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Structure 1.3 HL

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Exceptions to the trend in first ionisation energy

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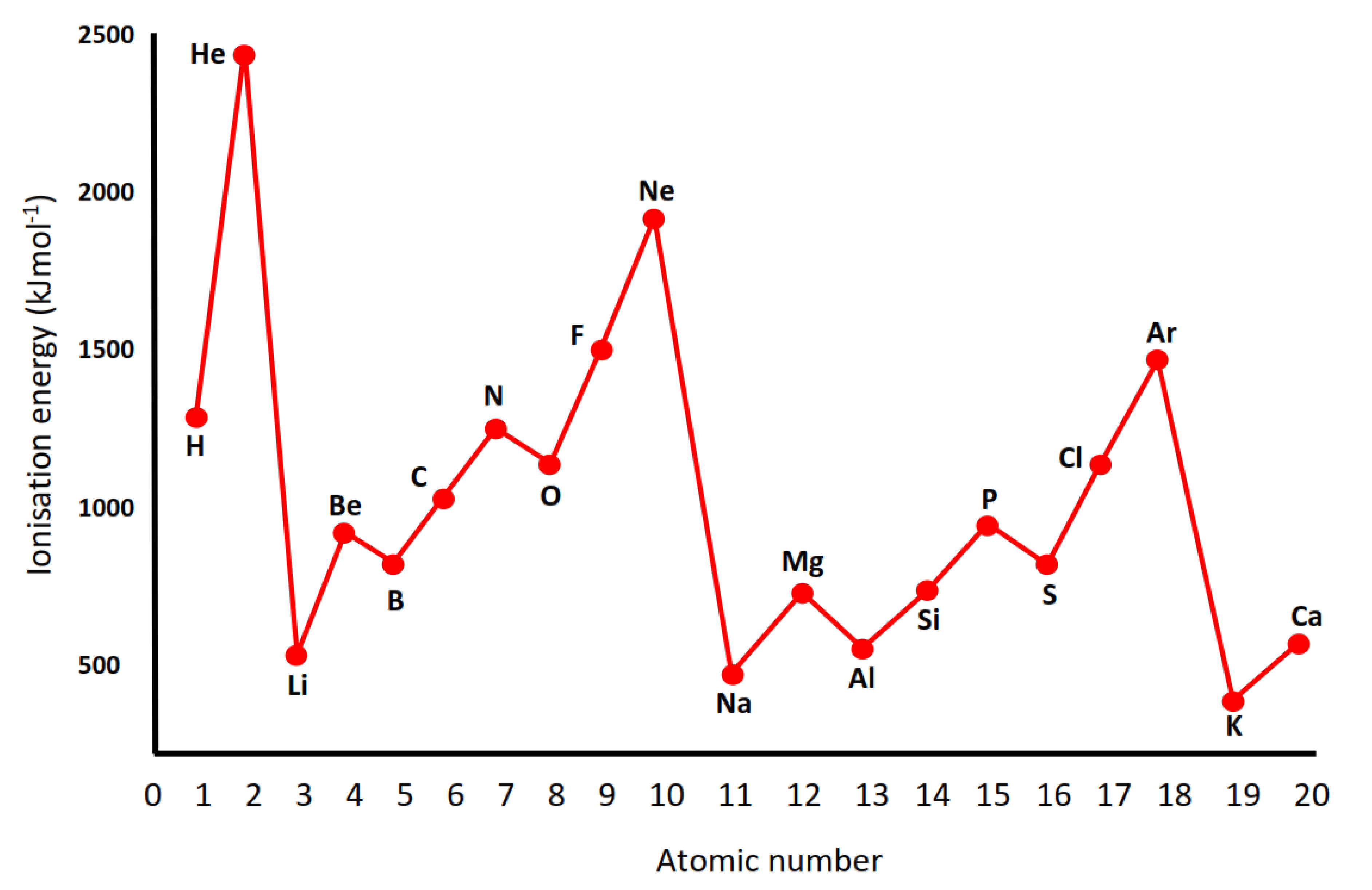
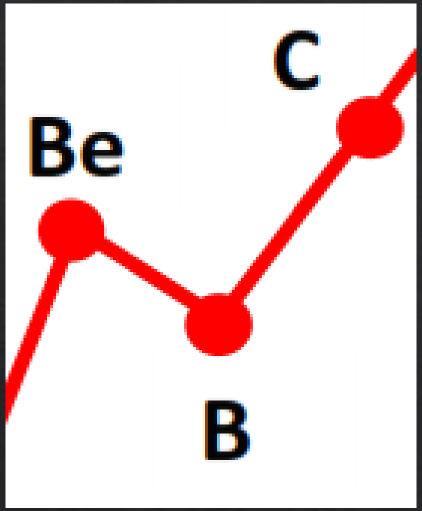
Ionisation energy



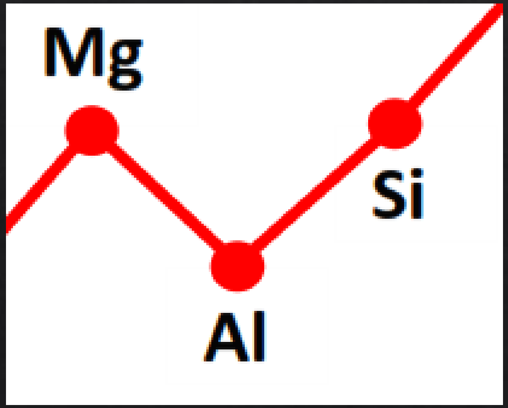
Ionisation energy



Be has the electron configuration $1s^2 2s^2$

B has the electron configuration $1s^2 2s^2 2p^1$

Electrons in p orbitals are slightly higher in energy and further from the nucleus than electrons in s orbitals, therefore they require less energy to remove.



A similar explanation can be applied for the decrease in ionisation energy from Mg to Al, except that the electron configurations are $1s^2 2s^2 2p^6 3s^2$ and $1s^2 2s^2 2p^6 3s^2 3p^1$

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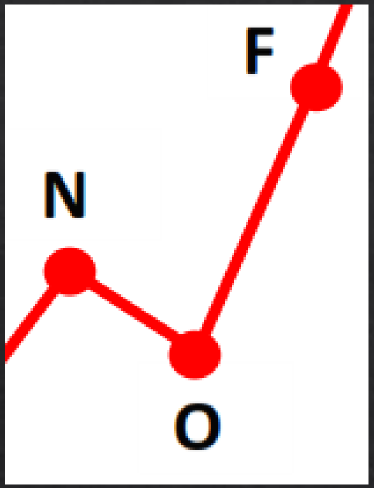
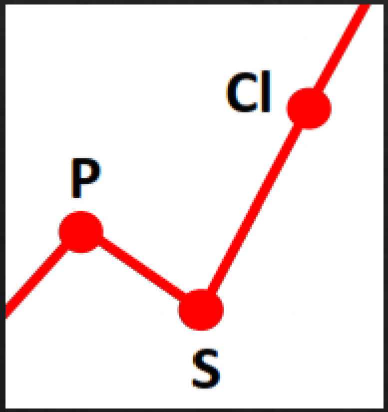
Ionisation energy





N has the electron configuration $1s^2\,2s^2\,2p^3$

O has the electron configuration $1s^2\,2s^2\,2p^4$

In 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.

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Calculating ionisation energy

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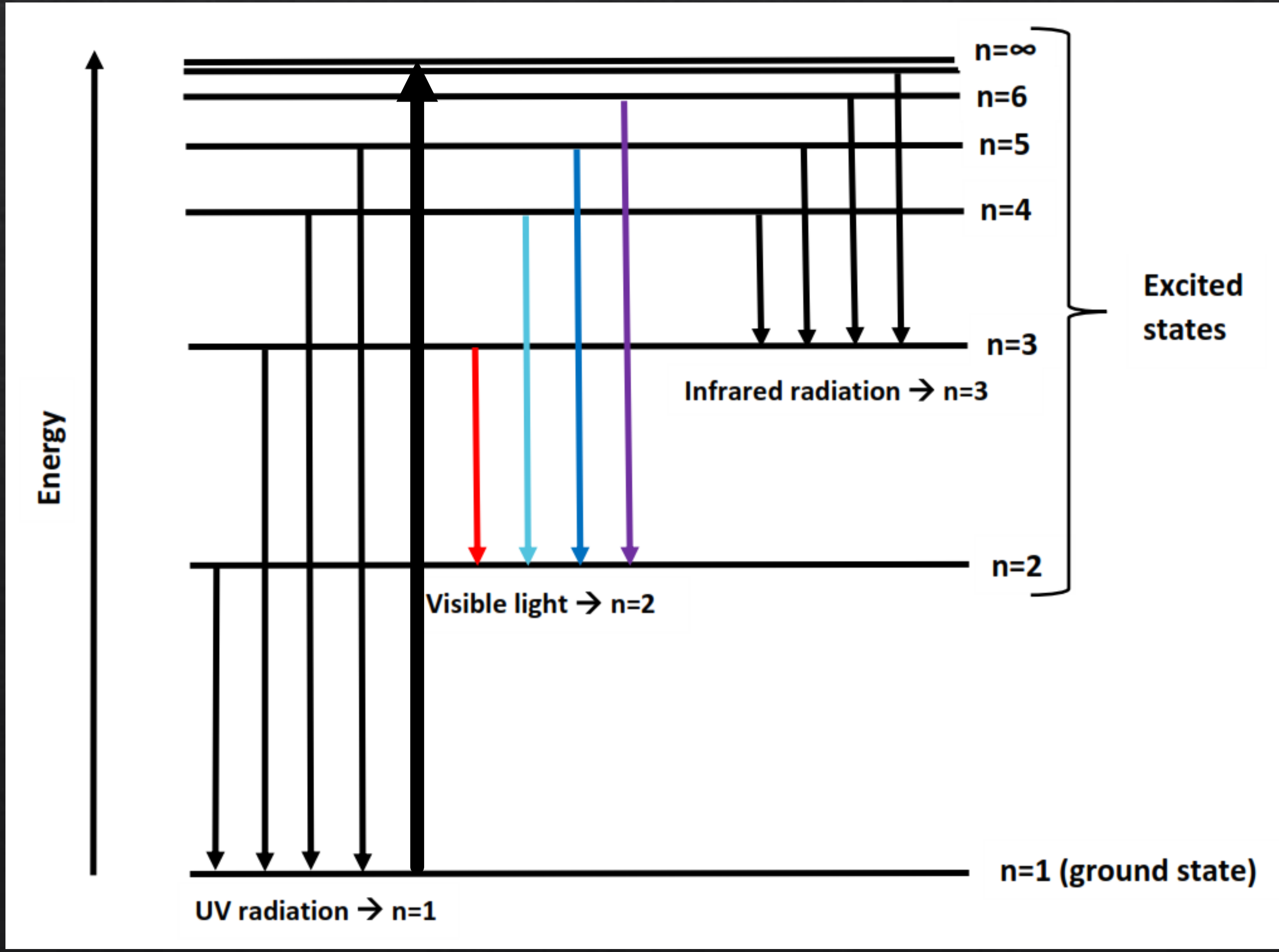
Ionisation energy

The ionisation energy of an atom can be calculated using the frequency (or wavelength) of the convergence limit.



The convergence limit is the frequency at which the spectral lines converge.

The ionisation energy corresponds to the energy required for the electron transition from n=1 to n=∞.

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Ionisation energy

The convergence limit for the hydrogen atom has a wavelength of 9.15×10^{-8} m. Calculate the ionisation energy (in kJ mol^{-1}).

$$E = h\nu$$

$$c = \nu\lambda$$

E – energy (J)
h – Planck's constant (6.63×10^{-34} J·s)
ν – frequency (s^{-1})
λ – wavelength (m)
c – speed of light (3.00×10^{8} m s^{-1})

Ionisation energy

The convergence limit for the hydrogen atom has a wavelength of 9.15×10^{-8} m. Calculate the ionisation energy (in kJ mol^{-1}).

$$c = \nu\lambda$$

$$3.00 \times 10^{8} = \nu \times 9.15 \times 10^{-8}$$

$$\nu = 3.00 \times 10^{8} / 9.15 \times 10^{-8}$$

$$\nu = 3.28 \times 10^{15}\ s^{-1}$$

Ionisation energy

$$E = h\nu$$

$$E = 6.63 \times 10^{-34} \times 3.28 \times 10^{15}\ \text{s}^{-1}$$

$$E = 2.17 \times 10^{-18}\ \text{J/atom}$$

For one mol of H atoms:

$$E = 2.17 \times 10^{-18} \times 6.02 \times 10^{23}$$

$$E = 1306340\ \text{J mol}^{-1} = 1310\ \text{kJ mol}^{-1}$$

Ionisation energy

The convergence limit for the sodium atom has a frequency of 1.24×10^{15} s^{-1}. Calculate the ionisation energy (in kJ mol^{-1}).

$$E = hv$$

$$E = 6.63 \times 10^{-34} \times 1.24 \times 10^{15}$$

$$E = 8.22 \times 10^{-19} \text{ J/atom}$$

For one mol of Na atoms:

$$E = 8.22 \times 10^{-19} \times 6.02 \times 10^{23}$$

$$E = 494844 \text{ J mol}^{-1} = 495 \text{ kJ mol}^{-1}$$

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Successive ionisation energies

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Successive ionisation energies

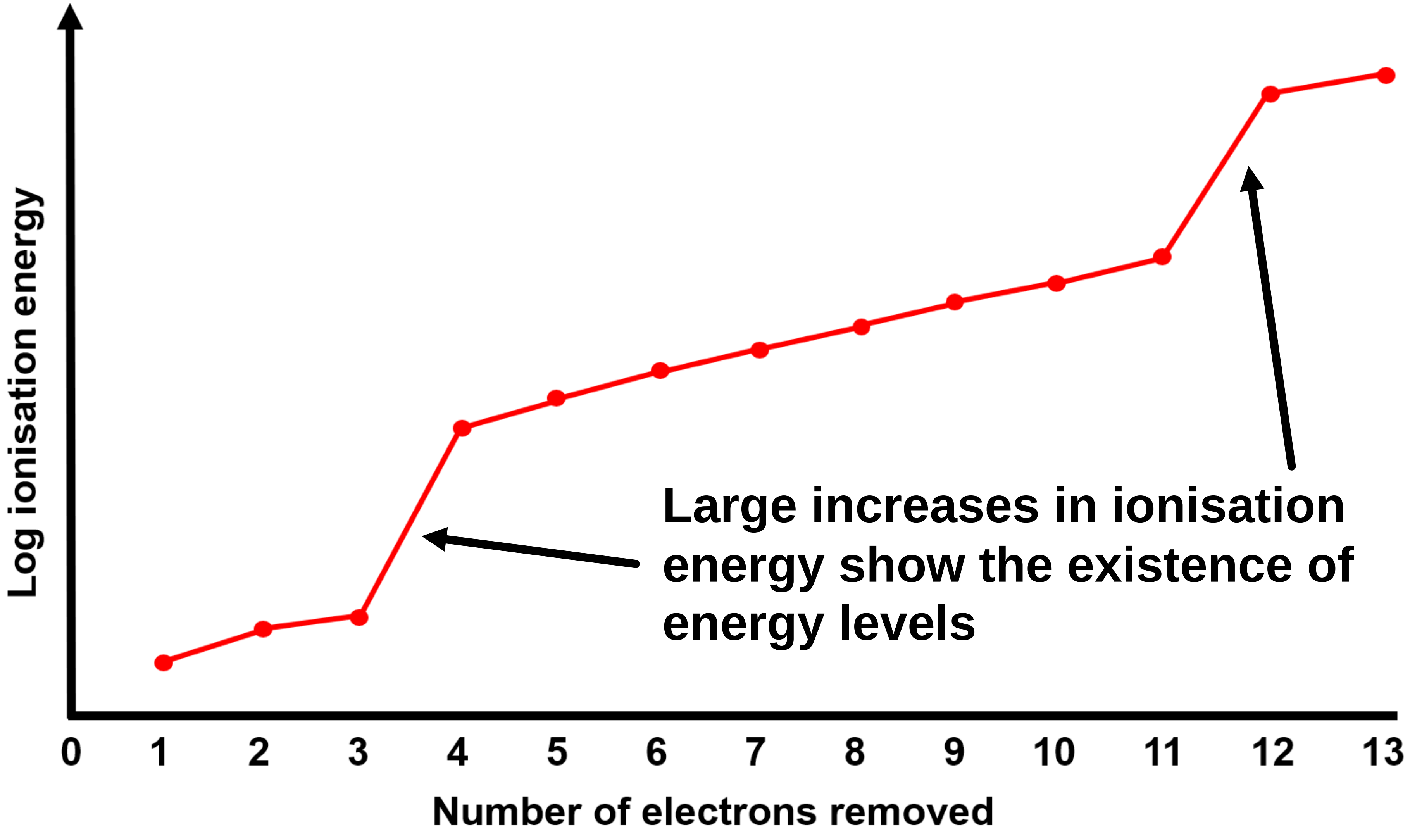
Ionisation	Equation	Electron configuration of ion	I.E. kJ mol^{-1}
1st	$Al_{(g)} \rightarrow Al^{+}_{(g)} + e^{-}$	$1s^2\ 2s^2\ 2p^6\ 3s^2$	578
2nd	$Al^{+}(g) \rightarrow Al^{2+}(g) + e^{-}$	$1s^2\ 2s^2\ 2p^6\ 3s^1$	1817
3rd	$Al^{2+}(g) \rightarrow Al^{3+}(g) + e^{-}$	$1s^2\ 2s^2\ 2p^6$	2745
4th	$Al^{3+}(g) \rightarrow Al^{4+}(g) + e^{-}$	$1s^2\ 2s^2\ 2p^5$	11575
5th	$Al^{4+}(g) \rightarrow Al^{5+}(g) + e^{-}$	$1s^2\ 2s^2\ 2p^4$	14380
6th	$Al^{5+}(g) \rightarrow Al^{6+}(g) + e^{-}$	$1s^2\ 2s^2\ 2p^3$	18376
7th	$Al^{6+}(g) \rightarrow Al^{7+}(g) + e^{-}$	$1s^2\ 2s^2\ 2p^2$	23293

Successive ionisation energies

Ionisation	Equation	Electron configuration of ion	I.E. kJ mol^{-1}
8th	$Al^{7+}(g) \rightarrow Al^{8+}(g) + e^-$	$1s^2\ 2s^2\ 2p^1$	27465
9th	$Al^{8+}(g) \rightarrow Al^{9+}(g) + e^-$	$1s^2\ 2s^2$	31853
10th	$Al^{9+}(g) \rightarrow Al^{10+}(g) + e^-$	$1s^2\ 2s^1$	38473
11th	$Al^{10+}(g) \rightarrow Al^{11+}(g) + e^-$	$1s^2$	42647
12th	$Al^{11+}(g) \rightarrow Al^{12+}(g) + e^-$	$1s^1$	201266
13th	$Al^{12+}(g) \rightarrow Al^{13+}(g) + e^-$		222316

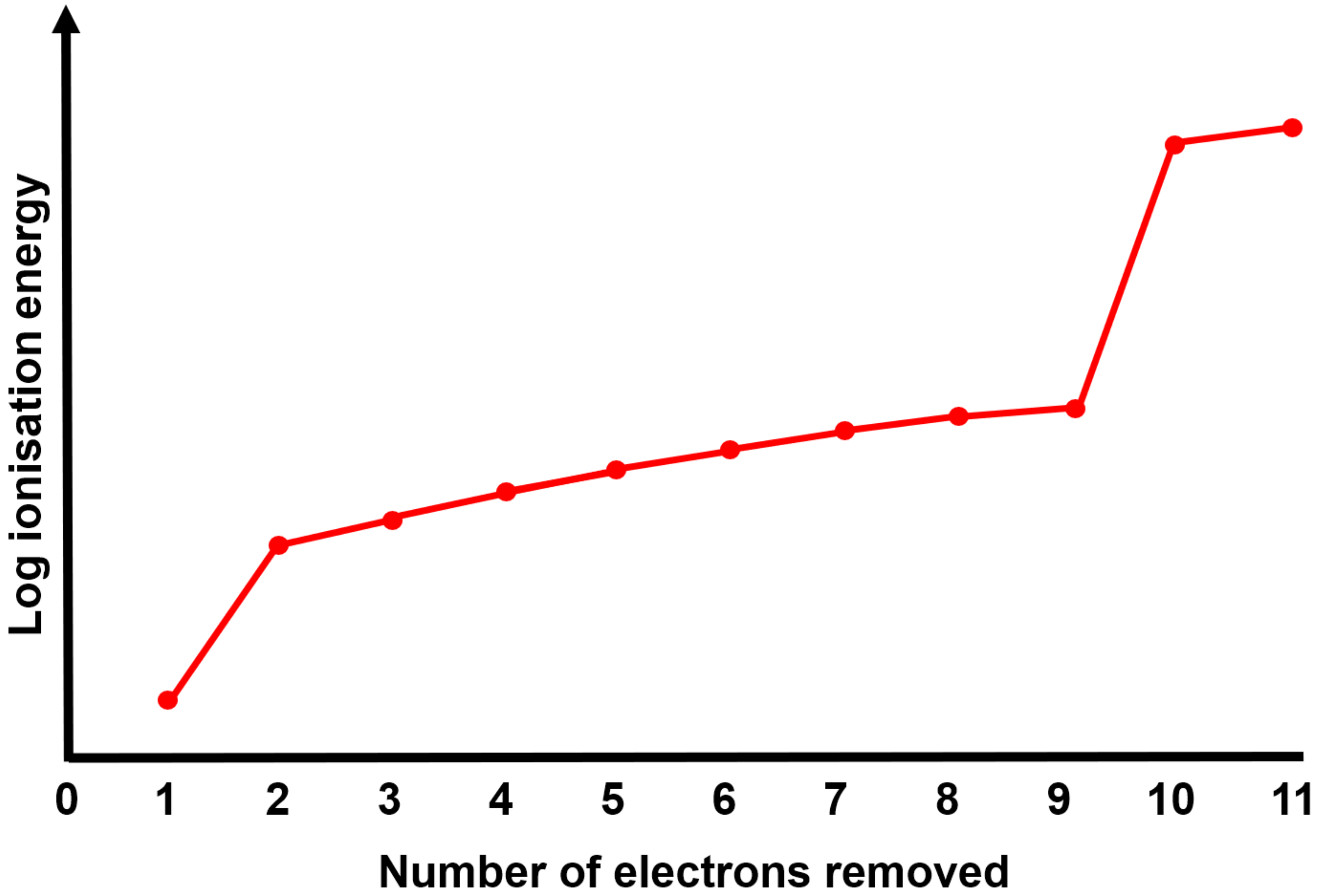
Successive ionisation energies

Successive ionisation energies of aluminium



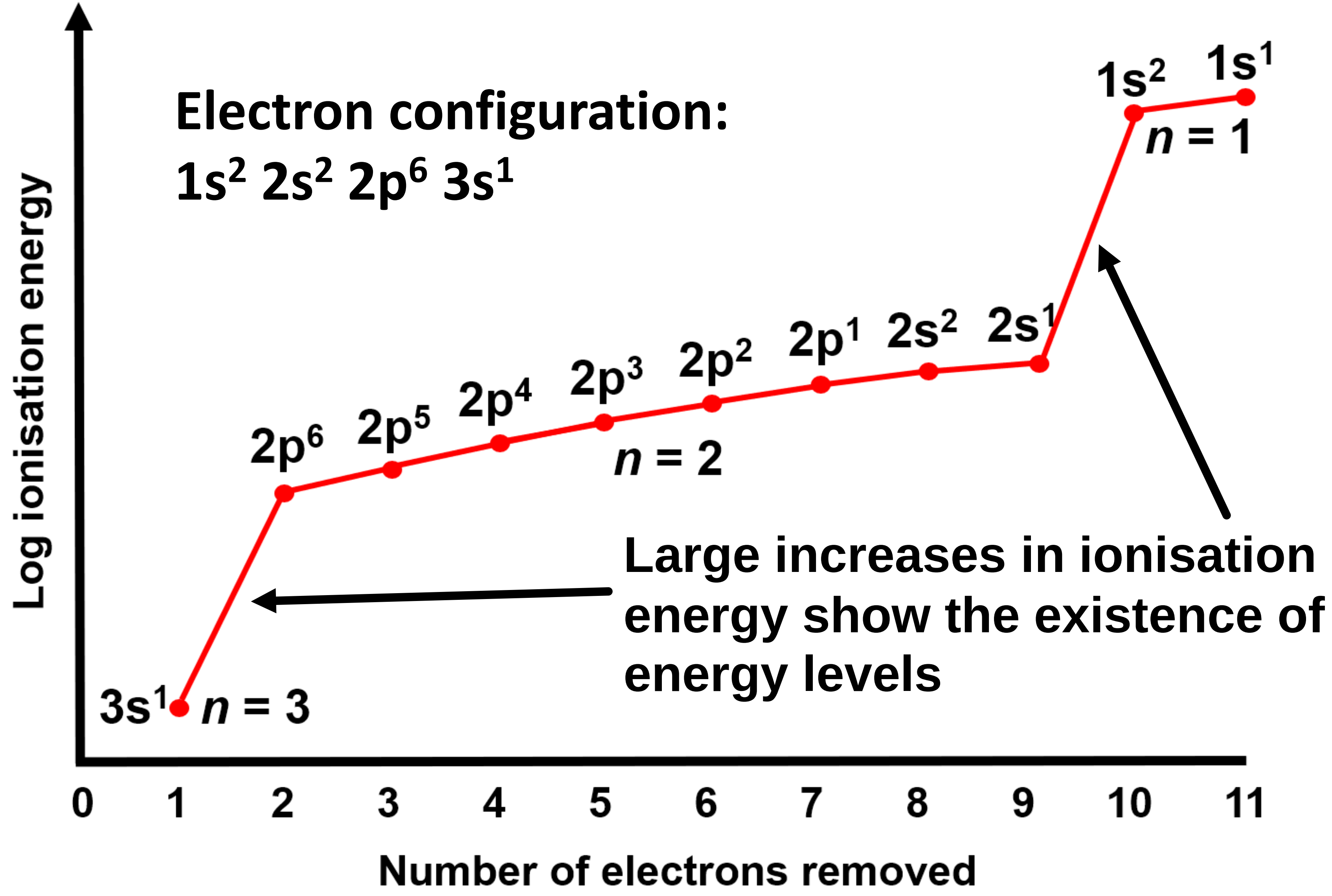
Successive ionisation energies

Successive ionisation energies of sodium



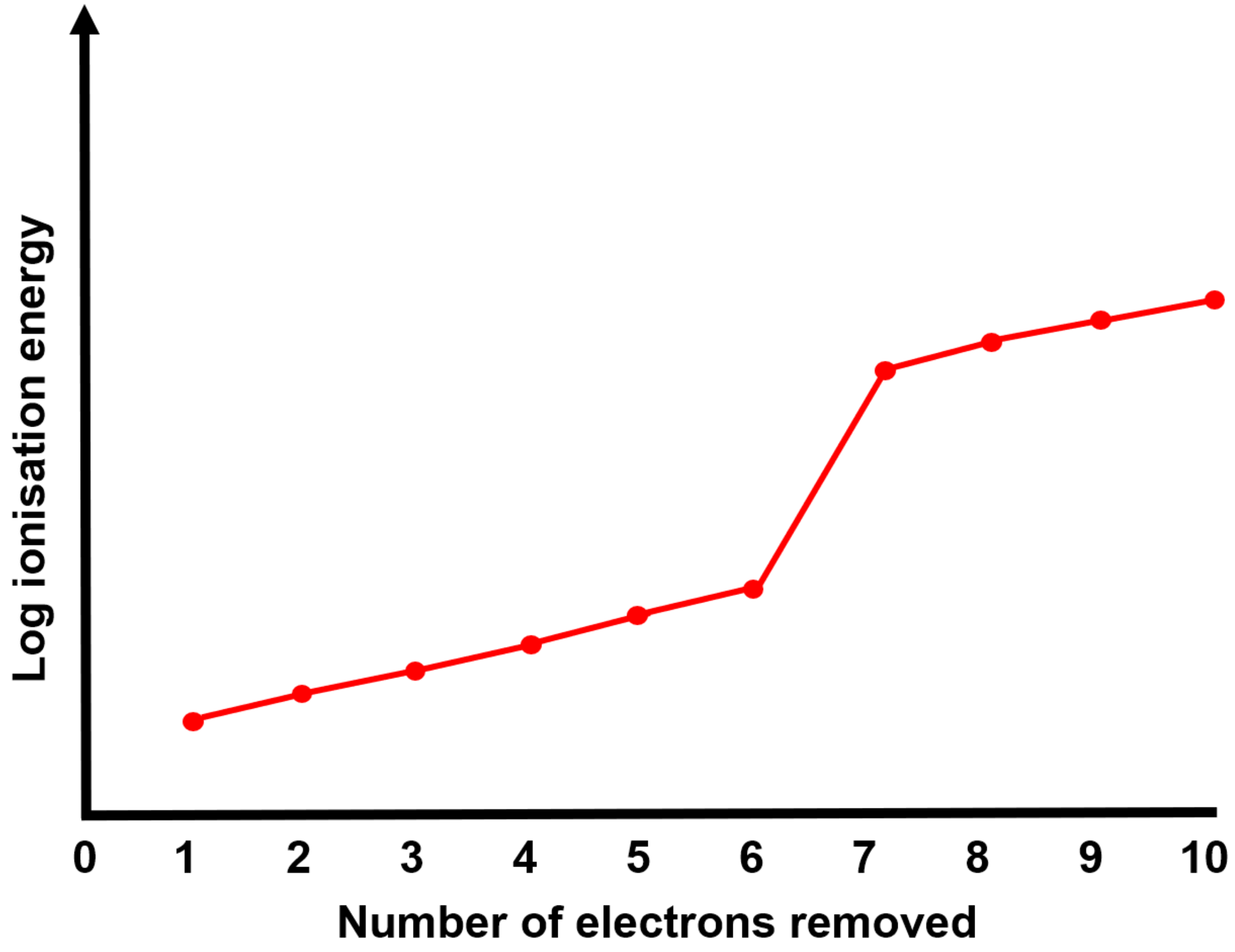
Successive ionisation energies

Successive ionisation energies of sodium



Successive ionisation energies

The first ten ionisation energies of an unknown element are shown on the graph. Determine to which group the element belongs.



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Successive ionisation energies

Values for the successive ionisation energies of the elements Na to S are shown in the table below.

Element	Group number	IE_1 kJ mol^{-1}	IE_2 kJ mol^{-1}	IE_3 kJ mol^{-1}	IE_4 kJ mol^{-1}	IE_5 kJ mol^{-1}	IE_6 kJ mol^{-1}	IE_7 kJ mol^{-1}
Na	1	496	4562	6912	9543	13353	16610	20114
Mg	2	738	1451	7733	10540	13630	17995	21703
Al	13	578	1817	2745	11575	14380	18376	23293
Si	14	787	1577	3231	4356	16091	19784	23783
P	15	1012	1903	2912	4956	6273	22233	25397
S	16	1000	2251	3361	4564	7013	8495	27106

Successive ionisation energies

For group 1 elements, the large increase is between the first and second ionisation energies.

For group 2 elements, the large increase is between the second and third ionisation energies.

For group 13 elements, the large increase is between the third and fourth ionisation energies.

For group 14 elements, the large increase is between the fourth and fifth ionisation energies.

For group 15 elements, the large increase is between the fifth and sixth ionisation energies (and so on).