

CHAPTER 1

Practice Exercises

1.1 $x = 12.3 \text{ g Cd}$

1.3 $2.24845 \times 12 \text{ u} = 26.9814 \text{ u}$

Review Questions

- 1.1 An atom is a chemical species comprising a central positively-charged nucleus surrounded by one or more negatively-charged electrons.

A covalent bond is a chemical bond which involves the sharing of electrons between neighbouring atoms.

An ion is a charged chemical species; the charge may be either positive or negative.

A cation is a positively-charged chemical species.

An anion is a negatively-charged chemical species.

An element is a chemical species comprised of only a single type of atom.

A compound is a chemical species comprised of two or more elements in a definite and unchanging proportion.

A reactant is a chemical species which is transformed in a chemical reaction

A chemical reaction is a process whereby one or more chemical species is/are transformed into different chemical species. This generally involves the making and/or breaking of chemical bonds.

A product is the species formed in a chemical reaction.

- 1.3 The Law of Conservation of Mass requires that atoms are indestructible. Elements combine in definite ratios as atoms. This guarantees that elements combine in definite mass ratios, assuming the atoms are indestructible.
- 1.5 Conservation of mass derives from the postulate that atoms are not destroyed in chemical reactions. The Law of Definite Proportions derives from the notion that compounds are always composed of the same types and numbers of atoms of the various elements in the compound.
- 1.7 Refer to table 1.1.
- 1.9 Nucleon is a name for any of the constituent particles of an atomic nucleus. We have studied both protons and neutrons.
- 1.11 The isotopes of an element have identical atomic numbers (number of protons) but differing number of neutrons, and thus differing masses.

- 1.13 (a) $^{131}_{53}\text{I}$
(b) $^{90}_{38}\text{Sr}$
(c) $^{137}_{55}\text{Cs}$
(d) $^{18}_9\text{F}$
- 1.15 (a) potassium
(b) zinc
(c) silicon
(d) tin
(e) manganese
(f) magnesium
(g) nickel
(h) aluminium
(i) carbon
(j) nitrogen
- 1.17 A period in the periodic table is a horizontal row of elements. A group is one of the vertical columns of the periodic table.
- 1.19 The atomic number is related to the chemistry of an element since the periodic table is based on atomic numbers and the mass numbers vary with the number of neutrons in the atom, which does not affect the chemistry of the elements as much as the number of protons.
- 1.21 Silver and gold are in the same periodic table group as copper, so they might well be expected to occur together in nature, because of their similar properties and tendencies to form similar compounds.
- 1.23 There is no space in the periodic table for another element of mass 73 u. Germanium has an atomic mass of 72.6 u and an atomic number of 32. Next to it on the periodic table is arsenic which has an atomic number of 33. In order for there to be a new element with an atomic mass of 73, it would be expected to be next to germanium and have one more proton. However, the known element arsenic has one more proton and has an atomic mass of 74.9 u.
- 1.25 ductility
- 1.27 The group 18 elements, sometimes called the noble gases: Helium, He; Neon, Ne; Argon, Ar; Krypton, Kr; Xenon, Xe; Radon, Rn.
- 1.29 Metalloids are semiconductors, metals are good conductors and nonmetals are insulators.
- 1.31 An orbital is a region in space where there is a non-zero probability of finding an electron.
- 1.33 The energies of the two situations are different. A ground state atom is of lower energy than an excited state atom.

Review Problems

- 1.35 Compound (c). An authentic sample of laughing gas must have a mass ratio of nitrogen/oxygen of 1.75 to 1.00. The only possibility in this list is (c), which has the ratio of mass of nitrogen to mass of oxygen of $8.84/5.05 = 1.75$.
- 1.37 $x = 29.3 \text{ g N}$
- 1.39 5.54 g ammonia. Using the same method as above we see that for every 4.56 g nitrogen there needs be 0.98 g hydrogen. According to the Law of Conservation of Mass there will be 5.54 g ammonia produced.
- 1.41 2.286 g oxygen. If there are twice as many oxygen atoms per nitrogen atom, there should be twice the mass of oxygen per mass of nitrogen ($2 \times 1.143 \text{ g}$).
- 1.43 $12 \times 1.6605402 \times 10^{-24} \text{ g} = 1.9926482 \times 10^{-23} \text{ g}$ for one ^{12}C atom
- 1.45 $12 \times 0.0839925 = 1.00791 \text{ u}$
- 1.47 2.0158 u
- 1.49 $(0.7899 \times 23.9850 \text{ u}) + (0.1000 \times 24.9858 \text{ u}) + (0.1101 \times 25.9826 \text{ u}) = 24.31 \text{ u}$
- 1.51 (a) 82 neutrons, 55 protons, 55 electrons
(b) 78 neutrons, 53 protons, 53 electrons
(c) 146 neutrons, 92 protons, 92 electrons
(d) 118 neutrons, 79 protons, 79 electrons
- 1.53 Consult the periodic table to find examples of various classes of elements.
- (a) Halogens are in Group 17
(b) Alkali metals are in Group 1
(c) Actinoids lie between Ra and Rf in the periodic table
(d) Noble gases are in Group 18

Additional Exercises

- 1.55 Atomic mass of Y = $\frac{5.07}{4} \times 28.07 \text{ u} = 35.6 \text{ u}$
- 1.57 Fe_3O_4
- 1.59 Therefore, the volume enclosed by the nucleus is:
$$V = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi (1 \times 10^{-15} \text{ m})^3 \approx 4 \times 10^{-45} \text{ m}^3$$

The volume enclosed by the atom is:
$$V = \frac{4}{3} \pi r^3 = \frac{4}{3} \pi (1 \times 10^{-10} \text{ m})^3 \approx 4 \times 10^{-30} \text{ m}^3$$

CHAPTER 2

Practice Exercises

2.1 $\frac{1}{2} mu^2$ will have units of mass \times (velocity) $^2 = \text{kg} \cdot (\text{m s}^{-1})^2 = \text{kg} \cdot \text{m}^2 \text{s}^{-2}$. (Note that the numbers and factors, such as $\frac{1}{2}$, are unit-less).

2.3

1. Since $1 \times 10^{-5} \text{ bar} = 1 \text{ pascal}$

$$0.3 \text{ bar} = \frac{0.3}{1 \times 10^{-5}} = 3 \times 10^4 \text{ pascal}$$

2. Since $7.50 \times 10^{-3} \text{ mm Hg} = 1 \text{ pascal}$

$$451 \text{ mm Hg} = \frac{1}{7.50 \times 10^{-3}} \times 451 = 6.01 \times 10^4$$

3. Since $9.87 \times 10^{-6} \text{ atmosphere} = 1 \text{ pascal}$

$$3.81 \text{ atmosphere} = \frac{1}{9.87 \times 10^{-6}} \times 3.81 = 3.86 \times 10^5 \text{ pascal}.$$

2.5 Writing the numbers in scientific notation helps us determine the number of significant figures.

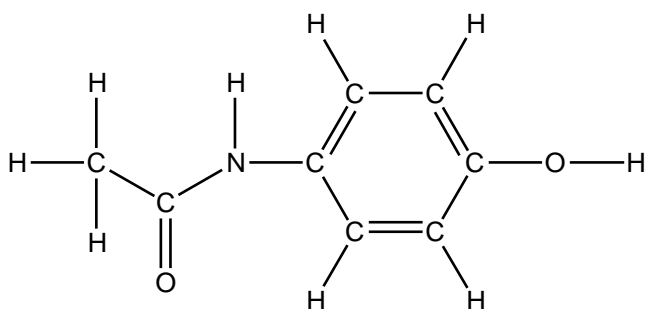
- (a) $1.000405 = 1.000405 \times 10^0$ (7 significant figures)
(b) $0.001000 = 1.000 \times 10^{-3}$ (4 significant figures)
(c) $1000010.0 = 1.0000100 \times 10^6$ (8 significant figures)

- 2.7
- (a) 42.0 g
(b) 30.0 mL
(c) 54.155 g
(d) 11.3 g
(e) 0.857 g mL^{-1}
(f) 8.3 m^3

2.9 The data set from Worker C has the best precision (all data are very close to the same value).

The data set from Worker A has the best accuracy (all data are very close to the correct value of 10.000 g).

2.11 The structural formula is:



The chemical formula is $\text{C}_8\text{H}_9\text{NO}_2$.

- 2.13 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$ (primary)
 $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_3$ (secondary)
 $(\text{CH}_3)_2\text{CHCH}_2\text{OH}$ (primary)
 $(\text{CH}_3)_3\text{COH}$ (tertiary)
- 2.15 $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$
 $(\text{CH}_3)_2\text{CHCOOH}$
- 2.17 (a) The two structural formulae represent constitutional isomers.
 (b) The two structural formulae represent the same compound
- 2.19 (a) propanone
 (b) pentanal

Review Questions

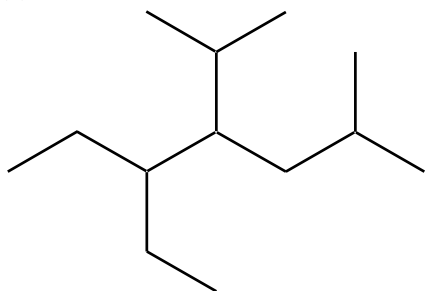
- 2.1 Measurements involve a comparison relative to a standard. The unit gives the number scientific meaning.
- 2.3 kilogram
- 2.5 force = mass \times acceleration. Therefore the units are $\text{kg} \times \text{m s}^{-2} = \text{kg m s}^{-2}$
- 2.7 (a) c
 (b) m
 (c) k
 (d) μ
 (e) n
 (f) p
 (g) M
- 2.9 The figures that are significant figures in a quantity are those that are known (measured) with certainty plus the last figure, which contains some uncertainty.
- 2.11 The maximum possible concentration of the toxin is 1.499 ug L^{-1} which reduces to 1.50 ug L^{-1} , correct to 3 significant figures.

- 2.13
1. All bonds except C—H bonds are shown as lines.
 2. C—H bonds and H atoms attached to carbon are not shown in the line structure.
 3. Single bonds are shown as one line; double bonds are shown as two lines; triple bonds are shown as three lines.
 4. Carbon atoms are not labelled. All other atoms are labelled with their elemental symbols.

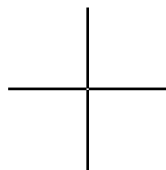
- 2.15
- (a) $\text{C}_{18}\text{H}_{36}\text{O}_2$
 - (b) SiCl_4
 - (c) $\text{C}_2\text{Cl}_3\text{F}_3$

2.17

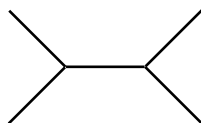
(a)



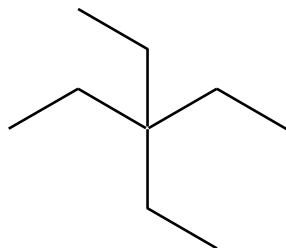
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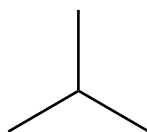
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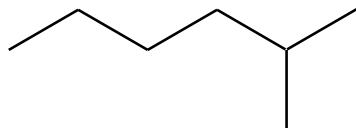
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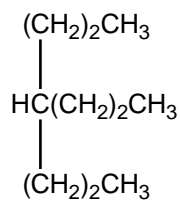
(e)



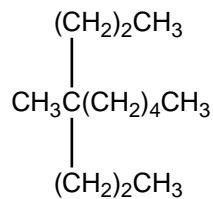
(f)



(b)



(c)



- 2.21
- (a) chlorine trifluoride
 - (b) hydrogen selenide
 - (c) chlorine dioxide
 - (d) antimony trichloride
 - (e) phosphorus pentachloride
 - (f) dinitrogen pentoxide
 - (g) dinitrogen tetrachloride
 - (h) ammonia (trivial name)

- 2.23 Unlike the alcohol function group, the aldehyde and carboxylic acid functional groups can only be situated at the end of a carbon chain and therefore only be attached to a single C atom.

Review Problems

2.25 To convert $^{\circ}\text{C}$ to K, add 273. To convert K to $^{\circ}\text{C}$, subtract 273.

- (a) 333 K
- (b) 243 K
- (c) 0°C
- (d) 26°C
- (e) 313 K

2.27 -269°C

- 2.29
- (a) 3
 - (b) 6
 - (c) 1
 - (d) 5
 - (e) 1
 - (f) 5

- 2.31
- (a) 4
 - (b) 4
 - (c) 4
 - (d) 2
 - (e) 3

- 2.33
- (a) 2.06 g mL^{-1}
 - (b) 4.02 mL
 - (c) 12.4 g mL^{-1}
 - (d) 0.276 g mL^{-1}
 - (e) 0.0006 m s^{-1}

- 2.35
- (a) 4.89×10^2
 - (b) 3.75×10^{-3}
 - (c) 8.23×10^4
 - (d) 1.225×10^{-2}
 - (e) 2.43×10^0
 - (f) 2.732×10^4

- 2.37
- (a) 0.000 000 052 7
 - (b) 712 000
 - (c) 0.000 000 043 5
 - (d) 0.023 5
 - (e) 40 000 000
 - (f) 3720

- 2.39
- (a) 6.3×10^9
 - (b) 2.0×10^{18}
 - (c) 5.5×10^{-9}
 - (d) 1.1×10^5
 - (e) 2.55×10^{-2}

2.41 (a) $92 \text{ dL} = 92 \times 10^{-1} \text{ L}$

$1 \text{ mL} = 1 \times 10^{-3} \text{ L}$

therefore $92 \text{ dL} = \frac{92 \times 10^{-1}}{1 \times 10^{-3}} \text{ mL} = 9200 \text{ mL}$

(b) $22 \text{ ng} = 22 \times 10^{-9} \text{ g}$

$1 \text{ } \mu\text{g} = 1 \times 10^{-6} \text{ g}$

therefore $22 \text{ ng} = \frac{22 \times 10^{-9}}{1 \times 10^{-6}} \text{ } \mu\text{g} = 2.2 \times 10^{-2} \text{ } \mu\text{g}$

(c) $83 \text{ pL} = 83 \times 10^{-12} \text{ L}$

$1 \text{ nL} = 1 \times 10^{-9} \text{ L}$

therefore $83 \text{ pL} = \frac{83 \times 10^{-12}}{1 \times 10^{-9}} \text{ nL} = 8.3 \times 10^{-2} \text{ nL}$

(d) $230 \text{ km} = 230 \times 10^3 \text{ m} = 2.30 \times 10^5 \text{ m}$

(e) $87.3 \text{ cm} = 87.3 \times 10^{-2} \text{ m}$

$1 \text{ km} = 1000 \text{ m}$

therefore $\frac{87.3 \times 10^{-2}}{1000} \text{ km} = 8.73 \times 10^{-4} \text{ km}$

(f) $238 \text{ mm} = 238 \times 10^{-3} \text{ m}$

$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$

therefore $238 \text{ mm} = \frac{238 \times 10^{-3}}{1 \times 10^{-9}} \text{ nm} = 2.38 \times 10^8 \text{ nm}$

2.43 (a) $183 \text{ nm} = 183 \times 10^{-9} \text{ m}$

$1 \text{ cm} = 1 \times 10^{-2} \text{ m}$

therefore $183 \text{ nm} = \frac{183 \times 10^{-9}}{1 \times 10^{-2}} \text{ cm} = 1.83 \times 10^{-5} \text{ cm}$

(b) $3.55 \text{ g} = 3.55 \times 10^1 \text{ dg}$

(c) $6.22 \text{ km} = 6.22 \times 10^3 \text{ m}$

$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$

therefore $6.22 \text{ km} = \frac{6.22 \times 10^3}{1 \times 10^{-9}} \text{ nm} = 6.22 \times 10^{12} \text{ nm}$

(d) $33 \text{ dm} = 33 \times 10^{-1} \text{ m}$

$1 \text{ mm} = 1 \times 10^{-3} \text{ m}$

therefore $33 \text{ dm} = \frac{33 \times 10^{-1}}{1 \times 10^{-3}} \text{ mm} = 3.3 \times 10^3 \text{ mm}$

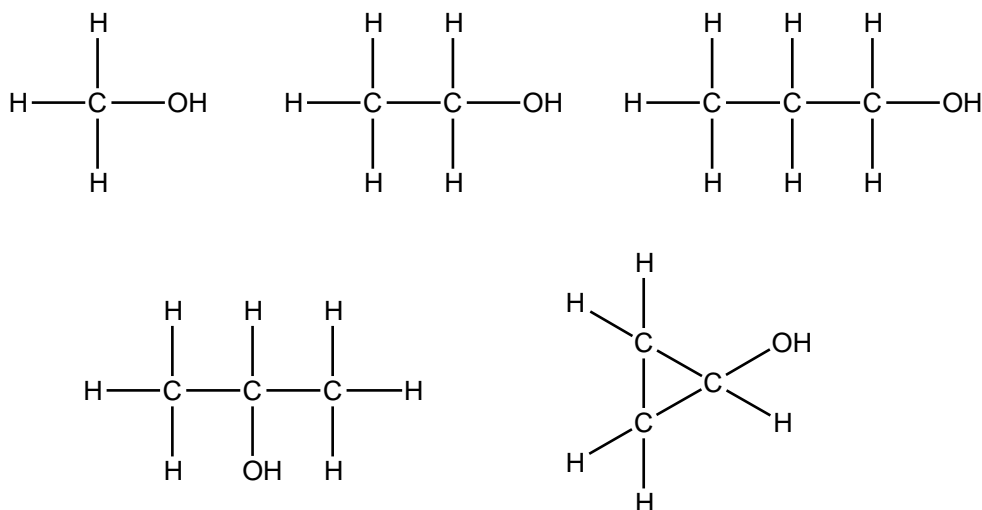
(e) $0.55 \text{ dm} = 0.55 \times 10^{-1} \text{ m}$
 $1 \text{ km} = 1000 \text{ m}$
 therefore $0.55 \text{ dm} = \frac{0.55 \times 10^{-1}}{1000} \text{ km} = 5.5 \times 10^{-5} \text{ km}$

(f) $53.8 \text{ ng} = 53.8 \times 10^{-9} \text{ g}$
 $1 \text{ pg} = 1 \times 10^{-12} \text{ g}$
 therefore $53.8 \text{ ng} = \frac{53.8 \times 10^{-9}}{1 \times 10^{-12}} \text{ pg} = 5.38 \times 10^4 \text{ pg}$

- 2.45 (a) alkyne
 (b) aldehyde
 (c) ketone

- 2.47 (a) identical
 (b) isomers
 (c) isomers
 (d) identical
 (e) identical

2.49 There are only 5 possible saturated alcohols with 3 or fewer C atoms per molecule:

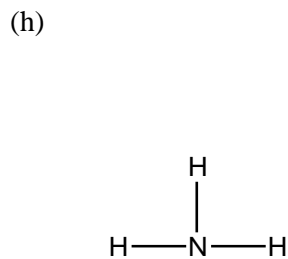
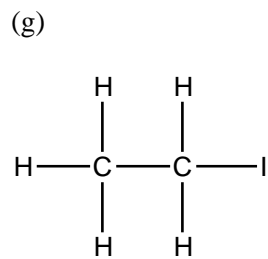
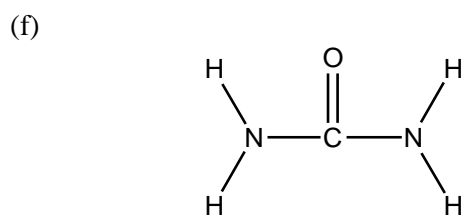
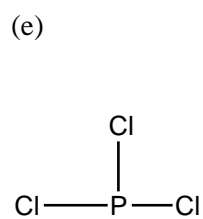
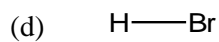
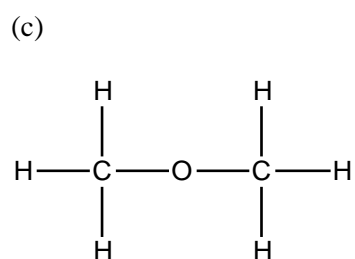
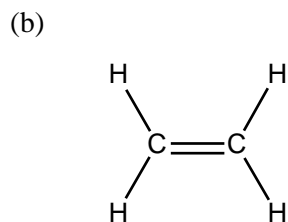
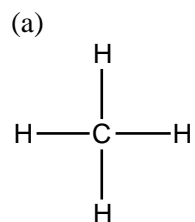


2.51 Determine the chemical formula from a ball-and-stick model by counting balls of each colour and consulting the colour code for the elements (appendix J):

- (a) CH_4
 (b) C_2H_4
 (c) $\text{C}_2\text{H}_6\text{O}$
 (d) HBr

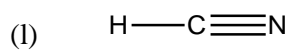
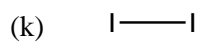
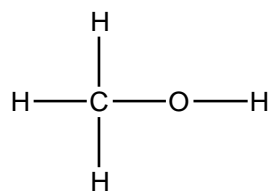
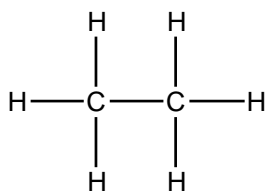
- (e) PCl_3
- (f) $\text{CH}_4\text{N}_2\text{O}$
- (g) $\text{C}_2\text{H}_5\text{I}$

2.53 Structural formulae are derived from ball-and-stick models by replacing the ‘sticks’ with lines and the ‘balls’ with elemental symbols:

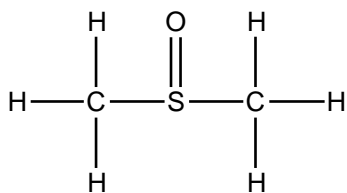


(i)

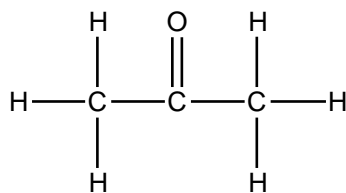
(j)



(m)

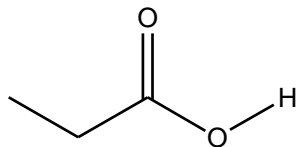


(n)

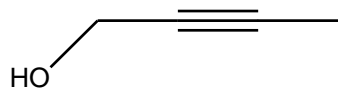


2.55 To convert a structural formula into a line structure, remove all hydrogen atoms bonded to carbon atoms and remove all C atom labels.

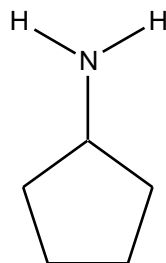
(a)



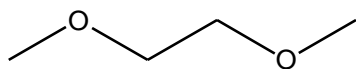
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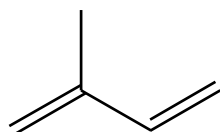
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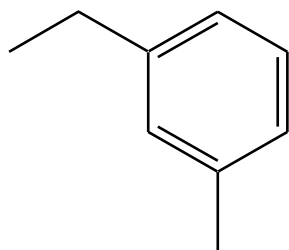
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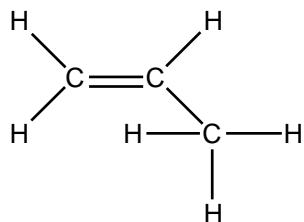
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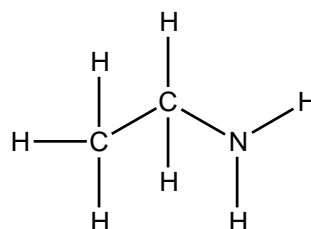
(f)



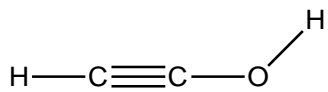
2.57 To convert a line structure into a structural formula, place a C atom at the end of each line and at each line intersection and then add sufficient hydrogen atoms to give each C atom 4 bonds:



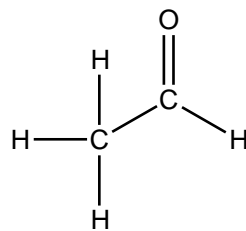
(a)



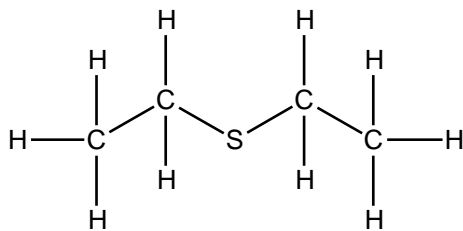
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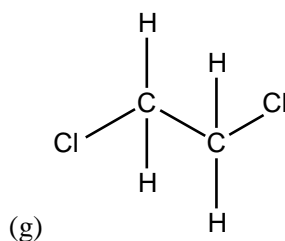
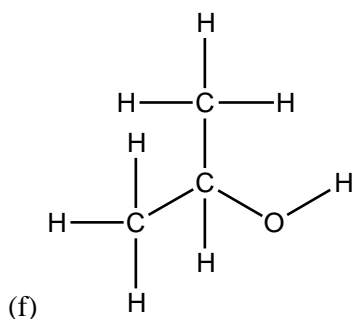
(c)



(d)



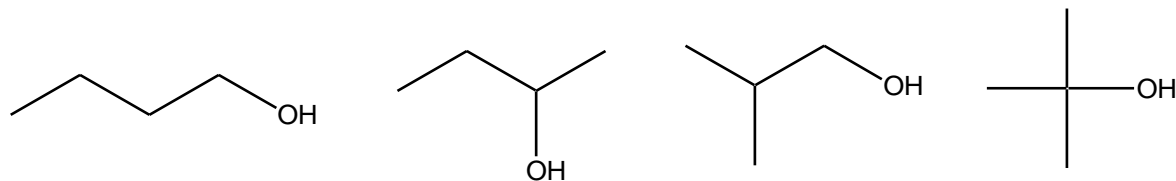
(e)



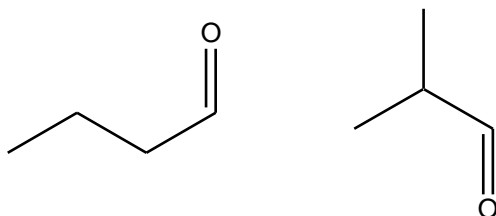
- 2.59 (a) i and vii; iv and v
 (b) The same compound as represented by iv and v is a constitutional isomer of the same compound as represented by i and vii; ii and iii are constitutional isomers; vi is a constitutional isomer of i, iv, v and vii.
 (c) viii is not a constitutional isomer of any compound.

- 2.61 (a) (iii)
 (b) (ii)
 (c) (ii)
 (d) (iii)
 (e) (ii)
 (f) (ii)

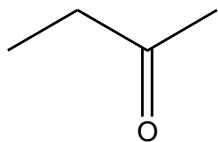
- 2.63 (a)



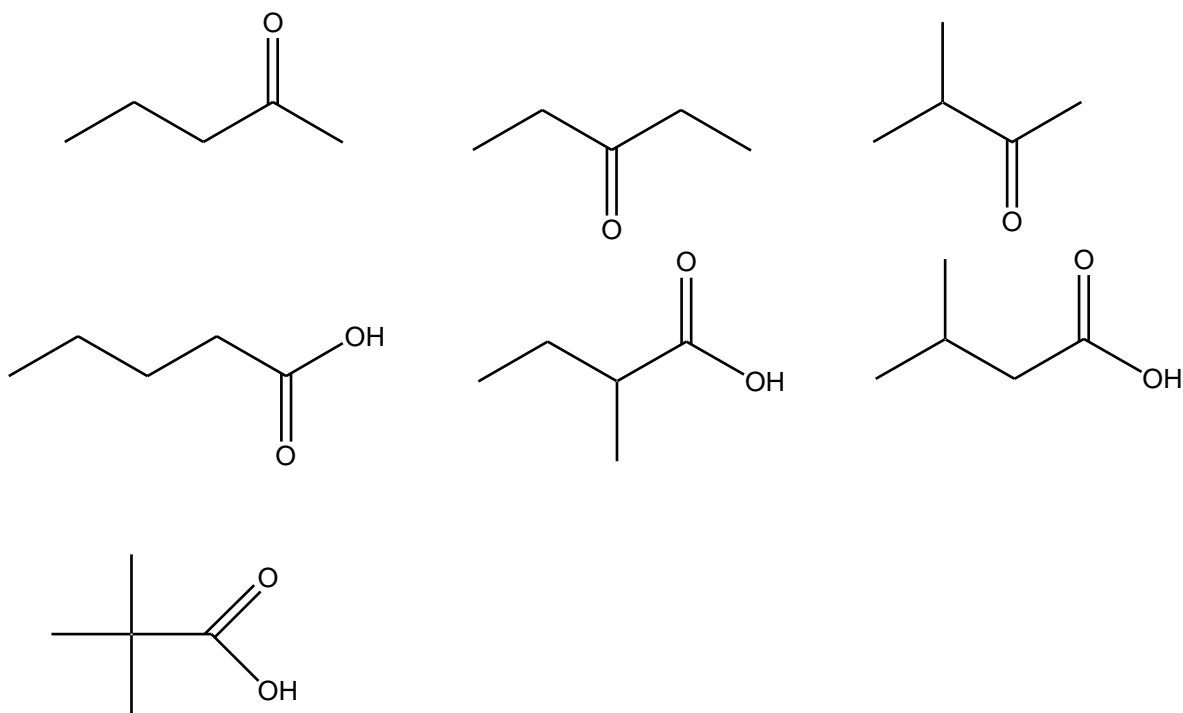
- (b)



- (c)



- (d)



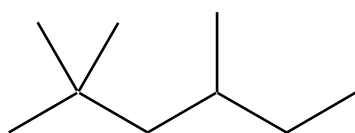
- 2.65 (a) NH_3
 (b) H_2S
 (c) $\text{C}_3\text{H}_7\text{Cl}$ (note: in the structural formula, the Cl is attached to the middle C atom)
 (d) SiO_2
 (e) N_2
 (f) SF_4
 (g) BrF_5
- 2.67 (a) germanium tetrachloride
 (b) dinitrogen tetrafluoride
 (c) lithium hydride
 (d) selenium dioxide
 (e) ethanol
- 2.69 (a) NaOCl
 (b) LiIO_4
 (c) MgBr_2
- 2.71 (a) ammonium sulfate
 (b) potassium bromide
 (c) hydrogen sulfide
 (d) sodium sulfide.
- 2.73 (a) KClO_3

- (b) NH_4HCO_3
- (c) AlCl_3
- (d) K_2O

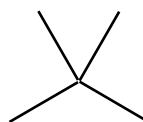
- 2.75
- (a) sodium nitrite
 - (b) magnesium phosphate
 - (c) potassium hydrogen sulfate
 - (d) caesium bromide
 - (e) aluminum perchlorate

2.77

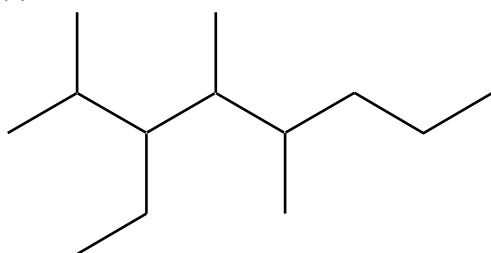
(a)



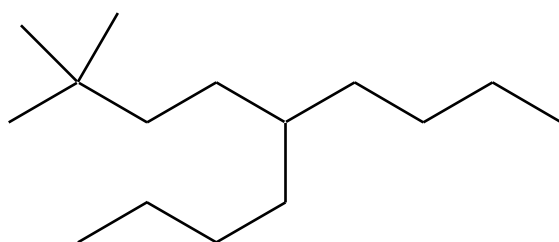
(b)



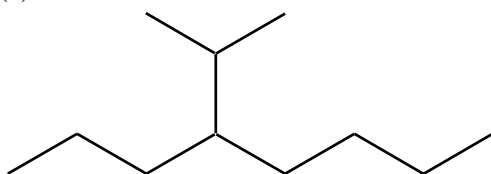
(c)



(d)



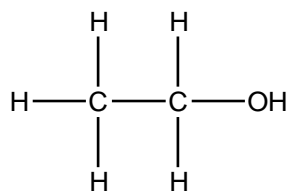
(e)



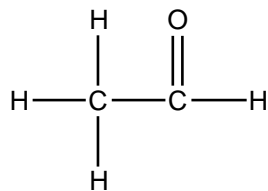
(f)



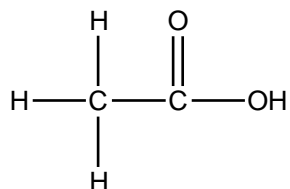
2.79 (a)



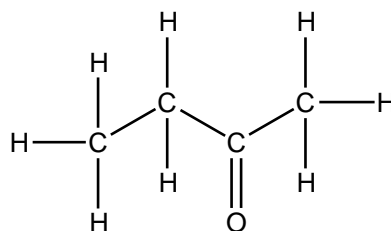
(b)



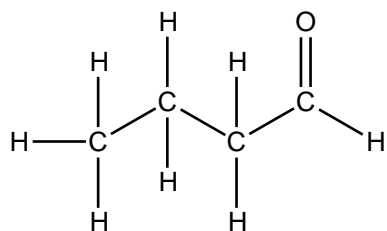
(c)



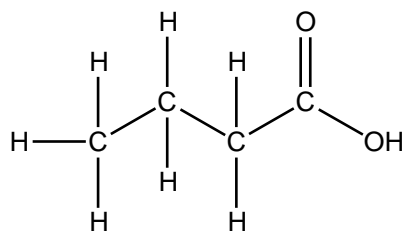
(d)



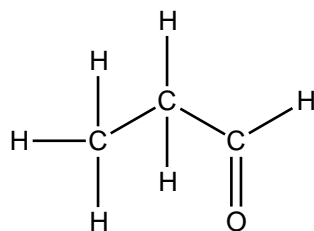
(e)



(f)



(g)



Additional Extras

2.81 5800 K has only two significant figures. Therefore subtracting 273 gives 5500 °C. However, in scientific notation, 5800 K is 5.800×10^3 , equivalent to 5527 °C.

- 2.83 (a) carbon dioxide
 (b) potassium nitrate
 (c) sodium chloride

- (d) sodium hydrogen carbonate
 - (e) sodium carbonate
 - (f) sodium hydroxide
 - (g) calcium oxide
 - (h) magnesium hydroxide
- 2.85 To obtain a chemical formula, convert a line structure into a structural formula by placing a C atom at the end of each line and at each line intersection. Then add sufficient hydrogen atoms to give each C atom 4 bonds. The chemical formula is then determined from the structural formula.
- (a) abscisic acid: $C_{15}H_{20}O_4$
 - (b) indole acetic acid: $C_{10}H_9NO_2$
 - (c) zeatin: $C_{10}H_{13}N_5O$
- 2.87
- (a) $NaNO_2$ and $NaNO_3$
 - (b) K_2CO_3 and $KHCO_3$
 - (c) I_2 and I^-
 - (d) $NaCl$ and $NaOCl$
 - (e) NO and NO_2
 - (f) $KClO_3$ and $KClO_4$
 - (g) NH_3 and NH_4^+
- 2.89
- (a) potassium chlorate
 - (b) potassium chlorite
 - (c) potassium hypochlorite
 - (d) potassium chloride
 - (e) sodium hydrogen phosphate
- 2.91 Jm^{-2}
- 2.93 $mol^{-2} L^2 s^{-1}$

CHAPTER 3

Practice Questions

3.1 1 Mg, 2 O, 4 H and 2 Cl (on each side).

3.3 $3 \text{ BaCl}_2(\text{aq}) + \text{Al}_2(\text{SO}_4)_3(\text{aq}) \rightarrow 3 \text{ BaSO}_4(\text{s}) + 2 \text{ AlCl}_3(\text{aq})$

3.5 $0.125 \text{ mol} \times 106 \text{ g mol}^{-1} = 13.3 \text{ g}$

3.7 $\text{g Fe} = \left(\frac{15.0 \text{ g Fe}_2\text{O}_3}{159.7 \text{ g mol}^{-1} \text{ Fe}_2\text{O}_3} \right) \left(\frac{2 \text{ mol Fe}}{1 \text{ mol Fe}_2\text{O}_3} \right) (55.8 \text{ g mol}^{-1} \text{ Fe}) = 10.49 \text{ g}$

3.9 %N = $0.1417/0.5462 \times 100 = 25.94\%$

%O = $0.4045/0.5462 \times 100 = 74.06\%$

Since the sum of %N and %O equals 100%, there are no other elements present.

3.11 It is convenient to assume that we have 100 g of the sample, so that the % mass represents masses. Thus there is 32.4 g of Na, 22.6 g of S and $(100.00 - 32.4 - 22.6) = 45.00 \text{ g}$ of O. Convert these masses to moles:

$$\text{mol Na} = \left(\frac{32.4 \text{ g Na}}{23.00 \text{ g mol}^{-1} \text{ Na}} \right) = 1.40 \text{ mol}$$

$$\text{mol S} = \left(\frac{22.6 \text{ g S}}{32.06 \text{ g mol}^{-1} \text{ S}} \right) = 0.70 \text{ mol}$$

$$\text{mol O} = \left(\frac{45.0 \text{ g O}}{16.00 \text{ g mol}^{-1} \text{ O}} \right) = 2.81 \text{ mol}$$

Next, we divide each of these mole amounts by the smallest in order to deduce the simplest whole number ratio:

For Na: $1.40 \text{ mol}/0.70 \text{ mol} = 2.0$

For S: $0.70 \text{ mol}/0.70 \text{ mol} = 1.0$

For O: $2.81 \text{ mol}/0.70 \text{ mol} = 4.0$

The empirical formula is therefore Na_2SO_4 .

3.13 $\text{mol O}_2 = (0.575 \text{ mol CO}_2) \left(\frac{5 \text{ mol O}_2}{3 \text{ mol CO}_2} \right) = 0.958 \text{ mol}$

3.15 First determine the mass of O_2 that is required to react completely with the given mass of ammonia:

$$\begin{aligned} \text{g O}_2 &= \left(\frac{30.00 \text{ g NH}_3}{17.03 \text{ g mol}^{-1} \text{ NH}_3} \right) \left(\frac{5 \text{ mol O}_2}{4 \text{ mol NH}_3} \right) (32.00 \text{ g mol}^{-1} \text{ O}_2) \\ &= 70.46 \text{ g} \end{aligned}$$

Since this is more than the amount that is available, we conclude that oxygen is the limiting reactant, and therefore:

$$\begin{aligned} \text{g NO} &= \left(\frac{40.00 \text{ g O}_2}{32.00 \text{ g mol}^{-1} \text{ O}_2} \right) \left(\frac{4 \text{ mol NO}}{5 \text{ mol O}_2} \right) (30.01 \text{ g mol}^{-1} \text{ NO}) \\ &= 30.01 \text{ g} \end{aligned}$$

$$3.17 \quad \text{mol Na}_2\text{SO}_4 = \left(\frac{3.550 \text{ g Na}_2\text{SO}_4}{142.1 \text{ g mol}^{-1} \text{ Na}_2\text{SO}_4} \right) = 0.02498 \text{ mol}$$

$$\text{L solution} = (100.0 \text{ mL}) \left(\frac{1 \text{ L}}{1000 \text{ mL}} \right) = 0.1000 \text{ L}$$

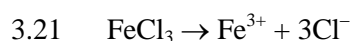
$$\text{M} = \left(\frac{\text{moles solute}}{\text{L solution}} \right) = \left(\frac{0.02498 \text{ mol Na}_2\text{SO}_4}{0.1000 \text{ L solution}} \right) = 0.2498 \text{ M}$$

$$3.19 \quad (V_{\text{dil}})(M_{\text{dil}}) = (V_{\text{conc}})(M_{\text{conc}})$$

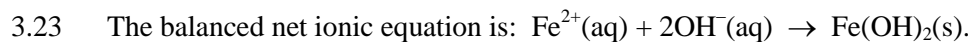
$$(100 \text{ mL})(0.125 \text{ M}) = (V_{\text{conc}})(0.500 \text{ M})$$

$$V_{\text{conc}} = (100 \text{ mL})(0.125 \text{ M}) / (0.500 \text{ M}) = 25.0 \text{ mL}$$

Therefore, mix 25.0 mL of 0.500 M H₂SO₄ with water to make 100 mL of total solution.



$$\text{M Fe}^{3+} = \left(\frac{0.40 \text{ mol FeCl}_3}{1 \text{ L FeCl}_3 \text{ soln}} \right) \left(\frac{1 \text{ mol Fe}^{3+}}{1 \text{ mol FeCl}_3} \right) = 0.40 \text{ M Fe}^{3+}$$



First determine the number of moles of Fe²⁺ present:

$$(60.0 \text{ mL FeCl}_2 \text{ solution}) \left(\frac{0.250 \text{ mol FeCl}_2}{1000 \text{ mL solution}} \right) \left(\frac{1 \text{ mol Fe}^{2+}}{1 \text{ mol FeCl}_2} \right) = 1.50 \times 10^{-2} \text{ mol Fe}^{2+}$$

Now, determine the amount of KOH needed to react with the Fe²⁺:

$$(1.50 \times 10^{-2} \text{ mol Fe}^{2+}) \left(\frac{2 \text{ mol OH}^-}{1 \text{ mol Fe}^{2+}} \right) \times \left(\frac{1 \text{ mol KOH}}{1 \text{ mol OH}^-} \right) \left(\frac{1000 \text{ mL solution}}{0.500 \text{ mol KOH}} \right) = 60.0 \text{ mL KOH}$$

$$3.25 \quad (a) \quad (0.736 \text{ g CaSO}_4) \left(\frac{1 \text{ mol CaSO}_4}{136.14 \text{ g CaSO}_4} \right) \left(\frac{1 \text{ mol Ca}^{2+}}{1 \text{ mol CaSO}_4} \right) = 5.41 \times 10^{-3} \text{ mol Ca}^{2+}$$

(b) Since all of the Ca^{2+} is precipitated as CaSO_4 , there were originally 5.41×10^{-3} moles of Ca^{2+} in the sample.

Review Problems

3.1 A chemical equation is balanced when there is the same number of each kind of atom on both the reactant and product side of the equation. This condition arises from the law of conservation of matter.

3.3 Coefficients

3.5 (a) Student B is correct.

(b) Student A wrote a properly balanced equation. However, by changing the subscript for the product of the reaction from an implied one, NaCl , to NaCl_2 , this student has changed the identity of the product. When balancing chemical equations, never change the value of the subscripts in chemical formulae.

3.7 'Mole' not 'mass' is the fundamental unit of chemistry. Stoichiometry is given by a balanced chemical equation, which is directly interpreted in 'moles'.

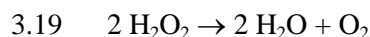
$$3.9 \quad \text{Amount of substance (moles)} = \frac{\text{Mass (g)}}{\text{Molar mass (g mol}^{-1}\text{)}}$$

3.11 There are the same number of molecules in 2.5 moles of H_2O and 2.5 moles of H_2 .

3.13 The statement '1.0 mole of oxygen' does not indicate whether this is atomic oxygen, O , or molecular oxygen, O_2 . The statement '64 g of oxygen' is not ambiguous because the source of oxygen is not important.

3.15 When balancing a chemical equation, changing the subscripts of a chemical formula changes the identity of the corresponding compound.

3.17 To determine the number of grams of sulfur that reacts with 1 gram of arsenic, the stoichiometric ratio of arsenic to sulfur in the compound is needed together with the molar masses of sulfur and arsenic.



$$3.21 \quad \left(\frac{\text{mmol}}{\text{mL}} \right) \left(\frac{1 \text{ mol}}{1000 \text{ mmol}} \right) \left(\frac{1000 \text{ mL}}{1 \text{ L}} \right) = \left(\frac{1000 \text{ mol}}{1000 \text{ L}} \right) = \left(\frac{\text{mol}}{\text{L}} \right)$$

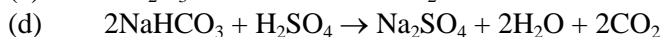
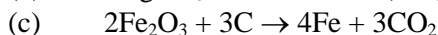
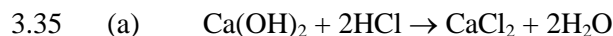
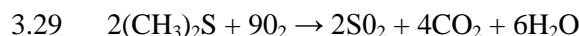
3.23 On dilution, the number of moles of HNO_3 in the solution has not changed but the concentration has decreased since water has been added.

3.25 Qualitative analysis is the use of experimental procedures to determine the elements that are present in a substance.

Quantitative analysis determines the percentage composition of a compound or the percentage of a component in a mixture.

Qualitative analysis answers the question, 'what is in the sample?' Quantitative analysis answers the question, 'how much is in the sample?'

3.27 The charge on Co is incorrect and the physical states of the reactants and products are not given. Balanced equation is: $3\text{Co}^{2+}(\text{aq}) + 2\text{HPO}_4^{2-}(\text{aq}) \rightarrow \text{Co}_3(\text{PO}_4)_2(\text{s}) + 2\text{H}^+(\text{aq})$.



3.37 O_2 is the limiting reagent.

$$3.39 \quad 1.56 \times 10^{21} \text{ atoms Na} \left(\frac{1 \text{ mol Na}}{6.022 \times 10^{23} \text{ atoms Na}} \right) = 2.59 \times 10^{-3} \text{ mole Na}$$

3.41 Based on the balanced equation: $2\text{NH}_3(\text{g}) \rightarrow \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$

Hence, the conversion factors are:

$$\left(\frac{1 \text{ mol N}_2}{2 \text{ mol NH}_3} \right) \text{ and } \left(\frac{3 \text{ mol H}_2}{2 \text{ mol NH}_3} \right)$$

To determine the moles produced, convert 'starting moles' to 'end moles':

$$0.145 \text{ mol NH}_3 \left(\frac{1 \text{ mol N}_2}{2 \text{ mol NH}_3} \right) = 0.0725 \text{ mol N}_2$$

The moles of hydrogen are:

$$0.145 \text{ mol NH}_3 \left(\frac{3 \text{ mol H}_2}{2 \text{ mol NH}_3} \right) = 0.218 \text{ mol H}_2$$

3.43 The empirical formula is NaTcO₄.

3.45 The empirical formula is C₂H₆O.

3.47 (a) $\text{g Fe} = (1.35 \text{ mol Fe})(55.85 \text{ g mol}^{-1} \text{ Fe}) = 75.4 \text{ g}$

(b) $\text{g O} = (24.5 \text{ mol O})(16.00 \text{ g mol}^{-1} \text{ O}) = 392 \text{ g}$

(c) $\text{g Ca} = (0.876 \text{ mol Ca})(40.08 \text{ g mol}^{-1} \text{ Ca}) = 35.1 \text{ g}$

3.49 $\text{mol Ni} = \left(\frac{17.7 \text{ g Ni}}{58.69 \text{ g mol}^{-1} \text{ Ni}} \right) = 0.302 \text{ mol}$

3.51 (a) $\text{g Ca}_3(\text{PO}_4)_2 = \left(\frac{1.25 \text{ mol Ca}_3(\text{PO}_4)_2}{310.18 \text{ g mol}^{-1} \text{ Ca}_3(\text{PO}_4)_2} \right) = 388 \text{ g}$

(b) $\text{g Fe}(\text{NO}_3)_3 = \left(\frac{0.625 \text{ mol Fe}(\text{NO}_3)_3}{241.87 \text{ g mol}^{-1} \text{ Fe}(\text{NO}_3)_3} \right) = 151 \text{ g}$

(c) $\text{g C}_4\text{H}_{10} = \left(\frac{0.600 \text{ mol C}_4\text{H}_{10}}{58.12 \text{ g mol}^{-1} \text{ C}_4\text{H}_{10}} \right) = 34.9 \text{ g}$

(d) $\text{g (NH}_4)_2\text{CO}_3 = \left(\frac{1.45 \text{ mol (NH}_4)_2\text{CO}_3}{96.11 \text{ g mol}^{-1} \text{ (NH}_4)_2\text{CO}_3} \right) = 139 \text{ g}$

3.53 3.43 kg fertiliser

3.55 $\text{g O} = \left(\frac{7.14 \times 10^{21} \text{ atoms N}}{6.02 \times 10^{23} \text{ atoms mol}^{-1} \text{ N}} \right) \left(\frac{5 \text{ mol O}}{2 \text{ mol N}} \right) (16.0 \text{ g mol}^{-1} \text{ O}) = 0.474 \text{ g}$

3.57 (a) $(0.11 \text{ mol Au(CN)}_2^-) \left(\frac{1 \text{ mol Zn}}{2 \text{ mol Au(CN)}_2^-} \right) (65.39 \text{ g mol}^{-1} \text{ Zn}) = 3.6 \text{ g Zn}$

(b) $(0.11 \text{ mol Au(CN)}_2^-) \left(\frac{2 \text{ mol Au}}{2 \text{ mol Au(CN)}_2^-} \right) (197.0 \text{ g mol}^{-1} \text{ Au}) = 22 \text{ g Zn}$

$$\begin{aligned} \text{(c)} \quad (\text{CN})_2^- &= (0.11 \text{ mol Zn}) \left(\frac{2 \text{ mol Au}(\text{CN})_2^-}{1 \text{ mol Zn}} \right) (249.0 \text{ g mol}^{-1} \text{ Au}(\text{CN})_2^-) \\ &= 55 \text{ g Au} \end{aligned}$$

$$3.59 \quad \text{mol O}_2 = \left(\frac{1000 \text{ g H}_2\text{O}_2}{34.01 \text{ g mol}^{-1} \text{ H}_2\text{O}_2} \right) \left(\frac{1 \text{ moles O}_2}{2 \text{ mole H}_2\text{O}_2} \right) = 14.70 \text{ mol}$$

$$\text{kg O}_2 = (14.70 \text{ moles O}_2) (32.00 \text{ g mol}^{-1} \text{ O}_2) \left(\frac{1 \text{ kg O}_2}{1000 \text{ g O}_2} \right) = 0.470 \text{ kg}$$

3.61 Since more than this minimum amount is available, FeCl_3 is present in excess and AgNO_3 is the limiting reactant.

3.63 9.2 g

$$\begin{aligned} 3.65 \quad \text{(a)} \quad \text{g NaCl} &= 0.125 \text{ L soln} (0.200 \text{ mol L}^{-1} \text{ NaCl}) (58.44 \text{ g mol}^{-1} \text{ NaCl}) \\ &= 1.46 \text{ g} \end{aligned}$$

$$\begin{aligned} \text{(b)} \quad \text{g C}_6\text{H}_{12}\text{O}_6 &= 0.250 \text{ L soln} (0.360 \text{ mol L}^{-1} \text{ C}_6\text{H}_{12}\text{O}_6) (180.2 \text{ g mol}^{-1} \text{ C}_6\text{H}_{12}\text{O}_6) \\ &= 16.2 \text{ g} \end{aligned}$$

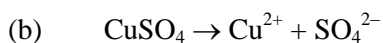
$$\begin{aligned} \text{(c)} \quad \text{g H}_2\text{SO}_4 &= 0.250 \text{ L soln} (0.250 \text{ mol L}^{-1} \text{ H}_2\text{SO}_4) (98.08 \text{ g mol}^{-1} \text{ H}_2\text{SO}_4) \\ &= 6.13 \text{ g} \end{aligned}$$

3.67 The 25.0 mL of H_2SO_4 must be diluted to 300 mL.



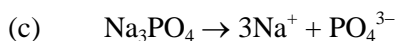
$$\text{M Cr}^{2+} = (0.25 \text{ mol L}^{-1} \text{ Cr}(\text{NO}_3)_2) \left(\frac{1 \text{ mol Cr}^{2+}}{1 \text{ mol Cr}(\text{NO}_3)_2} \right) = 0.25 \text{ M}$$

$$\text{M NO}_3^- = (0.25 \text{ mol L}^{-1} \text{ Cr}(\text{NO}_3)_2) \left(\frac{2 \text{ mol NO}_3^-}{1 \text{ mol Cr}(\text{NO}_3)_2} \right) = 0.50 \text{ M}$$



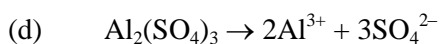
$$\text{M Cu}^{2+} = (0.10 \text{ mol L}^{-1} \text{ CuSO}_4) \left(\frac{1 \text{ mol Cu}^{2+}}{1 \text{ mol CuSO}_4} \right) = 0.10 \text{ M}$$

$$\text{M SO}_4^{2-} = (0.10 \text{ mol L}^{-1} \text{ CuSO}_4) \left(\frac{1 \text{ mol SO}_4^{2-}}{1 \text{ mol CuSO}_4} \right) = 0.10 \text{ M}$$



$$\text{M Na}^+ = \left(0.16 \text{ mol L}^{-1} \text{ Na}_3\text{PO}_4\right) \left(\frac{3 \text{ mol Na}^+}{1 \text{ mol Na}_3\text{PO}_4}\right) = 0.48 \text{ M}$$

$$\text{M PO}_4^{3-} = \left(0.16 \text{ mol L}^{-1} \text{ Na}_3\text{PO}_4\right) \left(\frac{1 \text{ mol PO}_4^{3-}}{1 \text{ mol Na}_3\text{PO}_4}\right) = 0.16 \text{ M}$$



$$\text{M Al}^{3+} = \left(0.075 \text{ mol L}^{-1} \text{ Al}_2(\text{SO}_4)_3\right) \left(\frac{2 \text{ mol Al}^{3+}}{1 \text{ mol Al}_2(\text{SO}_4)_3}\right) = 0.15 \text{ M}$$

$$\text{M SO}_4^{2-} = \left(0.075 \text{ mol L}^{-1} \text{ Al}_2(\text{SO}_4)_3\right) \left(\frac{3 \text{ mol SO}_4^{2-}}{1 \text{ mol Al}_2(\text{SO}_4)_3}\right) = 0.22 \text{ M}$$

$$\text{M Ca}^{2+} = \left(0.060 \text{ mol L}^{-1} \text{ Ca(OH)}_2\right) \left(\frac{1 \text{ mol Ca}^{2+}}{1 \text{ mol Ca(OH)}_2}\right) = 0.060 \text{ M}$$

$$\text{M OH}^- = \left(0.060 \text{ mol L}^{-1} \text{ Ca(OH)}_2\right) \left(\frac{2 \text{ mol OH}^-}{1 \text{ mol Ca(OH)}_2}\right) = 0.12 \text{ M}$$

3.71 mL NiCl_2 soln

$$= 0.020 \text{ L soln} \left(0.15 \text{ mol L}^{-1} \text{ Na}_2\text{CO}_3\right) \left(\frac{1 \text{ mol NiCl}_2}{1 \text{ mol Na}_2\text{CO}_3}\right) \left(\frac{1000 \text{ mL soln}}{0.25 \text{ mol NiCl}_2}\right)$$

$$= 12.0 \text{ mL}$$

g NiCO_3

$$= 0.012 \text{ L NiCl}_2 \text{ soln} \left(0.25 \text{ mol L}^{-1} \text{ NiCl}_2\right) \left(\frac{1 \text{ mol NiCO}_3}{1 \text{ mol NiCl}_2}\right) (118.7 \text{ g mol}^{-1} \text{ NiCO}_3)$$

$$= 0.36 \text{ g}$$

3.73 13.3 mL

3.75 (a) 0.492 g

(b) For nitrate: 0.161 M

For Na^+ : 0.235 M

For phosphate: 0.0247 M

Additional Exercises

$$3.77 \quad \text{g NaCl} = (0.277 \text{ g AgCl}) \left(\frac{1 \text{ mol AgCl}}{143.32 \text{ g AgCl}} \right) \left(\frac{1 \text{ mol NaCl}}{1 \text{ mol AgCl}} \right) (58.44 \text{ g mol}^{-1} \text{ NaCl})$$

$$= 0.113 \text{ g}$$

The entire sample was NaCl.

$$3.79 \quad V_2 = 50 \text{ mL}$$

$$3.81 \quad (a) \quad 0.366 \text{ mol L}^{-1} \text{ Na}_3\text{PO}_4$$

$$(b) \quad 0.0417 \text{ L}$$

$$(c) \quad 1.22 \text{ mol L}^{-1}$$

3.83 The empirical formula of the compound is determined from the information given however, its molar mass is needed to determine the molecular formula.

$$3.85 \quad (a) \quad 1.44 \text{ g}$$

$$(b) \quad 2.96 \times 10^{19} \text{ ions}$$

(c) The overall charge on $\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8$ is zero and since the charge on aluminium, phosphate and hydroxide is 3+, 3- and 1-, respectively, the charge on Cu is 2+.

$$3.87 \quad (a) \quad \text{C} = 23.6\%$$

$$\text{H} = 3.18\%$$

$$\text{N} = 13.8\%$$

$$\text{O} = 41.0\%$$

$$\text{P} = 18.3\%$$

$$(b) \quad 6.23 \times 10^{15} \text{ atoms}$$

$$(c) \quad 1.52 \times 10^{-9} \text{ g}$$

$$(d) \quad 0.0117 \text{ g}$$

3.89 Since one molecule of vitamin B₁₂ contains one atom of Co, then 1 mole of vitamin B₁₂ contains 1 mole of Co. Since the molar mass of Co is 58.93 g mol⁻¹, 4.34% of the mass of vitamin B₁₂ is 58.93 g. Hence the molar mass of vitamin B₁₂ is 1358 g mol⁻¹.

$$3.91 \quad M_{d2} = 0.174 \text{ mol L}^{-1}$$

$$3.93 \quad 2.49 \times 10^{20} \text{ molecules}$$

$$3.95 \quad (a) \quad 54.84 \text{ g S}$$

$$(b) \quad 1.10 \times 10^{23} \text{ molecules}$$

$$(c) \quad 1.88 \text{ mol}$$

(d) Since the density of water is 1.00 g mL^{-1} , there is 0.05 g of $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ per mL of solution.

3.97 Remaining SiO_2

$$= ((1.25 - 0.506) \text{ mol SiO}_2) (60.09 \text{ g mol}^{-1}) = 44.7 \text{ g}$$

Remaining C

$$= ((6.24 - 1.01) \text{ mol C}) (12.01 \text{ g mol}^{-1}) = 62.8 \text{ g}$$

Remaining Cl_2

$$= ((1.06 - 1.01) \text{ mol Cl}_2) (70.90 \text{ g mol}^{-1}) = 3.545 \text{ g}_2$$

CHAPTER 4

Practice Exercises

4.1 $2.14 \times 10^{10} \text{ s}^{-1}$ or Hz

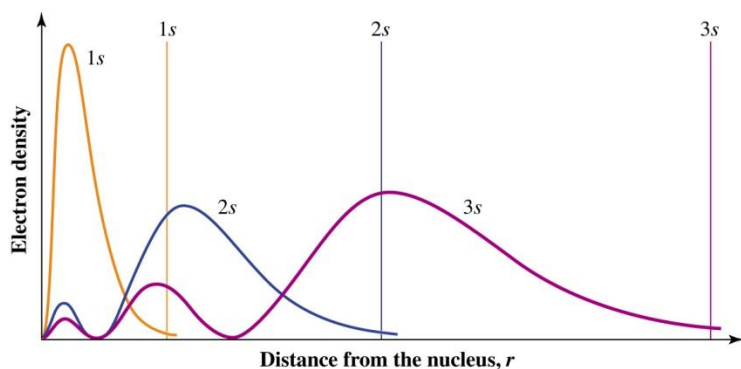
4.3 $\Delta E_{\text{atom}} = -4.56 \times 10^{-19} \text{ J atom}^{-1}$

$\Delta E_{\text{mol}} = -2.74 \times 10^5 \text{ J mol}^{-1}$ or -274 kJ mol^{-1}

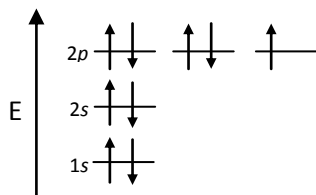
4.5 excitation energy = $471 \text{ kJ mol}^{-1} + 275 \text{ kJ mol}^{-1} = 746 \text{ kJ mol}^{-1}$ Hg

4.7 $\lambda_{\text{proton}} = 1.39 \times 10^{-12} \text{ m}$ or $1.39 \times 10^{-3} \text{ nm}$

4.9



4.11



Shorthand notation: $1s^2 2s^2 2p^5$

4.13 $[\text{He}] 2s^2 2p^3$

$2s^2$ $n = 2, l = 0, m_l = 0, m_s = +\frac{1}{2}$
 $n = 2, l = 0, m_l = 0, m_s = -\frac{1}{2}$

$2p^5$ $n = 2, l = 1, m_l = +1, m_s = +\frac{1}{2}$
 $n = 2, l = 1, m_l = +1, m_s = -\frac{1}{2}$
 $n = 2, l = 1, m_l = 0, m_s = +\frac{1}{2}$
 $n = 2, l = 1, m_l = 0, m_s = -\frac{1}{2}$
 $n = 2, l = 1, m_l = -1, m_s = +\frac{1}{2}$

4.15 $\text{Sc}^{3+}, \text{Cu}^+, \text{Zn}^{2+}$

- 4.17 Metals: Ga
 Metalloids: Ge and As
 Non-metals: Se, Br and Kr

Review Questions

4.1 (a)
$$V_{\text{atom}} = \frac{[MM(\text{g/mol})][10^{-3} \text{ kg/g}]}{[\rho(\text{kg/m}^3)][N_A]}$$

(b) $d \cong (V)^{1/3}$

(c) Ag: Thickness = $(6.5 \times 10^6 \text{ atoms})(2.574 \times 10^{-10} \text{ m}) = 1.7 \times 10^{-3} \text{ m}$
 Pb: Thickness = $(6.5 \times 10^6 \text{ atoms})(3.119 \times 10^{-10} \text{ m}) = 2.0 \times 10^{-3} \text{ m}$

- 4.3 Liquids and solids have limited compressibility, indicating that their component atoms have impenetrable volumes. Gases deviate from the ideal gas equation when compressed, displaying volumes that are greater than those predicted.

4.5 (a) $\lambda = \left(\frac{2.998 \times 10^8 \text{ m s}^{-1}}{4.77 \times 10^9 \text{ s}^{-1}} \right) = 6.29 \times 10^{-2} \text{ m}$

(b) $\lambda = \left(\frac{2.998 \times 10^8 \text{ m s}^{-1}}{28.9 \times 10^3 \text{ s}^{-1}} \right) = 1.04 \times 10^4 \text{ m or } 1.04 \times 10^6 \text{ cm}$

(c) $\lambda = \left(\frac{2.998 \times 10^8 \text{ m s}^{-1}}{60 \text{ s}^{-1}} \right) = 5.0 \times 10^6 \text{ m or } 5.0 \times 10^9 \text{ mm}$

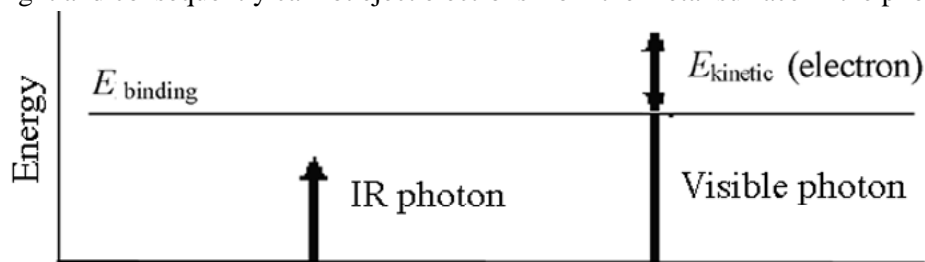
(d) $\lambda = \left(\frac{2.998 \times 10^8 \text{ m s}^{-1}}{2.88 \times 10^6 \text{ s}^{-1}} \right) = 1.04 \times 10^2 \text{ m or } 1.04 \times 10^8 \mu\text{m}$

4.7 (a) $E_{\text{photon}} = 1.237 \times 10^{-18} \text{ J per photon}$
 $\lambda = 1.61 \times 10^{-7} \text{ m}$
 $\nu = 1.86 \times 10^{15} \text{ s}^{-1} \text{ or Hz}$

(b) $E_{\text{photon}} = 3.55 \times 10^{-19} \text{ J}$
 $\lambda = 5.60 \times 10^{-7} \text{ m}$
 $\nu = 5.35 \times 10^{14} \text{ s}^{-1} \text{ or Hz}$

- 4.9 In order for a phototube to generate an electric current, the energy of the photon striking the metal surface of the tube must exceed the binding energy. Infrared light has lower energy than visible

light and consequently cannot eject electrons from the metal surface in the phototub



$$4.11 \quad \Delta E_{8-1} = (E_8 - E_1) = \frac{-2.18 \times 10^{-18} \text{ J}}{8^2} - \frac{-2.18 \times 10^{-18} \text{ J}}{1^2} = 2.146 \times 10^{-18} \text{ J}$$

$$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ m/s})}{2.146 \times 10^{-18} \text{ J}} = 9.257 \times 10^{-8} \text{ m or } 92.57 \text{ nm}$$

$$\Delta E_{9-1} = (E_9 - E_1) = \frac{-2.18 \times 10^{-18} \text{ J}}{9^2} - \frac{-2.18 \times 10^{-18} \text{ J}}{1^2} = 2.153 \times 10^{-18} \text{ J}$$

$$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ m/s})}{2.153 \times 10^{-18} \text{ J}} = 9.227 \times 10^{-8} \text{ m or } 92.27 \text{ nm}$$

4.13 (a) $1.45 \times 10^{-9} \text{ m or } 1.45 \text{ nm}$

(b) $6.38 \times 10^{-9} \text{ m or } 6.38 \text{ nm}$

(c) $4.41 \times 10^{-6} \text{ m or } 4.41 \mu\text{m}$

| 4.15 | n | l | m_l | m_s |
|------|-----|-----|-------|-------|
| | 6 | 1 | +1 | +1/2 |
| | 6 | 1 | +1 | -1/2 |
| | 6 | 1 | 0 | +1/2 |
| | 6 | 1 | 0 | -1/2 |
| | 6 | 1 | -1 | +1/2 |
| | 6 | 1 | -1 | -1/2 |

4.17 (a) non-existent: l must be positive

(b) actual

(c) non-existent: m_l cannot be larger than l

(d) actual

- 4.19 (a) 3p
(b) 2s
(c) 1s
(d) 2p

4.21 An electron contour surface representation gives a realistic three dimensional picture of the shape of an orbital. However, it fails to show regions inside the contour where the electron density may be zero. Consequently, the contour surfaces of 1s, 2s, 3s etc. all appear spherical.

4.23 A hydrogen atom contains only one electron, so there is no screening effect. In the absence of screening, orbital energy depends only on n and Z , so all $n = 3$ orbitals have identical energy. electron and the amount of screening decreases as l increases.

4.25 (a) The ionisation energy of the He $2p$ orbital (0.585×10^{-18} J) is not much greater than that of the H $2p$ orbital (0.545×10^{-18} J). These similar values indicate nearly equal effective nuclear charges due to nearly complete screening. In the absence of screening, the He $2p$ orbital has four times the ionisation energy of the H $2p$ orbital.

(b) The ionisation energy of the He⁺ $2p$ orbital (2.18×10^{-18} J) is four times greater than that of the H $2p$ orbital (0.545×10^{-18} J). A four-fold increase when Z doubles indicates a Z^2 dependence.

4.27 The column location of an element is the indicator of how many valence electrons it has. Remember that s electrons as well as those in the filling block count as valence electrons: O, fourth column of p block, $4p + 2s = 6$ valence electrons; V, third column of d block, $3d + 2s = 5$ valence electrons; Rb, 1 valence electron; Sn, second column of p block, $2s + 2p = 4$ valence electrons; and Cd, end of d block, 2 valence electrons.

4.29



- 4.31 (a) C, $Z = 6$, [He] $2s^2 2p^2$
(b) Cr, $Z = 24$, exception, [Ar] $4s^1 3d^5$
(c) Sb, $Z = 51$, [Kr] $5s^2 4d^{10} 5p^3$
(d) Br, $Z = 35$, [Ar] $4s^2 3d^{10} 4p^5$

4.33 The value of E_{i2} is almost ten times that of E_{i1} , indicating that the second electron removed is a core electron rather than a valence electron. The elements in Group 1 contain only one valence electron, so this is a Group 1 element. An electron affinity around -50 kJ/mol is consistent with this assignment (see figure 4.36). The element is Cs.

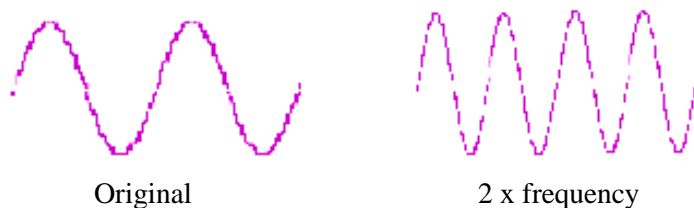
4.35 Stable anions form from elements in Columns 16 (dianions) and 17 (monoanions). Stable cations form from metals. Ca, Cu, Cs, and Cr are all metals and are found in ionic compounds as cations. Cl is found in ionic compounds as a -1 anion. C is not found as an atomic ion.

- 4.37 Non-metals are found in the upper right portion of the periodic table, metalloids along a diagonal running through the *p* block, and all other elements are metals. Thus, C and Cl are non-metals, and Ca, Cu, Cs, and Cr are metals.

Review Problems

- 4.39 (a) The photoelectric effect is a phenomenon describing electrons that are ejected from a metal surface when light of a sufficient frequency strikes the metal. Increasing the frequency of the light increases the kinetic energy of the ejected electrons. Increasing the intensity of the light increases the number of electrons ejected.
- (b) Particle-wave duality refers to an electron or photon having properties of both a particle and a wave.
- (c) Electron spin is a quantised property of electrons. Electrons can behave in only one of two ways when in a magnetic field.
- (d) The Heisenberg uncertainty principle states that the position of a moving electron cannot be defined. This is due to the particle-wave duality of an electron, since waves do not have a position. Heisenberg proved that because the position and momentum of a wave-particle are linked, it is not possible to know both at the same time. The more accurately we know the momentum, the less accurately we know the position and vice versa.

4.41



- 4.43 (a) $5.0 \times 10^{-19} \text{ J}$
- (b) $3 \times 10^5 \text{ ms}^{-1}$
- (c) $2 \times 10^{-9} \text{ m}$ or 2 nm

| | | | | | | |
|------|------------------------------------|------|------|------|------|------|
| 4.45 | λ (nm) | 487 | 514 | 543 | 553 | 578 |
| | ν (10^{14} s^{-1}) | 6.16 | 5.83 | 5.52 | 5.42 | 5.19 |
| | E (kJ mol^{-1}) | 246 | 233 | 220 | 216 | 207 |

- 4.47 (a) Shielding refers to the ability of electrons to partially cancel the attraction of an incoming negative electron to the positive nucleus.

- (b) All electrons are described by a set of four quantum numbers (principle quantum number, azimuthal quantum number, magnetic quantum number and spin quantum number) and the Pauli exclusion principle states that each electron in an atom must have a unique set of these quantum numbers. Thus, any orbital can contain a maximum of two electrons and these two electrons must have opposite spin quantum numbers.
- (c) The aufbau principle is used to predict the ground-state electron configuration of an atom or ion. It states that each successive electron is placed in the next available lowest-energy orbital, in accordance with the Pauli exclusion principle.
- (d) Hund's rule governs the way electrons are arranged in orbitals of equal energy. It states that electrons are arranged such that there is a maximum number of electrons with the same spin orientation as this is the lowest energy configuration.
- (e) Valence electrons are those that are responsible for chemical activity, which is governed by the spatial and energetic accessibility of these electrons. Electrons occupying the largest orbitals of an atom are spatially accessible, and those electrons occupying the highest energy occupied orbitals of an atom are energetically accessible.

4.49 Periodic trends are the variations in physical and chemical properties of the elements and their compounds in moving from left to right in the periodic table. Across a period, the valence orbitals are filling so as to approach a stable noble gas configuration.

First ionisation energy tends to increase across a period. This is because it requires more energy to remove an electron from an atom that has a filled, or close to filled, outer shell. This is a result of the increased attraction between the electrons and the nucleus as the valence orbitals are filled. Hence E_{i1} is highest for those elements which have noble gas electron configurations, followed by the halogens. The lowest E_{i1} values across a period are for the elements of Group 1, since losing their valence electron gives them the stable noble gas electron configuration. However there are some irregularities in this trend, such as the tendency for E_{i1} to be lower than the trend predicts when the ionisation results from the ejection of a p -orbital electron.

Electron affinity tends to become more negative across a period and tends to be negative as in most cases energy is released when adding the first electron. This is due to the increasing attraction between the electron and the nuclear charge across the periodic table. The E_{EA} values generally become more negative due to the decreasing size of the atom across the periodic table. The most negative values are for the halogens because when an electron is added, these atoms reach noble gas electron configuration. Again this trend is not regular, as the E_{EA} values for Group 2 elements and the noble gases are positive, as in the first case, their ns orbitals were already filled and in the latter, the atoms have filled np orbitals.

4.51 Size increases with increasing n value and for the same value of n , decreases with increasing Z (increasing electrical attraction). Cl , Cl^- , and K^+ all have $n = 3$ for the valence electrons, whereas Br^- has $n = 4$, so Br^- is the largest of this group. Among the others, the extra electron in Cl^- makes it larger than Cl and K^+ has higher Z than Cl , so the order of decreasing radius is: $Br^- > Cl^- > Cl > K^+$

- 4.53 (a) In a one-electron atom or ion, orbital energy depends only on n and Z , both of which are the same for the hydrogen atom $2s$ and $2p$ orbitals.
- (b) In multi-electron atoms, orbitals with the same n value but different l values are screened to different extents. The orbital with the lower l value is less screened, and hence is more stable.
- 4.55 S^+ , with three unpaired electrons, has more unpaired electrons than S or S^- .
- 4.57 (a) Mg has the second smallest radius among alkaline earths and S has an anion that is isoelectronic with Ar, the Row 3 noble gas: MgS .
- (b) K, beginning of Row 4, has a cation isoelectronic with Ar at the end of Row 3, and the Row 2 element with the highest electron affinity is F: KF .
- (c) Be is the alkaline earth element with the highest second ionisation energy and it combines in 1:2 ratio with elements from Row 17: $BeCl_2$.

Additional Exercises

4.59 Minimum kinetic energy: $7.83 \times 10^{-19} \text{ J}$

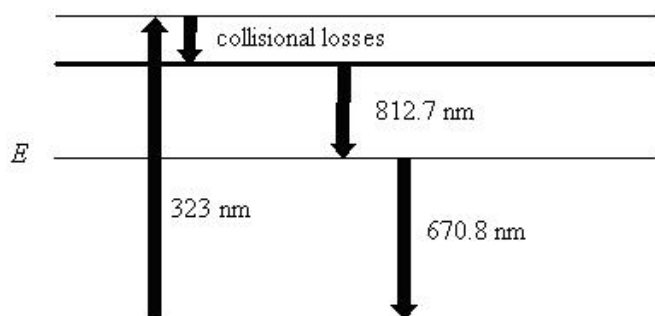
Wavelength: $5.55 \times 10^{-10} \text{ m}$

$$4.61 \quad u = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34} \text{ J s}}{(1.6749 \times 10^{-27} \text{ kg})(7.5 \times 10^{-11} \text{ m})} = 5.3 \times 10^3 \text{ m/s}$$

$$E_{\text{kinetic}} = \frac{1}{2} mu^2$$

$$E_{\text{kinetic}} = \frac{1}{2} (1.6749 \times 10^{-27} \text{ kg})(5.3 \times 10^3 \text{ m/s})^2 = 2.3 \times 10^{-20} \text{ J}$$

4.63

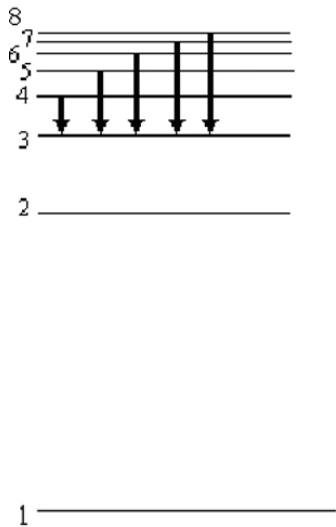


$$\text{Fraction lost} = \frac{7.5 \times 10^{-20} \text{ J}}{6.15 \times 10^{-19} \text{ J}} = 0.12$$

4.65 $n_1 = 4$ and $n_2 = 2$

4.67 1.9×10^{17} photons emitted per minute

4.69



1st Line = $n = 4$ to $n = 3$

2nd Line = $n = 5$ to $n = 3$

3rd Line = $n = 6$ to $n = 3$

4th Line = $n = 7$ to $n = 3$

5th Line = $n = 8$ to $n = 3$

4.71 (a) Binding energy is the energy required to eject an electron from an atom.

For metal A, electrons are not ejected until a frequency of $4.0 \times 10^{14} \text{ s}^{-1}$ is reached, therefore the binding energy is the energy corresponding to this frequency:

$$E = h\nu = (6.626 \times 10^{-34} \text{ J s})(4.0 \times 10^{14} \text{ s}^{-1}) = 2.7 \times 10^{-19} \text{ J}$$

Similarly for metal B at a frequency of $6.5 \times 10^{14} \text{ s}^{-1}$

$$E = h\nu = (6.626 \times 10^{-34} \text{ J s})(6.5 \times 10^{14} \text{ s}^{-1}) = 4.3 \times 10^{-19} \text{ J}$$

Therefore, metal B has the higher binding energy because higher frequency photons are required to generate photoelectrons.

(b) Kinetic energy = photon energy – binding energy

$$E_{\text{photon}} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ m/s})}{1.25 \times 10^{-7} \text{ m}} = 1.59 \times 10^{-18} \text{ J}$$

Hence, using this photon energy and the binding energy calculated in part (a), the kinetic energies are:

$$\text{Metal A: } 1.59 \times 10^{-18} \text{ J} - 0.27 \times 10^{-18} \text{ J} = 1.32 \times 10^{-18} \text{ J}$$

$$\text{Metal B: } 1.59 \times 10^{-18} \text{ J} - 0.43 \times 10^{-18} \text{ J} = 1.16 \times 10^{-18} \text{ J}$$

- (c) The wavelength range over which electrons can be ejected from one metal but not from the other corresponds to the frequency range of $4.0 \times 10^{14} \text{ s}^{-1}$ to $6.5 \times 10^{14} \text{ s}^{-1}$:

$$\text{At } 4.0 \times 10^{14} \text{ s}^{-1} \quad \lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{4.0 \times 10^{14} \text{ s}^{-1}} = 7.5 \times 10^{-7} \text{ m or } 750 \text{ nm}$$

$$\text{At } 6.5 \times 10^{14} \text{ s}^{-1} \quad \lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{6.5 \times 10^{14} \text{ s}^{-1}} = 4.6 \times 10^{-7} \text{ m or } 460 \text{ nm}$$

Thus, the wavelength range over which photons can eject electrons from one metal but not the other is 460 nm to 750 nm.

- 4.73 To determine configurations of ions, start with the ground state configuration of the neutral atom and then remove electrons:

Ce has valence configuration $6s^2 5d^1 4f^1$; remove the two s electrons: $\text{Ce}^{2+}, 5d^1 4f^1$

La has valence configuration $6s^2 5d^1$; remove one s electron: $\text{La}^+, 6s^1 5d^1$

Ba has the 'normal' configuration, $6s^2$

These differ because of the nearly-equal energies of the $6s$, $5d$, and $4f$ orbitals.

- 4.75 Cl^- is larger than K^+ because although these ions have the same number of electrons, K^+ and Ar have a larger Z . By similar arguments $\text{Ar} > \text{K}^+$.

Thus, $a = \text{Cl}^-$, $b = \text{K}^+$, and $c = \text{Ar}$.

- 4.77 The data in appendix C indicate that noble gas elements have unfavourable electron affinities (> 0) and relatively large first ionisation energies ($> 1350 \text{ kJ mol}^{-1}$). Consequently, these are unlikely to either gain or lose electrons to form stable chemical compounds. Nevertheless, Xe and Kr (to a lesser extent) do form compounds.

- 4.79 The filling pattern after $7p$ mirrors the pattern after $6p$: $8s$, then $5g$ (or perhaps $6f$).

- 4.81 (a) Successive ionisation energies for any element increase because there is less effective screening as electrons are removed. The fourth ionisation energy is much greater than any of the other three because the electron removed comes from the $2p$ rather than an $n = 3$ orbital.

(b) As electrons are removed, the reduction in screening results in tighter binding and a smaller ion; thus $\text{Al}^{4+} < \text{Al}^{3+} < \text{Al}^{2+} < \text{Al}^+$.

(c) Electron affinity is the energy released when an electron is added, so it is the reverse of ionisation energy and thus Al^{4+} has the largest (most negative) electron affinity.

- 4.83 (a) Be is $1s^2 2s^2$ and B is $1s^2 2s^2 2p^1$. Although B has a higher Z value, the combination of a less stable highest occupied orbital in B and electron–electron repulsion in Be accounts for B having a lower E_{il} than Be.

- (b) S is $[\text{Ne}] 3s^2 3p^4$ and P is $[\text{Ne}] 3s^2 3p^3$. Here, increased electron–electron repulsion in S, for which one of the p orbitals is doubly occupied, destabilises the electron more than the stabilisation provided by an increased Z value.