an atom trapped within cavities of crystal lattices of organic and inorganic compounds. Noble gases can form endohedral fullerene compounds, in which the noble gas atom is trapped inside a fullerene molecule (Figure 11.16).



**Figure 11.16:** A skeletal structure of He@C<sub>60</sub>.

#### 11.1.4 Bibliography

- L. Pauling, *J. Am. Chem. Soc.*, 1933, **55**, 1895.
- M. Saunders, H. A. Jiménez-Vázquez, R. J. Cross, and R. J. Poreda, *Science*, 1993, **259**, 1428.