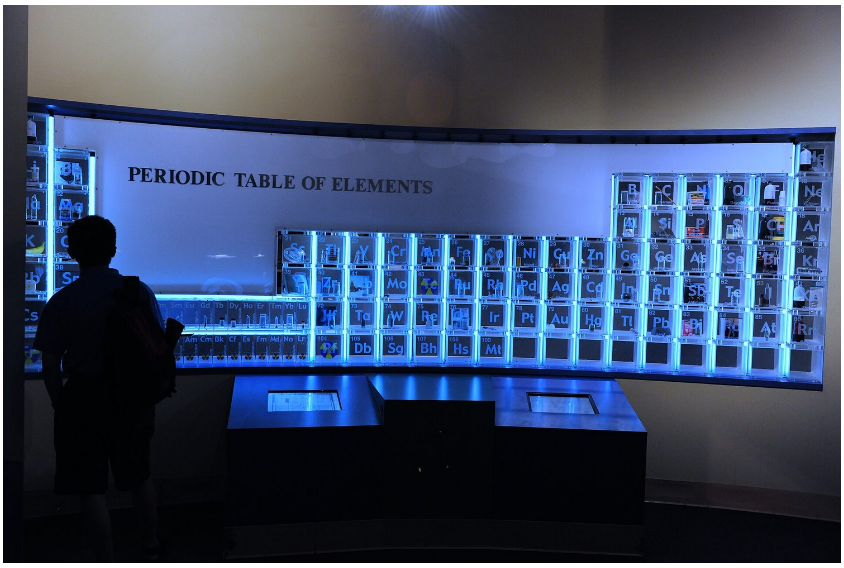
The Periodic Table: chemical periodicity

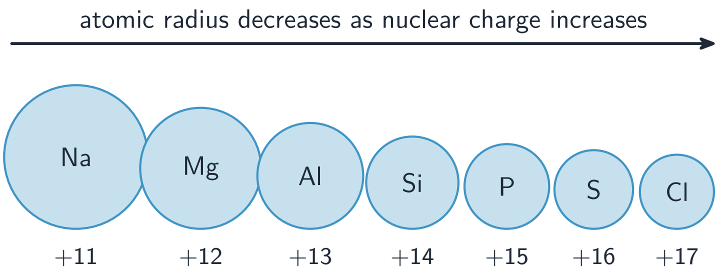
A-Level Chemistry

Physical properties across Period 3



Properties repeat in a regular pattern across each period of the table.

Periodicity 周期性 means that properties repeat in a regular pattern as you go across each **period** 周期 of the Periodic Table. Period 3 (Na to Ar) is the standard example.



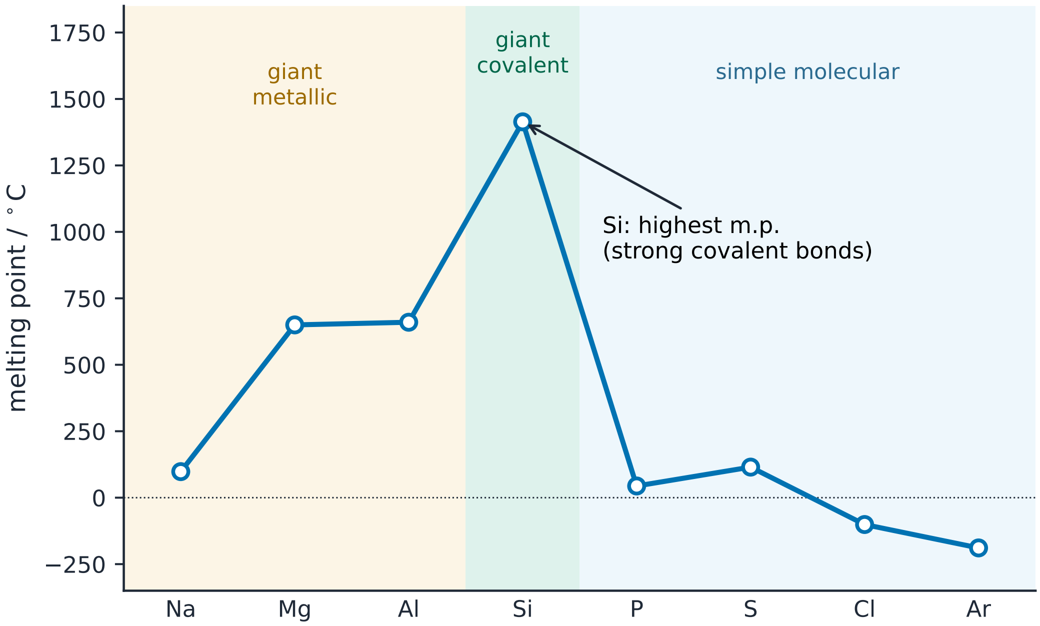
Atomic radius decreases across Period 3: the rising nuclear charge pulls the same outer shell inwards

Property	Trend across Period 3
atomic radius 原子半径	gets smaller (more nuclear charge pulls the same shell in)
ionic radius 离子半径	positive ions are small; from P^{3-} onwards the negative ions are larger
melting point 熔点	rises to a peak at silicon, then falls sharply
electrical conductivity 导电性	high for Na, Mg, Al; almost zero from Si onwards

The melting point and conductivity follow from the structure and bonding:

- **Na, Mg, Al** are **giant metallic** 金属晶体. Melting points rise (Na → Al) because each atom gives more delocalised electrons and the ions get smaller, so the bonding is stronger. They conduct well.

- **Si** is **giant molecular** 原子晶体 (giant covalent). It has the highest melting point, because strong covalent bonds must be broken. It barely conducts.
- **P, S, Cl, Ar** are **simple molecular** 分子晶体 (or single atoms). Their melting points are low, because only weak intermolecular forces break. They do not conduct.



Melting point across Period 3 peaks at silicon (giant covalent); it is high for the metals and low for the simple molecular elements

Chemical properties across Period 3

Reactions with oxygen, chlorine and water

With **oxygen**:

$$4Na + O_2 \rightarrow 2Na_2O \qquad 2Mg + O_2 \rightarrow 2MgO \qquad 4Al + 3O_2 \rightarrow 2Al_2O_3$$

$$P_4 + 5O_2 \rightarrow P_4O_{10} \qquad S + O_2 \rightarrow SO_2$$

With **chlorine**:

$$2Na + Cl_2 \rightarrow 2NaCl \qquad Mg + Cl_2 \rightarrow MgCl_2 \qquad 2Al + 3Cl_2 \rightarrow 2AlCl_3$$

$$Si + 2Cl_2 \rightarrow SiCl_4 \qquad 2P + 5Cl_2 \rightarrow 2PCl_5$$

With **water** (only Na and Mg react):

$$2Na + 2H_2O \rightarrow 2NaOH + H_2 \qquad Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$$

Sodium reacts fast; magnesium reacts only very slowly with cold water.

Oxidation number of the oxides and chlorides

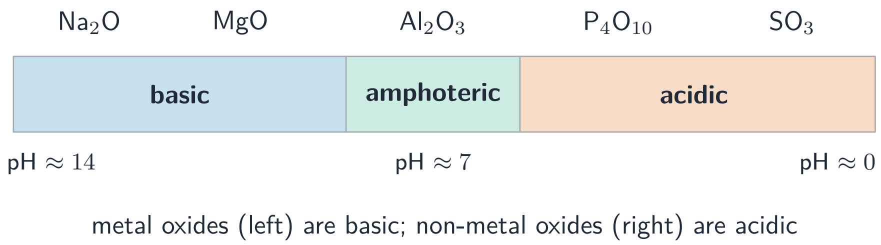
The **oxidation number** 氧化数 of the Period 3 element in its oxide or chloride rises across the period, because it equals the number of outer-shell (**valence shell** 价层) **electrons** 电子 the atom uses in bonding:

Oxides	**Na_2O**	**MgO**	**Al_2O_3**	**P_4O_{10}**	**SO_2 / SO_3**
oxidation number	+1	+2	+3	+5	+4 / +6

The chlorides NaCl, $MgCl_2$, $AlCl_3$, $SiCl_4$, PCl_5 show oxidation numbers +1 to +5 in the same way.

Oxides with water, and acid–base behaviour

Across the period the **oxides** 氧化物 change from basic to acidic:



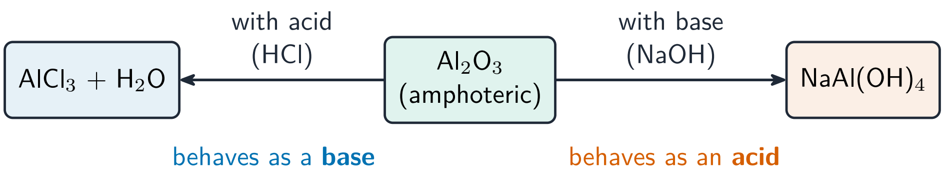
The Period 3 oxides change from basic (the metals) through amphoteric (Al_2O_3) to acidic (the non-metals)

Oxide	**With water**	**Acid–base nature**	**Approximate pH**
Na_2O	$Na_2O + H_2O \rightarrow 2NaOH$	basic	13–14
MgO	$MgO + H_2O \rightarrow Mg(OH)_2$	basic	9–10
Al_2O_3	insoluble	**amphoteric** 两性	7
SiO_2	insoluble	weakly acidic	7
P_4O_{10}	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	acidic	1–2
SO_3	$SO_3 + H_2O \rightarrow H_2SO_4$	strongly acidic	0–1

Metal oxides (left) are basic; non-metal oxides (right) are acidic. Al_2O_3 and its **hydroxide** 氢氧化物 $Al(OH)_3$ are amphoteric —they react with **both** acids and bases:

$$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$$

$$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$$



Aluminium oxide is amphoteric —it reacts with acids (behaving as a base) and with bases (behaving as an acid)

Chlorides with water

- NaCl and $MgCl_2$ are ionic. They simply dissolve, giving a near-neutral solution.
- $SiCl_4$ and PCl_5 are covalent. They undergo **hydrolysis** 水解 (react with water) to make acidic solutions and fumes of HCl:

$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl \qquad PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$$

Explaining the trends

These trends follow from the change in bonding and **electronegativity** 电负性. On the left, the elements are metals with low electronegativity, so their oxides and chlorides are ionic and basic (or neutral). On the right, the elements are non-metals with high electronegativity, so their oxides and chlorides are covalent and acidic. You can use a chloride's or oxide's properties (melting point, conductivity, effect on water) to suggest whether its bonding is ionic or covalent.

Periodicity of other elements

The same idea works for any group. If you know the pattern down a group and across a period, you can:

- **predict** the properties of an element from its position (for example, a Group 1 element will be a reactive metal forming a +1 ion).
- **deduce** the likely position and identity of an unknown element from its physical and chemical properties.