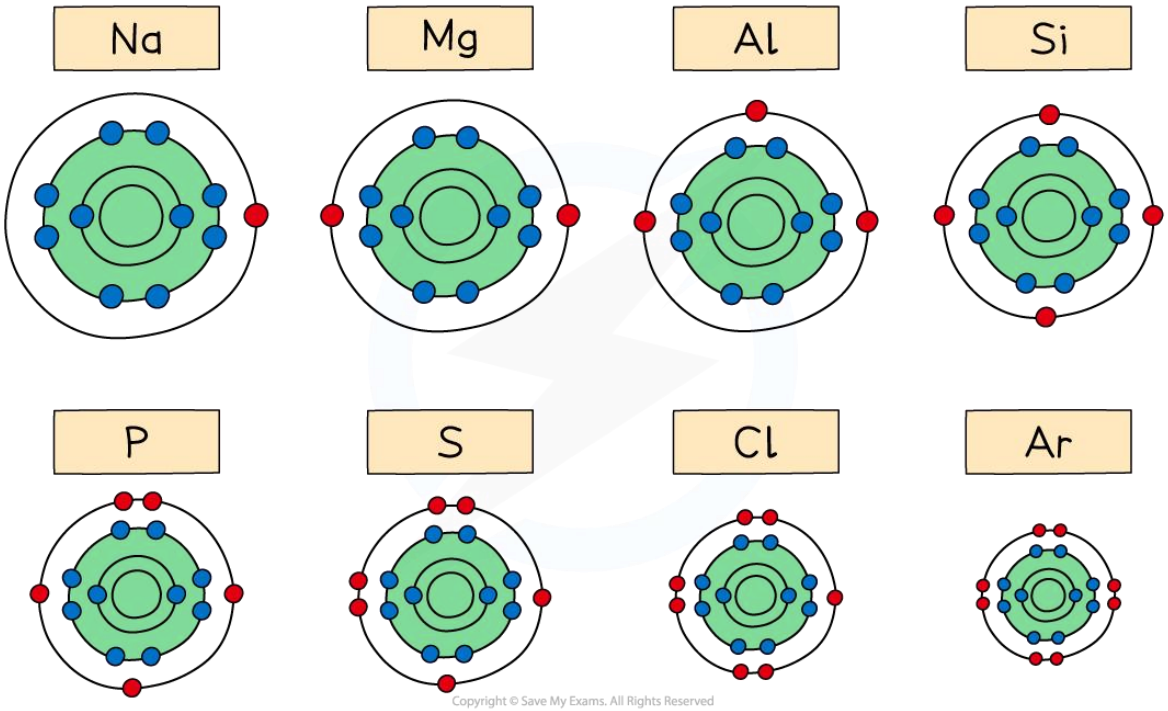
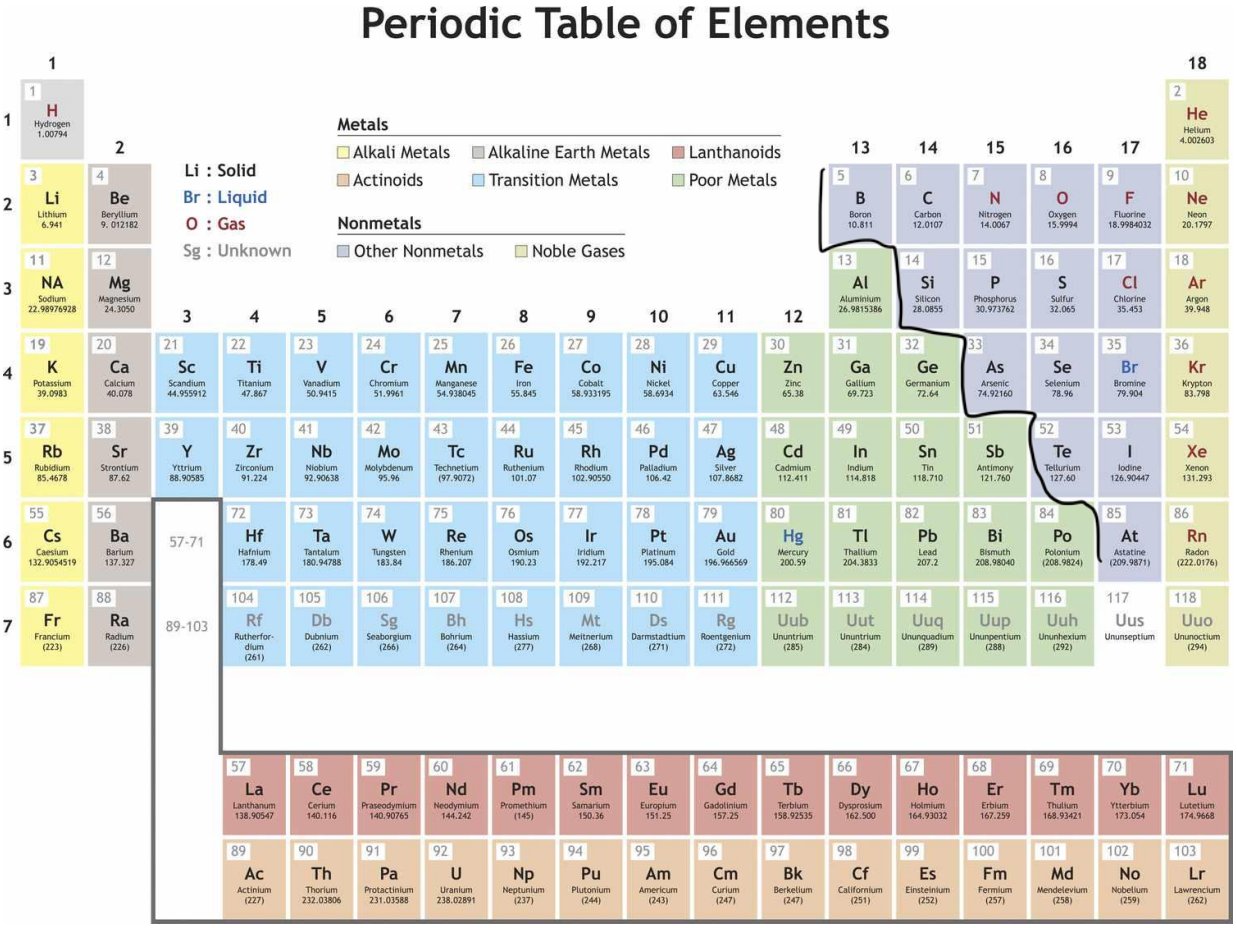
The Periodic Table: chemical periodicity

Review



Periodic Law states that chemical and physical properties of elements repeat in a predictable way when elements are arranged by increasing atomic number.



1. Periodicity of physical properties

atomic radii

Silicon ion: Si^{4+} (lose electron)

The atomic radius decreases across a period because the increasingly positive nuclear charge pulls the electrons in the outer shell closer to the nucleus.

ionic radii

Ions of Period 3 Elements	Na^+	Mg^{2+}	Al^{3+}	Si^{4+}	P^{3-}	S^{2-}	Cl^-	Ar
Ionic Radius (nm)	0.095	0.065	0.050	0.041	0.212	0.184	0.181	No data

Look at the elements in Period 2 of the Periodic Table in Appendix 1. Using your knowledge of Period 3 elements, predict and explain the relative sizes of:

a the atomic radii of lithium and fluorine

b a lithium atom and its ion, Li^+

c an oxygen atom and its ion, O^{2-}

d a nitride ion, N^{3-}, and a fluoride ion, F^-.

mg S

The elements magnesium and sulfur each form doubly charged ions.

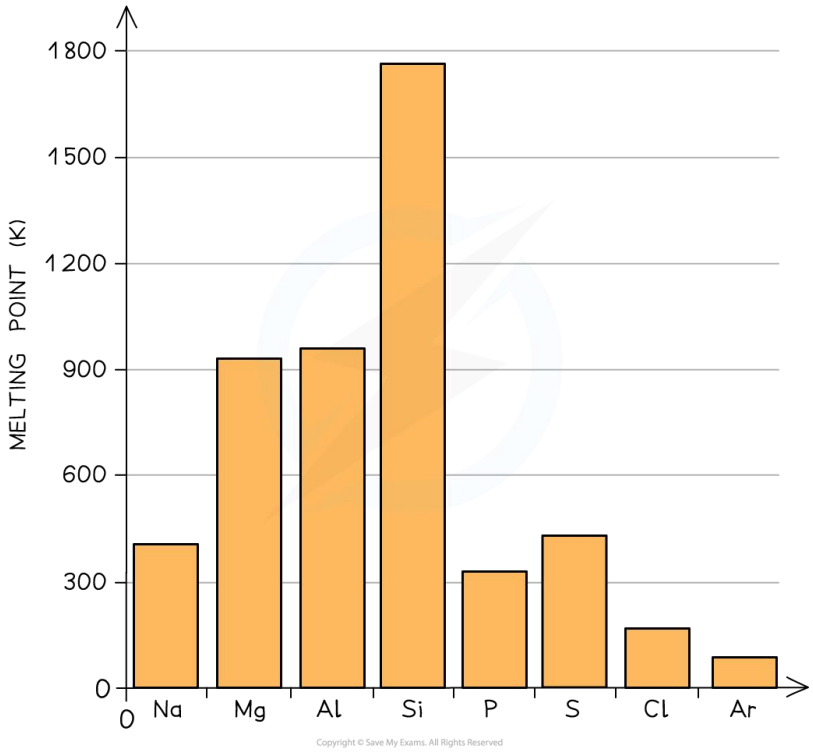
How do the atomic radii and ionic radii of these elements compare?

	atomic radius		ionic radius	atomic radius		ionic radius
A	Mg	>	Mg^{2+}	S	>	S^{2-}
B	Mg	>	Mg^{2+}	S	<	S^{2-}
C	Mg	<	Mg^{2+}	S	>	S^{2-}
D	Mg	<	Mg^{2+}	S	<	S^{2-}

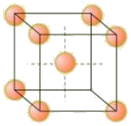
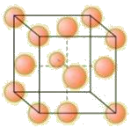
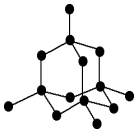
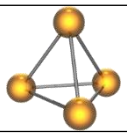
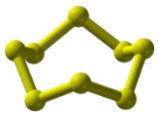
more electron

melting points

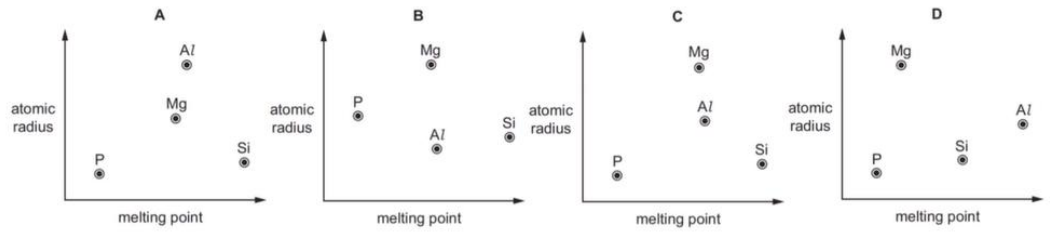
Period 3 element	sodium (Na)	magnesium (Mg)	aluminium (Al)	silicon (Si)	phosphorus (P)	sulfur (S)	chlorine (Cl)	argon (Ar)
Bonding	metallic	metallic	metallic	covalent	covalent	covalent	covalent	-
Structure	giant metallic	giant metallic	giant metallic	giant molecular	simple molecular	simple molecular	simple molecular	simple molecular



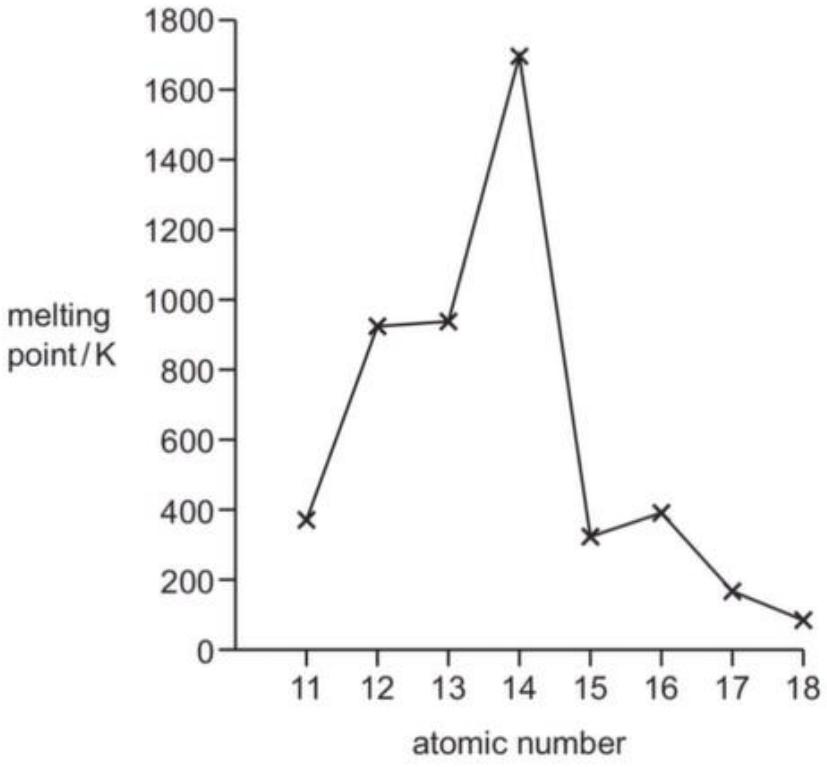
Structure

Group	1	2	3	4
Element	Sodium	Magnesium	Aluminium	Silicon
Character	Metal			Metalloid
Structure	Giant metallic lattice			Macromolecular
Bonding	Metallic bond between cations and delocalized e^-			Covalent bonds between atoms
Diagram				
Group	5	6	7	0
Element	Phosphorous	Sulphur	Chlorine	Argon
Character	Non-metals			
Structure	Simple molecular covalent			Simple atoms
Bonding	Intra = covalent Inter = weak VDWs			Atoms held by VDWs
Diagram				

Which diagram correctly shows the atomic radii of the elements Mg, Al, Si and P plotted against their melting points?



A plot of the melting points of the elements across the third period is shown.



(i) Explain the increase in melting point from atomic number 11 to 12.

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..... [2]

(ii) Suggest a reason why the increase from atomic number 12 to 13 is much smaller than the increase from atomic number 11 to 12.

(iii) State and explain the pattern of the melting points from atomic number 15 to 18.

.....

.....

.....

..... [3]

(iv) Explain why the element with atomic number 14 has a melting point so much higher than the rest of the elements in the third period.

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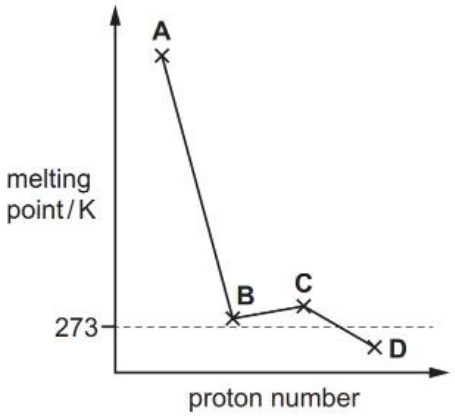
The relative melting points of four consecutive elements in the Periodic Table are shown in the graph.

The elements all have proton numbers less than 20.

Which element is in Group 16?



Electrical Conductivity

Q. Which rows correctly show the relative conductivities of the three Period 3 elements?

	Greatest conductivity	→	Least conductivity
1	sodium	silicon	chlorine
2	aluminium	magnesium	phosphorus
3	sulfur	silicon	phosphorus

A. 1, 2 and 3 are correct

B. 1 and 2 only are correct

C. 2 and 3 only are correct

D. 1 only is correct

Which rows correctly show the relative electrical conductivities of the sets of three Period 3 elements?

	greatest conductivity	→	least conductivity
1	sodium	silicon	chlorine
2	aluminium	magnesium	phosphorus
3	sulfur	silicon	phosphorus

A. 1, 2 and 3 are correct
B. 1 and 2 only are correct
C. 2 and 3 only are correct
D. 1 only is correct

Electronegativity

Element	Na	Mg	Al	Si	P	S	Cl	Ar
Electronegativity	0.9	1.2	1.5	1.8	2.1	2.5	3.0	–

first ionisation energies

Which row is correct?

	statement	reason
A	The first ionisation energy of phosphorus is greater than that of magnesium.	electron is lost from a 3p orbital in both cases
B	The melting point of phosphorus is greater than that of magnesium.	phosphorus has more valence electrons than magnesium
C	The atomic radius of phosphorus is smaller than that of magnesium.	phosphorus has greater nuclear charge than magnesium
D	The electrical conductivity of phosphorus is smaller than that of magnesium.	bonding changes from ionic in magnesium to covalent in phosphorus

The fifth to eighth ionisation energies of four elements in Period 3 of the Periodic Table are shown.

Which row refers to chlorine?

	ionisation energies /kJ mol^{-1}			
	fifth	sixth	seventh	eighth
A	6280	21 200	25 900	30 500
B	6990	8 490	27 100	31 700
C	6540	9 330	11 000	33 600
D	7240	8 790	12 000	13 800

The eight elements sodium to argon are in the same period of the Periodic Table.

The equation corresponding to the first ionisation energy is shown.

$$X(g) \rightarrow X^{+}(g) + e^{-}$$

For which of these eight elements is the electron in this equation removed from a filled orbital?

A. Mg, Al, Si, P, S, Cl and Ar
B. A, Si, P, S, Cl and Ar only
C. Mg, S, Cl and Ar only
D. S, Cl and Ar only

↳ filled orbital

Electronegativity

Increases across period because the bonded e^- are in the same energy level but are attracted more strongly as no. of protons increases

2. Periodicity of chemical properties

Reactions of Period 3 elements with oxygen

Element	sodium	magnesium	aluminium
Formula and state of oxide	$Na_2O(s)$	$MgO(s)$	$Al_2O_3(s)$
Equation	$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$	$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$
Observation	vigorously, yellow flame	vigorously, white flame	×
Reaction of oxide with water	$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$	$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2(aq)$	×

Element	silicon	phosphorous	sulphur
Formula and state of oxide	$SiO_2(s)$	$P_4O_{10}(s)$	$SO_2(g)$ $SO_3(g)$
Equation	$Si(s) + O_2(g) \rightarrow SiO_2(s)$	$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$	$S(s) + O_2(g) \rightarrow SO_2(g)$ $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
Observation	slowly	vigorously, yellow/ white flame	gently, blue flame
Reaction of oxide with water	×	$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$	$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$

	Chemical Equation	Reaction Conditions	Reaction	Flame	Product
Na	$4Na(s) + O_2(g) \longrightarrow 2Na_2O(s)$	Heated	Vigorously	Bright yellow flame	White solid
Mg	$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$	Heated	Vigorously	Bright white flame	White solid
Al	$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$	Powdered Al	Fast	Bright white flame	White powder
Si	$Si(s) + O_2(g) \longrightarrow SiO_2(s)$	Powdered Si Heat strongly	Slowly	Bright white sparkles	White powder
P	$4P(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$	Heated	Vigorously	Yellow or white flame	White clouds
S	$S(s) + O_2(g) \longrightarrow SO_2(g)$	Powdered S is heated	Gently	Blue flame	Toxic fumes

Period 3 oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2, SO_3
Acid/base nature	Basic	Basic	Amphoteric	Acidic	Acidic	Acidic

$SiO_2 + 2NaOH \rightarrow H_2O + Na_2SiO_3$

Hot conc. base

Two oxides of Period 3 elements are added separately to water. Both react to form colourless solutions. One solution is alkaline, the other is acidic.

What could be the two oxides?

A. ~~Al_2O_3~~ and SiO_2
B. ~~Al_2O_3~~ and P_4O_{10}
C. Na_2O and P_4O_{10}
D. Na_2O and SiO_2

X and Y are two elements in Period 3 of the Periodic Table. They combine to form compound Z.

X forms a soluble acidic oxide. The oxidation number of X in this oxide is +4.

Y forms an amphoteric oxide.

What is the formula of compound Z?

A. AlP
B. Al_2S_3
C. Si_2P_5
D. SiS_2

Which oxide is insoluble in aqueous sodium hydroxide?

A. MgO
B. Al_2O_3 → soluable in base
C. P_4O_{10}
D. SO_2

Which element, when burned in oxygen, can form an oxide that is a reducing agent?

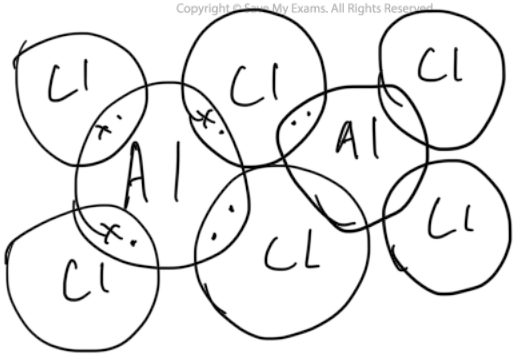
A. Na
B. Mg
C. Al
D. S

Which oxide does **not** react with cold, dilute sodium hydroxide to produce a salt?

A. Al_2O_3
B. P_4O_{10}
C. SO_2
D. SiO_2

Reactions of Period 3 elements with chlorine

Period 3 chloride	S NaCl	S $MgCl_2$	S Al_2Cl_6	l $SiCl_4$	S PCl_5	g SCl_2
Chemical bonding	Ionic	Ionic	Covalent	Covalent	Covalent	Covalent
Structure	Giant ionic	Giant ionic	Simple molecular	Simple molecular	Simple molecular	Simple molecular
Observations	White solids dissolve to form colourless solutions		Chlorides react with water, giving off white fumes of hydrogen chloride gas form HCl			
pH of formed solution	7	6.5	3	2	2	2



Element X, in Period 3, has the following properties.

- Its oxide has a giant structure.
- It forms covalent bonds with chlorine.
- Its oxide will neutralise HCl(aq).

What is element X?

A. Mg
B. Al → Ionic
C. Si X
D. P

Three test-tubes, X, Y and Z, each contain water.

- A small amount of NaCl is added to test-tube X.
- A small amount of $SiCl_4$ is added to test-tube Y.
- A small amount of $AlCl_3$ is added to test-tube Z.

After a short time, two drops of universal indicator solution are added to each test-tube.

Which statements can be correct?

1. The pH in test-tube X is 7.
2. The pH in test-tube Y is 2.
3. The pH in test-tube Z is 2.

A. 1, 2 and 3 are correct
B. 1 and 2 only are correct
C. 2 and 3 only are correct
D. 1 only is correct

X, Y and Z are three elements in the third period.

- X reacts with chlorine to give a liquid product.
- Y reacts with chlorine to give a solid product that dissolves in water to give a solution of pH 7.
- Z reacts with chlorine to give a solid product that dissolves in water to give a solution of pH 6.

Which elements are good conductors of electricity?

A. X and Y
B. Y and Z
C. Y only
D. Z only

L and M are elements in Period 3 of the Periodic Table.

- The oxide of L is a solid at room temperature. This oxide has a giant structure.
- The chloride of L does not react with water.
- Argon is the only element in Period 3 with a lower melting point than M.

Which formula represents a compound of elements L and M?

A. Al_2S_3
B. MgS
C. $NaCl$
D. PCl_5

A sample of $SiCl_4$ is added to cold water.

Which statement describes the mixture formed at the end of the reaction?

A. acidic solution with no precipitate
B. acidic solution with white precipitate
C. neutral solution with no precipitate
D. neutral solution with white precipitate

Magnesium chloride, $MgCl_2$, and silicon tetrachloride, $SiCl_4$, are separately added to water.

What are the approximate pH values of the solutions formed?

	$MgCl_2$	$SiCl_4$
A	0-3	0-3
B	0-3	6-7
C	6-7	0-3
D	6-7	6-7

Effect of water on oxides and hydroxides of Period 3 elements

Magnesium oxide and magnesium hydroxide are commonly used in indigestion remedies (Figure 10.11). These basic compounds neutralise excess acid in the stomach, relieving the pain:

$MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$

$Mg(OH)_2(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + 2H_2O(l)$

Aluminium oxide does not react or dissolve in water, which is why an oxide layer can protect aluminium metal from corrosion. However, it does react and dissolve when added to acidic or alkaline solutions.

- With acid:

  $Al_2O_3(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2O(l)$
- With hot, concentrated alkali:

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

When aluminium oxide reacts with an acid it behaves like a base: it forms a salt (aluminium sulfate in the example with dilute sulfuric acid above) plus water.

When it reacts with an alkali it behaves like an acid: reacting to form a salt (sodium tetrahydroxoaluminate in the example with sodium hydroxide above).

Compounds that can act as both acids and bases, such as aluminium oxide, are called **amphoteric**.

Silicon dioxide is also insoluble in water. Water cannot break down its giant molecular structure. However, it will react with and dissolve in hot, concentrated alkali:

$SiO_2(s) + 2NaOH(aq) \rightarrow Na_2SiO_3(aq) + H_2O(l)$

Silicon dioxide acts as an acid when it reacts with sodium hydroxide, forming a salt (sodium silicate) plus water. It does not react with acids, so it is classed as an acidic oxide.

Phosphorus(V) oxide reacts vigorously and dissolves in water to form an acidic solution of phosphoric(V) acid (pH 2):

$$P_4O_{10}(s) + 6H_2O(l) \rightarrow \underset{\text{phosphoric(V) acid}}{4H_3PO_4(aq)}$$

The oxides of sulfur, SO_2 and SO_3, both react and dissolve in water, forming acidic solutions (pH 1):

$$SO_2(g) + H_2O(l) \rightarrow \underset{\text{sulfurous acid (also known as sulfuric(IV) acid)}}{H_2SO_3(aq)}$$

$$SO_3(g) + H_2O(l) \rightarrow \underset{\text{sulfuric(VI) acid}}{H_2SO_4(aq)}$$

Period 3 oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2, SO_3
Relative melting point	high	high	very high	very high	low	low
Electrical conductivity when in liquid state	good	good	good	none	none	none
Chemical bonding	ionic	ionic	ionic (with a degree of covalent character)	covalent	covalent	covalent
Structure	giant ionic	giant ionic	giant ionic	giant covalent	simple molecular	simple molecular

When added to water, which oxides will **not** cause a change in pH?

1. Al_2O_3
2. SiO_2
3. P_4O_{10}

A. 1, 2 and 3 are correct
B. 1 and 2 only are correct
C. 2 and 3 only are correct
D. 1 only is correct

Sodium, aluminium and silicon are three elements in Period 3. Each element forms an oxide.
Which row has three correct properties of these oxides?

	sodium oxide	aluminium oxide	silicon dioxide
A	basic	basic	amphoteric
B	giant ionic	giant ionic	simple molecular
C	high melting point	low melting point	high melting point
D	reacts with water	no reaction with water	no reaction with water

Element Z has a giant structure.

The chloride of Z reacts with water to give a solution with a pH less than 5.

Which pair shows two elements which could be Z?

A. aluminium, magnesium
B. aluminium, silicon
C. phosphorus, magnesium
D. phosphorus, silicon

Element Q readily oxidises in air. The oxide produced reacts with water to form a solution of very low pH.

Where could element Q be found in the Periodic Table?

	period	group
A	2	1
B	2	14
C	3	14
D	3	15

X and Y are elements of the third period.

X and Y are individually heated in excess chlorine. Each product is purified and then separately added to water, producing two solutions. Both solutions have a pH of less than 5.

What could be X and Y?

A. Na and P
B. Mg and Al
C. Mg and Si
D. Si and P

Which statements are correct?

1. Aluminium chloride dissolves in water to give an acidic solution.
2. Magnesium chloride dissolves in water to give a solution of pH close to 7.
3. Sodium chloride dissolves in water to give an alkaline solution.

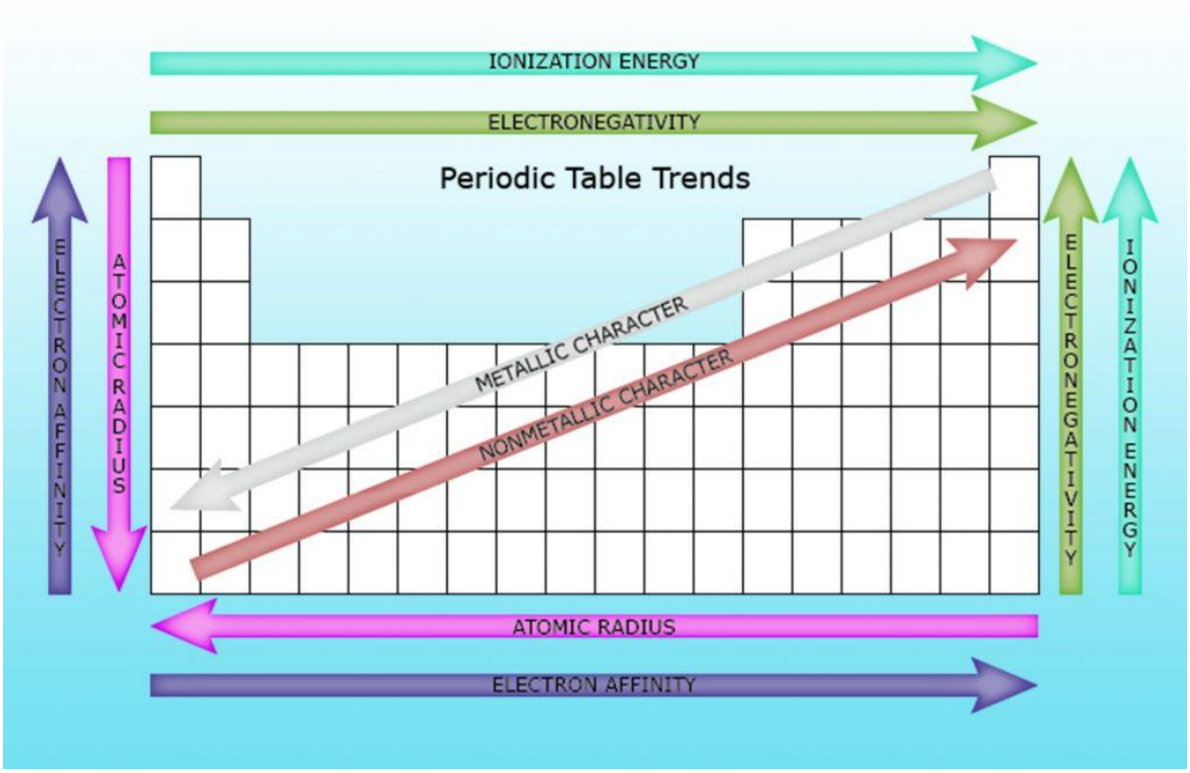
A. **1**, **2** and **3** are correct

B. **1** and **2** only are correct

C. **2** and **3** only are correct

D. **1** only is correct

3.Summary



Summary of Periodicity Trends

The periodicity of these properties follows trends as you move across a row or period of the periodic table or down a column or group:

Moving Left → Right

Moving Top → Bottom