Halogen: (group VII elements)

Group VII elements are called Halogens. They are all non metals. The word halogen is derived from two Greek words *halo* and *gen*. Halo means salt while gen means producer. Hlogens are therefore salt producers. They include:

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic number</th>
<th>Electronic configuration</th>
<th>Charge of ion</th>
<th>Valency</th>
<th>State at Room Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine</td>
<td>F</td>
<td>9</td>
<td>2:7</td>
<td>F⁻</td>
<td>1</td>
<td>Pale yellow gas</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>17</td>
<td>2:8:7</td>
<td>Cl⁻</td>
<td>1</td>
<td>Pale green gas</td>
</tr>
<tr>
<td>Bromine</td>
<td>Br</td>
<td>35</td>
<td></td>
<td>Br⁻</td>
<td>1</td>
<td>Red liquid</td>
</tr>
<tr>
<td>Iodine</td>
<td>I</td>
<td>53</td>
<td></td>
<td>I⁻</td>
<td>1</td>
<td>Grey Solid</td>
</tr>
<tr>
<td>Astatine</td>
<td>At</td>
<td>85</td>
<td></td>
<td>At⁻</td>
<td>1</td>
<td>Radioactive</td>
</tr>
</tbody>
</table>

All halogen atoms have seven electrons in the outer energy level. They acquire/gain one electron in the outer energy level to be stable. They therefore are monovalent.

The number of energy levels increases down the group from Fluorine to Astatine. The more the number of energy levels the bigger/larger the atomic size. e.g.

The atomic size/radius of Chlorine is bigger/larger than that of Fluorine because Chlorine has more/3 energy levels than Fluorine (2 energy levels).

Atomic radius and ionic radius of Halogens increase down the group as the number of energy levels increases.

The atomic radius of Halogens is smaller than the ionic radius. This is because they react by gaining/acquiring extra one electron in the outer energy level. The effective nuclear attraction on the more/extra electrons decreases. The incoming extra electron is also repelled causing the outer energy level to expand to reduce the repulsion and accommodate more electrons.

**Table showing the atomic and ionic radius of four Halogens**

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic number</th>
<th>Atomic radius(nM)</th>
<th>Ionic radius(nM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine</td>
<td>F</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bromine</td>
<td>Br</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iodine</td>
<td>I</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astatine</td>
<td>At</td>
<td>85</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>number</td>
<td>0.064</td>
<td>0.136</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>Fluorine</td>
<td>F</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>17</td>
<td>0.099</td>
<td>0.181</td>
</tr>
<tr>
<td>Bromine</td>
<td>Br</td>
<td>35</td>
<td>0.114</td>
<td>0.195</td>
</tr>
<tr>
<td>Iodine</td>
<td>I</td>
<td>53</td>
<td>0.133</td>
<td>0.216</td>
</tr>
</tbody>
</table>

The atomic radius of Chlorine is 0.099nM. The ionic radius of Cl\(^{-}\) is 0.181nM. This is because Chlorine atom/molecule reacts by gaining/acquiring extra one electrons. The more extra electrons/energy level experience less effective nuclear attraction/pull towards the nucleus. The outer energy level expand/increase to reduce the repulsion of the existing and incoming gained/acquired electrons.

**Electronegativity**

The ease of gaining/acquiring extra electrons is called electronegativity. All halogens are electronegative. Electronegativity decreases as atomic radius increase. This is because the effective nuclear attraction on outer electrons decreases with increase in atomic radius. The outer electrons experience less nuclear attraction and thus ease of gaining/acquiring extra electrons decrease. The electronegativity of the halogens decrease down the group from fluorine to Astatine. This is because atomic radius increases down the group and thus decrease electron attracting power down the group from fluorine to astatine.

Fluorine is the most electronegative element in the periodic table because it has the small atomic radius.

**Electron affinity**

The minimum amount of energy required to gain/acquire an extra electron by an atom of element in its gaseous state is called 1\(^{st}\) electron affinity. The SI unit of electron affinity is kilojoules per mole/kJ\text{ mole}^{-1}. Electron affinity depend on atomic radius. The higher the atomic radius, the less effective the nuclear attraction on outer energy level electrons and thus the lower the electron affinity. For halogens the 1\(^{st}\) electron affinity decrease down the group as the atomic radius increase and the effective nuclear attraction on outer energy level electrons decrease. Due to its small size/atomic radius Fluorine shows exceptionally low electron affinity. This is because a lot of energy is required to overcome the high repulsion of the existing and incoming electrons.

Table showing the electron affinity of halogens for the process

\[
X + e^{-} \rightarrow X^{-}
\]
The higher the electron affinity the more stable the ion. i.e. Cl\(^-\) is a more stable ion than Br\(^-\) because it has a more negative / exothermic electron affinity than Br\(^-\).

Electron affinity is different from ionization energy.

Ionization energy is the energy required to lose/donate an electron in an atom of an element in its gaseous state while electron affinity is the energy required to gain/acquire extra electron by an atom of an element in its gaseous state.

Electronegativity.

- Electron affinity is the energy required to gain an electron in an atom of an element in gaseous state. It involves the process:

  \[ \text{X(g)} + \text{e}^- \rightarrow \text{X}^-(\text{g}) \]

Electronegativity is the ease/tendency of gaining/acquiring electrons by an element during chemical reactions.

### Table showing the physical properties of Halogens

<table>
<thead>
<tr>
<th>Halogen</th>
<th>Formula of molecule</th>
<th>Electrical conductivity</th>
<th>Solubility in water</th>
<th>Melting point(°C)</th>
<th>Boiling point(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorine</td>
<td>F(_2)</td>
<td>Poor</td>
<td>Insoluble/soluble in tetrachloromethane</td>
<td>-238</td>
<td>-188</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl(_2)</td>
<td>Poor</td>
<td>Insoluble/soluble in tetrachloromethane</td>
<td>-101</td>
<td>-35</td>
</tr>
<tr>
<td>Bromine</td>
<td>Br(_2)</td>
<td>Poor</td>
<td>Insoluble/soluble in tetrachloromethane</td>
<td>-7</td>
<td>59</td>
</tr>
<tr>
<td>Iodine</td>
<td>I(_2)</td>
<td>Poor</td>
<td>Insoluble/soluble in tetrachloromethane</td>
<td>114</td>
<td>184</td>
</tr>
</tbody>
</table>

**State at room temperature**
Fluorine and Chlorine are gases, Bromine is a liquid and Iodine is a solid. Astatine is radioactive.

All halogens exist as diatomic molecules bonded by strong covalent bond. Each molecule is joined to the other by weak intermolecular forces/Van-der-waals forces.

**Melting/Boiling point**

The strength of intermolecular/Van-der-waals forces of attraction increase with increase in molecular size/atomic radius. Iodine has therefore the largest atomic radius and thus strongest intermolecular forces to make it a solid.

Iodine sublimes when heated to form purple vapour. This is because Iodine molecules are held together by weak van-der-waals/intermolecular forces which require little heat energy to break.

**Electrical conductivity**

All Halogens are poor conductors of electricity because they have no free/delocalized electrons.

**Solubility in polar and non-polar solvents**

All halogens are soluble in water(polar solvent).

When a boiling tube containing either chlorine gas or bromine vapour is separately inverted in a beaker containing distilled water and tetrachloromethane (non-polar solvent), the level of solution in boiling tube rises in both water and tetrachloromethane. This is because halogens are soluble in both polar and non-polar solvents. Solubility of halogens in water/polar solvents decrease down the group. Solubility of halogens in non-polar solvent increase down the group.

The level of water in chlorine is higher than in bromine and the level of tetrachloromethane in chlorine is lower than in bromine.

**Caution:** Tetrachloromethane, Bromine vapour and Chlorine gas are all highly toxic/poisonous.

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**Chemical properties**

**(i) Displacement reactions**

**Experiment**
- Place separately in test tubes about 5cm³ of sodium chloride, Sodium bromide and Sodium iodide solutions.

- Add 5 drops of chlorine water to each test tube:

- Repeat with 5 drops of bromine water instead of chlorine water

**Observation**

**Using Chlorine water**

- Yellow colour of chlorine water fades in all test tubes except with sodium chloride.
- Coloured Solution formed.

**Using Bromine water**

- Yellow colour of bromine water fades in test tubes containing sodium iodide.
- Coloured Solution formed.

**Explanation**

The halogens displace each other from their solution. The more electronegative displace the less electronegative from their solution.

Chlorine is more electronegative than bromine and iodine. On adding chlorine water, bromine and iodine are displaced from their solutions by chlorine.

Bromine is more electronegative than iodide but less than chlorine. On adding Bromine water, iodine is displaced from its solution but not chlorine.

**Chemical /ionic equations**

**With Fluorine**

\[
\begin{align*}
F_2(g) & \quad + \quad 2NaCl(aq) \quad \rightarrow \quad 2NaF(aq) \quad + \quad Cl_2(aq) \\
F_2(g) & \quad + \quad 2Cl^-(aq) \quad \rightarrow \quad 2F^-(aq) \quad + \quad Cl_2(aq) \\
F_2(g) & \quad + \quad 2NaBr(aq) \quad \rightarrow \quad 2NaF(aq) \quad + \quad Br_2(aq) \\
F_2(g) & \quad + \quad 2Br^-(aq) \quad \rightarrow \quad 2F^-(aq) \quad + \quad Br_2(aq) \\
F_2(g) & \quad + \quad 2NaI(aq) \quad \rightarrow \quad 2NaF(aq) \quad + \quad I_2(aq) \\
F_2(g) & \quad + \quad 2I^-(aq) \quad \rightarrow \quad 2F^-(aq) \quad + \quad I_2(aq)
\end{align*}
\]

**With chlorine**

\[
\begin{align*}
Cl_2(g) & \quad + \quad 2NaCl(aq) \quad \rightarrow \quad 2NaCl(aq) \quad + \quad Br_2(aq) \\
Cl_2(g) & \quad + \quad 2Br^-(aq) \quad \rightarrow \quad 2Cl^-(aq) \quad + \quad Br_2(aq)
\end{align*}
\]
\[ \text{Cl}_2(\text{g}) + 2\text{NaI}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{I}_2(\text{aq}) \]
\[ \text{Cl}_2(\text{g}) + 2\text{I}^-(\text{aq}) \rightarrow 2\text{Cl}^-(\text{aq}) + \text{I}_2(\text{aq}) \]

With Bromine
\[ \text{Br}_2(\text{g}) + 2\text{NaI}(\text{aq}) \rightarrow 2\text{NaBr}(\text{aq}) + \text{I}_2(\text{aq}) \]
\[ \text{Br}_2(\text{g}) + 2\text{I}^-(\text{aq}) \rightarrow 2\text{Br}^-(\text{aq}) + \text{I}_2(\text{aq}) \]

**Reaction of halogens with metals**

Expt
- Pass a stream of dry chlorine gas over heated iron wool as shown.

**Fig 2.7 (a) pg 46**
Record your observations. For bromine and iodine, heat the iron wool in a test tube in which bromine and iodine vapour is generated and passed over the wool as shown.

**Figs 2.7 (b) and 2.7(c)**
The test tube should be held with a test tube holder. Alternatively, using a deflagrating spoon, place hot iron wool into a gas jar of chlorine.

**Explanation**
- Reaction between iron and a halogen results in formation of a salt. Chlorine reacts more vigorously with iron to form dark-brown crystals of iron(III) chloride.
- Hot iron glows in bromine vapour to form dark-red crystals of iron(III) bromide.
- Iodine vapour reacts slowly with hot iron to form grayish black crystals of iron(II) iodide. Iodine is not reactive enough to form a salt with iron.

**NB** concentrated sodium hydroxide is used to react with excess chlorine so that it does not escape into air since it is poisonous.

Halogens also react with heated zinc to form zinc salts.

**Equations for the reactions Pg 47**

**Reaction of Halogens with water**
- Bubble chlorine gas through water in a conical flask for a few minutes using the set-up below.

**Fig 2.8 pg 48**
Observe the colour of the resulting solution. Test the solution with litmus paper.

NB The experiment should be carried out in a fume chamber or in the open air.

It will be observed that chlorine gas dissolves in water to form chlorine water. Chlorine water is a mixture of hydrochloric acid and chloric(I) acid.

**Equations pg 48**

Chlorine water changes blue litmus paper to red showing that the solution is acidic. The litmus paper is then bleached (decolourised). The bleaching action is by chloric(I) acid. Chloric(I) acid is unstable and decomposes to form hydrochloric acid and an atom of oxygen. The oxygen atom then combines with the dye in the litmus paper to form a colourless compound. The bleaching action is only possible in the presence of water.

NB Chlorine gas does not bleach a dry litmus paper since chloric(I) acid is not formed.

Chlorine water has yellow colour due to the presence of chloric(I) acid. On exposure to sunlight, chlorine water is decolourised. This is because sunlight decomposes chloric(I) acid into oxygen gas and hydrochloric acid. This reaction does not occur in the dark.

-Equation pg 49

- Figs 2.9(a) and (b) pg 49

**Uses of halogens and their compounds**

**Florine**
- Manufacture of P.T.F.E (Poly tetra fluoroethene) a synthetic fiber.
- Reduce tooth decay when added in small quantities in tooth paste.

NB – Large quantities of fluorine /fluoride ions in water cause browning of teeth/flourosis.

-Hydrogen fluoride is used to engrave words /pictures in glass.

**Bromine**
- Silver bromide is used to make light sensitive photographic paper/films.

**Iodine**
- Iodine dissolved in alcohol is used as medicine to kill bacteria in skin cuts. It is called tincture of iodine.

**Chlorine**
- Chlorine is used to make bleaches used in paper and textile industries.
Chlorine is added to water to kill micro-organisms in water treatment works.

Chlorine is used in manufacture of a plastic called poly vinyl chloride (PVC).

 Chlorine is used in large scale manufacture of hydrochloric acid.

Noble gases.

Are group VIII elements. They are all non-metals. Noble gases occupy about 1.0% of the atmosphere as colourless gaseous mixture. Argon is the most abundant with 0.9%.

They exists as monatomic molecules with very weak van-der-waals / intermolecular forces holding the molecules.

They include:

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Atomic number</th>
<th>Electron structure</th>
<th>State at room temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>He</td>
<td>2</td>
<td>2:</td>
<td>Colourless gas</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>10</td>
<td>2:8</td>
<td>Colourless gas</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>18</td>
<td>2:8:8</td>
<td>Colourless gas</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
<td>36</td>
<td></td>
<td>Colourless gas</td>
</tr>
<tr>
<td>Xenon</td>
<td>Xe</td>
<td>54</td>
<td></td>
<td>Colourless gas</td>
</tr>
<tr>
<td>Radon</td>
<td>Rn</td>
<td>86</td>
<td></td>
<td>Radioactive</td>
</tr>
</tbody>
</table>

All noble gas atoms have a stable duplet (two electrons in the 1st energy level) or octet (eight electrons in other outer energy level) in the outer energy level. They therefore do not acquire/gain extra electron in the outer energy level or donate/lose.

They therefore are therefore zerovalent.

The number of energy levels increases down the group from Helium to Radon. The more the number of energy levels the bigger/larger the atomic size/radius. e.g.

The atomic size/radius of Argon is bigger/larger than that of Neon because Argon has more/3 energy levels than Neon (2 energy levels).

Atomic radius of noble gases increase down the group as the number of energy levels increases. The effective nuclear attraction on the outer electrons thus decrease down the group.
The noble gases are generally unreactive because the outer energy level has the stable octet/duplet. The stable octet/duplet in noble gas atoms lead to a comparatively very high 1st ionization energy. This is because losing/donating an electron from the stable atom require a lot of energy to lose/donate and make it unstable.

As atomic radius increase down the group and the 1st ionization energy decrease. Very electronegative elements like Oxygen and Fluorine are able to react and bond with lower members of the noble gases.e.g

Xenon reacts with Fluorine to form a covalent compound XeF₆. This is because the outer electrons/energy level if Xenon is far from the nucleus and thus experience less effective nuclear attraction.

Noble gases have low melting and boiling points. This is because they exist as monatomic molecules joined by very weak intermolecular/van-der-waals forces that require very little energy to weaken and form liquid and break to form a gas.

The intermolecular/van-der-waals forces increase down the group as the atomic radius/size increase from Helium to Radon. The melting and boiling points thus increase also down the group.

Noble gases are insoluble in water and are poor conductors of electricity.

<table>
<thead>
<tr>
<th>Element</th>
<th>Formula of molecule</th>
<th>Electrical conductivity</th>
<th>Solubility in water</th>
<th>Atomic radius(nM)</th>
<th>1st ionization energy</th>
<th>Melting point(°C)</th>
<th>Boiling point(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>He</td>
<td>Poor</td>
<td>Insoluble</td>
<td>0.128</td>
<td>2372</td>
<td>-270</td>
<td>-269</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>Poor</td>
<td>Insoluble</td>
<td>0.160</td>
<td>2080</td>
<td>-249</td>
<td>-246</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>Poor</td>
<td>Insoluble</td>
<td>0.192</td>
<td>1520</td>
<td>-189</td>
<td>-186</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
<td>Poor</td>
<td>Insoluble</td>
<td>0.197</td>
<td>1350</td>
<td>-157</td>
<td>-152</td>
</tr>
<tr>
<td>Xenon</td>
<td>Xe</td>
<td>Poor</td>
<td>Insoluble</td>
<td>0.217</td>
<td>1170</td>
<td>-112</td>
<td>-108</td>
</tr>
<tr>
<td>Radon</td>
<td>Rn</td>
<td>Poor</td>
<td>Insoluble</td>
<td>0.221</td>
<td>1134</td>
<td>-104</td>
<td>-93</td>
</tr>
</tbody>
</table>

**Uses of noble gases**

- Argon is used in light bulbs to provide an inert environment to prevent oxidation of the bulb filament
- Argon is used in arch welding as an insulator.
- Neon is used in street and advertisement light
- Helium is mixed with Oxygen during deep sea diving and mountaineering.
- Helium is used in weather balloon for meteorological research instead of Hydrogen because it is unreactive/inert. Hydrogen when impure can ignite with an explosion.
- Helium is used in making thermometers for measuring very low temperature