1 Aluminium is a Group 13 element that forms a number of compounds.

Table 1.1

atom or ion	number of protons	number of neutrons
^{27}Al	13	14
$^{28}Al^{3+}$	13	15

(a) (i) Complete Table 1.1 to show the number of particles in each atom or ion. [2]

(ii) Complete Figure 1.1 to show the electronic configuration of an aluminium atom.

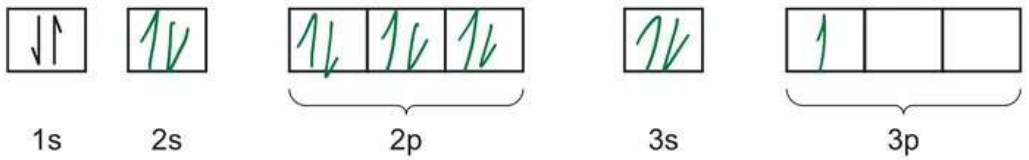


Figure 1.1

[1]

(b) Deduce the formula of aluminium nitrate(V).

$Al(NO_3)_3$ [1]

(c) $AlCl_3$ dimerises to form Al_2Cl_6. Al_2Cl_6 is shown in Figure 1.2.

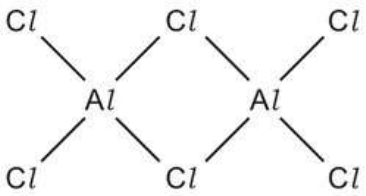


Figure 1.2

Describe how coordinate (dative covalent) bonds form when two $AlCl_3$ molecules combine to form Al_2Cl_6.

One Cl atom in each $AlCl_3$ molecule donates a pair of electrons to empty orbital of Al of the other molecule [1]

(d) Aluminium forms the $AlCl_4^-$ ion. The dot-and-cross diagram for $AlCl_4^-$ in Figure 1.3 shows the arrangement of outer electrons.

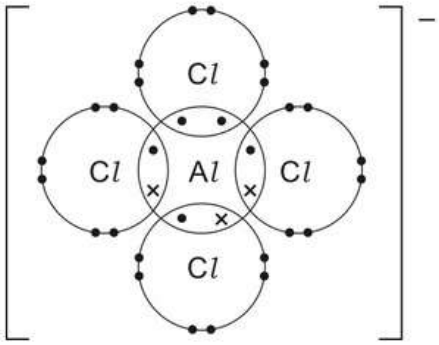


Figure 1.3

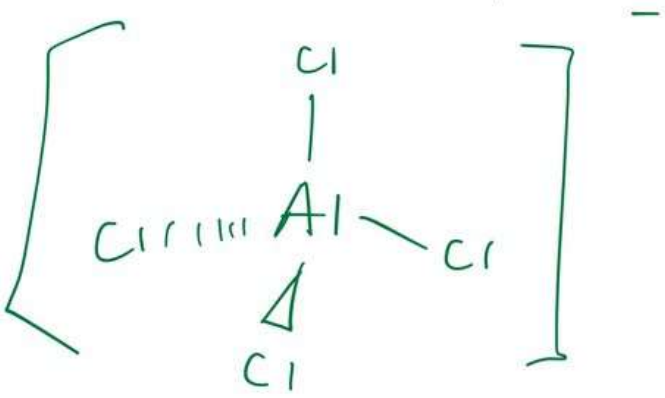
(i) Use Figure 1.3 and VSEPR theory to name the shape of the $AlCl_4^-$ ion and to predict the Cl–Al–Cl bond angle.

name of shape Tetrahedral

bond angle 109.5°

[2]

(ii) Draw the three-dimensional shape of the $AlCl_4^-$ ion.



[1]

[Total: 8]

2 **(a)** **(i)** Nitrogen, N_2, contains sigma (σ) and pi (π) bonds.

Describe how a pi (π) bond is formed.

Sideway overlap of p orbitals of the 2 N atoms

[2]

(ii) Explain the lack of reactivity of nitrogen.

- triple N≡N bond
- Non-polar

[2]

(b) Nitrogen is used to manufacture ammonia, NH_3, in the Haber process. An iron catalyst is used.

(i) Complete the reaction pathway diagram in Figure 2.1 to show the effect of adding an iron catalyst to the reaction of nitrogen and hydrogen.

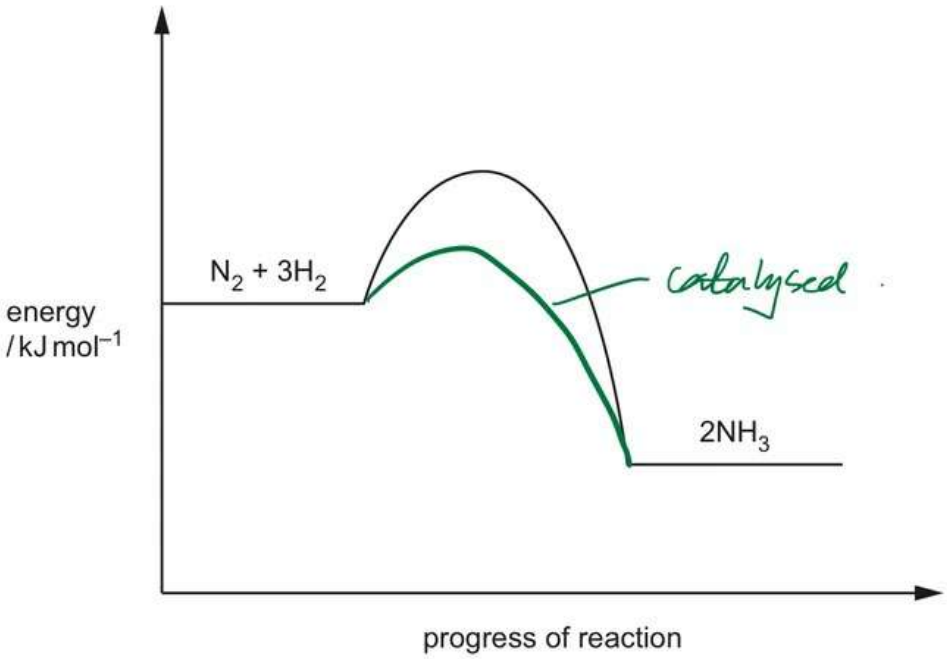


Figure 2.1

[1]

(ii) State the temperature and pressure used in the Haber process.

temperature = 450°C

pressure = low atm

[2]

(c) The equation for the Haber process is shown.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Three separate experiments are carried out using mixtures of $N_2(g)$ and $H_2(g)$ to find the amount of $NH_3(g)$ produced at equilibria under different conditions.

(i) In experiment 1, 3.55 mol of $N_2(g)$ and 8.60 mol of $H_2(g)$ are mixed and left to reach equilibrium.

At equilibrium, 3.24 mol of NH_3 is present.

Complete Table 2.1.

Table 2.1

	$N_2(g)$	$H_2(g)$	$NH_3(g)$
initial amount / mol	3.55	8.60	0
change in amount / mol	(-) 1.62	(-) 4.86	3.24
amount at equilibrium / mol	1.93	3.74	3.24

[3]

(ii) In experiment 2, under different conditions $N_2(g)$ and $H_2(g)$ are mixed and left to reach equilibrium.

Table 2.2 shows the amount, in mol, at equilibrium of $N_2(g)$, $H_2(g)$ and $NH_3(g)$.

Table 2.2

	$N_2(g)$	$H_2(g)$	$NH_3(g)$
amount at equilibrium / mol	0.874	1.340	0.347

Calculate the mole fraction of $NH_3(g)$ in the equilibrium mixture in experiment 2.

$$\frac{0.347}{0.874 + 1.340 + 0.347}$$

mole fraction of $NH_3(g)$ = ... 0.135 ..... [2]

(iii) The expression for the equilibrium constant, K_p, for the Haber process is shown.

$$K_p = \frac{p(NH_3)^2}{p(N_2) \times p(H_2)^3}$$

Describe what is meant by partial pressure.

Pressure exerted by a specific gas in a mixture of gases

..... [1]

(iv) In experiment 3, the mixture at equilibrium contains the following partial pressures of $N_2(g)$ and $H_2(g)$.

$p(N_2) = 1590\,kPa$
$p(H_2) = 1750\,kPa$

For experiment 3, the equilibrium constant, K_p, is $8.49 \times 10^{-7}\,kPa^{-2}$.

Calculate the partial pressure, in kPa, of $NH_3(g)$ at equilibrium.

$$8.49 \times 10^{-7} = \frac{P(NH_3)^2}{1590 \times 1750^3}$$

$$P(NH_3) = \sqrt{8.49 \times 10^{-7} \times 1590 \times 1750^3}$$

$p(NH_3)$ = 2690 kPa [3]

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(d) Explain the effect of increasing temperature on rate of reaction.

Higher kinetic energy of molecules.
More molecules with E ≥ Ea.
Higher frequency of successful collision.
Rate increases. [3]

(e) Figure 2.2 shows the Boltzmann distribution for a sample of X(g) at temperature T_1.

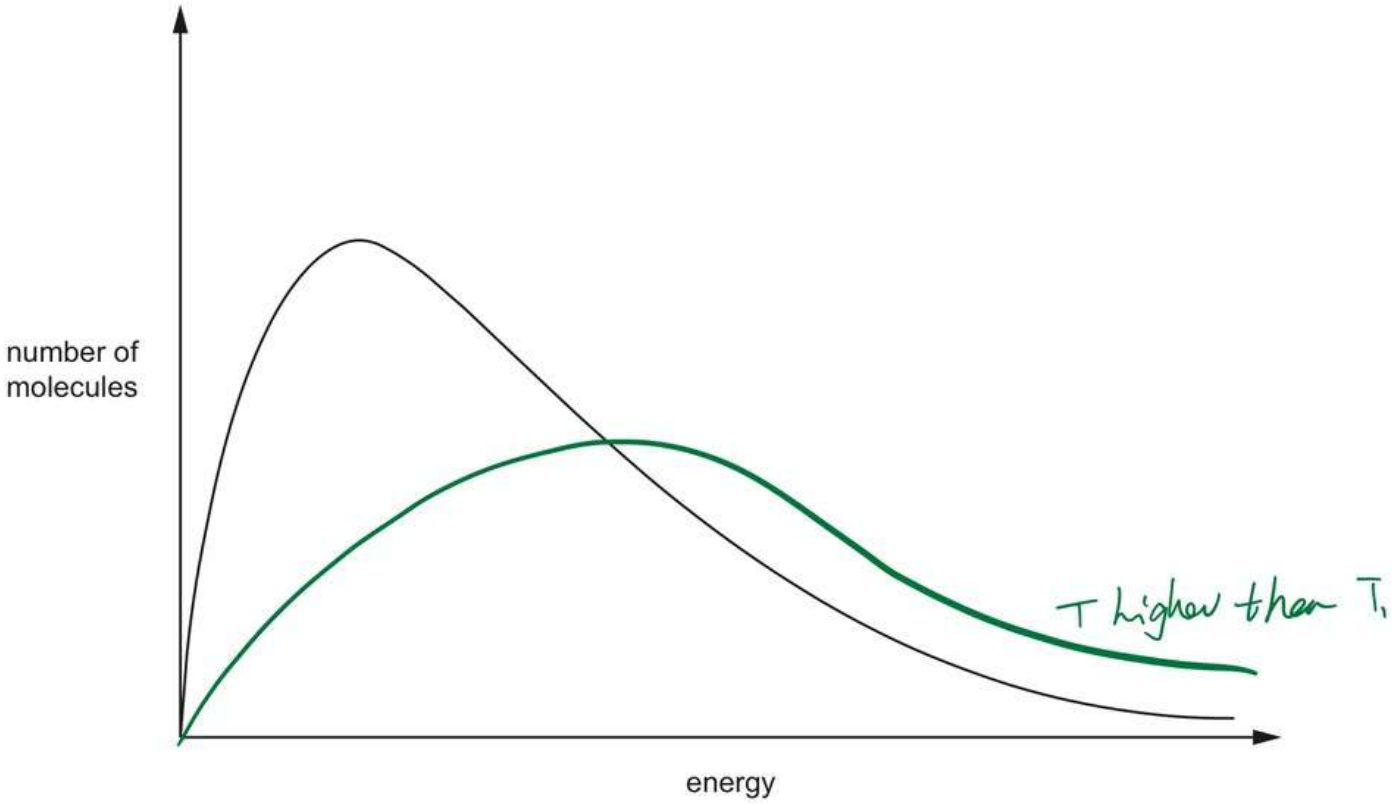


Figure 2.2

Sketch a curve on Figure 2.2 to show the Boltzmann distribution for the sample of X(g) at a temperature higher than T_1. [2]

[Total: 21]

3 **(a)** **(i)** State the trend in atomic radius of the elements across Period 3.

Decreases [1]

(ii) State the formula of the oxide formed when sodium reacts with oxygen.

Na_2O [1]

(iii) Write an equation for the reaction of MgO with water.

$MgO + H_2O \rightarrow Mg(OH)_2$ [1]

(b) Table 3.1 shows some of the physical properties of Period 3 chlorides.

Table 3.1

	melting point /°C	boiling point /°C	type of bonding	type of structure
NaCl	801	1413	I	G
$SiCl_4$	–69	58	C	S

(i) Complete Table 3.1 using the abbreviations shown.

M = metallic
C = covalent
I = ionic
S = simple
G = giant

[2]

(ii) State the formula of the phosphorus-containing product formed when PCl_5 reacts with an excess of water. Suggest the pH of the resulting solution.

formula = H_3PO_4

pH of solution = 1 (1–3)

[2]

(c) **(i)** Describe what is observed when white solid strontium nitrate decomposes on heating.

Red-brown gas [1]

(ii) State the trend in solubility down the Group 2 hydroxides.

Increases [1]

[Total: 9]

4 **(a)** Alcohol **S** has the structural formula $CH_3C(OH)(CH_3)CH_2CH_3$.

Classify alcohol **S**.

Tertiary (3°) ..... [1]

(b) Figure 4.1 shows compound **T**.

T

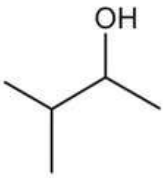


Figure 4.1

Tests are carried out on **T** using different reagents.

Complete Table 4.1 to show the observations of each test on **T**. If no reaction occurs, write 'no reaction' in the relevant box.

Table 4.1

reagent	observations
Na	effervescence / fizzing.
acidified $K_2Cr_2O_7$	orange to green.
alkaline I_2(aq)	yellow ppt.

[3]

(c) Compound **W** is an aliphatic primary alcohol.

W is oxidised by acidified $KMnO_4$ when heated under reflux. Figure 4.2 shows the infrared spectrum of the resulting product.

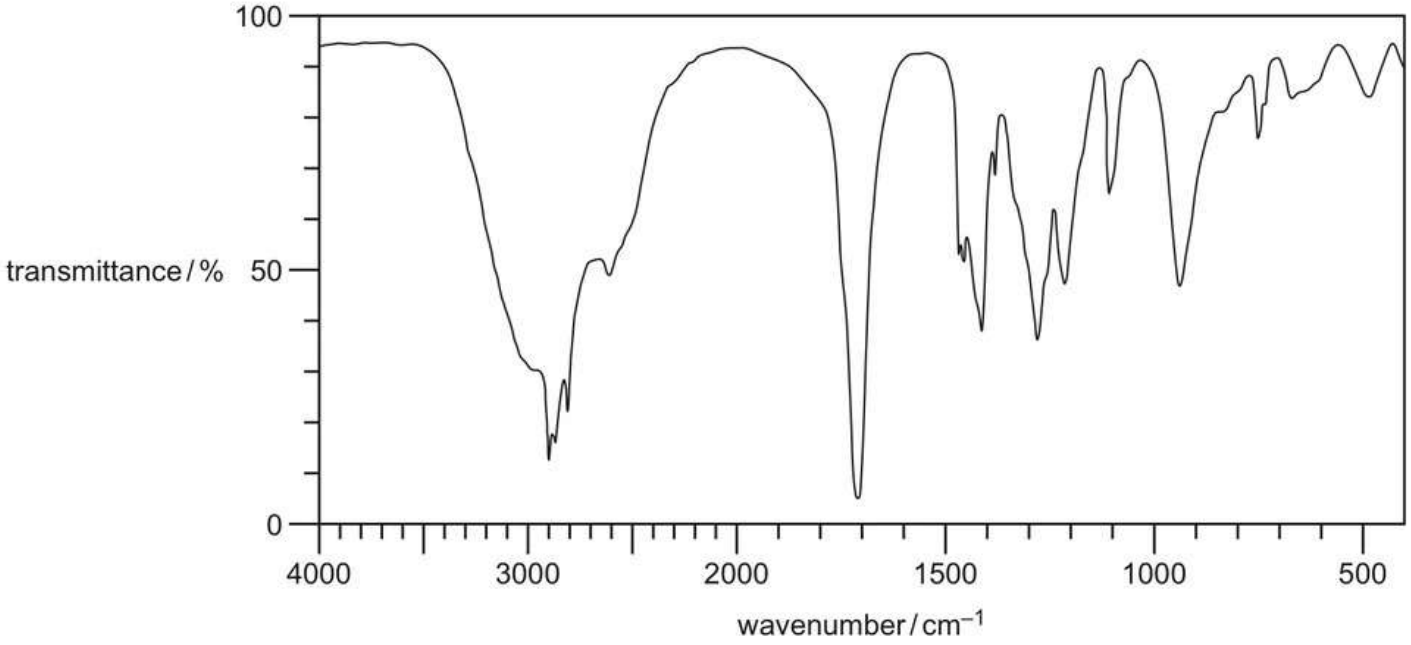


Figure 4.2

Table 4.2

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

The infrared spectrum in Figure 4.2 confirms that **W** is a primary alcohol.

Use Figure 4.2 to identify **two** absorbances that confirm **W** is a primary alcohol. State the bond and functional group containing the bond for each absorbance.

- Peak at 1670 - 1740 indicates C=O of carboxyl or carbonyl
- Peak at 2500 - 3000 indicates O-H of carboxyl

Only primary alcohol can be oxidised to carboxylic acid at the conditions. [2]

(d) Butane is converted to pentanenitrile via a two-step synthesis, as shown in Figure 4.3.

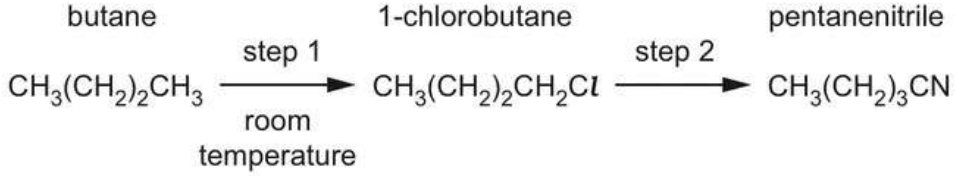


Figure 4.3

(i) Suggest the reagent and conditions for each step in Figure 4.3.

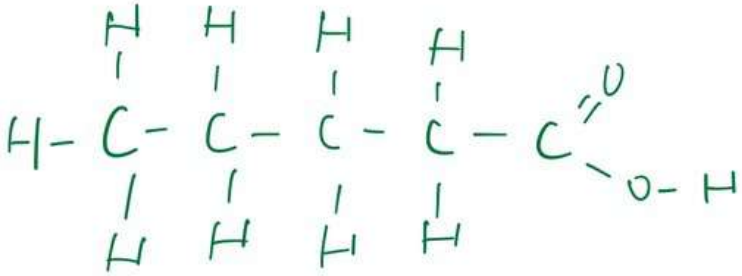
step 1 $Cl_2(g)$ UV light

step 2 KCN in ethanol heat (under reflux)

[2]

(ii) Pentanenitrile reacts with dilute acid.

Draw the displayed formula of the organic product made in this reaction.



[1]

[Total: 9]

5 Long-chain alkanes from crude oil can be cracked to make alkenes.

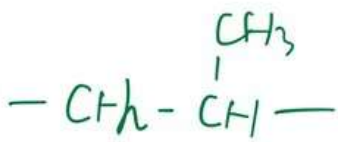
(a) State the conditions used for the cracking of alkanes.

Al$_2$O$_3$ heat.

[1]

(b) Propene is an alkene that is made by cracking. Alkenes are used in addition polymerisation.

(i) Draw **one** repeat unit of the addition polymer formed from propene.



[1]

(ii) The disposal of poly(alkenes) by combustion produces harmful products.

State **one** other disadvantage associated with the disposal of poly(alkenes) such as poly(propene).

Non-biodegradable. Hence waste of landfills [1]

(iii) Aqueous bromine is used to test for the presence of the C=C bond in propene.

State what is observed when aqueous bromine is mixed with propene.

Decolorised. [1]

(c) But-1-ene and but-2-ene are structural isomers.

State the type of structural isomerism shown by but-1-ene and but-2-ene.

Positional [1]

(d) But-2-ene reacts with HBr(g). The HBr acts as an electrophile in the reaction.

(i) State how HBr acts as an electrophile in terms of electron transfer.

H has partial positive charge, accept lone pair from ..... [1]

(ii) Complete Figure 5.1 to show the mechanism for the reaction of but-2-ene with HBr. C=C of alkene

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

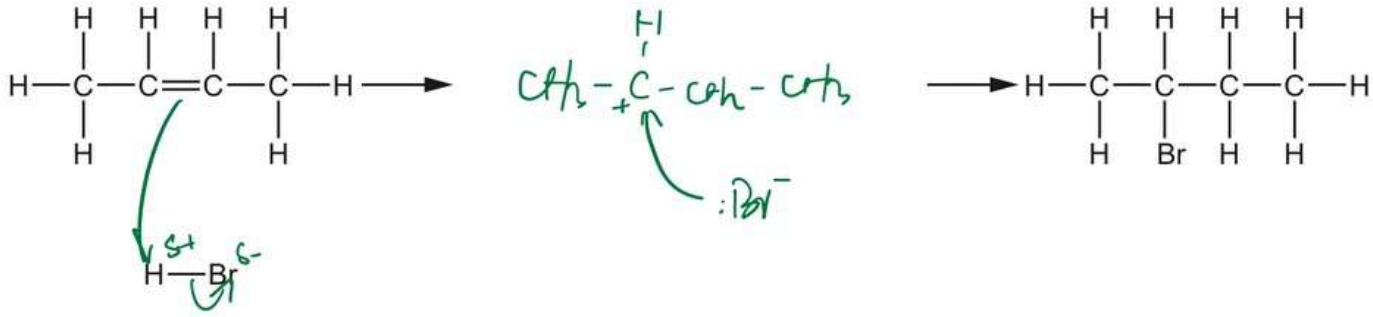


Figure 5.1

[4]

(e) But-1-ene and bromine, Br_2, react in an electrophilic addition reaction to make product **P**.

Give the systematic name for **P**.

1,2 - dibromobutane ..... [1]

(f) Figure 5.2 shows the structure of methylpropene.

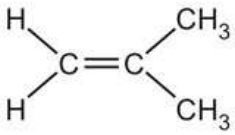
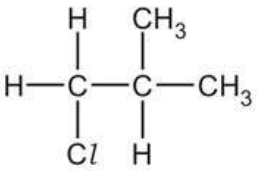


Figure 5.2

Methylpropene reacts with HC*l* to produce products **Q** and **R**.

Q



R

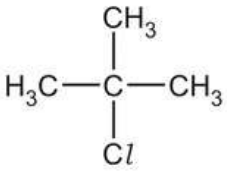


Figure 5.3

Explain why **R** is the major product in this reaction.

R is produced via a 3° carbocation, which is more stable due to inductive effect of the adjacent alkyl groups, reducing charge on C+. [2]

[Total: 13]

Important values, constants and standards

molar gas constant	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,C\,mol^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23}\,mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,C$
molar volume of gas	$V_m = 22.4\,dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,kJ\,kg^{-1}\,K^{-1}$ ($4.18\,J\,g^{-1}\,K^{-1}$)

The Periodic Table of Elements

Group																	
1	2											13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	5	6	7	8	9	10	11	12	13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key

atomic number
atomic symbol
name
relative atomic mass

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –