Noble Gases

Introduction

Helium is the first member of group 18 or zero of the periodic table. It consists of six elements helium (*He*), Neon (*Ne*), argon (*Ar*), krypton (*Kr*), xenon (*Xe*) and radon (*Rn*). Zero group occupies the intermediate position between the elements of VIIA (17th) and IA (1st) groups. These are collectively called as inactive gases or inert gases. However, these are now called noble gases as some compounds of these gases have been obtained under certain specific conditions.

Electronic configuration

Elements	Electronic configuration ($ns^2\ np^6$)
$_2He$	$1s^2$
$_{10}Ne$	$1s^2, 2s^2 2p^6$
$_{18}Ar$	$1s^2, 2s^2 2p^6, 3s^2 3p^6$
$_{36}Kr$	$1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^{10}, 4s^2 4p^6$
$_{54}Xe$	$1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^{10}, 4s^2 4p^6 4d^{10} 4f^{14}, 5s^2 5p^6$
$_{86}Rn$	$1s^2, 2s^2 2p^6, 3s^2 3p^6 3d^{10}, 4s^2 4p^6 4d^{10} 4f^{14}, 5s^2 5p^6 5d^{10}, 6s^2 6p^6$

Properties

Atomic radii: The atomic radii of noble gases increases on moving down the group and their atomic radii correspond to the van der Waal's radii.

Boiling points: The m.pt. and b.pt. increases from *He* to *Rn*, because of increase in magnitude of Vander Waal's forces.

Polarizabiltiy: The polarizability increases down the group, $He < Ne < Ar < Kr < Xe$

Ionisation energy and electron affinity: Noble gases have stable $ns^2 np^6$ fully filled electronic configuration, so these have no tendency to add or lose electron. Therefore, ionisation energy of noble gases is very high. On the other hand their electron affinity is zero.

Heat of vaporisation: They posses very low values of heat of vapourisation, because of presence of very weak Vander Waal's forces of attraction between their monoatomic molecules. However the value of heat of vaporisation increases with atomic number down the group and this shows that there is an increasing polarizability of the larger electronic clouds of the elements with higher atomic number.

Solubility in water: They are slightly soluble in water. Their solubility generally increases with the increase in atomic number down the group.

Adsorption by charcoal: All of them except helium are adsorbed by charcoal at low temperature. The extent of adsorption increases down the group.

Characteristic spectra: All of them give characteristic spectra, by which they can be identified.

Liquification of gases: It is difficult to liquify noble gases as their atoms are held by weak Vander Waal's forces. Ease of liquification increases down the group from *He* to *Rn*. Helium has the lowest boiling point (4.18 *K*) of any known substance. The ease of liquification increases down the group due to increase in intermolecular forces.

Occurrence : Due to the inert nature of noble gases, they always occur in the free state. Except radon, all these gases are present in atmosphere in the atomic state.

Element	*He*	*Ne*	*Ar*	*Kr*	*Xe*
Abundance (Volume %)	5.2×10^{-4}	1.8×10^{-3}	9.3×10^{-1}	1.4×10^{-3}	8.7×10^{-6}

He is also present in natural gas to the extent of 2 to 7%.

Isolation

(i) **Helium** : It is commercially obtained from natural gas. The natural gas contains hydrocarbons (methane etc.), CO_2, H_2S and He as the main constituents.

The natural gas is compressed to about 100 atm and cooled to 73 *K*. *He* remains unliquefied while other gases get liquefied. About 99% pure *He* is prepared by this method.

(ii) **Argon, Neon, Krypton and Xenon:** These gases are prepared by the fractionation distillation of liquid air. Fractional distillation of air gives O_2, N_2 and mixture of noble gases. The individual gases may be obtained by adsorption of air on coconut charcoal. The charcoal adsorbs different gases at different temperatures and can be collected.

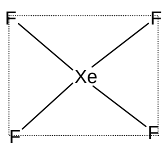
(iii) **Radon:** It can be obtained by radioactive disintegration of radium (226), ${}_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + {}_{2}\alpha^{4}$.

Structure of Xenon compounds

The structure of xenon compounds are explained on the basis of VSEPR theory as well as the concept of hybridization.

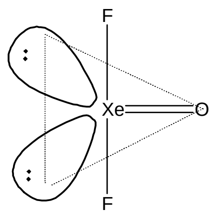
Molecule	Total electron pairs (BP + LP)	Hybridisation	Shape
XeF_2	5	Sp^3d	**Linear**
XeF_4	6	Sp^3d^2	**Square planar**
XeF_6	**7**	**sp^3d^3**	**Distorted octahedral**

The structures of oxyfluorides and oxides of xenon can be best explained by the concept of hybridization. The structures of compounds are shown below



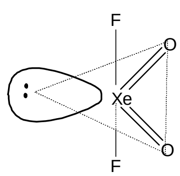
XeF_4

square pyramidal



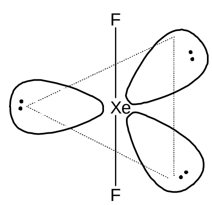
$XeOF_2$

T - shaped



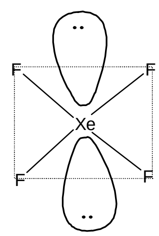
XeO_2F_2

Distorted Trigonal bipyramidal



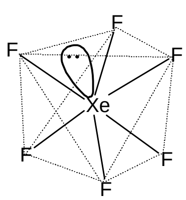
XeF_2

Linear



XeF_4

square planar



XeF_6

Distorted octahedral

Xenon difluoride

(XeF_2) is formed when a mixture of Xenon and fluorine in the ratio 1 : 3 by volume is passed through a nickel tube at 673 K, $Xe + Fe \xrightarrow{\text{Ni, 673K}} XeF_2$

Structure : XeF_2 has trigonalbipyramid geometry due to sp^3 d-hybridization of Xe. Three equatorial positions are occupied by lone pairs of electrons giving a linear shape to the molecule.

Properties: XeF_2 is a colourless crystalline solid, reacts with H_2 to give Xe and HF. It is hydrolysed completely by water, $2XeF_2 + 2H_2O \rightarrow 2Xe + O_2 + 4HF$.

It also forms addition compounds with reactive pentafluorides like SbF_5, TaF_5 etc.

$$XeF_2 + 2SbF_5 \rightarrow XeF_2.2SbF_5$$

It is a mild fluorinating agent and hence reacts with benzene to give fluorobenzene.

Xenon tetrafluoride

(XeF_4) is prepared by heating a mixture of xenon and fluorine in the ratio 1 : 5 in a nickel vessel at 673 K and then suddenly cooling it in acetone. XeF_4 is also formed when an electric discharge is passed through a mixture of xenon and excess of fluorine, $Xe + 2F_2 \xrightarrow{\text{Ni, 673K}} XeF_4$

Structure : XeF_4 has square planar shape due to sp^3d^2 hybridization of Xe giving octahedral geometry with two trans positions occupied by lone pairs of electrons.

Properties: XeF_4 is a colourless, crystalline solid, soluble in anhydrous HF, reacts with H_2 to form Xe and HF and reacts with water to give highly explosive solid, XeO_3. (complete hydrolysis), $6XeF_4 + 12H_2O \rightarrow 4Xe + 2XeO_3 + 24HF + 3O_2$

Partial hydrolysis yields $XeOF_2$, $XeF_4 + H_2O \xrightarrow{193\text{K}} XeOF_2 + 2HF$

It also forms addition compounds with SbF_5, $XeF_4 + SbF_5 \rightarrow [XeF_3]^+[SbF_6]^-$.

It also acts as a strong fluorinating agent.

Xenon hexafluoride

(XeF_6) is prepared by heating a mixture of xenon and fluorine in the ratio 1 : 20 at 473—523 K under a pressure of 50 atmospheres.

$$Xe + 3F_2 \xrightarrow{473-523\,K,\ 50\,atm.} XeF_6$$

Structure: XeF_6 has pentagonal bipyramid geometry due to sp^3d^3 hybridization. One trans position is occupied by a lone pair giving a distorted octahedral shape.

Properties : It is colourless, crystalline solid, highly soluble in anhydrous HF giving solution which is a good conductor of electricity, $HF + XeF_6 \rightarrow XeF_5^+ + HF_2^-$.

It is the most powerful fluorinating agent and reacts with H_2 to give Xe and HF. Partial hydrolysis of XeF_6 yields $XeOF_4$ and complete hydrolysis yields xenon trioxide, XeO_3.

$XeF_6 + H_2O \rightarrow XeOF_4 + 2HF;\ XeF_6 + 3H_2O \rightarrow XeO_3 + 6HF$

It forms addition compounds with alkali metal fluorides (except LiF) of the formula XeF_6. MF where M represents the alkali metal.

Oxides

Xenon forms two oxides such as xenon trioxide (XeO_3) and xenon tetraoxide (XeO_4).

Xenon trioxide

(XeO_3) is prepared by complete hydrolysis of XeF_4 and XeF_6

$$6XeF_4 + 12H_2 \rightarrow 2XeO_3 + 4Xe + 3O_2 + 24HF;\quad XeF_6 + 3H_2O \rightarrow XeO_3 + 6HF$$

Structure :XeO_3 has tetrahedral geometry due to sp^3 hybridization of Xe. One of the hybrid orbitals contains a lone pair of electrons giving a trigonal pyramidal shape. The molecule has three Xe = O double bonds containing $p\pi - d\pi$ overlapping.

Properties : It is a colourless solid, highly explosive and powerful oxidizing agent.

Xenon tetraoxide

(XeO_4) is prepared by the action of conc. H_2SO_4 on sodium or barium xenate(Na_4XeO_6; Ba_2XeO_6) at room temperature,

$$Na_4XeO_6 + 2H_2SO_4 \rightarrow XeO_4 + 2Na_2SO_4 2H_2O\ ;$$

$$Ba_2XeO_6 + 2H_2SO_4 \rightarrow XeO_4 + 2BaSO_4 + 2H_2O$$

XeO_4 is purified by vacuum sublimation at 195 K.

Structure :XeO_4 has tetrahedral structure due to sp^3hybridization of Xe. There are four $Xe–O$ double bonds containing $p\pi - d\pi$ overlapping.

Properties : It is quite unstable gas and decomposes to xenon and oxygen, $XeO_4 \rightarrow Xe + 2O_2$.

Oxyfluorides :

Xenon forms three types of oxy fluorides such as xenon oxydifluoride ($XeOF_2$), xenon oxytetrafluride $XeOF_4$ and xenon dioxydifluoride (XeO_2F_2).

Xenon oxydifluoride

($XeOF_2$) is formed by partial hydrolysis of XeF_4 at 193 K,

$$XeF_4 + H_2O \xrightarrow{193\,K} XeOF_2 + 2HF.$$

Structure: $XeOF_2$ has trigonalbipyramid geometry due to sp^3d-hybridization of Xe. Two equatorial positions are occupied by lone pairs of electrons giving a T-shape to the molecule. There is one $Xe–O$ double bond containing $p\pi - d\pi$ overlapping.

Xenon oxytetrafluoride

($XeOF_4$) is prepared by partial hydrolysis of XeF_6; $XeF_6 + H_2O \rightarrow XeOF_4 + 2HF$. It can also be prepared by the reaction of SiO_2 with XeF_6, $2XeF_6 + SiO_2 \rightarrow 2XeOF_4 + SiF_4$.

Structure : $XeOF_4$ has octahedral geometry due to sp^3d^2 hybridization of Xe. One trans position is occupied by a lone pair giving pyramid shape to the molecule. There is one $Xe–O$ double bond containing $p\pi - d\pi$ overlapping.

Properties : It is a colourless volatile liquid which melts at 227 K. It reacts with water to give XeO_2F_2 and XeO_3,

$XeOF_4 + H_2O \rightarrow XeO_2 + 2HF$,

$XeO_2F_2 + H_2O \rightarrow XeO_3 + 2HF$.

It is reduced by H_2 to Xe, $XeOF_4 + 3H_2 \rightarrow Xe + H_2O + 4HF$

Xenon dioxydifluoride

(XeO_2F_2) is formed by partial hydrolysis of $XeOF_4$ or XeF_6

$$XeOF_4 + H_2O \rightarrow XeO_2F_2 + 2HF\ ;\ \ XeF_6 + 2H_2O \rightarrow XeO_2F_2 + 4HF$$

It can also be prepared by mixing XeO_3 and $XeOF_4$ at low temperature (195K). The product is purified by fractional distillation, $XeO_3 + XeOF_4 \xrightarrow{195\,K} 2XeO_2F_2$

Structure : XeO_2F_2 has trigonalbipyramid geometry due to sp^3d-hybridization of Xe. One equatorial position is occupied by a lone pair of electrons giving a see-saw structure (shape) to the molecule. There are two $Xe–O$ double bonds containing $p\pi - d\pi$ overlapping.

Properties : It is a colourless solid which melts at 303 K. It is easily hydrolysed to give XeO_3

$$XeO_2F_2 + H_2O \rightarrow XeO_3 + 2HF$$

Uses of noble gases

(i) He is used for filling of balloons and air ships because of its non-inflammability and high power (which is 92.6% to that of hydrogen).

(ii) Oxygen-helium (1 : 4) mixture is used for treatment of asthma and for artificial respiration in deep sea diving because unlike nitrogen, helium is not soluble in blood even under high pressure.

(iii) Helium is also used for creating inert atmosphere in chemical reactions.

(iv) Liquid helium is used as a cryogenic fluid to produce and maintain extremely low temperatures for carrying out researches and as a coolant in atomic reactors and super conducting magnets.

(v) It is also used in low temperature gas thermometry and as a shield gas for arc welding.

(vi) Argon is used for creating inert atmosphere in chemical reactions, welding and metallurgical operations and for filling in incandescent and fluorescent lamps. It is also used in filling Geiger-Counter tubes and thermionic tubes.

(vii) Krypton and xenon are also used in gas filled lamps. A mixture of krypton and xenon is also used in some flash tubes for high speed photography.

(viii) Radon is used in radioactive research and therapeutics and in the non-surgical treatment of cancer and other malignant growths.