The Periodic Table

The arrangement of the Periodic Table, trends across a period and down a group, the Group I alkali metals, the Group VII halogens and their displacement reactions, the transition elements and the noble gases.

8.1 Arrangement of elements

The **Periodic Table** arranges the elements in order of increasing **proton number** (atomic number).

- A **period** is a **horizontal row**. The period number is the **number of occupied electron shells**.
- A **group** is a **vertical column**. For Groups I to VII, the group number is the **number of outer-shell electrons**. Group VIII (the noble gases) has a full outer shell.

Metals and non-metals

The **metals** are on the **left** and in the **centre** of the table, and the **non-metals** are on the **right**. A stepped line separates them. Moving from left to right **across a period**, the elements change from **metallic to non-metallic** character. In Period 3, sodium, magnesium and aluminium are metals, silicon is in between, and phosphorus, sulfur, chlorine and argon are non-metals.

The **oxides** change too: metal oxides are **basic**, aluminium oxide is **amphoteric**, and non-metal oxides are **acidic**.

Groups and ions

The group number tells you the **charge on the ion** that the element forms:

Group	I	II	III	V	VI	VII
ion formed	1+	2+	3+	3−	2−	1−

> **Elements in the same group have similar chemical properties because they have the same number of electrons in their outer shell.**

The properties change in a **regular** way down a group, because the outer electrons are in shells that get **further from the nucleus**. This means you can **predict the properties** of an element from its position, and find a **trend** in a group from the data you are given.

> TRY IT

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> The table gives the melting points of some Group I elements. Predict the melting point of caesium, which is below potassium. Lithium $181\ ^\circ\text{C}$, sodium $98\ ^\circ\text{C}$, potassium $63\ ^\circ\text{C}$.

The melting points **fall** down the group, so the melting point of caesium is **lower than** $63\ ^\circ\text{C}$ (it is about $29\ ^\circ\text{C}$).

8.2 Group I properties

The **Group I alkali metals** are lithium, sodium and potassium (then rubidium and caesium). They are **relatively soft** metals (they can be cut with a knife), shiny when freshly cut but they **tarnish quickly** in air, so they are stored under **oil**. They have **low densities** for metals, and **low melting points**, and they have **one outer electron**, which is why they form $1+$ **ions** and are very reactive.

Trends down Group I

Trend down Group I	Explanation
melting point decreases	the metallic bonding gets weaker as the atoms get bigger
density increases (in general)	the atoms get heavier more quickly than they get bigger
reactivity increases	the outer electron is **further from the nucleus** and more shielded, so it is **lost more easily**

Reaction with water

All the alkali metals react with water to give **hydrogen** and a **metal hydroxide** (an alkaline solution, which turns universal indicator purple):

$$2\,\text{Na}\,(\text{s}) + 2\,\text{H}_2\text{O}\,(\text{l}) \longrightarrow 2\,\text{NaOH}\,(\text{aq}) + \text{H}_2\,(\text{g})$$

$$2\,\text{K}\,(\text{s}) + 2\,\text{H}_2\text{O}\,(\text{l}) \longrightarrow 2\,\text{KOH}\,(\text{aq}) + \text{H}_2\,(\text{g})$$

Metal	Observations in water
lithium	floats, fizzes steadily
sodium	floats, melts to a ball, fizzes quickly and darts about on the surface
potassium	floats, melts, fizzes very fast and the hydrogen burns with a **lilac** flame. May make a loud noise

Prediction. Rubidium and caesium are **more reactive** than potassium (a very violent reaction), have **lower melting points** and are **denser**.

Note Academy

8.3 Group VII properties

The **Group VII halogens** are non-metals made of **diatomic molecules** (Cl_2, Br_2, I_2). They have **seven outer electrons** and form $1-$ **ions** (halide ions).

Halogen	Appearance at room temperature and pressure
chlorine	pale yellow-green **gas**
bromine	red-brown **liquid** (which gives off an orange-brown vapour)
iodine	grey-black **solid** (which gives a purple vapour on heating)

Trends down Group VII

- The **density increases** (gas, then liquid, then solid).
- The **melting point and boiling point increase**.
- The **reactivity decreases**. Fluorine is the most reactive and astatine the least.

Explanation. A halogen atom reacts by **gaining** one electron. Going down the group, the outer shell is **further from the nucleus**, so the **attraction** for an incoming electron is **weaker**. The atom gains an electron less easily, so it is **less reactive**.

Displacement reactions

A **more reactive halogen displaces a less reactive halogen** from a solution of its halide.

	$KCl(aq)$	$KBr(aq)$	$KI(aq)$
chlorine water	no reaction	orange/brown (bromine)	brown (iodine)
bromine water	no reaction	no reaction	brown (iodine)
iodine solution	no reaction	no reaction	no reaction

$$Cl_2(aq) + 2\,KBr(aq) \longrightarrow 2\,KCl(aq) + Br_2(aq)$$

$$Cl_2(aq) + 2\,Br^-(aq) \longrightarrow 2\,Cl^-(aq) + Br_2(aq)$$

$$Br_2(aq) + 2\,KI(aq) \longrightarrow 2\,KBr(aq) + I_2(aq)$$

The halogen is **reduced** (it gains electrons) and the halide ion is **oxidised** (it loses electrons), so these are redox reactions. The order of reactivity is **chlorine > bromine > iodine**.

Note Academy

TRY IT

Predict what you would see if bromine water is added to potassium chloride solution, and say why.

No reaction. Bromine is **less reactive** than chlorine, so it cannot displace chlorine from chloride ions.

TRY IT

Predict the state and colour of astatine and its reactivity compared with iodine.

Astatine is below iodine, so it is a **black solid** (a darker colour, with a higher melting point) and it is **less reactive** than iodine.

8.4 Transition elements

The **transition elements** form a block of metals in the middle of the Periodic Table, between Group II and Group III (for example iron, copper, zinc, chromium, manganese and nickel).

The transition elements are metals that have high densities, high melting points, variable oxidation numbers, form coloured compounds, and often act as catalysts.

Property	Example
high density and high melting point	iron melts at $1538\ ^\circ C$, while sodium melts at $98\ ^\circ C$
variable oxidation numbers	iron forms Fe^{2+} and Fe^{3+}, and copper forms Cu^{+} and Cu^{2+}
coloured compounds	copper(II) compounds are **blue**, iron(II) is **green**, iron(III) is **orange-brown**, and manganate(VII) is **purple**
catalysts	iron in the Haber process, vanadium(V) oxide in the Contact process, nickel in hydrogenation of alkenes, platinum in catalytic converters

Compared with the Group I metals, transition elements are **harder and stronger**, have **much higher melting points and densities**, and are **much less reactive** (they react only slowly with water and oxygen).

8.5 Noble gases

The **Group VIII noble gases** (helium, neon, argon, krypton, xenon) are **unreactive, monatomic gases** (single atoms, not molecules).

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Noble gases are unreactive because they have a full outer shell of electrons (a stable electronic configuration). Their atoms do not need to gain, lose or share electrons.

Because they are unreactive and do not form bonds, they exist as **single atoms**. The boiling points increase down the group.

Uses that depend on being unreactive or of low density: **helium** in balloons and airships (low density and non-flammable, unlike hydrogen), **argon** in filament light bulbs (to stop the hot filament from burning) and for welding, and **neon** in advertising signs.

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