

Periodic Table of the Chemical Elements



**Macroconcepts of
Change and Patterns**

Part Two:

Properties and Patterns of the:

1. Alkali Metals*

2. Halogens*

3. Noble Gases*

4. Transition Metals*

*Click on a link to go directly to that chapter.

Periodic Table of the Chemical Elements



What periodic trends are there in *Group 1 (Group I)* of the Periodic Table?

Group 1 (Group I)
The Alkali Metals

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Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



Lithium – Li

- Atomic Number = 3
- Relative Atomic Mass = 6.9
 - Melting Point = 180 °C
 - Boiling Point = 1330 °C
 - Density = 0.53 g cm⁻¹
- Atomic Radius = 0.123 nm
 - First Ionization Energy = 519 kJ mol⁻¹
 - Electronegativity = 1.0



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



Sodium – Na

- Atomic Number = 11
- Relative Atomic Mass = 23.0
- Melting Point = 97.8 °C
- Boiling Point = 890 °C
- Density = 0.97 g cm⁻¹
- Atomic Radius = 0.157 nm
 - First Ionization Energy = 494 kJ mol⁻¹
- Electronegativity = 0.9



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



Potassium – K

- Atomic Number = 19
- Relative Atomic Mass = 39.1
 - Melting Point = 63.7 °C
 - Boiling Point = 774 °C
 - Density = 0.86 g cm⁻¹
- Atomic Radius = 0.203 nm
 - First Ionization Energy = 418 kJ mol⁻¹
 - Electronegativity = 0.8



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

Rb **37**
85.468



Rubidium

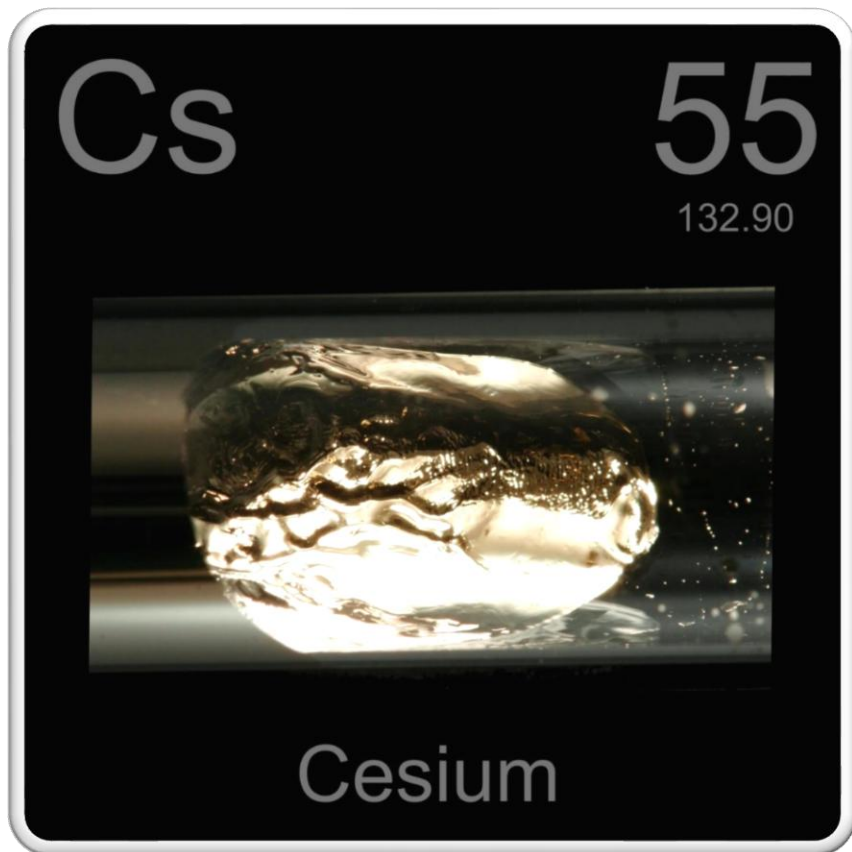
Rubidium – Rb

- Atomic Number = 37
- Relative Atomic Mass = 85.5
- Melting Point = 38.9 °C
- Boiling Point = 688 °C
- Density = 1.53 g cm⁻¹
- Atomic Radius = 0.216 nm
 - First Ionization Energy = 402 kJ mol⁻¹
- Electronegativity = 0.8



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



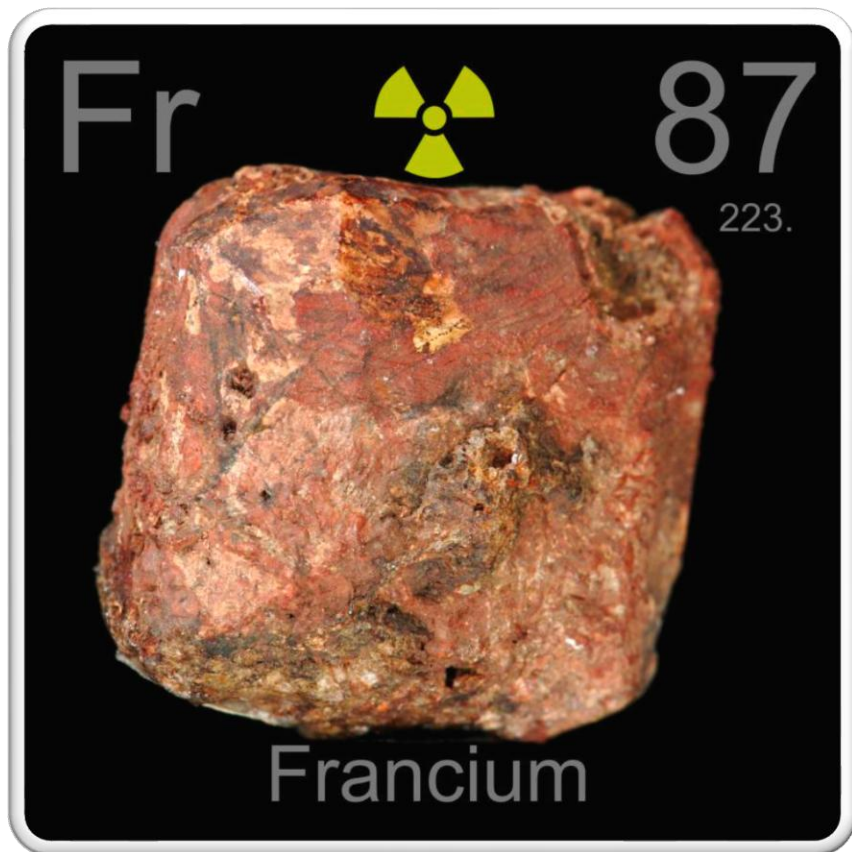
Cesium – Cs

- Atomic Number = 55
- Relative Atomic Mass = 132.9
- Melting Point = 28.7 °C
- Boiling Point = 690 °C
- Density = 1.90 g cm⁻¹
- Atomic Radius = 0.235 nm
 - First Ionization Energy = 376 kJ mol⁻¹
- Electronegativity = 0.7



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



Francium – Fr

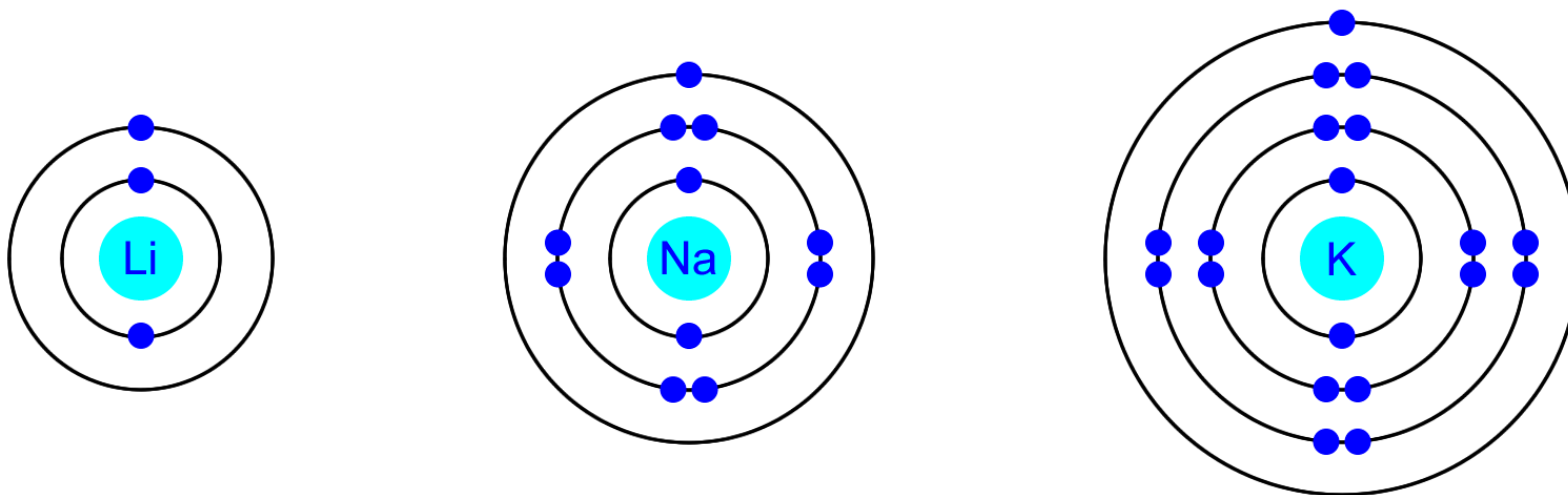
- Atomic Number = 87
- Relative Atomic Mass = 223
- Melting Point = 27.0 °C
- Boiling Point = 677 °C
- Density = 1.87 g cm⁻¹
- Atomic Radius = 0.348 nm
 - First Ionization Energy = 381 kJ mol⁻¹
- Electronegativity = 0.7



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Lithium (Li) , sodium (Na) and potassium (K) are the first three elements in Group 1 of the Periodic Table – the alkali metals.



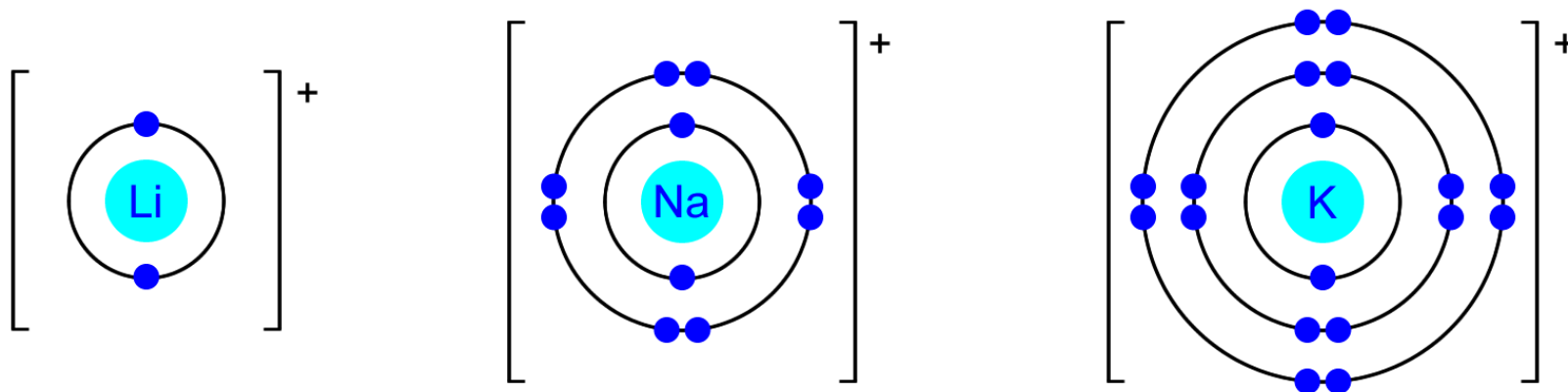
- The Group 1 metals all have a single electron in their valence shell. This electron is located in an s-orbital, and the Group 1 metals are referred to as s-block elements.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- When the Group 1 metals react, each atom loses its single valence electron to form a cation with a single positive charge and the electronic configuration of a noble gas.




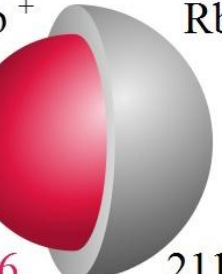


- All of the Group 1 metals have a valency of one, meaning that their compounds all have similar formulae, e.g. Li_2CO_3 , Na_2CO_3 , K_2CO_3 , Rb_2CO_3 , Cs_2CO_3 and Fr_2CO_3 .



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals





Li ⁺		Li
90		134
Na ⁺		Na
116		154
K ⁺		K
152		196
Rb ⁺		Rb
166		211

- When the Group 1 metals react to obtain a noble gas electronic configuration, the resulting cation has a *smaller radius* than the original atom. This is due to the loss of an electron shell (the original valence shell is lost) e.g. a sodium atom has three electron shells (2,8,1) while a sodium ion only has two electron shells (2,8).



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

Li ⁺ 90		Li 134
Na ⁺ 116		Na 154
K ⁺ 152		K 196
Rb ⁺ 166		Rb 211

- The valence electrons of a sodium ion also experience a greater effective nuclear charge compared to the valence electron of a neutral sodium atom.

$$Z_{\text{eff}}(\text{Na}) = 11 - 10 = +1$$

$$Z_{\text{eff}}(\text{Na}^+) = 11 - 2 = +9$$

- This increased electrostatic force of attraction between the positively charged nucleus and negatively charged electrons in the valence shell of the alkali metal cation results in the alkali metal cation having a smaller radius as compared to the corresponding atom.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Melting points of the Group 1 metals *decrease* while descending the Group.
- While descending the Group, metallic bonding becomes *weaker*.
 - While descending Group 1, the radius of the cation increases. This means that the single positive charge on the cation is progressively spread-out over a larger and larger volume and *charge density* is said to *decrease*. As the *charge density* of the cation *decreases*, the electrostatic force of attraction between the cation and delocalised sea of electrons also *decreases*. Consequently, *less energy* is required to weaken the metallic bond and melting points *decrease* down the Group.



Periodic Table of the Chemical Elements

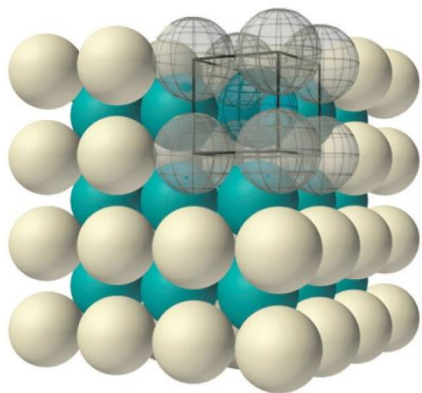
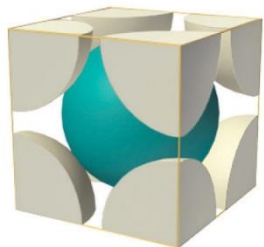
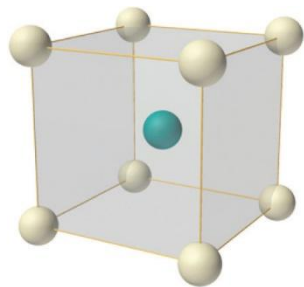
The Elements of Group 1 (Group I) – Alkali Metals

- Melting points of the Group 1 metals *decrease* while descending the Group.
- While descending the Group, metallic bonding becomes *weaker*.
- Descending Group 1, as the radius of the cation *increases*, so the distance between the positively charged nucleus and negatively charged sea of delocalised electrons also *increases*. This *weakens the electrostatic force of attraction* between the positively charged nucleus and negatively charged sea of delocalised electrons. Consequently, *less energy* is required to weaken the metallic bond and melting points *decrease* down the Group.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



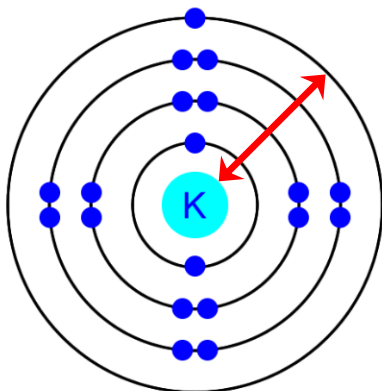
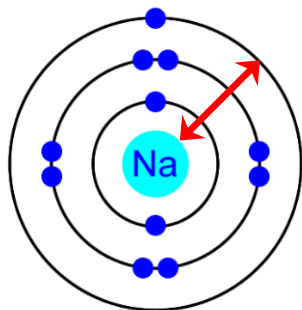
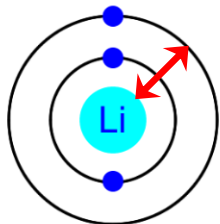
- The body-centred cubic structure of the Group 1 metals.

- Densities of the Group 1 metals *increase* while descending the Group.
- Lithium, sodium and potassium are the only three metallic elements that are less dense than water (1.00 g cm^{-3}).
- Descending Group 1, both the relative atomic masses and the atomic radii (volume) of the atoms increase. Overall, there is an increase in each element's mass per unit volume and density increases down the Group.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

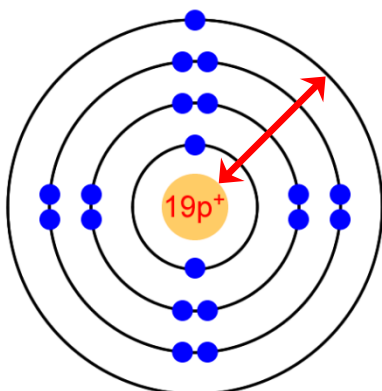
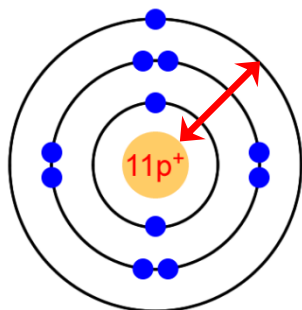
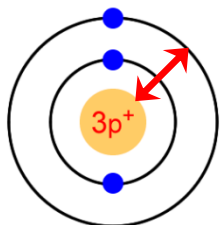


- Reactivity of the Group 1 metals *increases* upon descending the Group.
- The Group 1 metals react by *losing* their single valence electron to form a cation with the electronic configuration of a noble gas.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



- The number of protons in the nucleus of an atom (nuclear charge) and the number of electron shells around the nucleus of the atom *both increase* down a Group 1.

- Moving down Group 1, there is no significant change in the effective nuclear charge that the electron(s) in the valence shell of the atom experience, as the increasing nuclear charge and increasing shielding effect cancel each other e.g.

$$Z_{\text{eff}} (\text{Li}) = 3 - 2 = +1$$

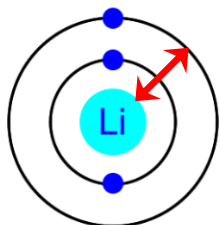
$$Z_{\text{eff}} (\text{Na}) = 11 - 10 = +1$$

$$Z_{\text{eff}} (\text{K}) = 19 - 18 = +1$$

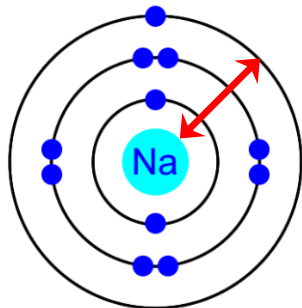


Periodic Table of the Chemical Elements

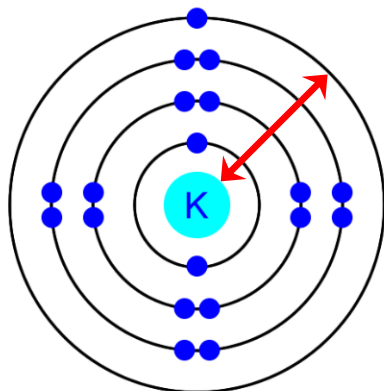
The Elements of Group 1 (Group I) – Alkali Metals



- The addition of a new electron shell to the atoms is significant because it means that the electron in the valence shell (lost when the metal reacts) is *further from the nucleus*.



- This *reduces the electrostatic force of attraction* between the positively charged nucleus and negatively charged electron in the valence shell (inverse square law).



- Less energy is required to remove an electron from the valence shell of the atom (first ionization energy decreases) and therefore the alkali metals become *more reactive* down the Group.

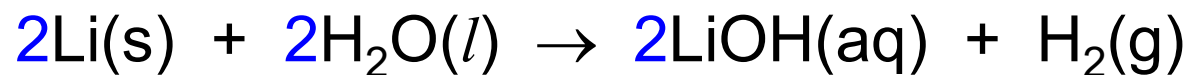


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



- The reaction between *lithium* and water.



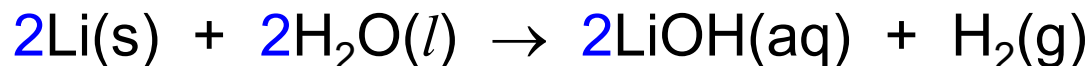
Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

The Reaction Between Lithium and Cold Water

- Lithium floats on the surface of the water (lithium is less dense than water) and moves about on the surface of the water. A gas is produced (effervescence). A “hissing” sound is heard.
- The reaction between lithium and water produces a solution of lithium hydroxide which is alkaline. This alkaline solution will turn universal indicator solution **blue** / **purple**.
- The reaction between lithium and water produces hydrogen gas. Recall: Hydrogen gas extinguishes a burning splint with a squeaky “pop” sound.

- lithium + water → lithium hydroxide + hydrogen

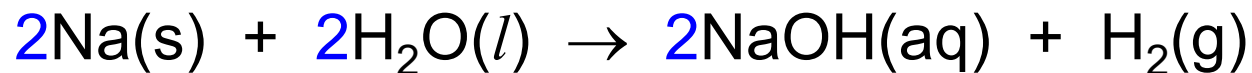


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



- The reaction between *sodium* and water.



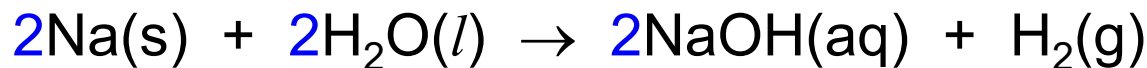
Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

The Reaction Between Sodium and Cold Water

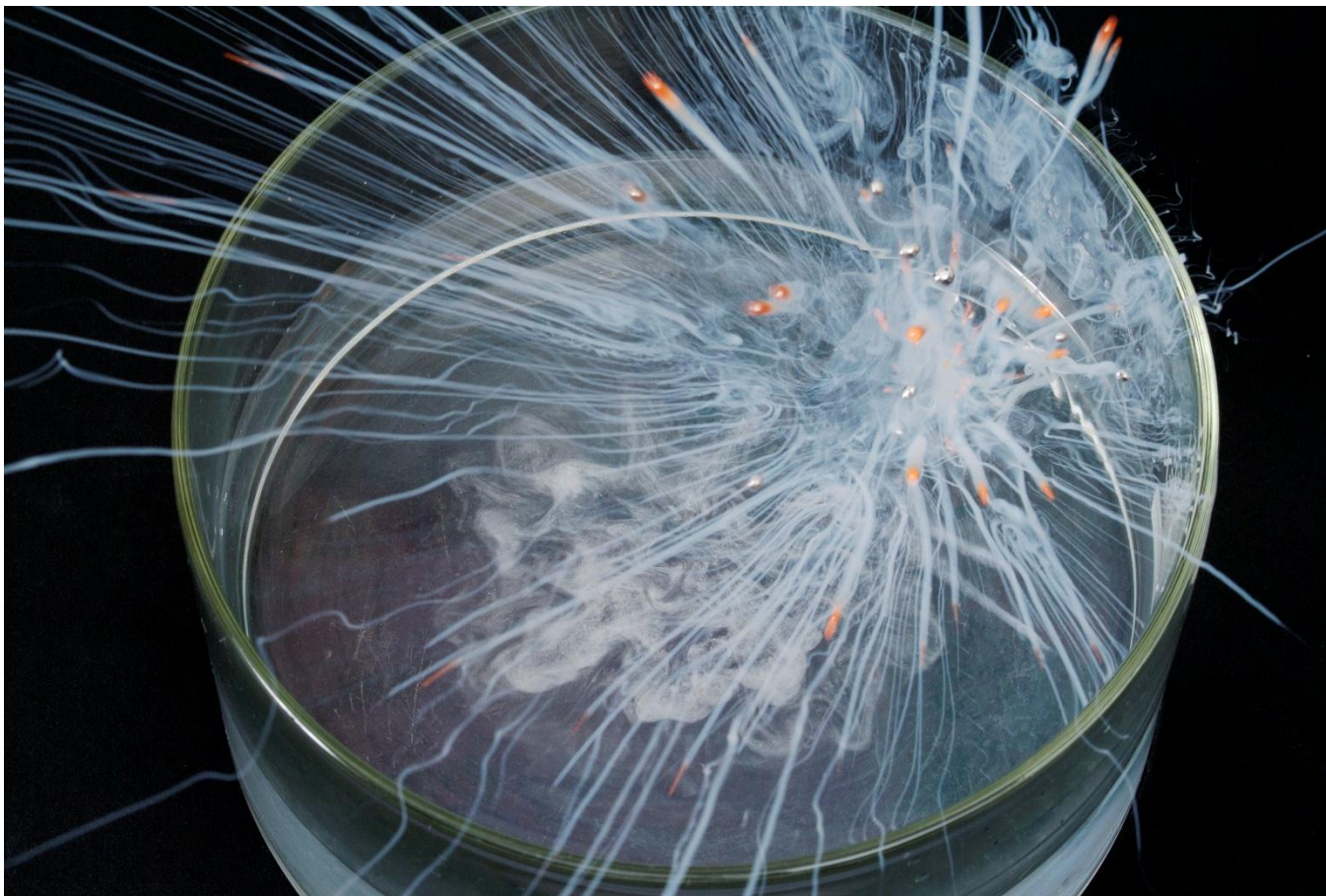
- Sodium floats on the surface of the water (sodium is less dense than water) and moves about on the surface of the water. A gas is produced (effervescence). Sparks are observed. A “hissing” sound is heard.
- The reaction between sodium and water produces a solution of sodium hydroxide which is alkaline. This alkaline solution will turn universal indicator solution **blue** / **purple**.
- The reaction between sodium and water produces hydrogen gas. The hydrogen gas ignites and burns with an **orange-yellow** flame. Recall: Hydrogen gas extinguishes a burning splint with a squeaky “pop” sound.

- sodium + water → sodium hydroxide + hydrogen

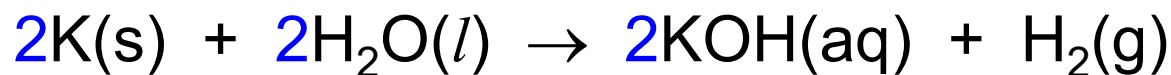


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



- The reaction between *potassium* and water.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

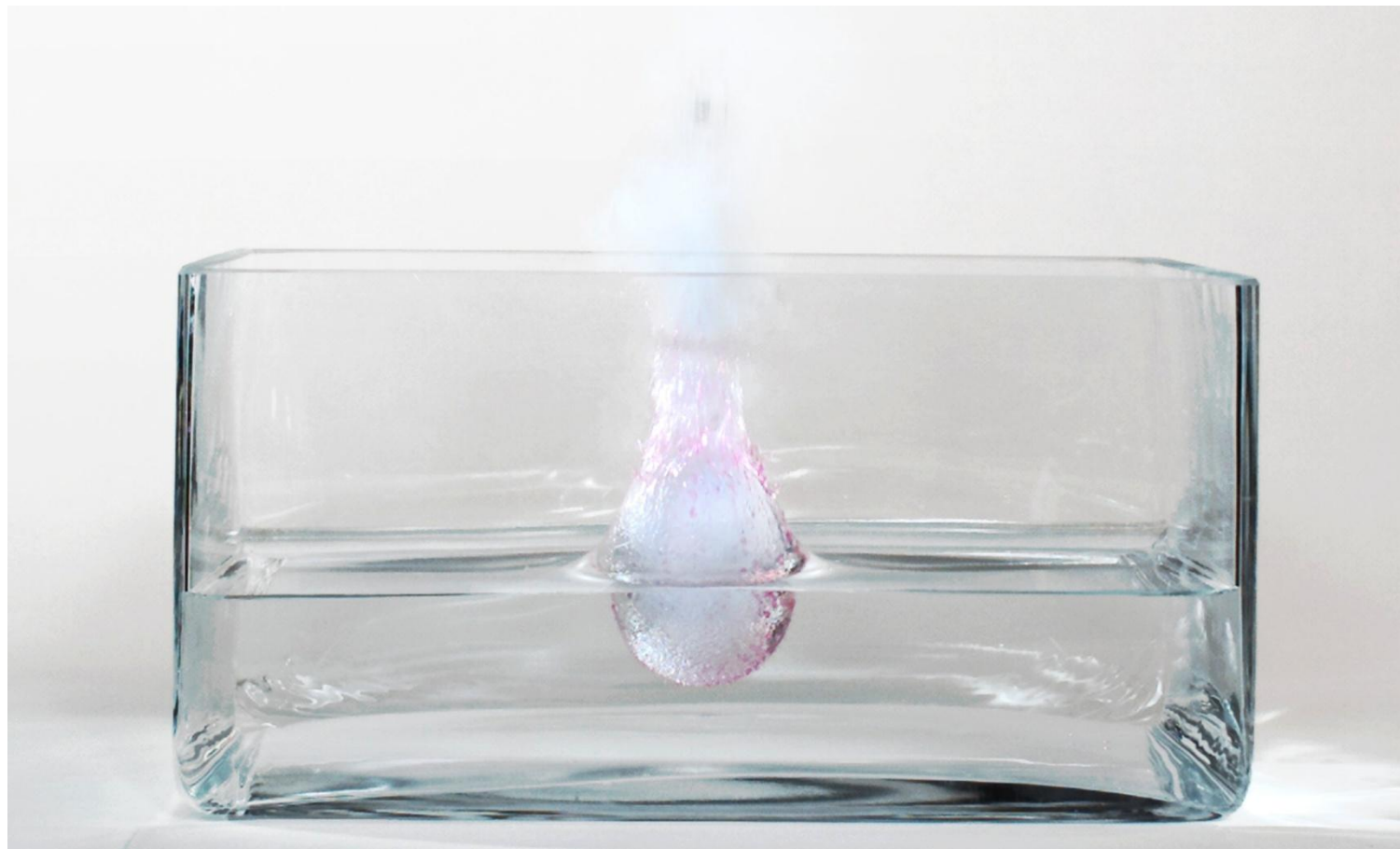
The Reaction Between Potassium and Cold Water

- Potassium floats on the surface of the water (potassium is less dense than water) and moves about on the surface of the water. A gas is produced (effervescence). Sparks are observed. A “hissing” sound is heard.
 - The reaction between potassium and water produces a solution of potassium hydroxide which is alkaline. This alkaline solution will turn universal indicator solution **blue / purple**.
 - The reaction between potassium and water produces hydrogen gas. The hydrogen gas ignites and burns with a **lilac** flame. Recall: Hydrogen gas extinguishes a burning splint with a squeaky “pop” sound.
- potassium + water → potassium hydroxide + hydrogen
$$2\text{K(s)} + 2\text{H}_2\text{O(l)} \rightarrow 2\text{KOH(aq)} + \text{H}_2\text{(g)}$$

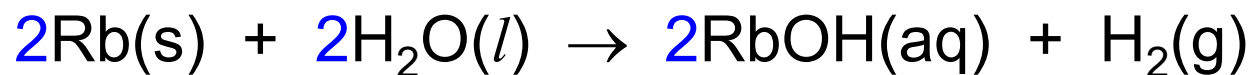


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals



- The reaction between *rubidium* and water.



Periodic Table of the Chemical Elements

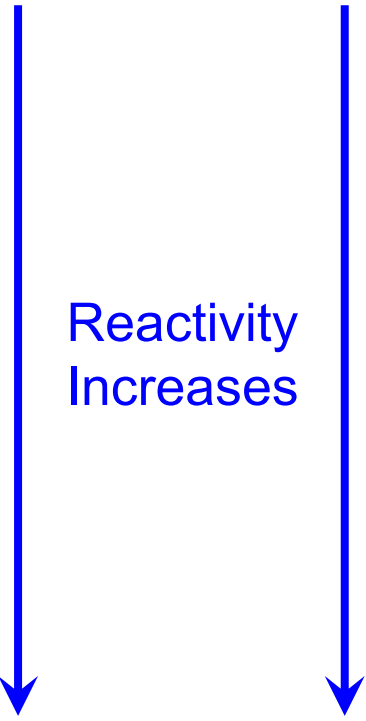
The Elements of Group 1 (Group I) – Alkali Metals

Similar	Different
<ul style="list-style-type: none">• Li, Na and K float on water.• Li, Na and K move about on the surface of the water.• Effervescence is observed.<ul style="list-style-type: none">• “Hissing” sound is heard.• Alkaline solution produced.	<ul style="list-style-type: none">• For Li, no flame is observed.<ul style="list-style-type: none">• For Na, the hydrogen gas burns with a yellow flame. The reaction is faster than the reaction between Li and water.• For K, the hydrogen gas burns with a lilac flame. The reaction is faster than the reaction between Na and water.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

 <p>Reactivity Increases</p>	Lithium	Less Reactive The valence shell is close to the nucleus and is not very well shielded. The electrostatic force of attraction between the positive nucleus and single valence electron is strong . It is difficult to remove the single valence electron from the atom.
	Sodium	
	Potassium	
	Rubidium	More Reactive The valence shell is far from the nucleus and is well shielded. The electrostatic force of attraction between the positive nucleus and single valence electron is weak . The single valence electron is easily removed from the atom.
	Caesium	

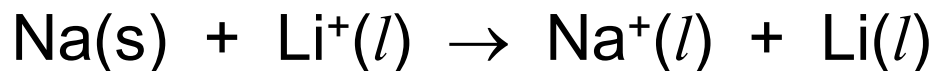
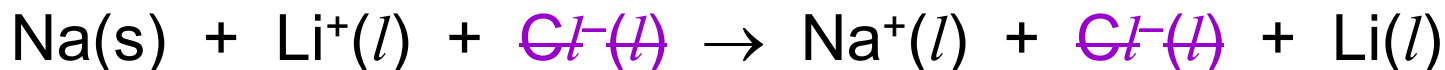
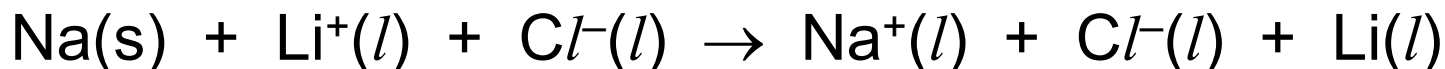
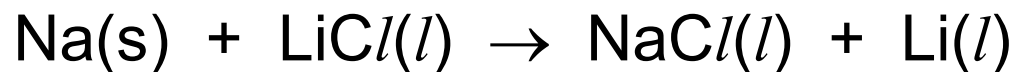


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Displacement reactions. A more reactive Group 1 metal will displace a less reactive Group 1 metal from its compounds.

sodium + lithium chloride \rightarrow sodium chloride + lithium

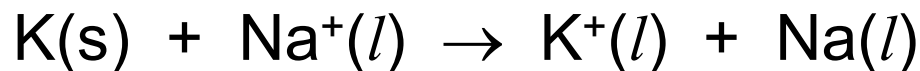
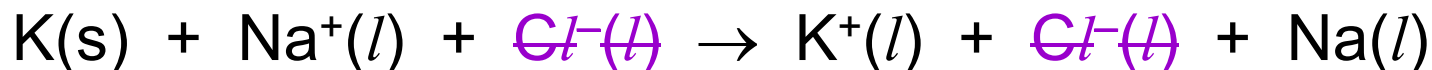
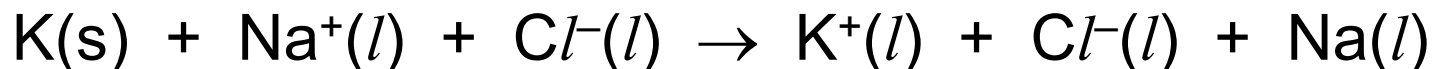
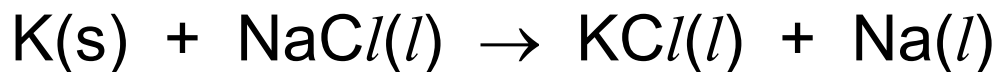


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Displacement reactions. A more reactive Group 1 metal will displace a less reactive Group 1 metal from its compounds.

potassium + sodium chloride → potassium chloride + sodium



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Thermal stability of the Group 1 carbonates.
- In Group 1, only lithium carbonate undergoes thermal decomposition at the temperature of a non-luminous Bunsen burner flame:

lithium carbonate → lithium oxide + carbon dioxide



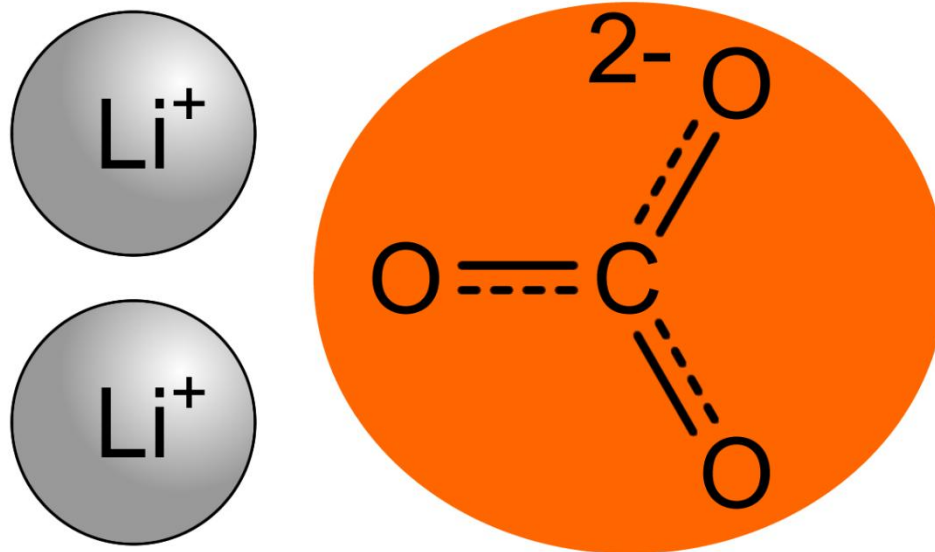
- The other Group 1 carbonates are thermally stable when heated by a Bunsen burner. In general, the thermal stability of the Group 1 metal carbonates *increases* down the Group, *i.e.* the Group 1 metal carbonates require higher and higher temperatures to decompose while moving down the Group.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Thermal stability of the Group 1 carbonates.



- Each one of the lithium cations has a single positive charge spread over a relatively *small volume*. This gives the small lithium cations a relatively *high charge density* compared to the larger cations of the other alkali metals.

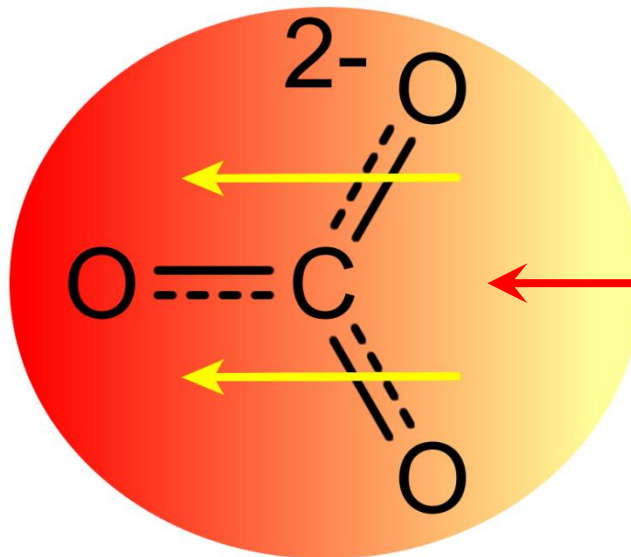
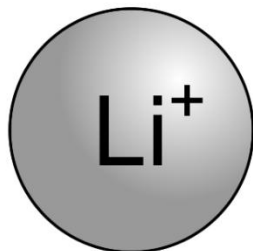
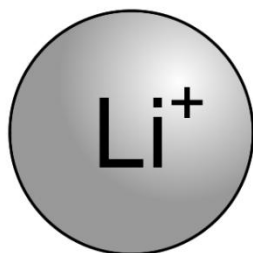


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Thermal stability of the Group 1 carbonates.

• The oxygen atom and electrons closest to the lithium cations will be attracted towards the high charge density on the lithium cations, readily forming lithium oxide, Li_2O .



• This carbon atom and two oxygen atoms will readily break away from the carbonate ion to form carbon dioxide, CO_2 .

- The high charge density on the lithium cations distorts and weakens the bonding in the carbonate ion, meaning that less energy (*i.e.* a lower temperature) is required for Li_2CO_3 to decompose into Li_2O and CO_2 .



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

- Thermal stability of the Group 1 nitrates.
 - Moving down Group 1, the nitrates become more thermally stable and higher temperatures (more thermal energy) are needed in order for them to decompose:

lithium nitrate → lithium oxide + nitrogen dioxide + oxygen



rubidium nitrate → rubidium nitrite + oxygen



Note: The less stable lithium nitrate decomposes more completely than the more stable rubidium nitrate.

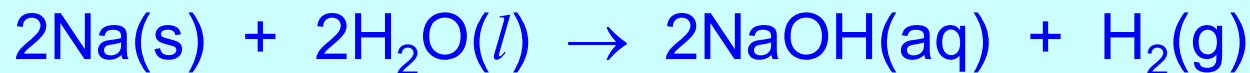


Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

Summary of the Group 1 Alkali Metals

- The alkali metals have some properties that are *atypical* of metals, e.g. they are relatively soft, have low melting points and have low densities.
- Atoms of the alkali metals react by losing their single valence electron to form ions with a charge of 1+.
- Melting points of the alkali metals *decrease* down the Group while densities of the elements *increase* down the Group.
- The alkali metals react with cold water to produce an alkaline solution and hydrogen gas, e.g.



Periodic Table of the Chemical Elements

The Elements of Group 1 (Group I) – Alkali Metals

Summary of the Group 1 Alkali Metals

- Reactivity *increases* down the Group as the single valence electron is moved further and further from the nucleus, reducing the electrostatic force of attraction between the nucleus and single valence electron.
- A more reactive alkali metal can displace a less reactive alkali metal from its compounds, e.g.
$$\text{Rb(s)} + \text{NaCl(l)} \rightarrow \text{RbCl(l)} + \text{Na(l)}$$
- Thermal stability of the alkali metal carbonates and nitrates increase down the group, *i.e.* higher temperatures are required to make them decompose.



Periodic Table of the Chemical Elements



What periodic trends are there in *Group 17 (Group VII)* of the Periodic Table?

Group 17 (Group VII)
The Halogens

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Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



Fluorine – F

- Atomic Number = 9
- Relative Atomic Mass = 19.0
- Melting Point = $-220\text{ }^{\circ}\text{C}$
- Boiling Point = $-188\text{ }^{\circ}\text{C}$
- Density* = 1.11 g cm^{-3}
- Atomic Radius = 0.072 nm
 - First Ionization Energy = 1680 kJ mol^{-1}
 - Electronegativity = 4.0

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



Chlorine – Cl

- Atomic Number = 17
- Relative Atomic Mass = 35.5
- Melting Point = $-101\text{ }^{\circ}\text{C}$
- Boiling Point = $-34.7\text{ }^{\circ}\text{C}$
- Density* = 1.56 g cm^{-1}
- Atomic Radius = 0.099 nm
 - First Ionization Energy = 1260 kJ mol^{-1}
 - Electronegativity = 3.0

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



Bromine – Br

- Atomic Number = 35
- Relative Atomic Mass = 79.9
 - Melting Point = $-7.2\text{ }^{\circ}\text{C}$
 - Boiling Point = $58.8\text{ }^{\circ}\text{C}$
 - Density = 3.12 g cm^{-1}
- Atomic Radius = 0.114 nm
 - First Ionization Energy = 1140 kJ mol^{-1}
 - Electronegativity = 2.8



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



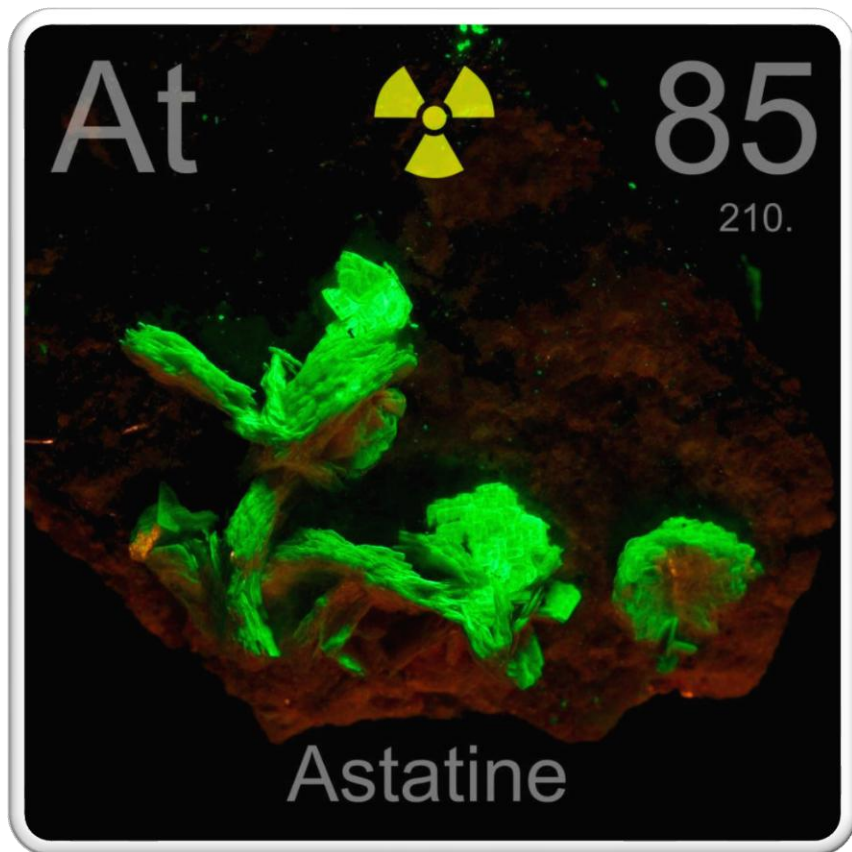
Iodine – I

- Atomic Number = 53
- Relative Atomic Mass = 126.9
 - Melting Point = 114 °C
 - Boiling Point = 184 °C
 - Density = 4.93 g cm⁻¹
- Atomic Radius = 0.133 nm
 - First Ionization Energy = 1010 kJ mol⁻¹
 - Electronegativity = 2.5



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



Astatine – At

- Atomic Number = 85
- Relative Atomic Mass = 210
- Melting Point = 302 °C
- Boiling Point = 380 °C
- Density = $\sim 7 \text{ g cm}^{-3}$
- Atomic Radius = 0.140 nm
 - First Ionization Energy = 920 kJ mol⁻¹
- Electronegativity = 2.2



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

• Chlorine

• Bromine

• Iodine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Colours of the Halogens			
halogen	colour of the pure element	colour in aqueous solution	colour in *hexane
chlorine – Cl_2	greenish-yellow gas	pale yellow	pale yellow
bromine – Br_2	reddish-brown gas / liquid	orange	orange-red
iodine – I_2	black solid / purple gas	brown	purple


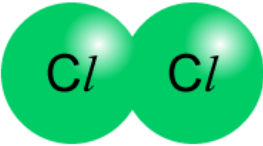
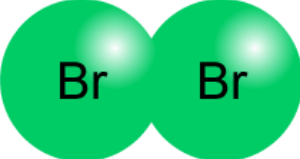
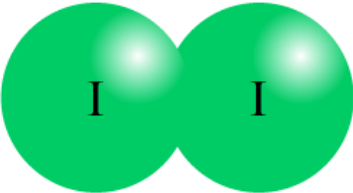
*hexane is a *non-polar solvent*

*an alternative non-polar solvent is *tetrachloromethane*



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Halogen	melting point /°C	boiling point /°C	covalent radius / pm	total number of electrons	relative molecular mass
	-220	-188	71	9 + 9 = 18	38.0
	-101	-35.0	99	17 + 17 = 34	71.0
	-7.20	58.8	114	35 + 35 = 70	159.8
	114	184	133	53 + 53 = 106	253.8



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- As the *number of electrons* within a single molecule of the element increases, so the *polarisability* of the molecule increases. This increases the strength of the *instantaneous dipole-induced dipole forces of attraction* (London dispersion forces) hence increasing the melting and boiling points.
- As the covalent radii of the atoms increases, so the *surface area* of the molecules also *increases*. The larger the surface area available for London dispersion forces to operate over, the stronger they become, increasing the melting and boiling points.
- As the *relative molecular mass* of the diatomic molecules *increases*, so the melting points and boiling points also *increase*. More energy is required to overcome the *inertia** of the molecules with the greater relative molecular mass.

***Note:** *Inertia* is the natural tendency of an object to stay at rest, or remain in motion.



Periodic Table of the Chemical Elements

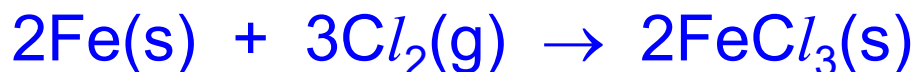
Elements of Group 17 (Group VII) – Halogens

- The Group 17 elements, also known as the halogens, are a family of diatomic non-metallic elements.
- The name halogen is derived from the Greek language and literally means *producer of salt* or *salt producer* because they react with metallic elements to form ionic compounds or salts:

sodium + chlorine → sodium chloride



iron + chlorine → iron(III) chloride

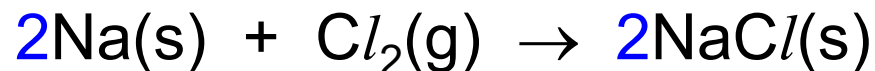


Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

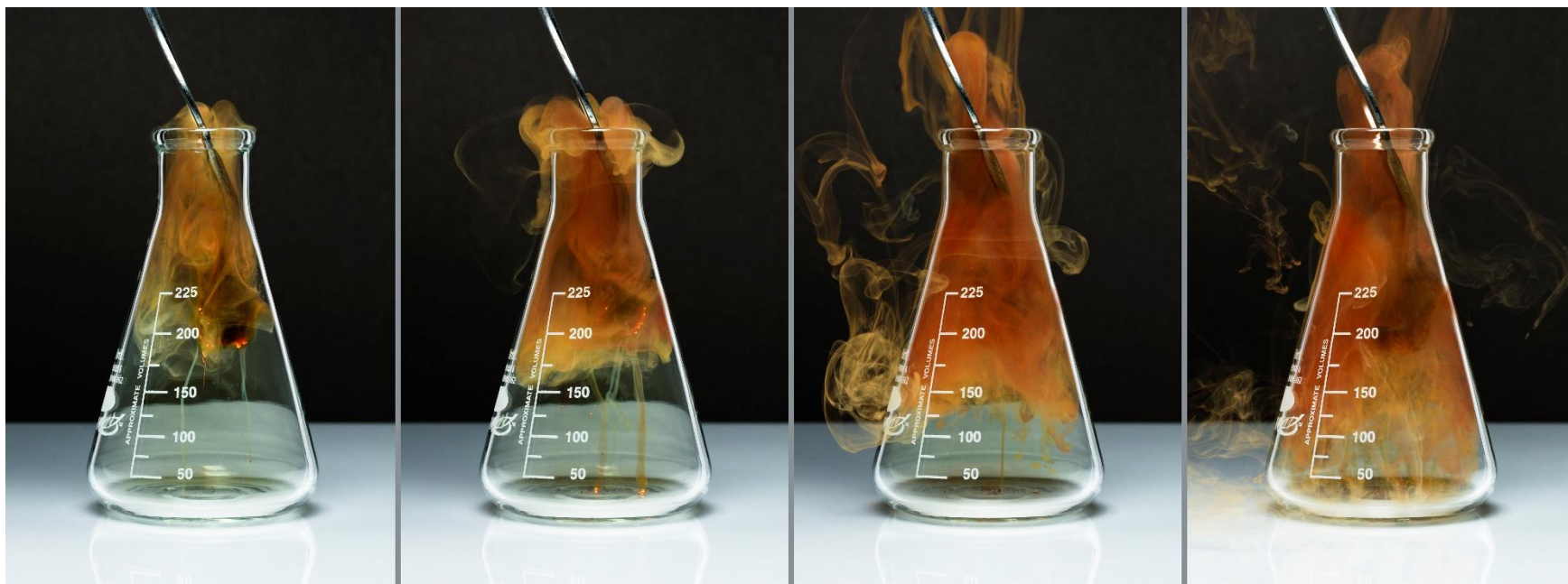


sodium + chlorine → sodium chloride

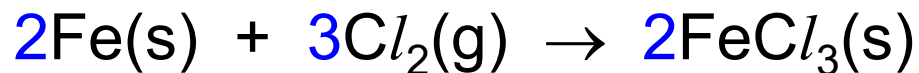


Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

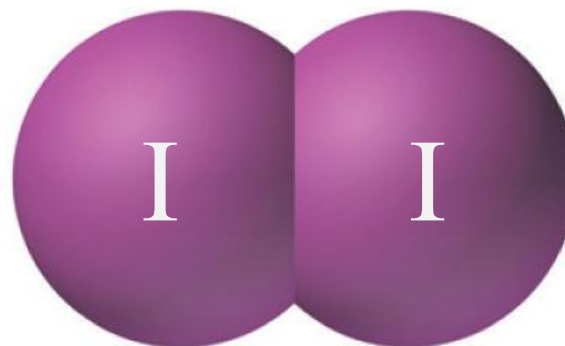
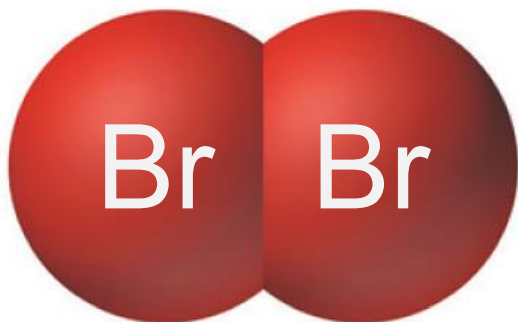
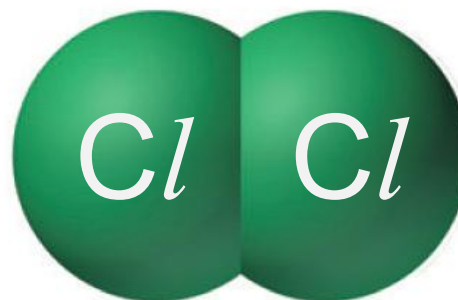
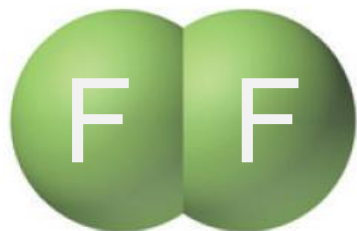


iron + chlorine \rightarrow iron(III) chloride



Periodic Table of the Chemical Elements

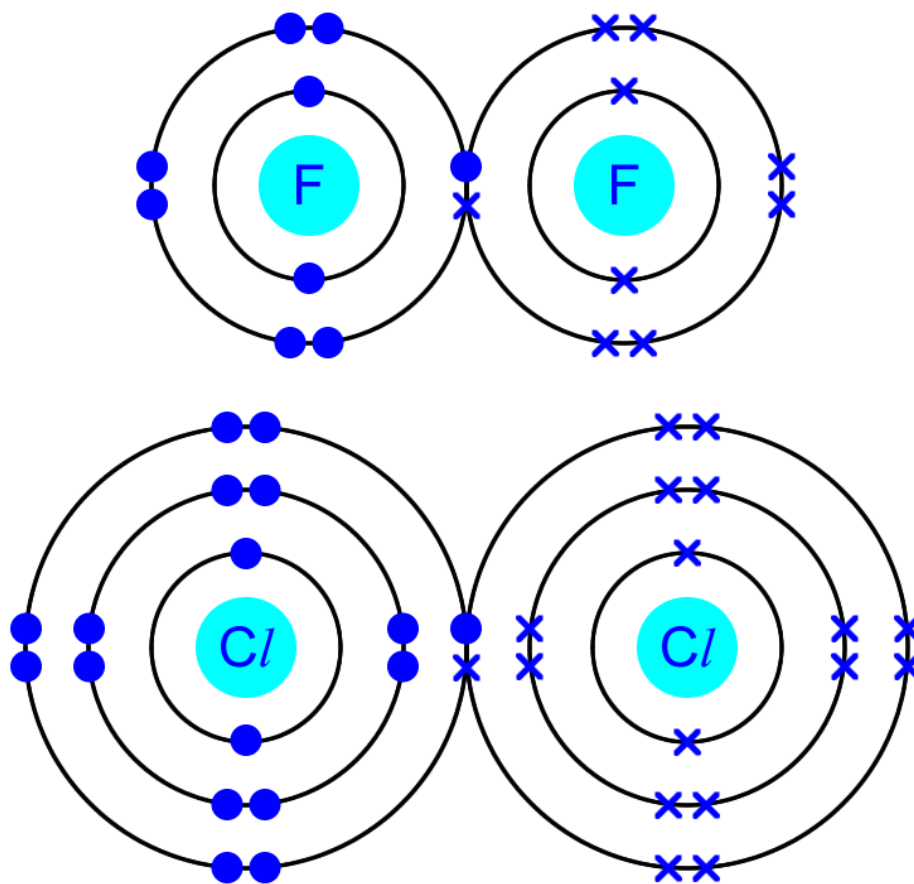
Elements of Group 17 (Group VII) – Halogens



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

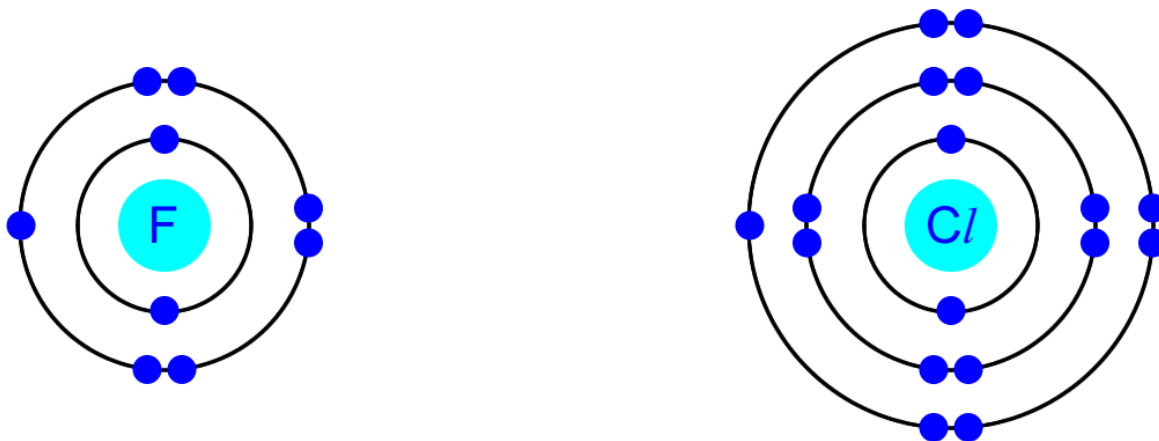
- Elemental halogens exist as *diatomic molecules* in which both atoms have stable noble gas electronic configurations.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- Fluorine (F) and chlorine (Cl) are the first two elements in Group 17 of the Periodic Table – the halogens.



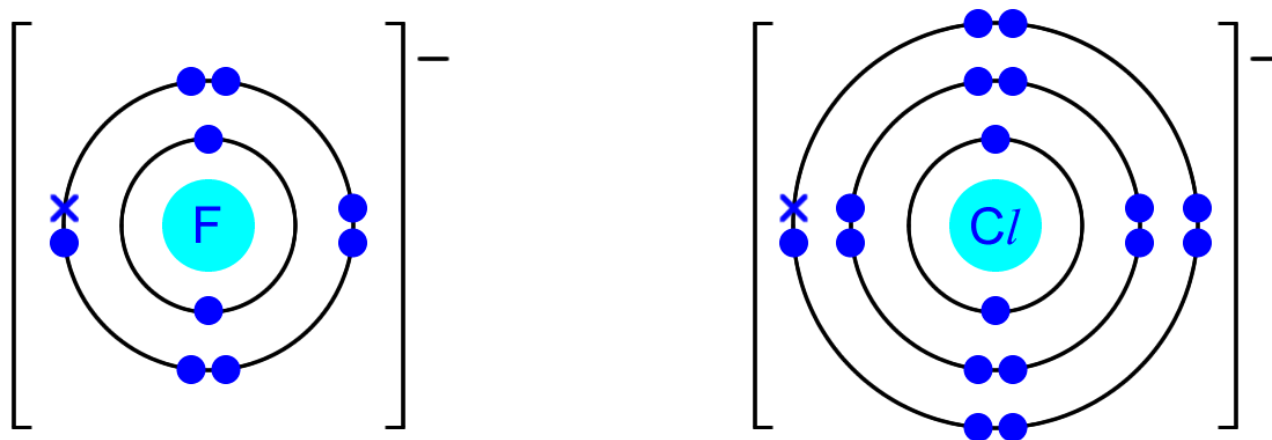
- The halogens all have seven electrons in their valence shell. These electrons are located in a combination of one s-orbital and three p-orbitals, and the halogens are referred to as p-block elements.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- When the halogens react, each atom gains a single electron to form an anion with a single negative charge and the electronic configuration of a noble gas.


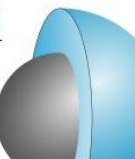
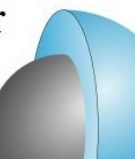
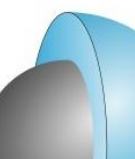


- All of the halogens have a valency of one, meaning that their compounds all have similar formulae, e.g. CaF₂, CaCl₂, CaBr₂, CaI₂, and CaAt₂.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

F 71		F ⁻ 119
Cl 99		Cl ⁻ 167
Br 114		Br ⁻ 182
I 133		I ⁻ 206

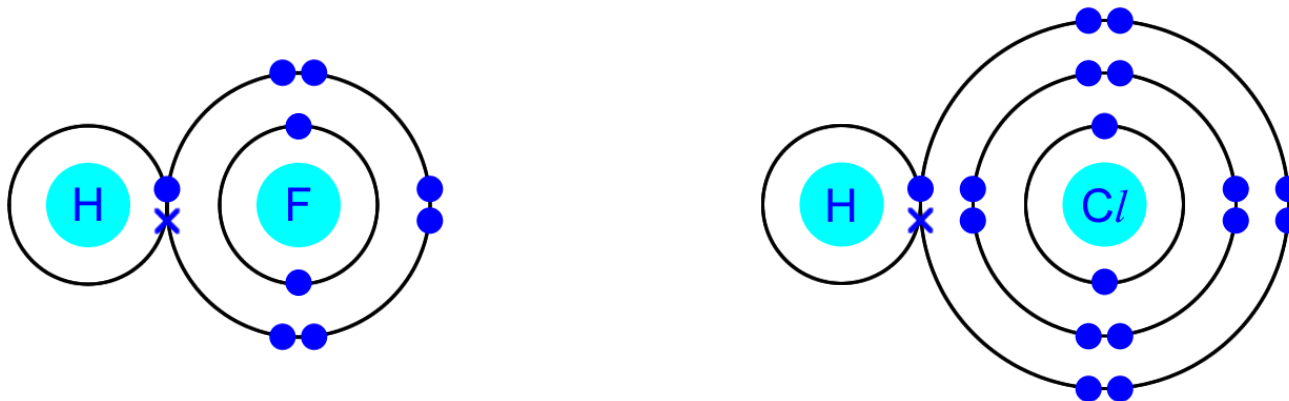
- When the halogens react to obtain a noble gas electronic configuration, the resulting anion has a *larger radius* than the original atom.
- This is due to the addition of a single electron into the valence shell of each atom. The *electrostatic force of repulsion* between the single new electron and the seven original electrons causes the radius of the anion to expand.



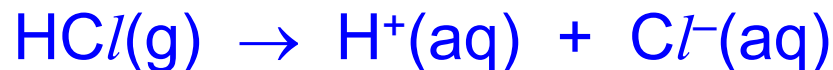
Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The halogens all form covalent hydrogen halides.



- These hydrogen halides are soluble in water and dissolve to form acidic solutions of hydrogen ions and halide ions:



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The colour of the halogens becomes darker while descending the Group.

Fluorine, F_2 – pale yellow gas

Chlorine, Cl_2 – greenish-yellow gas

Bromine, Br_2 – reddish-brown liquid

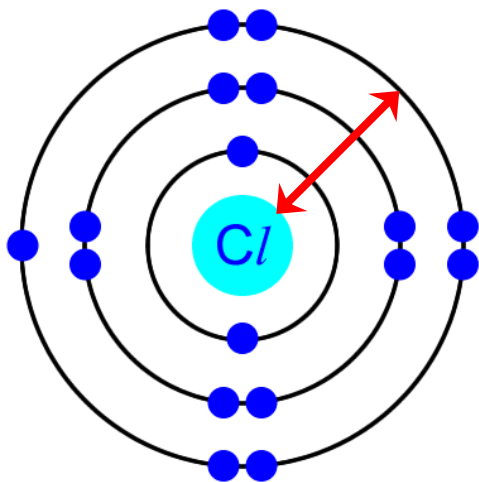
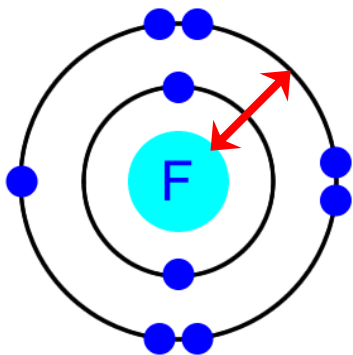
Iodine, I_2 – black solid

- Melting points increase down the Group of halogens as
i) the surface area of the molecule increases, ii) the number of electrons in a single molecule of the element increases, and iii) the relative molecular mass of the element increases; $F_2 = 38.0$, $Cl_2 = 71.0$,
 $Br_2 = 159.8$ and $I_2 = 253.8$.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

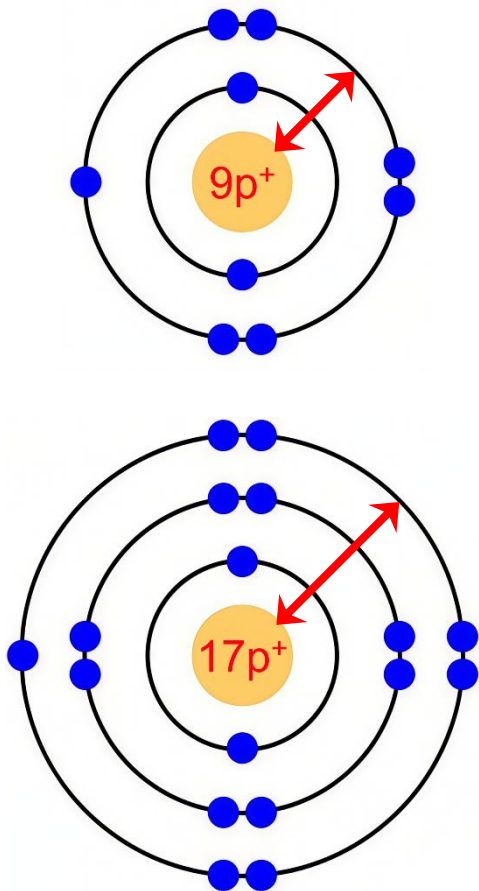


- Reactivity of the halogens *decreases* upon descending the Group.
- The halogens react by *gaining* a single electron into their valence shell to form an anion with the electronic configuration of a noble gas.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



- The number of protons in the nucleus of an atom (nuclear charge) and the number of electron shells around the nucleus of the atom *both increase* down a Group 17.
- Moving down Group 17, there is no significant change in the effective nuclear charge that the electron(s) in the valence shell of the atom experience, as the increasing nuclear charge and increasing shielding effect cancel each other e.g.

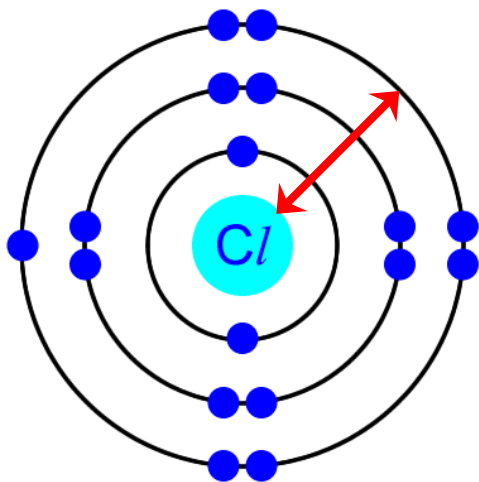
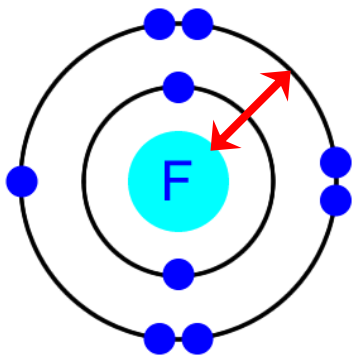
$$Z_{\text{eff}} (\text{F}) = 9 - 2 = +7$$

$$Z_{\text{eff}} (\text{Cl}) = 17 - 10 = +7$$



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

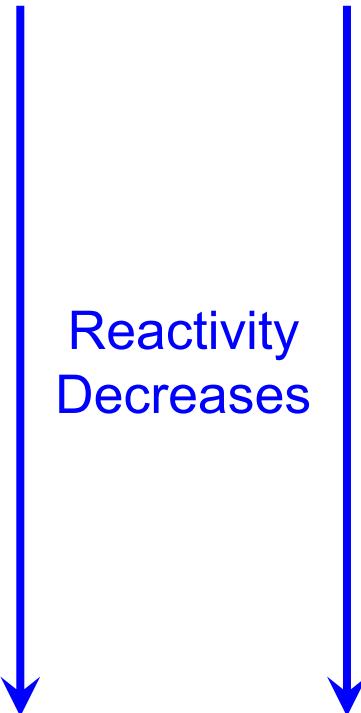


- The addition of a new electron shell to the atoms is significant because it means that the valence shell is *further from the nucleus*.
- This *reduces the electrostatic force of attraction* between the positively charged nucleus and negatively charged electrons in the valence shell (inverse square law).
- This means that it is more difficult for a halogen to attract an electron into its valence shell and obtain the electronic configuration of a noble gas. Consequently, the halogens become *less reactive* down the Group.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

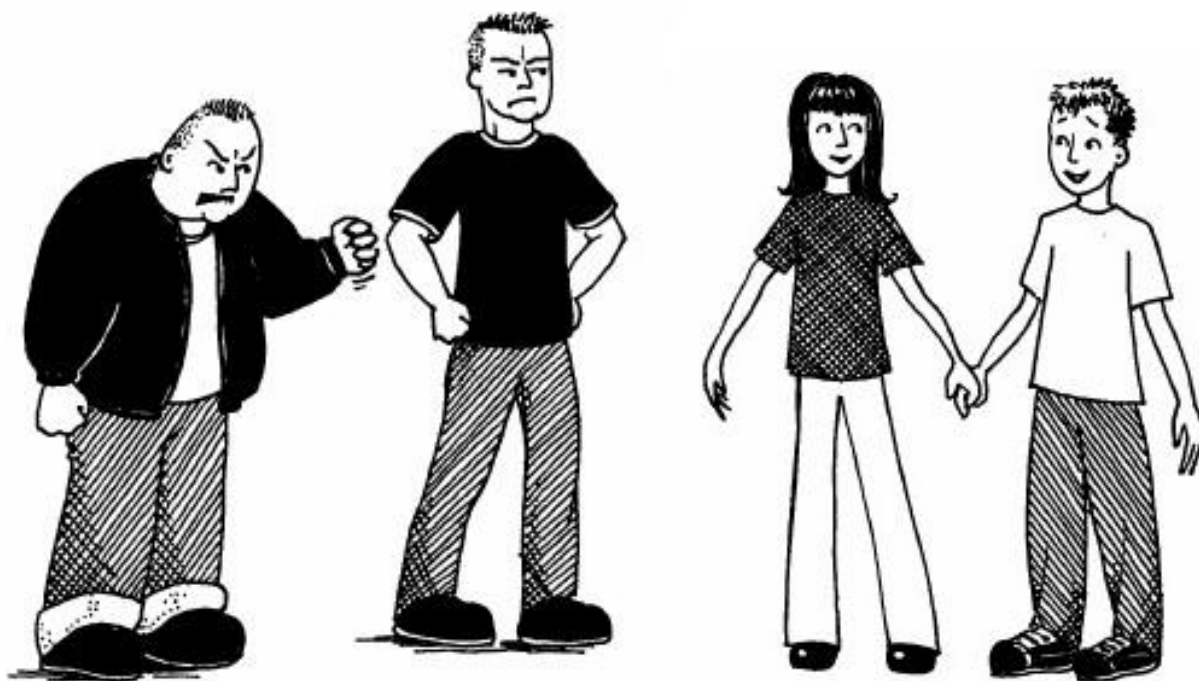
 <p>Reactivity Decreases</p>	Fluorine	More Reactive The valence shell is close to the nucleus and is not very well shielded. It is easy for the positive nucleus to attract a negative electron into the valence shell of the atom.
	Chlorine	
	Bromine	Less Reactive The valence shell is far from the nucleus and is well shielded. It is difficult for the positive nucleus to attract a negative electron into the valence shell of the atom.
	Iodine	



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- A more reactive halogen can displace a less reactive halogen from its compounds.



Fluorine

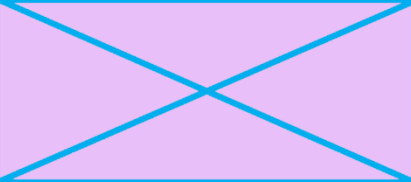
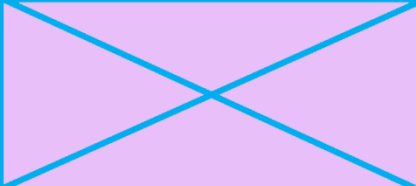
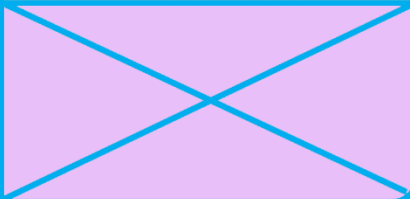
Chlorine

Sodium Bromide

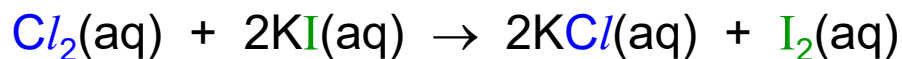
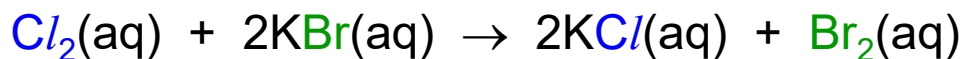


Periodic Table of the Chemical Elements

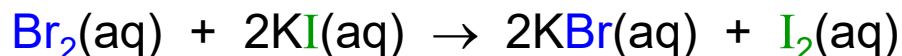
Elements of Group 17 (Group VII) – Halogens

halogen \ salt (aq)	potassium chloride	potassium bromide	potassium iodide
chlorine		$2\text{KCl} + \text{Br}_2$	$2\text{KCl} + \text{I}_2$
bromine	no reaction		$2\text{KBr} + \text{I}_2$
iodine	no reaction	no reaction	

- Cl_2 can displace Br_2 and I_2



- Br_2 can displace I_2



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



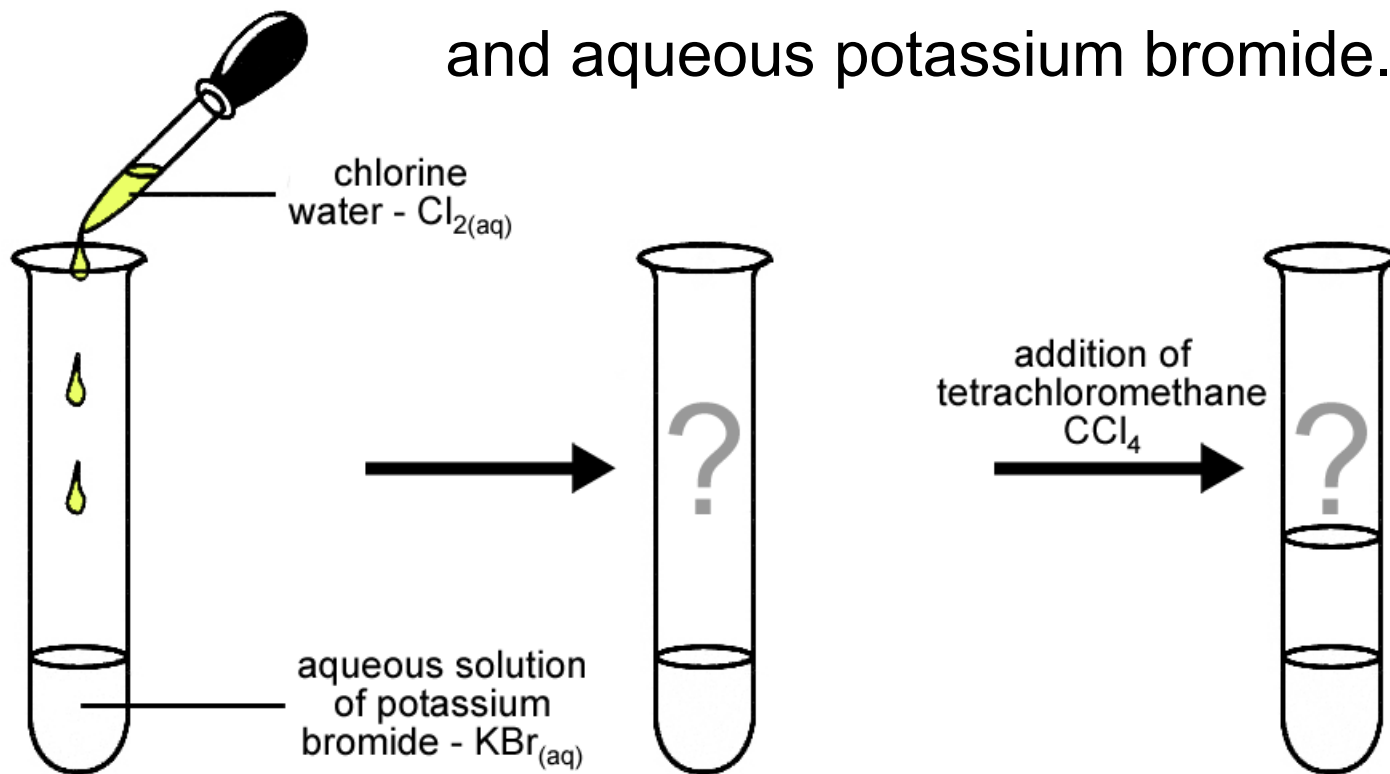
- Aqueous solutions of chlorine, bromine and iodine are added to aqueous solutions of potassium chloride, potassium bromide and potassium iodide.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium bromide.



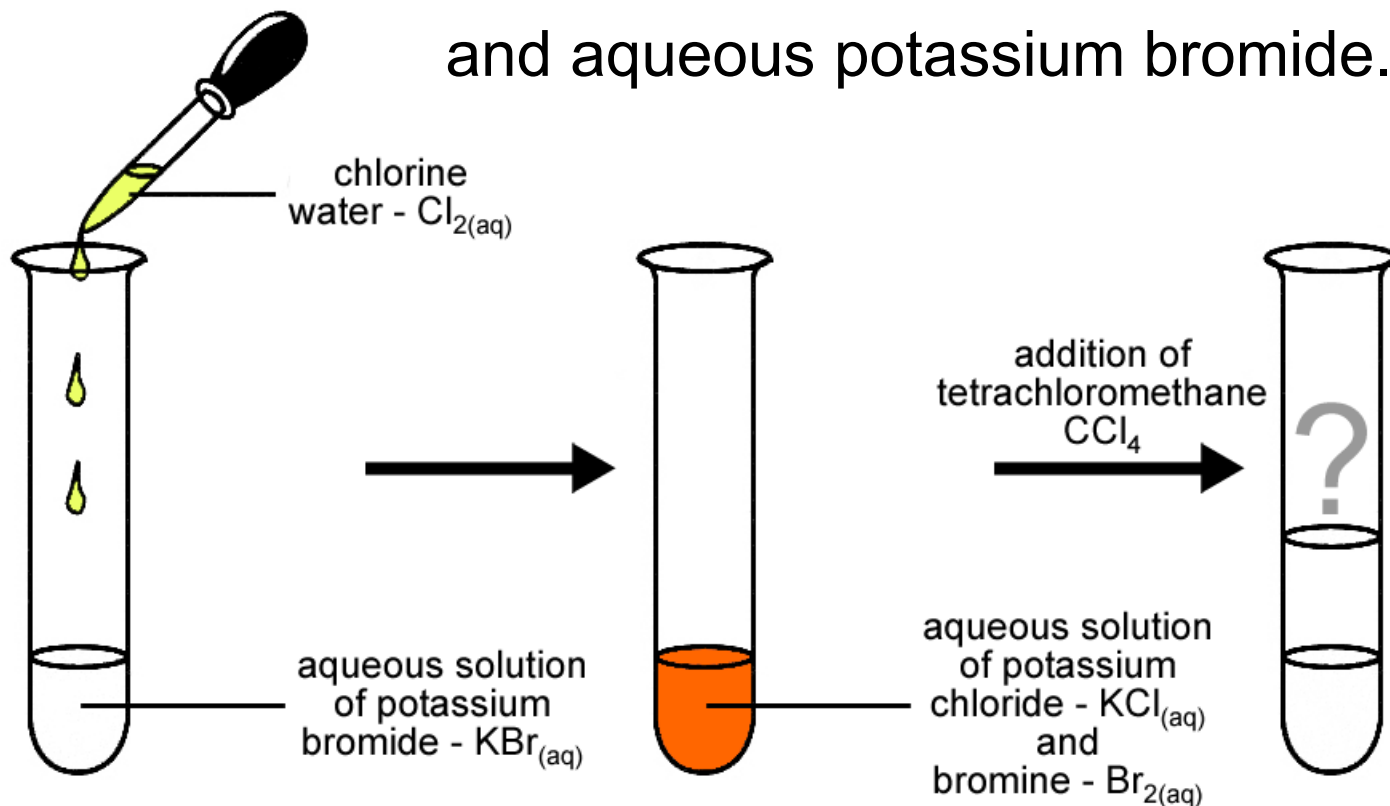
- Pale yellow aqueous chlorine.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium bromide.



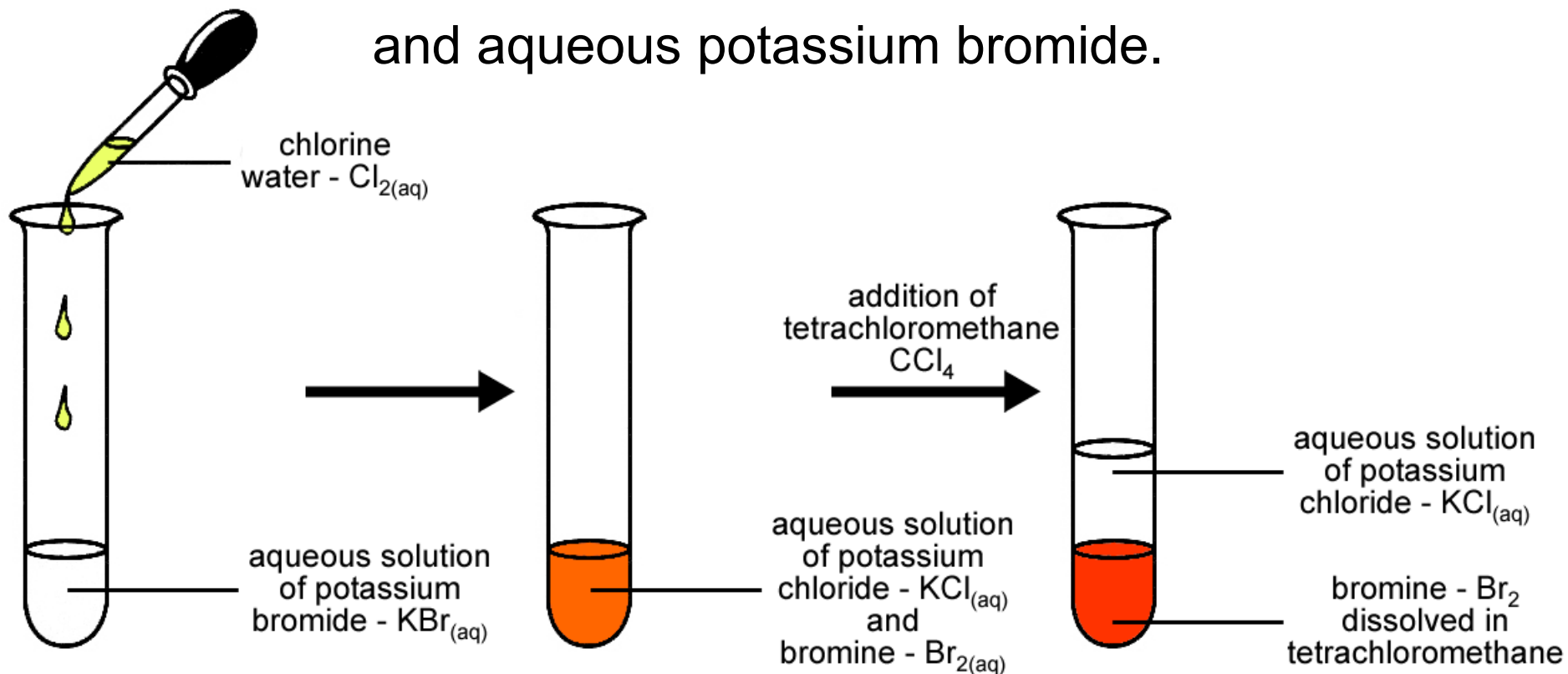
- Orange aqueous bromine.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium bromide.



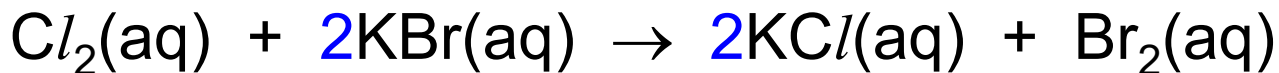
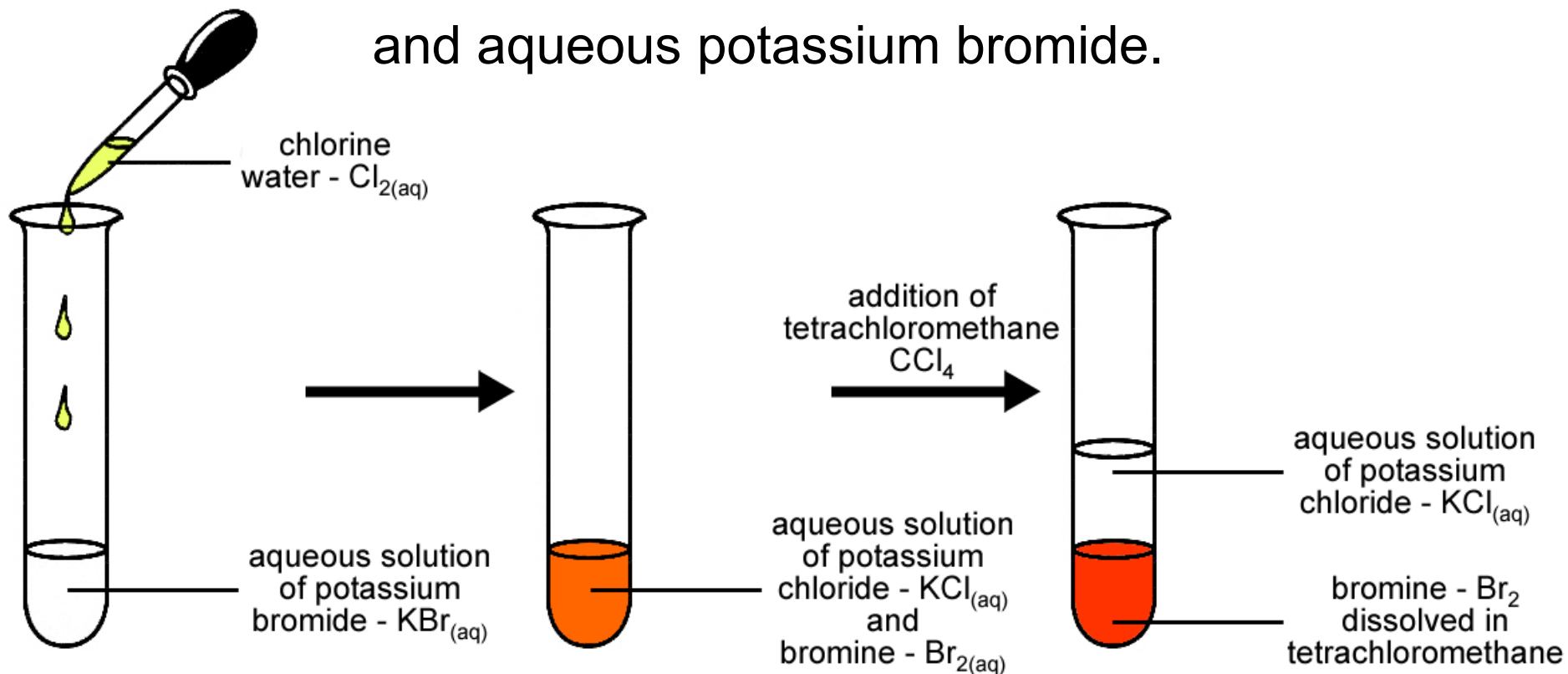
- Orange-red bromine dissolved in non-polar solvent.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium bromide.

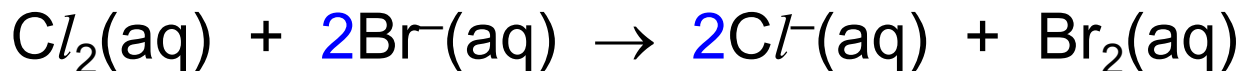
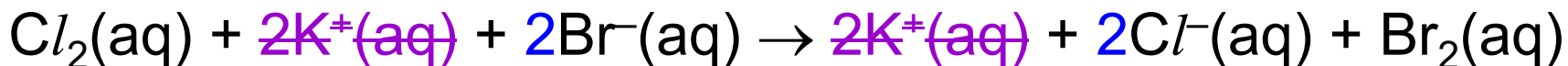
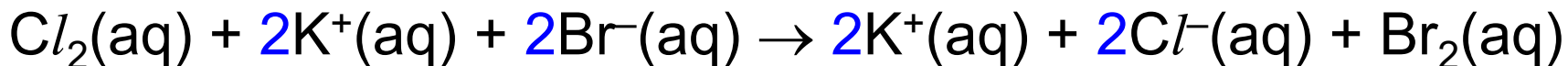
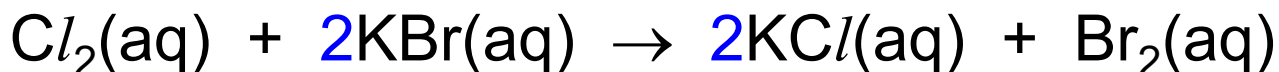


Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- Displacement reactions. A more reactive halogen will displace a less reactive halogen from its compounds.

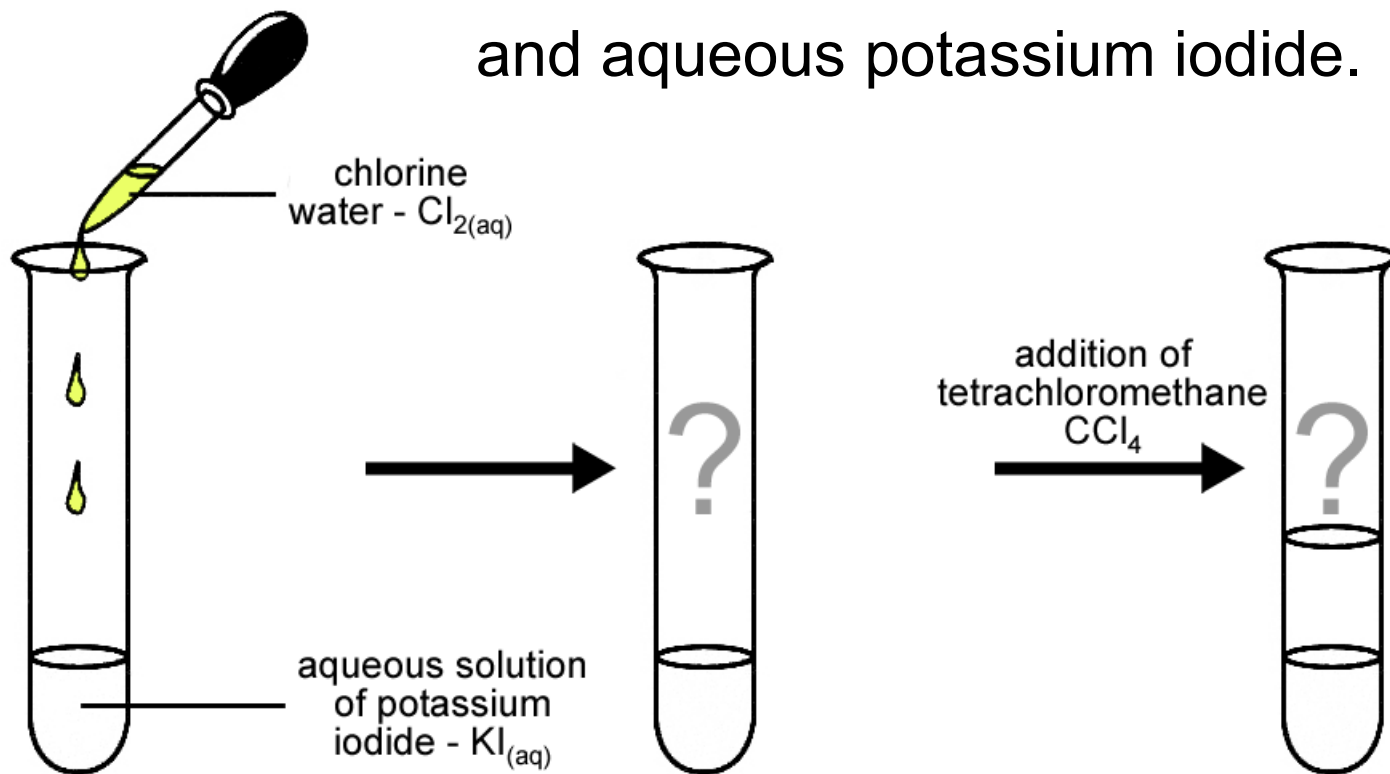
chlorine + potassium bromide → potassium chloride + bromine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium iodide.



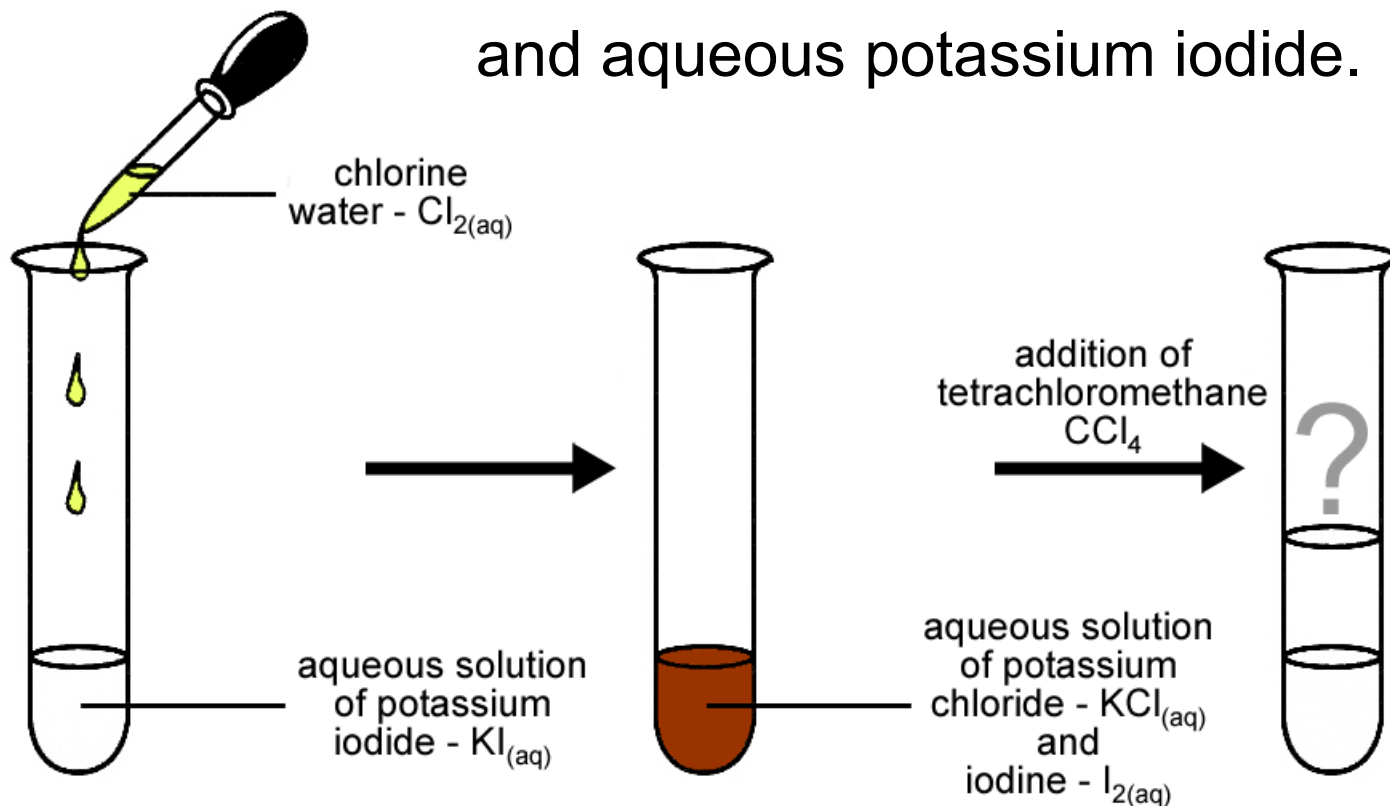
- Pale yellow aqueous chlorine.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium iodide.



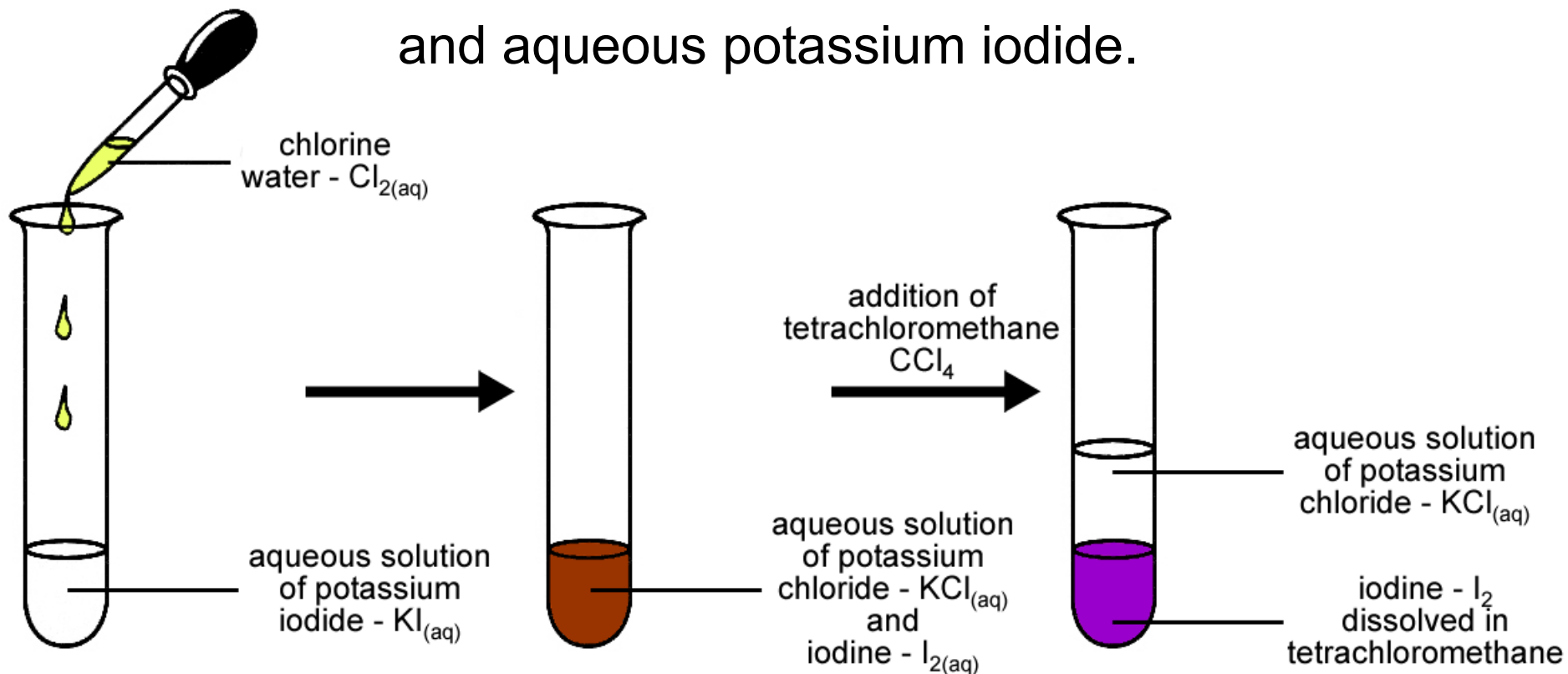
- Brown aqueous iodine.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium iodide.



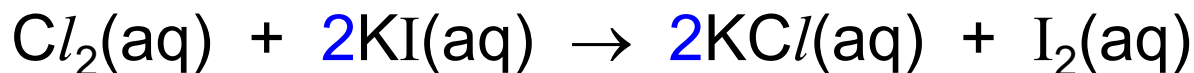
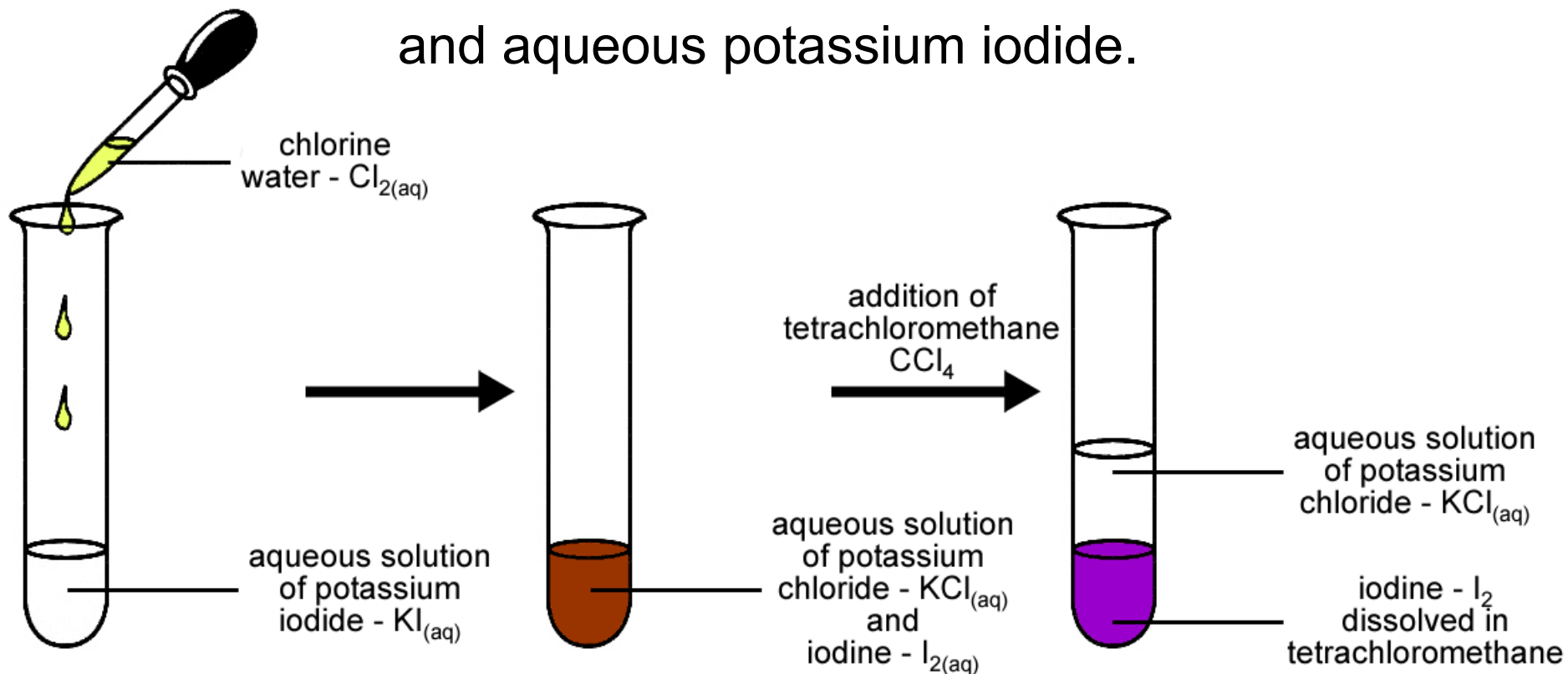
- Purple iodine dissolved in non-polar solvent.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between chlorine water and aqueous potassium iodide.

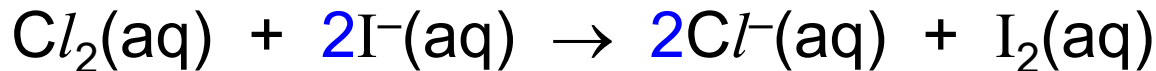
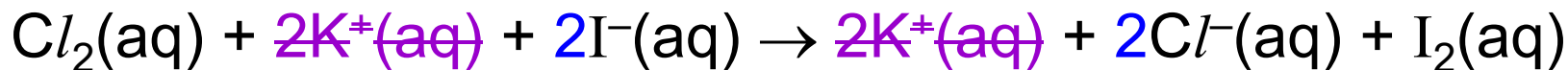
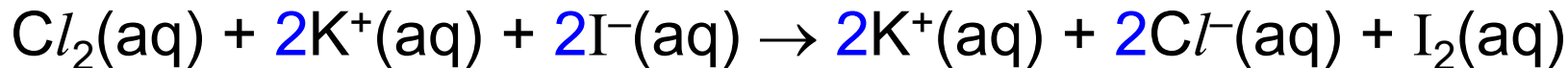
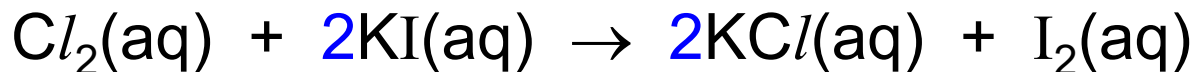


Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- Displacement reactions. A more reactive halogen will displace a less reactive halogen from its compounds.

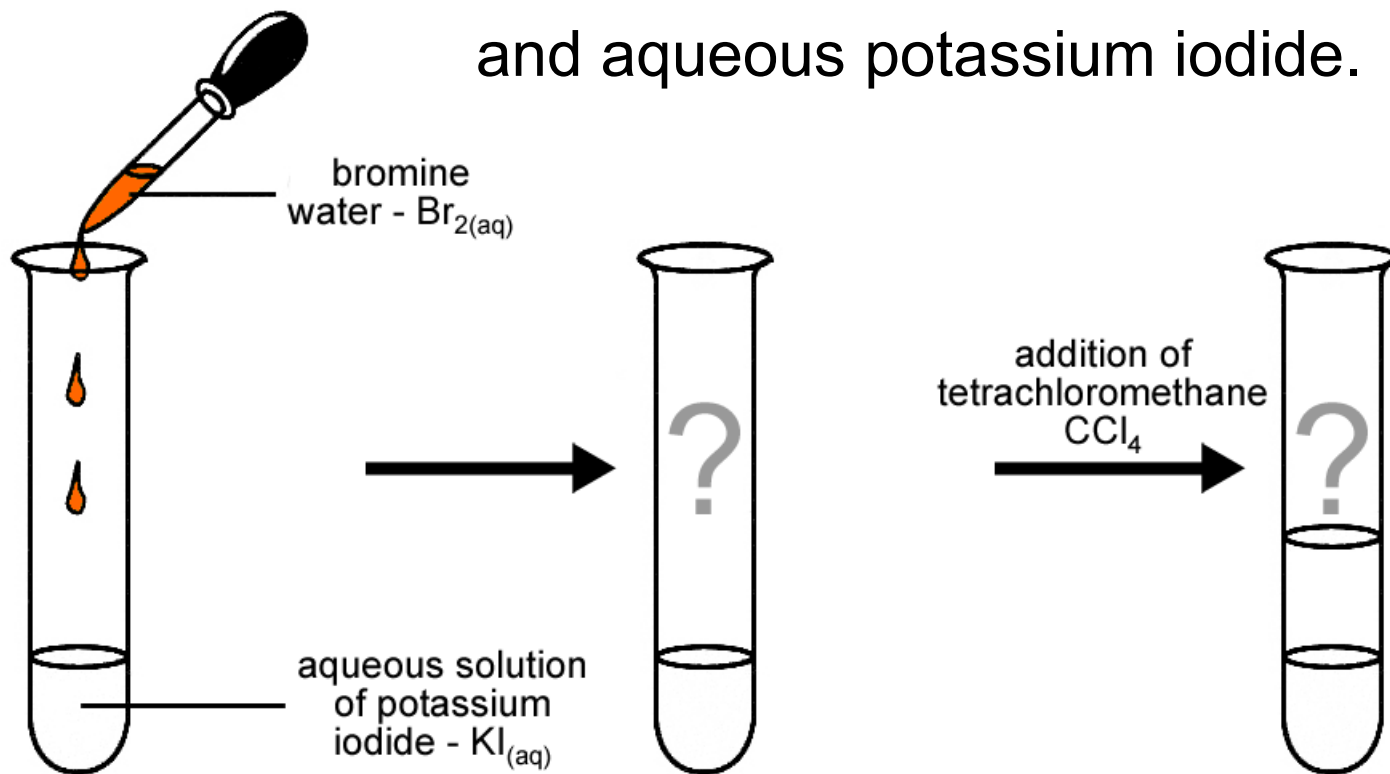
chlorine + potassium iodide → potassium chloride + iodine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between bromine water and aqueous potassium iodide.



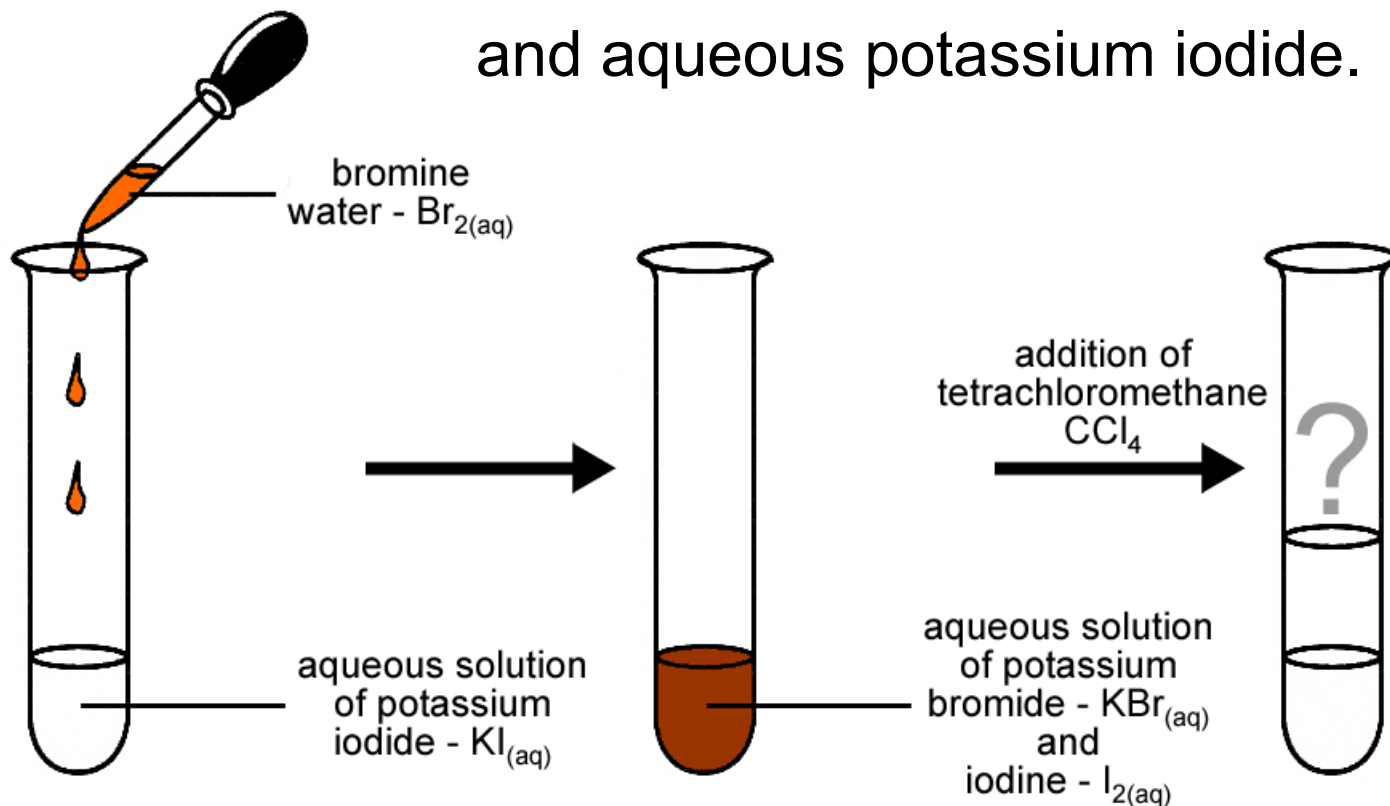
- Orange aqueous bromine.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between bromine water and aqueous potassium iodide.



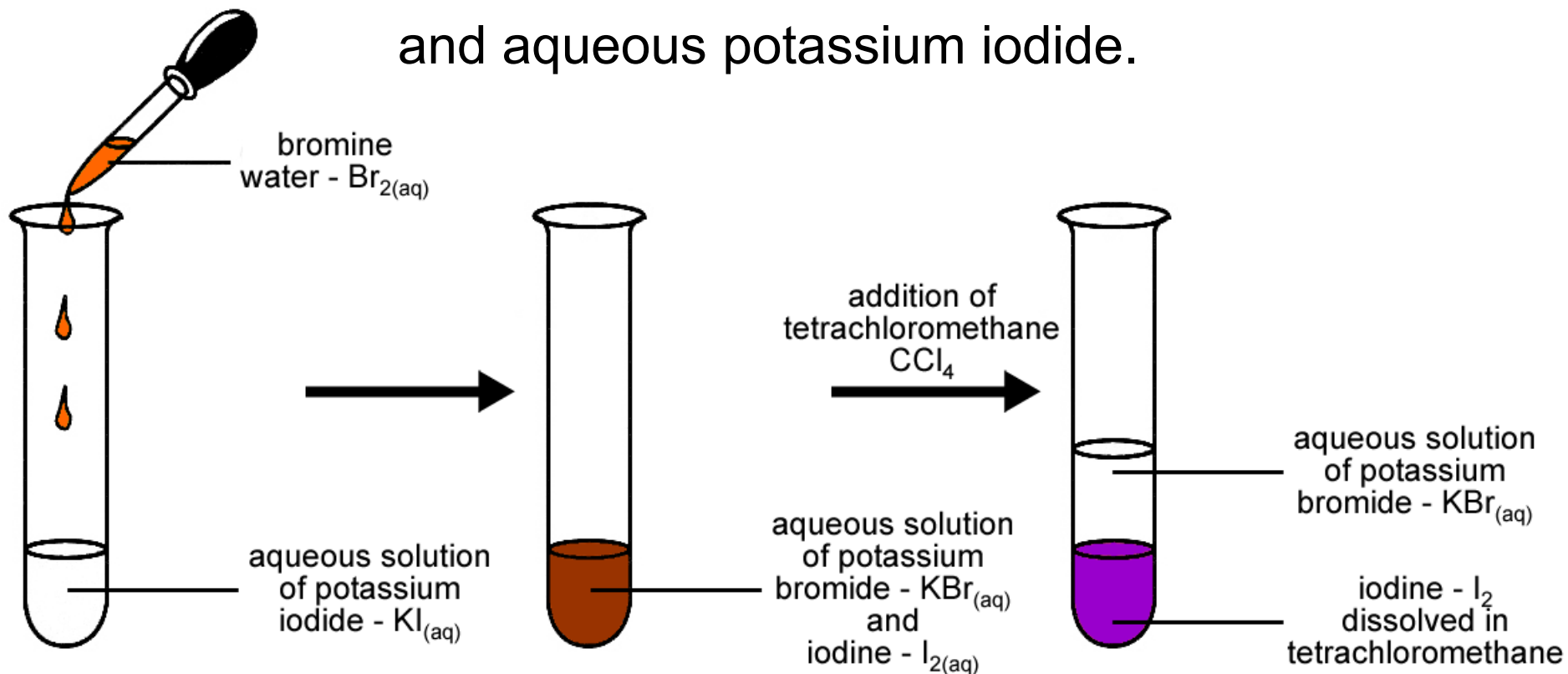
- Brown aqueous iodine.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between bromine water and aqueous potassium iodide.



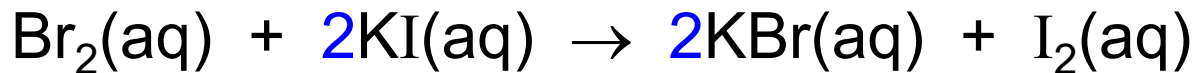
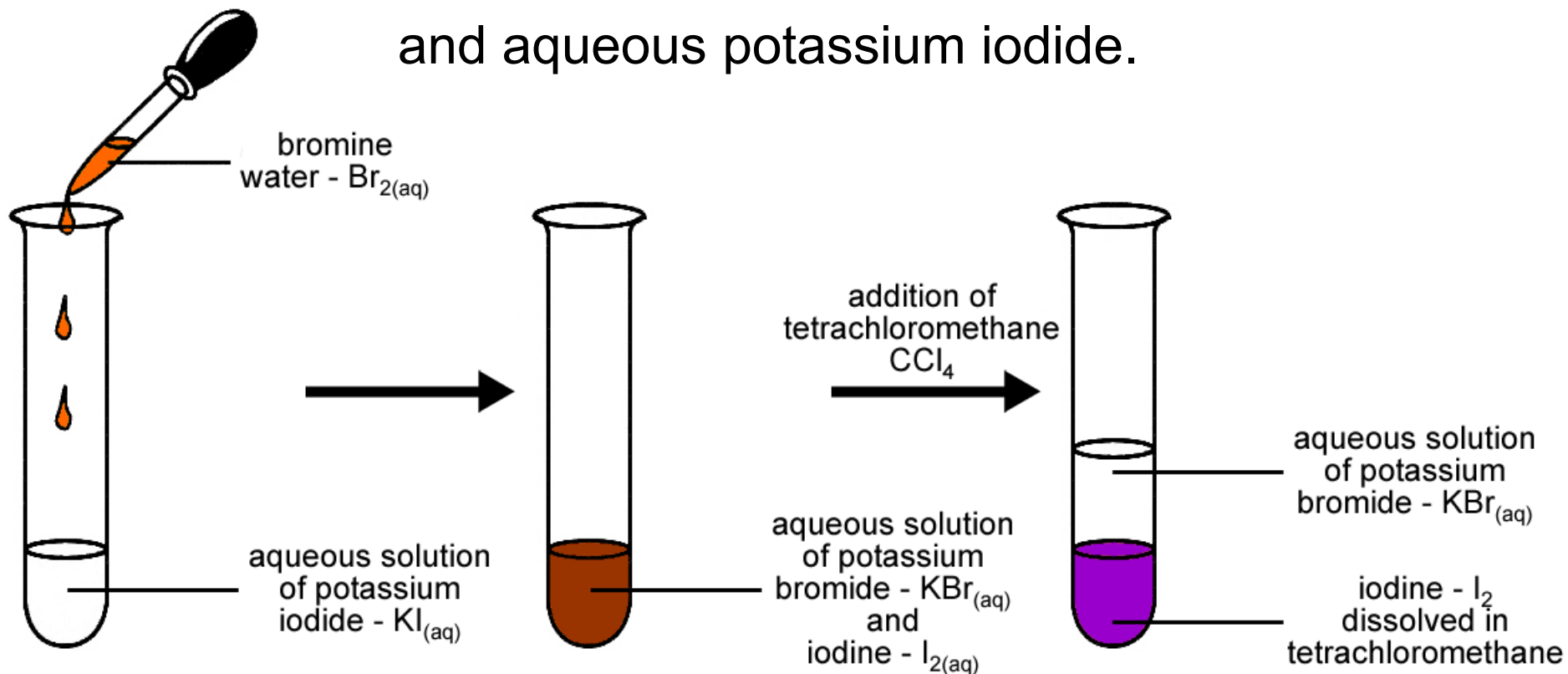
- Purple iodine dissolved in non-polar solvent.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

- The reaction between bromine water and aqueous potassium iodide.

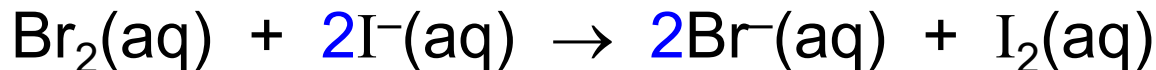
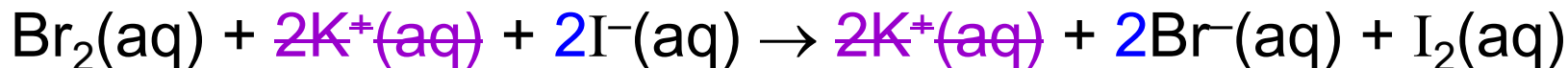
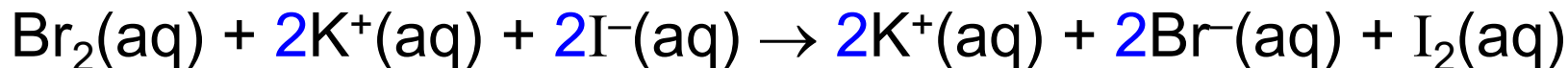
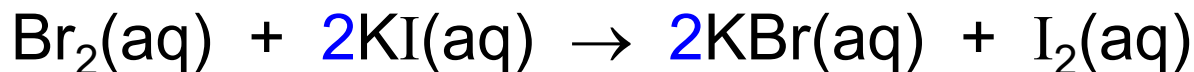


Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

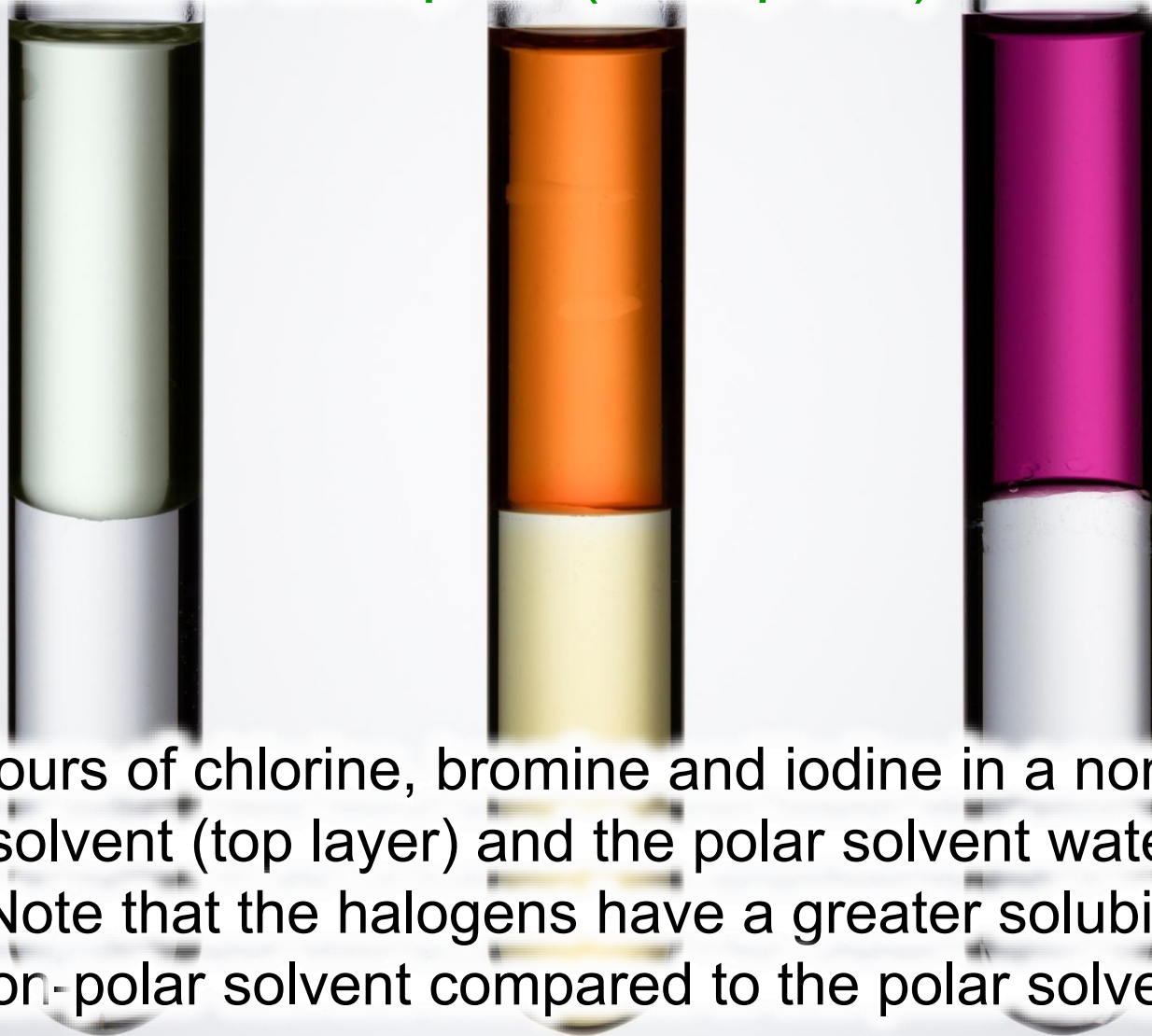
- Displacement reactions. A more reactive halogen will displace a less reactive halogen from its compounds.

bromine + potassium iodide → potassium bromine + iodine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens



- Colours of chlorine, bromine and iodine in a non-polar organic solvent (top layer) and the polar solvent water (bottom layer). Note that the halogens have a greater solubility in the non-polar solvent compared to the polar solvent.

Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Fluorine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Fluorine

- One of the main uses of fluorine is the manufacture of the polymer poly(tetrafluoroethene), also known as PTFE or Teflon. Teflon has the formula $(C_2F_4)_n$ where n is a large whole number in the range of approximately 1 000 to 10 000.
- Teflon is stable at high temperatures and, because of the strong C – C and C – F covalent bonds that make-up its structure, it is relatively unreactive and resistant to attack from other chemicals. These properties, coupled with its low coefficient of friction, make Teflon ideal to use as the coating of non-stick kitchen utensils.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Fluorine

- Hydrofluoric acid (HF) is used for etching glass.
- Chlorofluorocarbons, or CFCs, were once used as aerosol propellants, refrigerants and in the manufacture of expanded polystyrene. However, their inertness meant that, once in the Earth's atmosphere, they diffused into the stratosphere where they reacted with ozone (O_3) causing significant destruction of the Earth's ozone layer. CFCs are now banned. Note: The ozone layer is extremely important because it absorbs large amounts of harmful ultraviolet radiation from the sun, preventing it from reaching the Earth's surface.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Chlorine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Chlorine

- Chlorine kills bacteria – it is a disinfectant. It is used to treat drinking water and water in swimming pools. It is also used to make hundreds of consumer products from paper to paints, and from textiles to insecticides.
- Approximately 20% of the chlorine produced is used to make the polymer poly(vinylchloride), also known as PVC. PVC has the formula $(C_2H_3Cl)_n$ where n is a large whole number in the range of approximately 1 000 to 10 000. This is a very versatile plastic used in window frames, car interiors, electrical wiring insulation, water pipes, blood bags and vinyl flooring.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Chlorine

- Approximately 85% of pharmaceuticals use chlorine or its compounds at some stage in their manufacture.
 - In the past, chlorine was commonly used to make chloroform (an anaesthetic – CHCl_3) and carbon tetrachloride (a dry cleaning solvent – CCl_4). However, both of these chemicals are now strictly controlled as they can cause liver damage.
- Chlorine gas is itself very poisonous, and was used as a chemical weapon during the First World War.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Bromine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Bromine

- Bromine is used in many areas such as agricultural chemicals, dyestuffs, insecticides, pharmaceuticals and chemical intermediates. Some uses are being phased out for environmental reasons, but new uses continue to be found.
- Bromine compounds can be used as flame retardants. They are added to furniture foam, plastic casings for electronics and textiles to make them less flammable. However, the use of bromine as a flame retardant has been phased out because of toxicity concerns.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Bromine

- Compounds of bromine and carbon, often combined with other halogens, are used in halon fire extinguishers, e.g. Halon 2402, $C_2Br_2F_4$. Halons are used to fight fires in places where water would be inappropriate, such as in museums, on aeroplanes and in military vehicles.
- Silver bromide ($AgBr$) is a chemical used to make photographic film. When light strikes the silver bromide, it decomposes to form small dark crystals of silver metal. This forms the photographic *negative* from which the final photograph is developed.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Iodine



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Uses of Iodine

- Iodine has many commercial uses. Iodide salts are used in pharmaceuticals and disinfectants, printing inks and dyes, catalysts, animal feed supplements and photographic chemicals. Iodine is also used to make polarising filters for LCD displays.
- Iodide is added in small amounts to table salt, in order to avoid iodine deficiency affecting the thyroid gland. One of iodine's radioactive isotopes, iodine-131, is sometimes used to treat cancer of the thyroid gland.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Summary of the Group VII Halogens

- The halogens are a group of relatively reactive non-metallic elements.
- As the pure chemical element, the halogens are all *diatomic*; F_2 , Cl_2 , Br_2 , I_2 , At_2 .
- Melting points and boiling points both *increase* down the Group as the relative molecular masses of the diatomic elements *increase*. Fluorine and chlorine are both gases at room temperature and pressure while bromine is a liquid and iodine is a solid.



Periodic Table of the Chemical Elements

Elements of Group 17 (Group VII) – Halogens

Summary of the Group VII Halogens

- Colours of the elements become darker down the Group, from a pale yellow gas to a dark grey solid.
- The halogens react by gaining electrons. Each atom gains a single electron to form an ion with a charge of 1–.
- Reactivity *decreases* down the Group. As the valence shell is removed further from the nucleus, it becomes increasingly difficult to attract an electron into the valence shell.
- A more reactive halogen can displace a less reactive halogen from its compounds, e.g.



Periodic Table of the Chemical Elements



What periodic trends are there in *Group 18 (Group 0)* of the Periodic Table?

Group 18 (Group 0)
The Noble Gases

[Return to Main Menu](#)



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



Helium – He

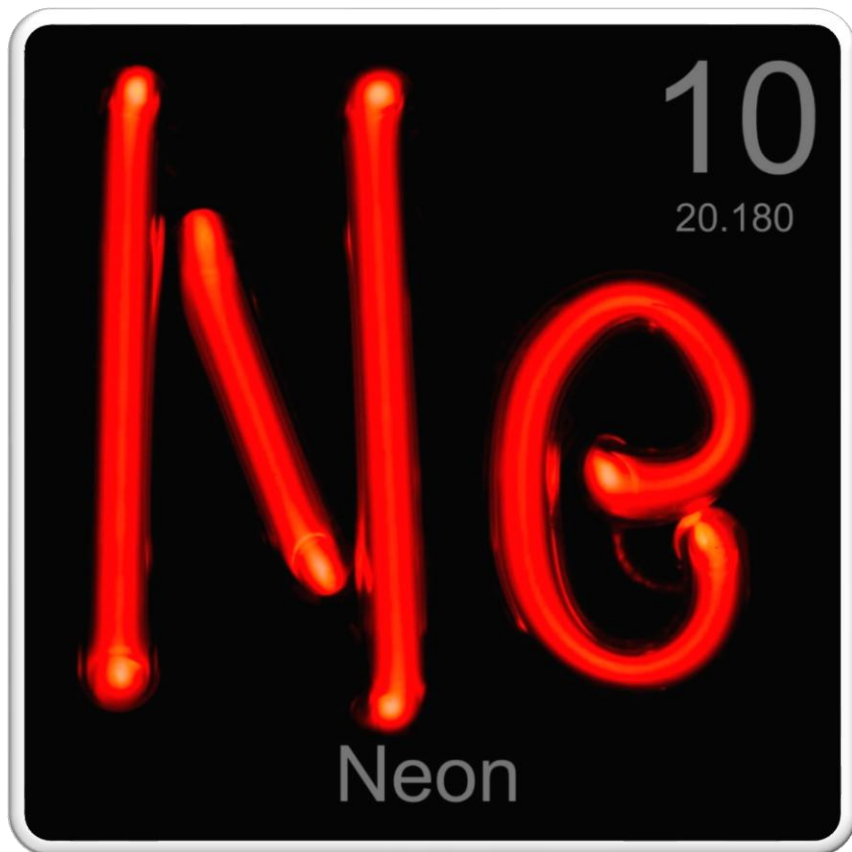
- Atomic Number = 2
- Relative Atomic Mass = 4.0
- Melting Point = $-270\text{ }^{\circ}\text{C}$
- Boiling Point = $-269\text{ }^{\circ}\text{C}$
- Density* = 0.147 g cm^{-1}
- Atomic Radius = 0.031 nm
 - First Ionization Energy = 2370 kJ mol^{-1}
 - Electronegativity = NA

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



Neon – Ne

- Atomic Number = 10
- Relative Atomic Mass = 20.2
- Melting Point = $-249\text{ }^{\circ}\text{C}$
- Boiling Point = $-246\text{ }^{\circ}\text{C}$
- Density* = 1.20 g cm^{-1}
- Atomic Radius = 0.038 nm
 - First Ionization Energy = 2080 kJ mol^{-1}
 - Electronegativity = NA

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



Argon – Ar

- Atomic Number = 18
- Relative Atomic Mass = 39.9
 - Melting Point = $-198\text{ }^{\circ}\text{C}$
 - Boiling Point = $-186\text{ }^{\circ}\text{C}$
 - Density* = 1.40 g cm^{-1}
- Atomic Radius = 0.071 nm
 - First Ionization Energy = 1520 kJ mol^{-1}
 - Electronegativity = NA

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



Krypton – Kr

- Atomic Number = 36
- Relative Atomic Mass = 83.8
- Melting Point = $-157\text{ }^{\circ}\text{C}$
- Boiling Point = $-152\text{ }^{\circ}\text{C}$
- Density* = 2.16 g cm^{-3}
- Atomic Radius = 0.088 nm
 - First Ionization Energy = 1350 kJ mol^{-1}
 - Electronegativity = NA

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



Xenon – Xe

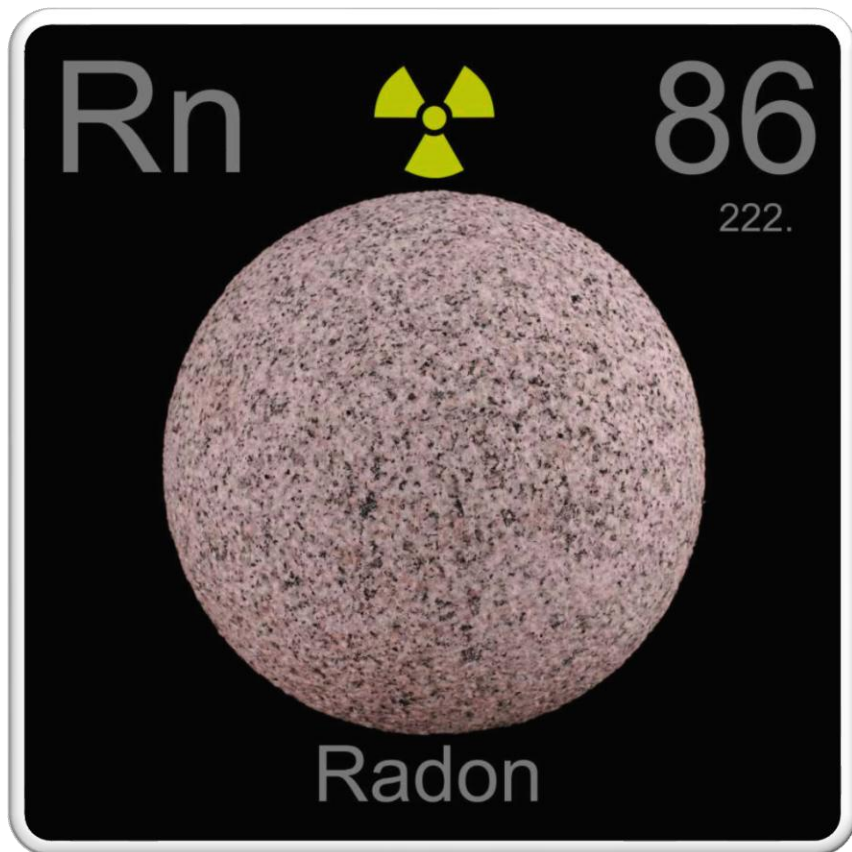
- Atomic Number = 54
- Relative Atomic Mass = 131.3
- Melting Point = $-112\text{ }^{\circ}\text{C}$
- Boiling Point = $-108\text{ }^{\circ}\text{C}$
- Density* = 3.52 g cm^{-3}
- Atomic Radius = 0.108 nm
 - First Ionization Energy = 1170 kJ mol^{-1}
 - Electronegativity = NA

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



Radon – Rn

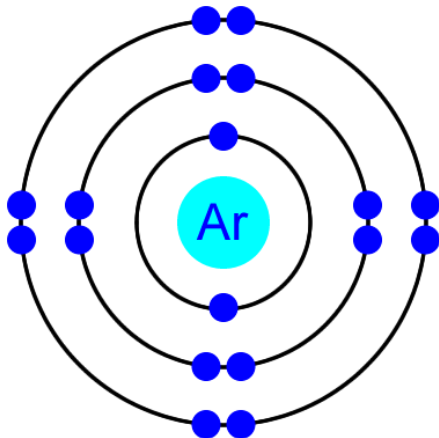
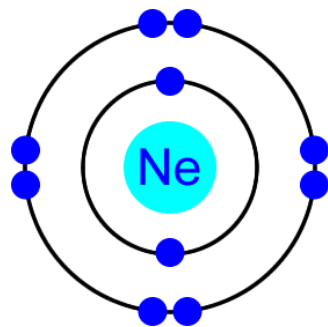
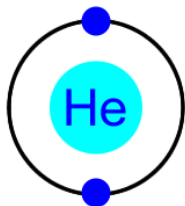
- Atomic Number = 86
- Relative Atomic Mass = 222
- Melting Point = $-71\text{ }^{\circ}\text{C}$
- Boiling Point = $-61.8\text{ }^{\circ}\text{C}$
- Density* = 4.40 g cm^{-1}
- Atomic Radius = 0.134 nm
 - First Ionization Energy = 1040 kJ mol^{-1}
 - Electronegativity = NA

*Density given is for the element in its liquid state.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



- Presence of noble gases in the Earth's atmosphere, measured by volume in parts per million (ppm):

Helium – 5.20

Neon – 18.20

Argon – 9340.00

Krypton – 1.10

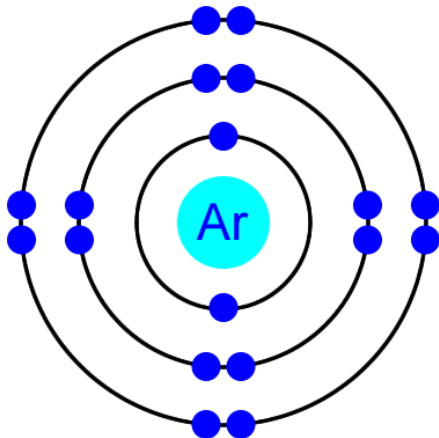
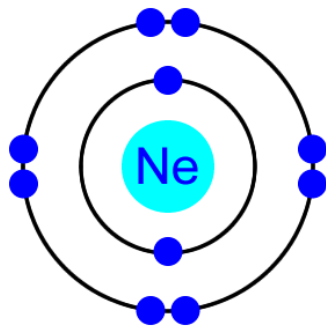
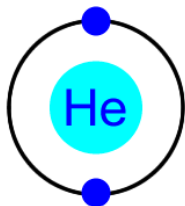
Xenon – 0.09

Radon – 0.06 to 0.18×10^{-19}



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



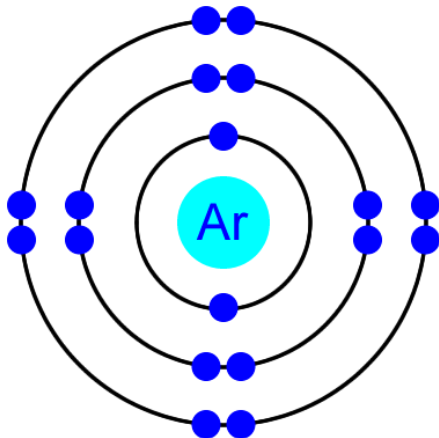
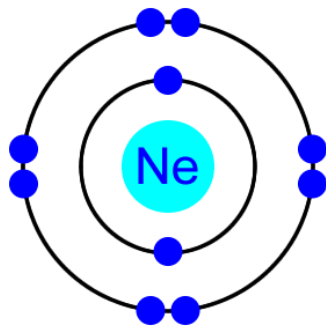
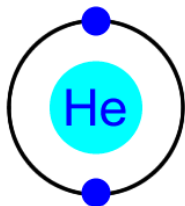
- The noble gases are colourless, odourless, non-metallic elements with boiling points that are well below room temperature.

- Atoms of the noble gases all have complete / full valence shells. They do not need to react (lose, gain or share electrons) in order to obtain a stable and low energy electronic configuration. As a consequence, the noble gases are *extremely unreactive*, but not completely inert.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

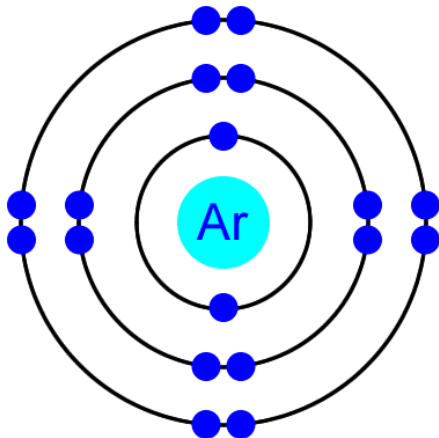
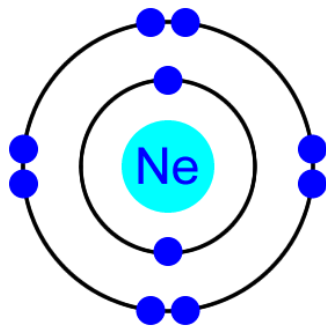
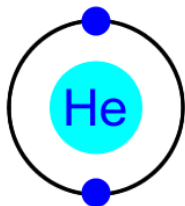


- The atoms of pure non-metallic elements tend to join together, through the formation of covalent bonds, to form either simple covalent molecules (e.g. Cl_2 , P_4 and S_8) or giant covalent structures (e.g. the allotropes of carbon, diamond and graphite).
- The noble gases are an exception. The noble gases are all *monatomic*, meaning that they exist as individual atoms instead of bonding together to form molecules.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

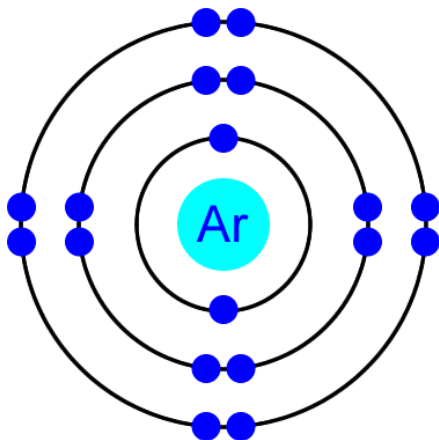
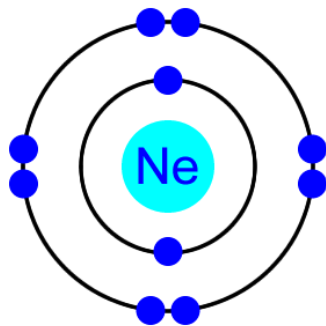
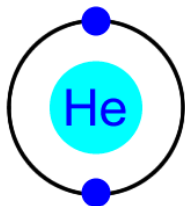


- Atoms of the noble gases all have complete / full valence shells. They do not need to react (lose, gain or share electrons) in order to obtain a stable and low energy electronic configuration. As a consequence, they exist as individual / single atoms.

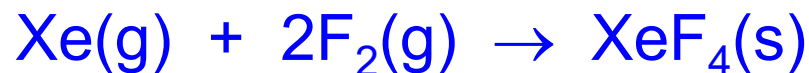


Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



- Some compounds of the noble gases have been formed, mostly by reacting the elements with highly reactive non-metals such as fluorine and oxygen. One of the first compounds of a noble gas to be prepared was xenon tetrafluoride, which is a crystalline solid:

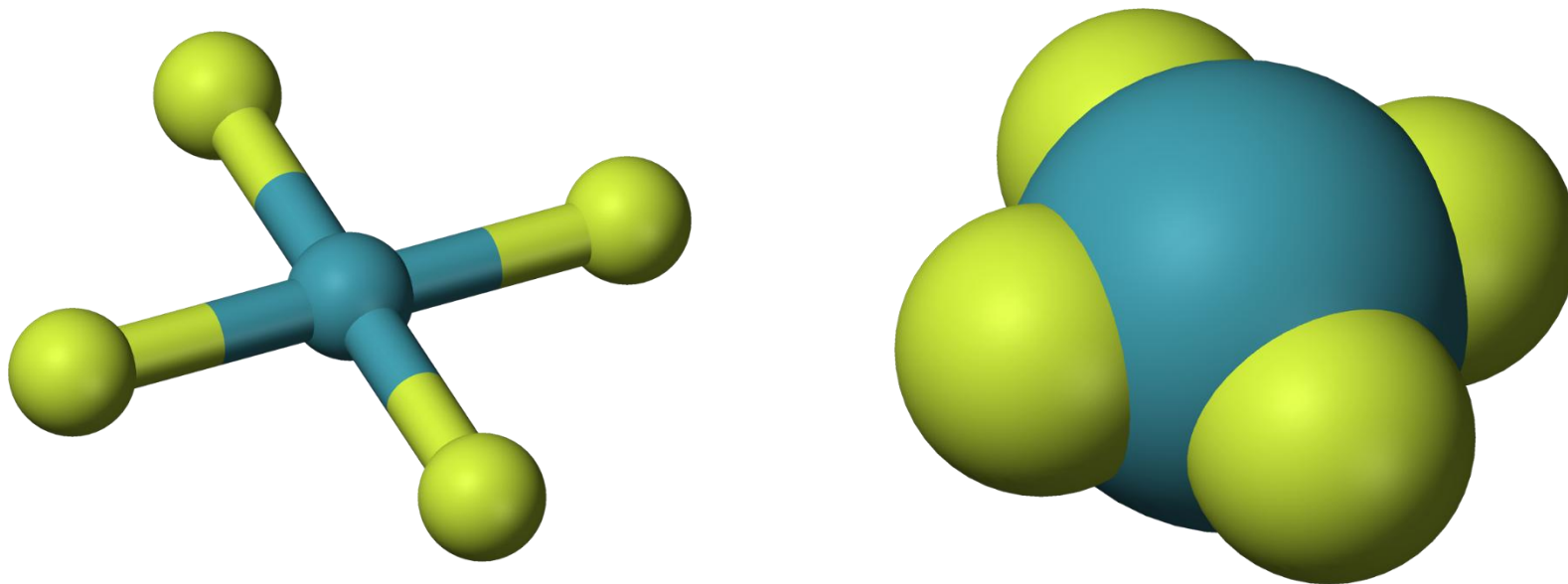


- This was achieved by heating xenon and fluorine to 400 °C with a nickel catalyst.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases



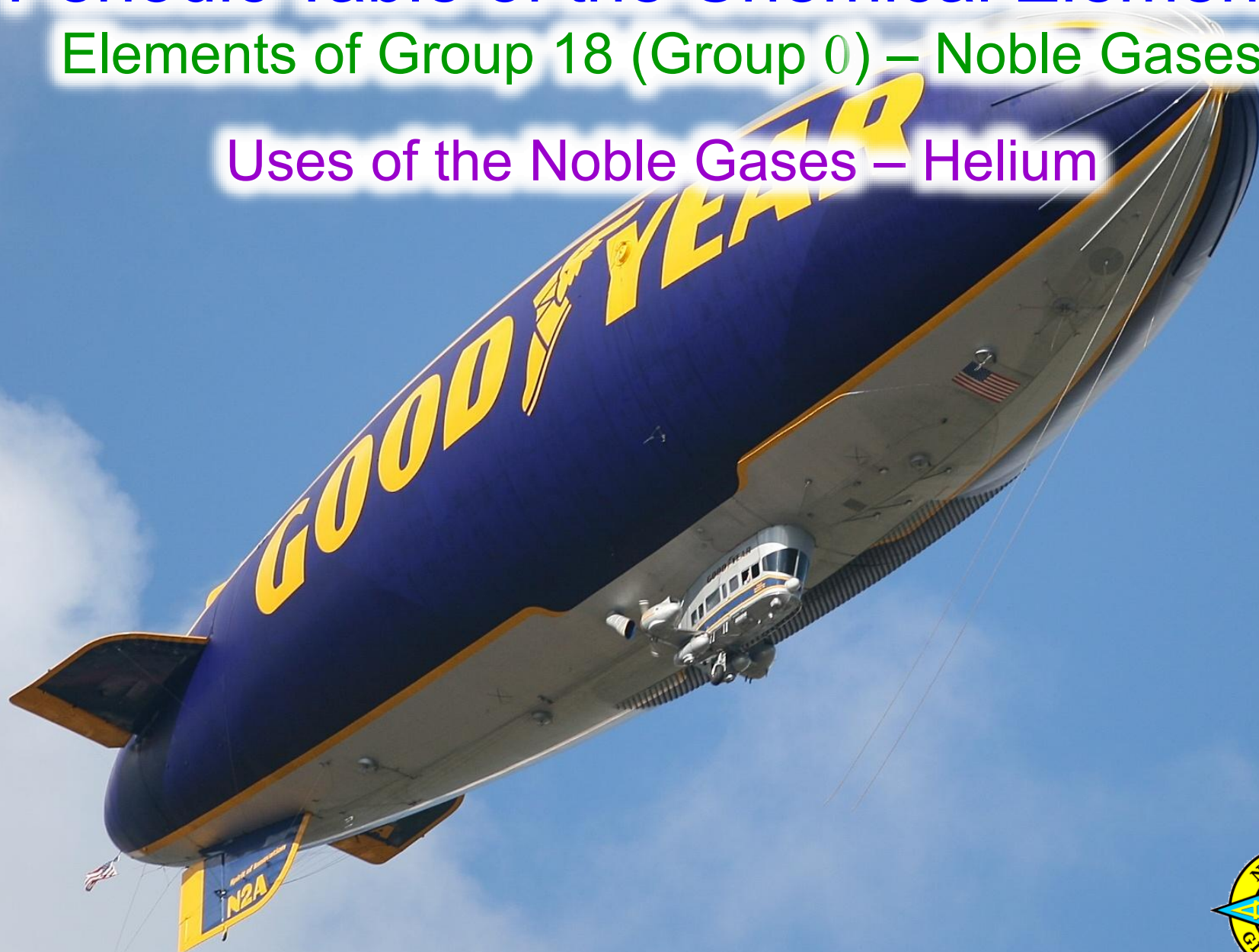
- The ball-and-stick and space-filled structures of xenon tetrafluoride.
- Xenon tetrafluoride reacts with cold water to produce xenon, hydrogen fluoride and oxygen:



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Helium



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Helium

- The fact that gaseous helium is both less dense than air and inert mean that it is ideal for producing buoyancy in airships – far safer than the highly flammable hydrogen gas that was once used for this purpose.
- Liquefied helium is used to cool superconducting magnets, such as those used in hospital MRI scanners, to cryogenic temperatures of approximately $-270\text{ }^{\circ}\text{C}$
- Helium is also used in helium-neon lasers, which produce the red light used in bar-code readers. Helium mixed with oxygen in a ratio of 4:1 produces the atmosphere breathed by deep-sea divers.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Neon



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Neon

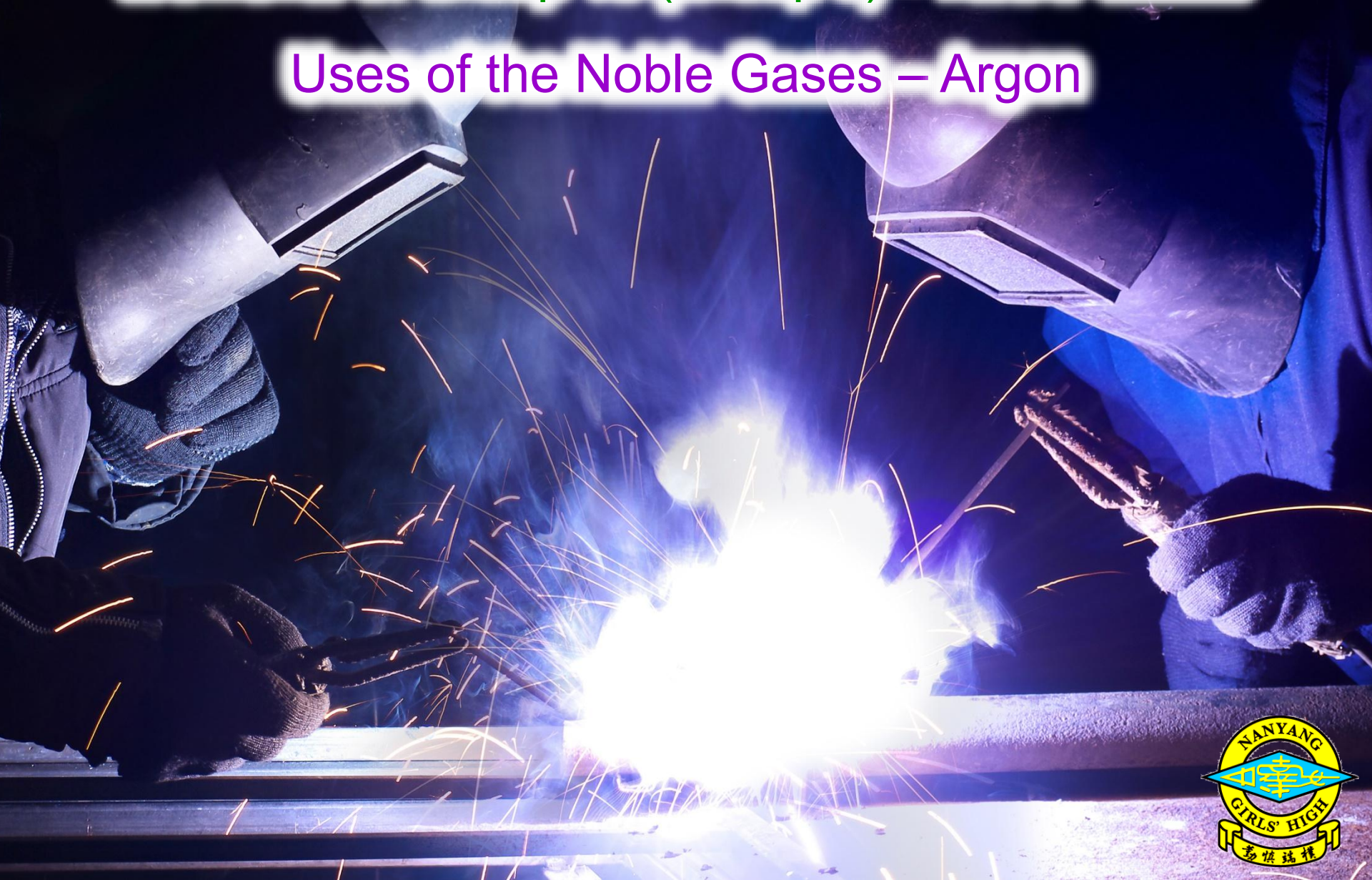
- The largest use of neon is in making the ubiquitous *neon signs* for advertising. In a vacuum discharge tube neon glows a reddish orange colour. Only the red signs actually contain pure neon. Others contain different gases to give different colours.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Argon



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Argon

- Argon is often used when an inert atmosphere is needed. It is used in this way for the production of titanium and other chemical elements that might react with oxygen and water vapour in the air. Argon is also used by welders to protect the hot, molten metal in the weld area from oxidising in contact with air. Neon is also used to fill incandescent light bulbs to stop oxygen from corroding the hot filament.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Krypton



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Krypton

- Krypton is used commercially as a filling gas for energy-saving fluorescent lights. It is also used in some flash lamps used for high-speed photography.
- Unlike the lighter gases in its group, it is reactive enough to form some chemical compounds. For example, krypton will react with fluorine to form krypton fluoride (KrF). Krypton fluoride is used in some lasers.
- From 1960 to 1983 the isotope krypton-86 was used to define the standard measure of length. One metre was defined as exactly 1,650,763.73 wavelengths of a line in the atomic spectrum of the isotope.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Xenon



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Xenon

- Xenon is used in certain specialised light sources. It produces a beautiful blue glow when excited by an electrical discharge. Xenon lamps are used by photographers, as sunbed lamps and as bactericidal lamps used in food preparation and processing.
- Xenon ion propulsion systems are used by several satellites to keep them in orbit.
- Xenon difluoride (XeF_2) is used to etch silicon microprocessors. It is also used in the manufacture of 5-fluorouracil, a drug used to treat certain types of cancer.



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Radon



Periodic Table of the Chemical Elements

Elements of Group 18 (Group 0) – Noble Gases

Uses of the Noble Gases – Radon

- Radon decays into radioactive polonium and alpha particles. This emitted radiation made radon useful in cancer therapy. Radon was used in some hospitals to treat tumours by sealing the gas in minute tubes, and implanting these into the tumour, treating the disease in situ.
- Pockets of radioactive radon gas are trapped beneath the earth's surface. Movement in the earth's crust, prior to an earthquake, can release the radon gas which can be detected using a Geiger counter and serve as a warning of the immanent danger.



Periodic Table of the Chemical Elements



What are the typical properties of the *transition metals*?

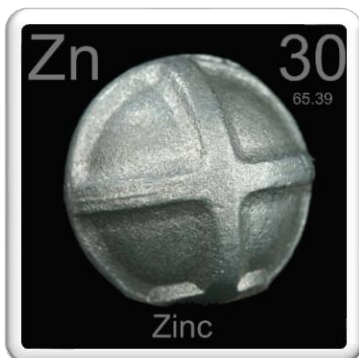
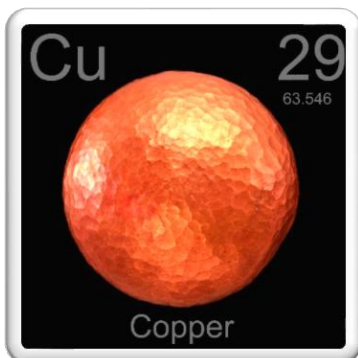
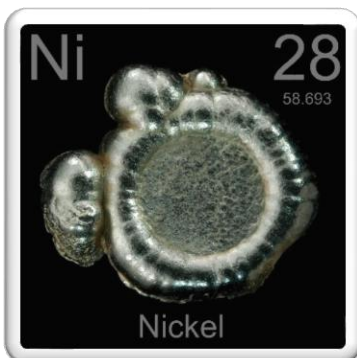
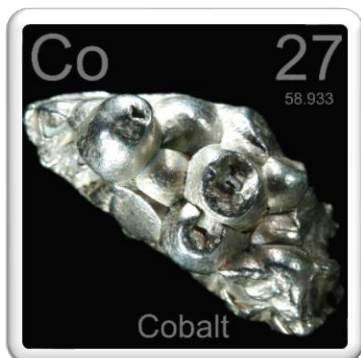
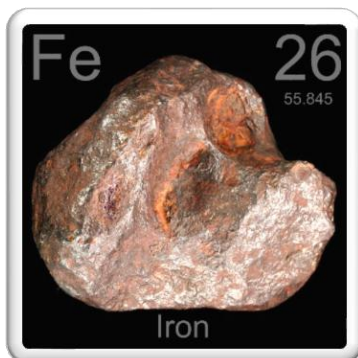
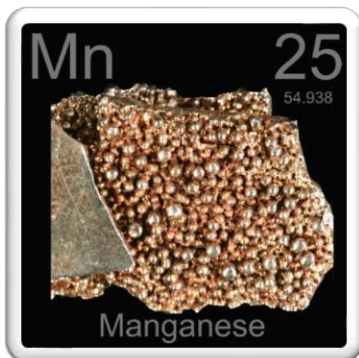
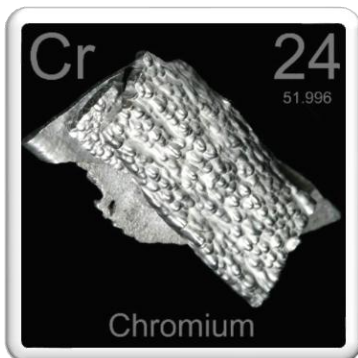
Groups 3 to 12
The Transition Metals

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Periodic Table of the Chemical Elements

The Transition Metals (d-block, Groups 3 – 12)



Periodic Table of the Chemical Elements

The Transition Metals (d-block, Groups 3 – 12)

- The transition metals have high melting points, high densities and are hard and strong – which are assumed to be typical properties of metallic elements. **Note:** The exceptions to this rule are the alkali metals which have low melting points, low densities and are relatively soft.

Element	Scandium Sc	Titanium Ti	Vanadium V	Chromium Cr	Manganese Mn	Iron Fe	Cobalt Co	Nickel Ni	Copper Cu	Zinc Zn
Melting Point / °C	1540	1675	1900	1890	1240	1535	1492	1453	1083	420
Density / g cm ⁻³	2.99	4.54	5.96	7.19	7.20	7.86	8.90	8.90	8.92	7.14

Note: Zinc is a d-block metal, but it is not always considered to be a transition metal. It has a low melting point, does not form coloured compounds, but – most importantly – *it only forms one positively charged ion, Zn²⁺*.



Periodic Table of the Chemical Elements

The Transition Metals (d-block, Groups 3 – 12)

- The transition metals are also good conductors of heat and electricity. In addition, they are malleable, ductile, sonorous and have a typical metallic lustre. In terms of their chemical properties, the transition metals form basic oxides.

Element	Scandium Sc	Titanium Ti	Vanadium V	Chromium Cr	Manganese Mn	Iron Fe	Cobalt Co	Nickel Ni	Copper Cu	Zinc Zn
Melting Point / °C	1540	1675	1900	1890	1240	1535	1492	1453	1083	420
Density / g cm ⁻³	2.99	4.54	5.96	7.19	7.20	7.86	8.90	8.90	8.92	7.14

Note: Zinc is a d-block metal, but it is not always considered to be a transition metal. It has a low melting point, does not form coloured compounds, but – most importantly – *it only forms one positively charged ion, Zn²⁺*.



Periodic Table of the Chemical Elements

The Transition Metals (d-block, Groups 3 – 12)

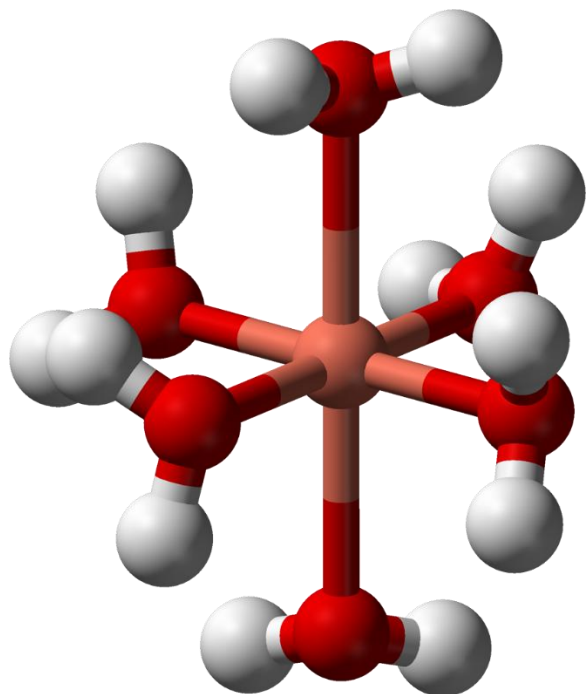
- The transition metals tend to form coloured compounds.



- For example, copper(II) sulfate is blue and potassium dichromate(VI) is orange.

Periodic Table of the Chemical Elements

The Transition Metals (d-block, Groups 3 – 12)



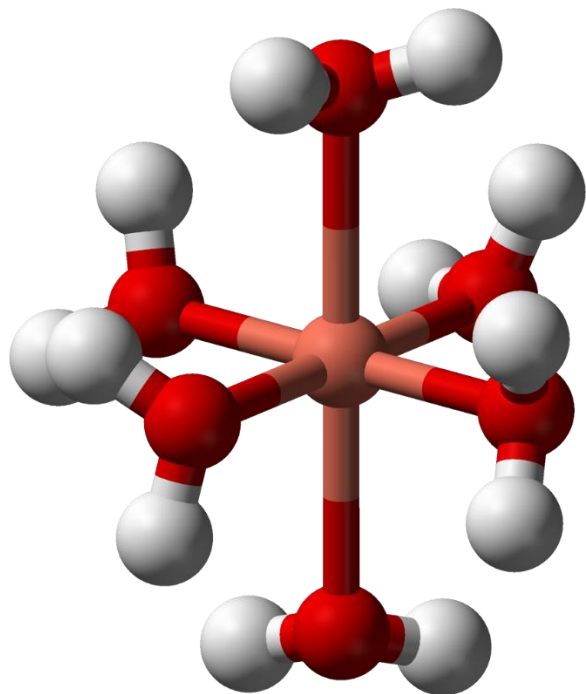
- Six water molecules bond to a copper(II) cation to form the blue hexaaquacopper(II) complex ion, $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

- Transition metal cations have incomplete d-orbitals.
- When dissolved in aqueous solution, neutral molecules and negatively charged ions (anions) surround the transition metal cation and bond to it, forming a *complex ion*.
- The molecules and anions that bond to the transition metal cation are referred to as *ligands*.



Periodic Table of the Chemical Elements

The Transition Metals (d-block, Groups 3 – 12)



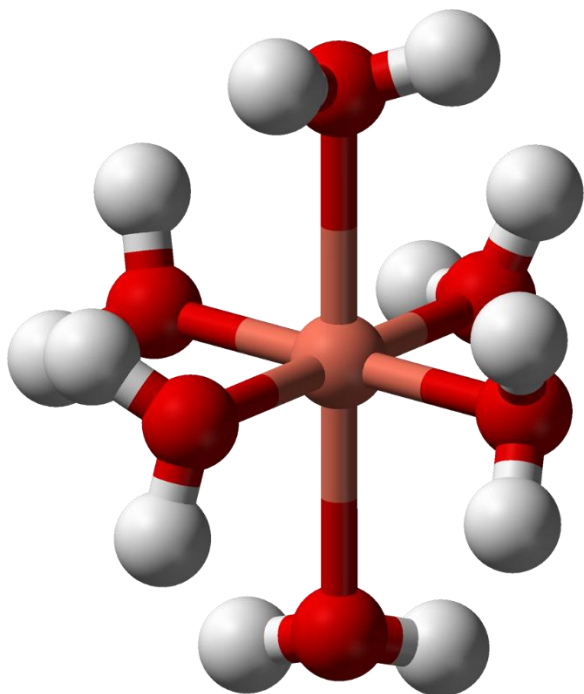
- Six water molecules bond to a copper(II) cation to form the blue hexaaquacopper(II) complex ion, $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

- When ligands bond to the transition metal cation, they affect the d-orbitals, causing them to no longer all have the same energy.
- Electrons in the d-orbitals can *absorb energy* from the visible part of the electromagnetic spectrum and move from a lower energy d-orbital to a higher energy d-orbital.



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- Six water molecules bond to a copper(II) cation to form the blue hexaaquacopper(II) complex ion, $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

- For example, the d-orbital electrons in Cu^{2+} absorb orange / red light from the visible part of the electromagnetic spectrum. After the orange / red part of the visible spectrum has been absorbed, what remains is the blue / green part of the visible spectrum, hence compounds containing Cu^{2+} ions often appear blue in colour.



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- Some information about three different compounds that contain the transition metal manganese are given below:

Compound of Manganese	Oxidation State of Manganese
Manganese(II) sulphate – MnSO_4	+2
Manganese(IV) oxide – MnO_2	+4
Potassium manganate(VII) – KMnO_4	+7

- Manganese is able to form ions with different *oxidation states*, something that is characteristic of almost all transition metals (exceptions are *silver*, only +1, and *zinc*, only +2).



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- Transition metals and their compounds can function as *catalysts*.
 - A catalyst is a chemical that allows a reaction to proceed via an *alternative route or pathway*.
 - The alternative route or pathway that the catalysed reaction follows has a *lower activation energy* compared to the original, uncatalyzed reaction.
 - This, in turn, *increases the frequency of effective collisions* between the reacting chemicals, hence increasing the rate of the chemical reaction.
 - The catalyst participates in the reaction, but is chemically unchanged at the end of the reaction.

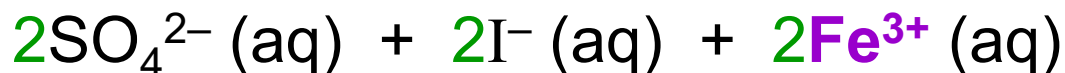
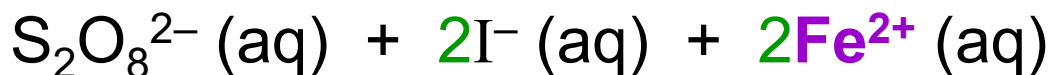


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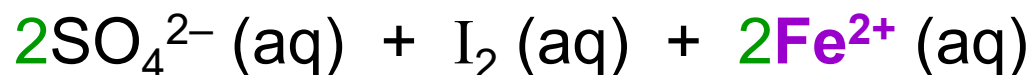
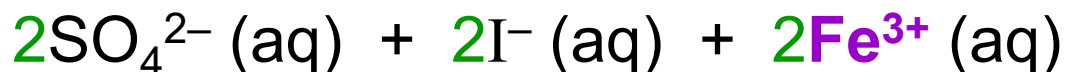
The Transition Metals (d-block, Groups 3 – 12)

- Transition metals can function as catalysts due to their ability to change oxidation state during a reaction, e.g. $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+} \rightarrow \text{Fe}^{2+}$ and $\text{Cu}^+ \rightarrow \text{Cu}^{2+} \rightarrow \text{Cu}^+$.
- For example, $\text{Fe}^{2+}(\text{aq})$ catalyses the reaction between $\text{S}_2\text{O}_8^{2-}(\text{aq})$ and $\text{I}^-(\text{aq})$. Note how $\text{Fe}^{2+}(\text{aq})$ is regenerated.

Reaction Stage 1:



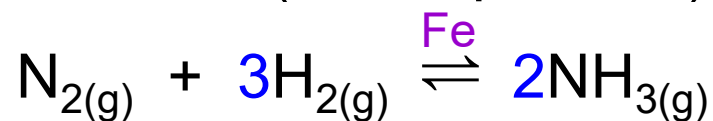
Reaction Stage 2:



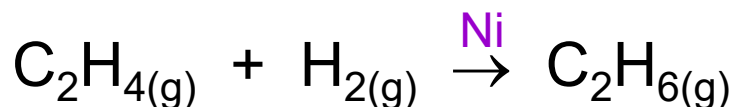
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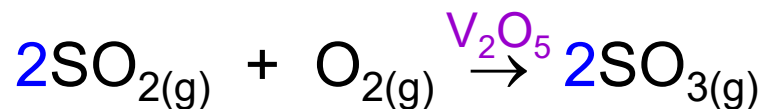
- **Iron – Fe:** Catalyst used in the industrial manufacture of ammonia (Haber process).



- **Nickel – Ni:** Catalyst used in the catalytic hydrogenation of plant oils during the manufacture of margarine.



- **Vanadium(V) Oxide – V₂O₅:** Catalyst used in the industrial manufacture of sulfuric acid (Contact process).



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Comparing Transition Metals and Alkali Metals

- Transition metals are typical metals. They are strong and have high melting points and high densities.
- Alkali metals are atypical metals. They are relatively soft and have low melting points and low densities.
 - Transition metals form coloured compounds.
- Compounds of the alkali metals are all colourless.



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The Transition Metals (d-block, Groups 3 – 12)

Comparing Transition Metals and Alkali Metals

- Transition metals have variable oxidation states*.
- Alkali metals only have an oxidation state of +1.
- Transition metals and their compounds function as catalysts because they have variable oxidation states.
- Alkali metals and their compounds do not function as catalysts because they only have a single oxidation state of +1.

*The exception is zinc, which only has an oxidation state of +2 in the Zn^{2+} ion.



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The Periodic Table of Chemical Elements
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- Photographs of the chemical elements taken from Theodore Gray's website:
www.periodictable.com
- Information about the uses of the chemical elements taken from:
<http://www.rsc.org/periodic-table>

