

Periodicity SL

IB CHEMISTRY SL

25 Mn Manganese 54.938045	16 S Sulfur 32.065	J	6 C Carbon 12.0107	2 He Helium 4.002602	25 Mn Manganese 54.938045
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Syllabus objectives

3.1 Periodic table

Understandings:

- The periodic table is arranged into four blocks associated with the four sub-levels—s, p, d, and f.
- The periodic table consists of groups (vertical columns) and periods (horizontal rows).
- The period number (n) is the outer energy level that is occupied by electrons.
- The number of the principal energy level and the number of the valence electrons in an atom can be deduced from its position on the periodic table.
- The periodic table shows the positions of metals, non-metals and metalloids.

Applications and skills:

- Deduction of the electron configuration of an atom from the element's position on the periodic table, and vice versa.

Guidance:

- The terms alkali metals, halogens, noble gases, transition metals, lanthanoids and actinoids should be known.
- The group numbering scheme from group 1 to group 18, as recommended by IUPAC, should be used.

3.2 Periodic trends

Understandings:

- Vertical and horizontal trends in the periodic table exist for atomic radius, ionic radius, ionization energy, electron affinity and electronegativity.
- Trends in metallic and non-metallic behaviour are due to the trends above.
- Oxides change from basic through amphoteric to acidic across a period.

Applications and skills:

- Prediction and explanation of the metallic and non-metallic behaviour of an element based on its position in the periodic table.
- Discussion of the similarities and differences in the properties of elements in the same group, with reference to alkali metals (group 1) and halogens (group 17).
- Construction of equations to explain the pH changes for reactions of Na_2O , MgO , P_4O_{10} , and the oxides of nitrogen and sulfur with water.

Guidance:

- Only examples of general trends across periods and down groups are required.
- For ionization energy the discontinuities in the increase across a period should be covered.
- Group trends should include the treatment of the reactions of alkali metals with water, alkali metals with halogens and halogens with halide ions.

Syllabus checklist

Objective	I am confident with this	I need to review this	I need help with this
Outline the meaning of the terms <i>group</i> and <i>period</i> with respect to the periodic table			
State the names of the different groups on the periodic table			
Deduce the electron configuration of an atom from its position on the periodic table and vice versa			
Outline the concept of effective nuclear charge			
Explain the trends in atomic radius down a group and across a period in the periodic table			
Explain the trends in ionic radius down a group and across a period in the periodic table			
Outline the meaning of the term <i>ionisation energy</i>			
Explain the trend in ionisation energy down a group and across a period in the periodic table			
Outline the reasons for the discontinuities in the increase in ionisation energy across a period			
Outline the meaning of the term <i>electronegativity</i>			
Explain the trend in electronegativity down a group and across a period in the periodic table			
Outline the meaning of the term <i>electron affinity</i>			
Explain the trend in electron affinity in the periodic table			

Describe the trend in melting point across a period (periods 2 and 3) in the periodic table			
Describe the trend in metallic character down a group and across a period in the periodic table			
State the changes in acid-base character for the period 3 oxides			
Write equations for the reactions of Na_2O , MgO , P_4O_{10} , and the oxides of nitrogen and sulfur with water			
Write equations for the reactions of the group 1 metals with water			
Describe the trends in the group 1 metals (melting point, ionisation energy, electronegativity, reactivity, metallic character)			
Describe the trends in the group 17 elements (boiling point, ionisation energy, electronegativity, reactivity)			
Write equations for the reactions of the group 17 elements with group 1 metals			
Write equations for the displacement reactions of group 17 elements with halide ions			

Introduction to the periodic table

- Elements in the periodic table are arranged in groups and periods.
- A group is a vertical column in the periodic table.
- Elements in the same group have the same number of electrons in the outer energy level (same number of valence electrons).
- A period is a horizontal row.
- Elements in the same period have the same number of occupied energy levels.
- Elements on the periodic table are arranged in order of increasing atomic number.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.01																	2 He 4.00
2	3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.90
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 † La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 ‡ Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (270)	108 Hs (269)	109 Mt (278)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Uut (286)	114 Uuq (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294)	118 Uuo (294)
			†	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97	
			‡	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)	

Names of the groups in the periodic table

- ◇ Group 1 – Alkali metals (Li, Na, K, Rb, Cs, Fr)
- ◇ Group 2 - Alkaline Earth metals (Be, Mg, Ca, Sr, Ba, Ra)
- ◇ Group 17 – Halogens (salt formers) (F, Cl, Br, I, At)
- ◇ Group 18 – Noble gases (He, Ne, Ar, Kr, Xe, Rn)
- ◇ Groups 3 – 11: Transition metals (elements)
- ◇ La – Lu: Lanthanides (lanthanoids)
- ◇ Ac – Lr: Actinides (actinoids)

Electron configurations and the periodic table

- The electron configuration of an element can be deduced from its position on the periodic table and vice-versa.
- The periodic table is divided into blocks (s, p, d, f).
- The block in which an element is located tells us which sub-level is in the process of being filled.

s-block elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	1 H 1.01																	2 He 4.00	
2	3 Li 6.94	4 Be 9.01																	
3	11 Na 22.99	12 Mg 24.31																	
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.90	
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29	
6	55 Cs 132.91	56 Ba 137.33	57 † La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)	
7	87 Fr (223)	88 Ra (226)	89 ‡ Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (270)	108 Hs (269)	109 Mt (278)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Uut (286)	114 Uuq (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294)	118 Uuo (294)	
			†	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97		
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Example:

- The electron configuration of Li is $1s^2 2s^1$
- Lithium is an s-block element in group 1 and period 2.
- Li has 2 occupied energy levels with the valence shell ($n=2$) containing 1 electron in the 2s sub-level.

Exercise:

Deduce the group number and period number of Ca, S and Kr from their positions in the periodic table.

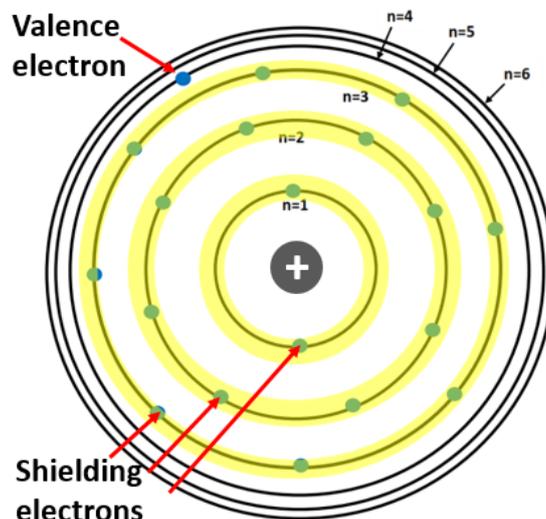
Ca group: period:

S group: period:

Kr group: period:

Electron shielding

- Electron shielding occurs when the inner (shielding) electrons shield the outer (valence) electrons from the full attraction of the nucleus.
- The valence electron(s) require less energy to remove than the inner electrons.



- Electron shielding remains fairly constant across a period (left to right) because the number of shielding electrons is the same across a period.
- Electron shielding increases down a group because the number of shielding electrons increase down a group.

Nuclear charge and effective nuclear charge (Z_{eff})

- The nuclear charge of an atom is given by the atomic number (the number of protons in the nucleus) and increases by one between successive elements in the periodic table, as a proton is added to the nucleus.
- The outer valence electrons do not experience the full attraction from the nucleus as they are shielded from the nucleus and repelled by inner electrons.
- Effective nuclear charge (Z_{eff}) is the net positive charge experienced by valence electrons.
- The effective nuclear charge is less than the actual nuclear charge.
- The effective nuclear charge can be approximated by the following equation, where Z is the atomic number and S is the number of shielding electrons.

$$Z_{\text{eff}} = Z - S$$

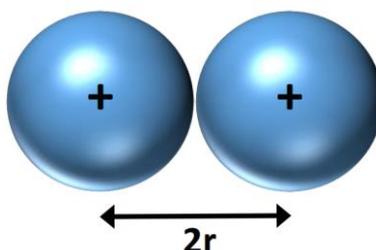
Z is the atomic number

S is the number of shielding electrons

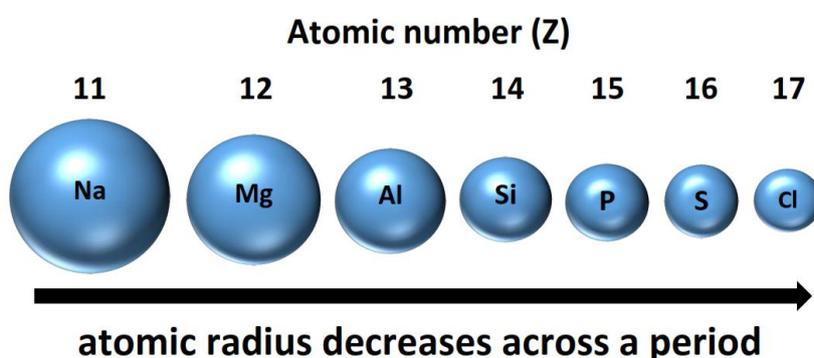
Exercise: Determine the effective nuclear charge for the above atom (potassium).

Atomic radius

- The atomic radius (van der Waals radius) is measured as half the distance between neighboring nuclei.
- Atomic and ionic radii values can be found in section 9 of the data booklet.



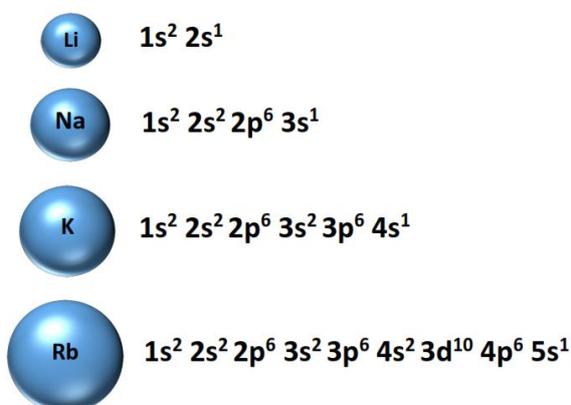
Trend across a period



Explanation for the trend:

- Nuclear charge increases across a period.
- Electrons are added to the same main energy level (electron shielding remains fairly constant across a period).
- The electrons are pulled closer to the nucleus, therefore, the atomic radius decreases.

Trend in atomic radius down a group

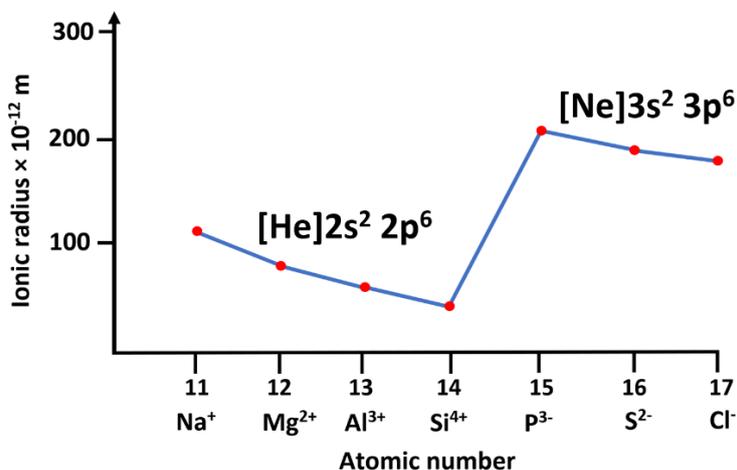


The atomic radius increases down a group because the number of occupied energy levels increases.

This results in a weaker attraction between the nucleus and the valence electrons.

Trends in ionic radius

- Ionic radius increases down a group because of the increasing number of occupied energy levels.
- Ionic radius decreases across a period for positive ions.
- It then increases as we get to the negative ions and then decreases again.



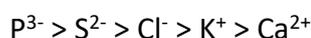
- The first four positive ions have two occupied energy levels and the negative ions have three occupied energy levels, therefore, the ionic radius increases.

Trend for isoelectronic ions

- The table below shows data for the ions N³⁻ to Al³⁺.

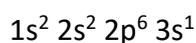
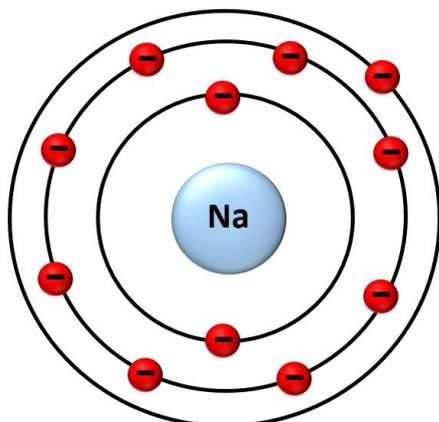
Ion	Atomic number	Electron configuration	Ionic radius ($\times 10^{-12}$ m)
N ³⁻	7	1s ² 2s ² 2p ⁶	146
O ²⁻	8	1s ² 2s ² 2p ⁶	140
F ⁻	9	1s ² 2s ² 2p ⁶	133
Na ⁺	11	1s ² 2s ² 2p ⁶	102
Mg ²⁺	12	1s ² 2s ² 2p ⁶	72
Al ³⁺	13	1s ² 2s ² 2p ⁶	54

- All six ions are isoelectronic (have the same electron configuration).
- The number of protons increases but the number of electrons remains the same.
- The attraction between the nucleus and electrons increases, which causes the ionic radius to decrease.
- The same trend can be seen for the ions P³⁻ to Ca²⁺.

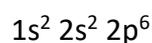
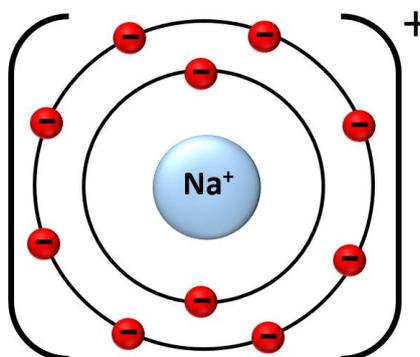


Positive ions (cations)

Sodium atom (160×10^{-12} m)



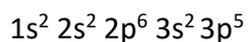
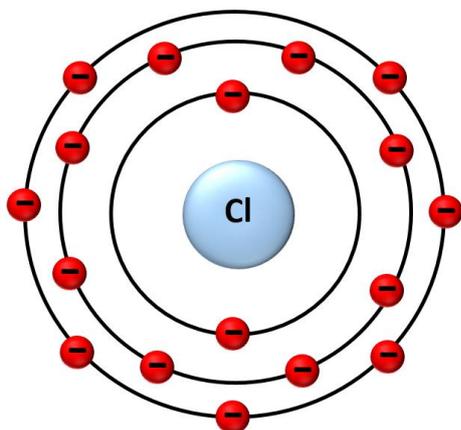
Sodium ion (102×10^{-12} m)



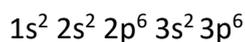
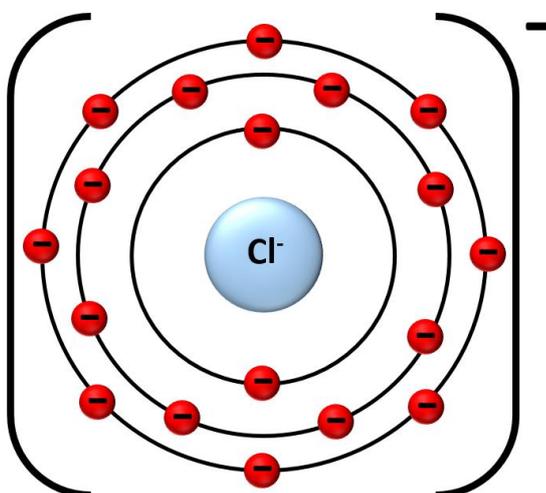
- Positive ions are smaller than their parent atoms.
- Positive ions have fewer occupied energy levels than their parent atoms.
- Positive ions have more protons than electrons which results in an increased attraction between the nucleus and electrons.

Negative ions (anions)

Chlorine atom (100×10^{-12} m)



Chloride ion (181×10^{-12} m)



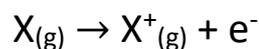
- Negative ions are bigger than their parent atoms.
- Negative ions have more electrons than protons which results in a decreased attraction between the nucleus and electrons.

Exercises:

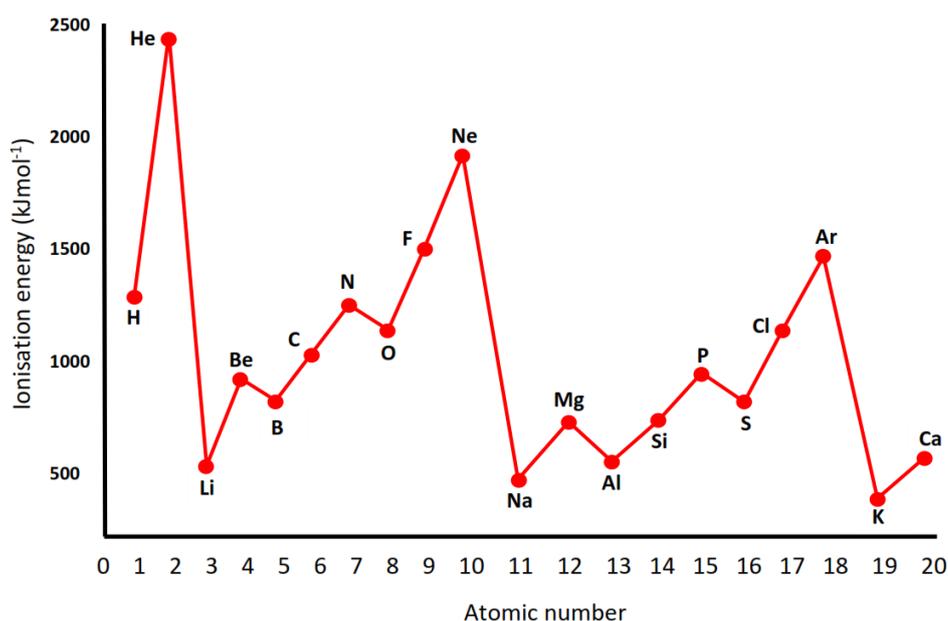
1. State and explain the trend in atomic radius down a group.
2. State and explain the trend in atomic radius across a period.
3. State and explain which is smaller, the lithium atom or the lithium ion (Li^+).
4. State and explain which is bigger, the fluorine atom or the fluoride ion (F^-).
5. Arrange the following in order of increasing atomic radius (smallest first): Cl, Si, Na.
Explain your reasoning.
6. Arrange the following in order of increasing radius: Mg^{2+} , Na^+ , O^{2-} , F^- , N^{3-} , Al^{3+} .
Explain your reasoning.

Ionisation energy

- The first ionisation energy of an element is the energy required to remove one mole of electrons from one mole of gaseous atoms to form one mole of gaseous ions.



- First ionisation energies are a measure of the attraction between the nucleus and the outermost electrons.



Two general trends can be seen from the above graph.

Down a group:

Ionisation energy decreases down a group.

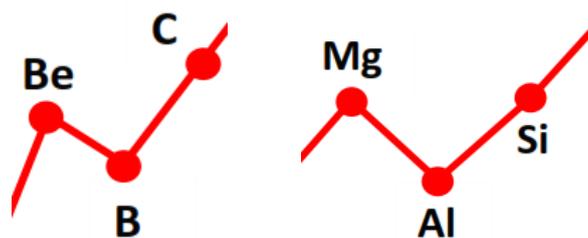
- As the number of occupied energy levels increases, the valence electrons are further from the nucleus which results in a weaker electrostatic attraction between nucleus and valence electrons.
- Increased electron shielding by the inner electrons reduces the electrostatic attraction between nucleus and valence electrons.

Across a period:

Ionisation energy increases across a period (left to right).

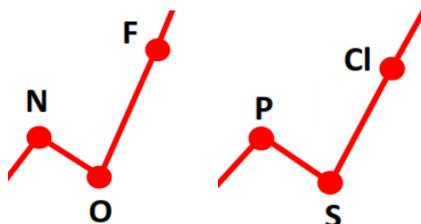
- As nuclear charge increases across a period, the electrostatic attraction between the nucleus and valence electrons increases.
- Atomic radius decreases across a period – valence electrons are closer to the nucleus which results in a stronger attraction between the nucleus and the valence electrons.

Discontinuities in ionisation energy across a period (Be to B and Mg to Al)



- Be has the electronic configuration $1s^2 2s^2$
- B has the electronic configuration $1s^2 2s^2 2p^1$
- Electrons in p orbitals are of higher energy and further from the nucleus than electrons in s orbitals, therefore they require less energy to remove.
- The same explanation can be applied for the drop in ionisation energy from Mg to Al, except that the electronic configurations are $1s^2 2s^2 2p^6 3s^2$ and $1s^2 2s^2 2p^6 3s^2 3p^1$

N – O and P – S



- N has the electronic configuration $1s^2 2s^2 2p^3$
- O has the electronic configuration $1s^2 2s^2 2p^4$
- For oxygen, the electron is removed from a doubly occupied p orbital. An electron in a doubly occupied orbital is repelled by the other electron and requires less energy to remove than an electron in a half-filled orbital.



Exercises:

1. Outline what is meant by *first ionisation energy*.
2. State and explain the trend in ionisation energy across period 3.
3. State and explain the trend in ionisation energy down group 1.
4. Explain the reason for the decrease in ionisation energy between Mg and Al.
5. Explain the reason for the decrease in ionisation energy between P and S.

Electronegativity

- Electronegativity is a measure of the ability of an atom to attract a bonding pair of electrons.
- Electronegativity is measured on a relative scale called the Pauling scale which assigns fluorine a value of 4.0 and francium a value of 0.7
- Electronegativity values of elements can be found in section 8 of the IB data booklet.

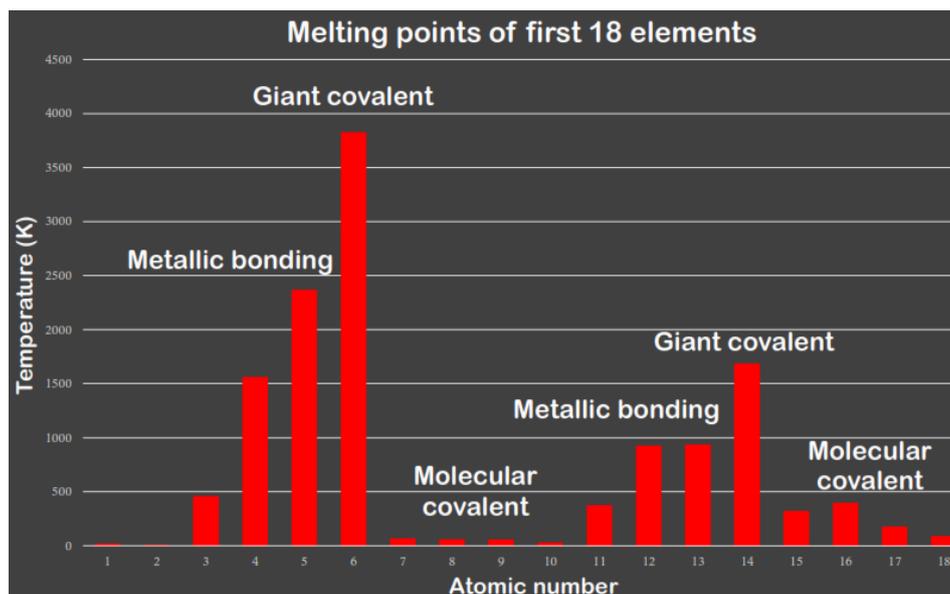
1312 -73		Element																2372																					
H 2.2		First ionization energy (kJ mol^{-1})																He																					
520 -60 900		Electronegativity																801 -27 1086 -122 1402 1314 -141 (+753) 1681 -328 2081																					
Li 1.0		Be 1.6																B 2.0		C 2.6		N 3.0		O 3.4		F 4.0		Ne											
496 -53 738		Na 0.9		Mg 1.3																578 -42 787 -134 1012 -72 1000 -200 (+545) 1251 -349 1520		Al 1.6		Si 1.9		P 2.2		S 2.6		Cl 3.2		Ar							
419 -48 590 -2 633 -18 659 -8 651 -51 653 -64 717		K 0.8		Ca 1.0		Sc 1.4		Ti 1.5		V 1.6		Cr 1.7		Mn 1.6		Fe 1.8		Co 1.9		Ni 1.9		Cu 1.9		Zn 1.6		579 -41 762 -119 944 -78 941 -195 1140 -325 1351		Ga 1.8		Ge 2.0		As 2.2		Se 2.6		Br 3.0		Kr	
403 -47 549 -5 600 -30 640 -41 652 -88 684 -72 702 -53 710 -101 720 -110 804 -54 731 -126 868		Rb 0.8		Sr 1.0		Y 1.2		Zr 1.3		Nb 1.6		Mo 2.2		Tc 2.1		Ru 2.2		Rh 2.3		Pd 2.2		Ag 1.9		Cd 1.7		558 -29 709 -107 831 -101 869 -190 1008 -295 1170		In 1.8		Sn 2.0		Sb 2.0		Te 2.1		I 2.7		Xe 2.6	
376 -46 503 -14 538 -45 659 -1 728 -31 759 -79 756 -14 814 -106 865 -151 864 -205 890 -223 1007		Cs 0.8		Ba 0.9		La 1.1		Hf 1.3		Ta 1.5		W 1.7		Re 1.9		Os 2.2		Ir 2.2		Pt 2.2		Au 2.4		Hg 1.9		589 -36 716 -35 703 -91 812 -183 -270 1037		Tl 1.8		Pb 1.8		Bi 1.9		Po 2.0		At 2.2		Rn	
393 -47 509 -10 499 -34		Fr 0.7		Ra 0.9		Ac 1.1																																	

- Electronegativity increases from left to right across a period for two reasons; the increase in nuclear charge and the decrease in atomic radius.
- Electronegativity decreases down a group because of increasing atomic radius (bonding electrons are further from the attraction of the nucleus).

Exercises:

- Define electronegativity.
- State and explain the trend in electronegativity across a period.
- State and explain the trend in electronegativity down a group.

Melting point



- Melting point depends on the type of bonding (covalent, ionic or metallic) and structure (ionic lattice, molecular covalent, giant covalent, or metallic structures).
- Melting point increases across a period as the strength of the metallic bond increases.
- It reaches a peak at carbon and silicon, both of which have giant covalent structures.
- Melting points then decrease for elements that have simple molecular structures with weak intermolecular forces.

Exercises:

1. What are two factors that determine the melting point of an element?
2. Describe and explain the general trend in melting point in the metals in periods 2 and 3.
3. Explain the reason for the peak in melting point in C (carbon) and Si (silicon).
4. Describe and explain the trend in melting point for the elements after C and Si in periods 2 and 3.

Metallic character

- The metallic character of an element can be defined as how easily an atom loses electrons.
- Metals tend to lose their outer electrons to form positive ions and non-metals tend to gain electrons to form negative ions.
- Metallic character decreases as you move from left to right across a period in the periodic table; increasing nuclear charge and decreasing atomic radius across a period means the outer electrons are held more tightly.
- Metallic character increases down a group in the periodic table as the outer electrons become easier to remove as the atomic radius increases.

Exercises:

1. State the property used to classify elements as metallic.
2. Describe and explain the trend in metallic character across a period and down a group.

Acid – base character of the period 3 oxides

Complete the table below showing the acid-base properties of period 3 oxides:

Formula and state at room temperature	Na ₂ O(s)	MgO(s)	Al ₂ O ₃ (s)	SiO ₂ (s)	P ₄ O ₁₀ (s)/ P ₄ O ₆ (s)	SO ₃ (l)/ SO ₂ (g)	Cl ₂ O ₇ (l)/ Cl ₂ O(g)
Acid–base Character	Basic		Amphoteric	Acidic			

- Metal oxides are basic.
- Aluminium oxide, an ionic oxide with some covalent character is amphoteric (can act as both an acid and a base).
- The remaining oxides have acidic properties.

Exercises:

1. Describe and explain the trend in the bonding of the oxides across period 3.
2. Describe the trend in acid-base character of the period 3 oxides.
3. Write equations for the reactions of Na₂O, MgO, SO₃, P₄O₁₀ and NO₂ with water.

Chemical properties of group 1 and group 17 elements

- The chemical properties of an element are determined by its electron configuration.
- Elements of the same group have similar chemical properties as they have the same number of electrons in their outer shells.

Group 1 – the alkali metals

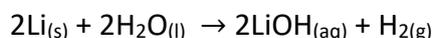
- Alkali metals are very reactive metals – they are shiny when cut, but quickly react with oxygen in air to form a layer of oxide.
- They are stored in oil to prevent the reaction with air.
- They have low densities – Li, Na and K float on water.
- They have low melting points – the melting point decreases down the group as the metallic bond weakens.
- Alkali metals react by losing their one valence electron to form positive ions.

3 Li 6.94
11 Na 22.99
19 K 39.10
37 Rb 85.47
55 Cs 132.91
87 Fr (223)

- Reactivity increases down the group.
- The atomic radius increases down a group as the number of occupied energy levels increases.
- Less energy is required to remove the outer electron (ionisation energy decreases).

Reactions with water

- The group 1 metals react with water to form hydrogen gas and the metal hydroxide.
- The resulting solution is alkaline (pH 12-14)



Exercises:

1. Explain why the alkali metals are stored in oil.

2. Which of the 3 alkali metals have a density of less than 1 g cm^{-3} (which float on water)?

- Describe and explain the trend in melting point down group 1.
- Describe and explain the trend in reactivity down group 1.
- Write a balanced chemical equation, complete with state symbols for the reaction of potassium and water.
- What pH would you expect the resulting solution to be? Explain your answer.

Group 17 – the halogens

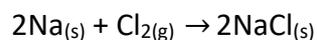
- The halogens (salt formers) are very reactive non-metal elements.
- They are coloured – Cl₂ is a yellow-green gas, Br₂ is a reddish-brown liquid, I₂ is a purple solid.
- They show a change from gases (F₂, Cl₂), to liquid (Br₂) to solid (I₂) as the molar mass increases down the group.
- The halogens are diatomic – they form molecules composed of two atoms bonded together.

9 F 19.00
17 Cl 35.45
35 Br 79.90
53 I 126.90
85 At (210)

- Reactivity decreases down the group.
- The halogens react by gaining one electron to form negative ions.
- As the atomic radius increases down the group (more occupied energy levels) the attraction for the extra electron decreases.
- The increasing number of occupied energy levels also increases the electron shielding between the nucleus and the outer energy level.

Reaction with group 1 metals

- The halogens react with group 1 metals to form ionic compounds. The halogen atom gains one electron from the group 1 metal to form a halide ion (X^-)
- The resulting ions both have the electron configuration of a noble gas.



Exercises:

1. Why are the group 17 elements also known as the halogens?
2. Describe the change in state of the group 17 elements down the group (under standard conditions).
3. Explain the meaning of the term *diatomic*.
4. Describe and explain the reactivity of the halogens down group 17.
5. Write a balanced symbol equation for the reaction of potassium and bromine.