# UNIT 3

## AMOUNT OF SUBSTANCE AND MEASUREMENT

## Answers

*Lesson 1 – Why are practicals important?*

**Activity 1.1: Understand risks and safety precautions in the laboratory**

Students should simply be encouraged to take time to discuss and present any of the laboratory safety precautions from the list above. It may be necessary to distribute colouring pencils and /or pens in order to motivate students to make an effort with their poster. The best posters should be displayed in the laboratory.

**Summary Activity 1.2: units of temperature**

- Kelvin, degrees celsius (and degrees Farenheit)
- 298 K, 373 K, 0 K
- 72 °C, 327 °C, -173 °C

**Test your knowledge 1.3: Interconverting important units in Chemistry**

(a) (i) 25000 g; (ii) 3200 g; (iii) 340 g
(b) (i) 2.5 x $10^{-5}$ $m^3$; (ii) 3.2 x $10^{-3}$ $m^3$; (iii) 3.4 x $10^{-4}$ $m^3$, (d) 1.5 x $10^{-4}$ $m^3$, (e) 0.12 $m^3$
(c) (i) 250 $dm^3$; (ii) 3200 $dm^3$; (iii) 0.025 $dm^3$; (iv) 0.15 $dm^3$; (v) 6.2 x $10^{-3}$ $dm^3$
(d) (i) 2.5 x $10^5$ $cm^3$, (b) 3.2 x $10^6$ $cm^3$, (c) 400 $cm^3$, (d) 15 $cm^3$, (e) 6200 $cm^3$

*Lesson 2 – What is a base quantity and what is a derived quantity?*

**Test your knowledge 2.1: Using base and derived quantities**

(a) Force (= mass x acceleration) $kgms^{-2}$
(b) Work done (= pressure x volume) $kgm^2s^{-2}$
(c) Power (= voltage x current) $kgm^2s^{-3}$
(d) Momentum (= mass x velocity) $kgms^{-1}$
(e) Rate of reaction (= concentration / time) $molm^{-3}s^{-1}$

**Test your knowledge 2.2: Measuring Volumes**

| Instrument | Advantage | Disadvantage |
|---|---|---|
| Pipette | very accurate | can only measure one volume |
| Volumetric flask | very accurate | can only measure one volume |
| Burette | Can measure any volume up to 50 $cm^3$ | Cannot measure the total volume present, it can only deliver a volume |
| Measuring cylinder | Easy to use | Not very accurate |

## UNIT 3 – AMOUNT OF SUBSTANCE AND MEASUREMENT

***Lesson 3 – What is density and how can we measure it?***

**Practical 3.1: Compare the densities of pure water and salt water**

Equipment needed per group: 100 $cm^3$ measuring cylinder, funnel, access to a mass balance, access to tap water, access to brine (50 $cm^3$ per group)

- Students should get a density close to 1.0 $gcm^{-3}$ for pure water
- The density of brine is close to 1.2 $gcm^{-3}$; brine is more dense than pure water because the $Na^+$ and $Cl^-$ ions occupy the spaces between the water molecules, providing extra mass without using any extra volume

**Practical 3.2: Measure the density of sand**

Equipment needed per group: 2 x 100 $cm^3$ measuring cylinders, access to a mass balance, access to tap water, access to sand (around 20 g per group), access to a spoon

- students should get a density close to 1.5 $gcm^{-3}$
- sand must be denser than water because it does not float on water
- The error in the measurement of volume is the biggest error, as measuring cylinders are not very accurate

**Test your knowledge 3.3: Using Avogadro's number**

(a) 0.0042 or $4.2 \times 10^{-3}$ (b) $1.5 \times 10^{23}$ (c) 0.05 (d) $1.2 \times 10^{22}$ (e) 15

***Lesson 4 – How can we work out how many moles we have in a sample?***

**Test your knowledge 4.1: Deducing relative molecular masses and relative formula masses**

(a) (i) 12.0; (ii) 16.0; (iii) 35.5; (iv) 23.0; (v) 1.0; (vi) 24.3
(b) (i) 32.0; (ii) 44.0; (iii) 71.0; (iv) 36.5; (v) 16.0; (vi) 18.0
(c) (i) 58.5; (iii) 106.0; (iv) 40.3; (v) 95.3; (v) 58.3

**Test your knowledge 4.2: Using mass measurements to calculate moles**

a) (i) 0.1; (ii) 0.078; (iii) 5450; (iv) 0.16, (v) 0.022
b) (ii) 3.55 g; (ii) 14.9 g; (iii) 5.56 g; (iv) 39900 g or 39.9 kg; (v) 6.85 g
c) (i) 28 g/mol; (ii) 40 g/mol; (iii) 160 g/mol; (iv) 28 g/mol; (v) 249.6 g/mol

***Lesson 5 – How can we work out how many moles we have in a solution?***

**Test your knowledge 5.1: Using moles, molarity and aqueous volume**

a) (i) 0.0025; (ii) 0.008; (iii) 0.015; (iv) 0.0025; (v) 0.0052
b) (i) 2.5 $moldm^{-3}$; (ii) 0.4 $moldm^{-3}$; (iii) 0.12 $moldm^{-3}$; (iv) 0.1 $moldm^{-3}$; (v) 2 $moldm^{-3}$
c) (i) 6.0 $moldm^{-3}$; (ii) 0.63 $moldm^{-3}$; (iii) 2.7 $moldm^{-3}$ (iv) 0.8 $moldm^{-3}$, (v) 2.9 $moldm^{-3}$

**Test your knowledge 5.2: Preparing Standard Solutions**

(a) moles needed = 250/1000 x 0.1 = 0.025; $m_r$ = 106 so mass needed = 0.025 x 106 = 2.65 g
(b) moles needed = 250/1000 x 0.1 = 0.025; $m_r$ = 174 so mass needed = 0.025 x 174 = 4.35 g

**Practical 5.3: Prepare 250 cm$^3$ of 0.1 moldm$^{-3}$ standard solutions of sodium chloride (NaCl) and sugar ($C_{12}H_{22}O_{11}$)**

Equipment needed per group: 250 cm$^3$ beaker, distilled water bottle, spatula, stirring rod, funnel, 250 cm$^3$ volumetric flask, weighing boat, access to 2 dp mass balance, access to NaCl, access fo sugar

- Mass of salt needed = 58.5 x 0.25 x 0.1 = 1.46 g
- Mass of sugar needed = 342 x 0.25 x 0.1 = 8.55 g

It ma be advisable to prepare the standard solution of NaCl together, as a class, with the teacher leading from the front showing the key steps, before allowing the students to prepare the sugar solution independently

*Lesson 6 – How can we prepare standard solutions by diluting concentrated solutions?*

**Demonstration 6.1: Prepare 250 cm$^3$ of a 0.1 moldm$^{-3}$ standard solution of HCl from a sample of concentrated HCl**

**(CAUTION – concentrated HCl is highly corrosive)**

**Equipment needed: concentrated HCl (corrosive); distilled water; one weighing bottle, one larger beaker (250 cm$^3$), one dropping pipette; one mass balance (2dp); one 250 cm$^3$ volumetric flask, one funnel**

1) Weigh out 2.53 g of concentrated HCl (put one of the small beakers onto the bass balance; place some of the concentrated HCl into the other small beaker; use the dropping pipette to add HCl from the stock beaker to the beaker on the mass balance until 2.53 g has been added
2) Add 100 cm$^3$ of water to a beaker, and then add the 2.53 g concentrated HCl and stir
3) Transfer the solution into a volumetric flask and add water until the base of the meniscus lies on the graduated mark on the volumetric flask, shaking well; use washings from the weighing bottle used to weigh the concentrated HCl and the empty beaker used for the initial dilution

**Practical 6.2: Prepare 250 cm$^3$ of a 0.1 moldm$^{-3}$ solution of hydrogen peroxide by diluting a 2.0 moldm$^{-3}$ solution**

**Equipment needed per group: around 20 cm$^3$ 2.0 moldm$^{-3}$ $H_2O_2$ or closest concentration available; one 25 cm$^3$ measuring cylinder, one dropping pipette, beaker (250 cm$^3$), one 250 cm$^3$ volumetric flask, one funnel**

1) dilution factor = 2/0.1 = 20 so volume needed = 250/20 = 12.5 cm$^3$
2) Use a dropping pipette for the final 2 – 3 cm$^3$ of $H_2O_2$
3) Use washings from the measuring cylinder

**Test your knowledge 6.3: Preparing standard solutions by dilution**

(a) Moles needed = 250/1000 x 0.1 = 0.025; mass of pure $HNO_3$ = 0.025 x 63 = 1.58 g; mass of conc. $HNO_3$ = 100/65 x 1.58 = 2.42 g
(b) Moles of NaOH = 5/1000 x 6 = 0.03; total volume of diluted solution = 0.03/0.1 = 0.3 dm$^3$ = 300 cm$^3$; So 300 – 5 = 295 cm$^3$ of water must be added

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***Lesson 7 – How can calculate the moles present in a gaseous sample?***

**Summary Activity 7.1: The Gas Laws**

- Because the particles are far apart and there are no forces between the particles
- The typical pressure exerted on the earth'y surface by its atmosphere; 100 kPa (also known as 1 atm)
- $P_1V_1/T_1 = P_2V_2/T_2$
- Boyle's Law, Charles' Law and Gay-Lussac's Law (any two of these can be used to derive the combined gas law)

**Test your knowledge 7.2: Using Avogadro's Law**

(a) 2.4 $dm^3$, (b) 7.2 $dm^3$, (c) 24 $dm^3$, (d) 0.5, (e) 0.005
Note: it doesn't matter what the gas is; the gas laws apply equally to all gases

**Demonstration 7.3: Measure the volume of a gas**

Equipment needed: conical flask, bung which fits conical flask and has delivery tube attached, gas syringe connectible to delivery tube (or trough of water and 100 $cm^3$ measuring cylinder), 50 $cm^3$ measuring cylinder, access to mass balance, access to 2.0 $moldm^{-3}$ HCl and marble chips
Using the measuring cylinder, pour around 50 $cm^3$ of 2.0 $moldm^{-3}$ HCl into the conical flask; ensure that the delivery tube with the bung is connected to the syringe; add 0.25 g – 0.30 g of marble chips and quickly replace the bung; the plunger in the syringe will move and the volume of gas can be measured (expect 50 – 70 $cm^3$ of gas)
Record the atmospheric temperature and inform the class
Moles of gas = n = PV/RT; Pressure = 100,000 Pa, R = 8.31; T = (eg) 20 °C = 293 K (use class measurement); V = (eg) 65 $cm^3$ = 6.5 x $10^{-5}$ $m^3$ (use class measurement); number of moles of gas produced = (100,000 x 6.5 x $10^{-5}$)/ (8.31 x 293) = 2.7 x $10^{-3}$ moles (this is an example using V = 65 $cm^3$) and T = 20 °C)

**Test your knowledge 7.4: Using the ideal gas equation**

(a) (i) 1.9 mol; (ii) 0.048 mol; (iii) 0.0022 mol; (iv) 4.0 mol; (v) 0.0024 mol
(b) (i) 1.2 $dm^3$, (ii) 6.2 $dm^3$, (iii) 9.1 $dm^3$, (iv) 2.5 $dm^3$, (v) 11 $dm^3$
(c) (i) 62 g, (ii) 2.1 g, (iii) 0.62 g, (iv) 280 g, (v) 0.11 g

***Lesson 8 – What is an empirical formula and how is it different from a molecular formula or a unit formula?***

**Summary Activity 8.1: Unit formula and molecular formula**

- Molecular formula: number of atoms of each element in one molecule: eg $C_6H_{12}O_6$ or $CO_2$
  Unit formula: simplest ratio of each particle in the compound: eg NaCl, $Ca(OH)_2$

### Test Your Knowledge 8.2: Empirical Formulae

a) ef: 62.08/12:10.34/1:27.58/16 = 5.17:10.34:1.72 = 3:6:1 so ef = $C_3H_6O$; efm = 58 and rmm = 58 so n = 58/58

b) ef: 22.02/12:4.59/1:27.73.39/79.9 = 1.84:4.59:0.92 = 2:5:1 so ef = $C_2H_5Br$

c) ef: 84.21/12: 15.79/1 = 7.01:15.79 = 1:2.25 = 4:9 so ef = $C_4H_9$; efm = 57 and rmm = 114 so n = 114/57 = 2 so mf = $C_8H_{18}O$

d) 7.8 – 0.6 = 7.2 g of C; ef: 72/12:6/1 = 6:6 = 1:1 so ef = CH; efm = 13 and rmm = 78 so n = 78/13 = 6 so mf = $C_6H_6$

e) ef: 3.36/55.8:1.44/16 = 0.06:0.09 = 1:1.5 = 2:3 so ef = $Fe_2O_3$

f) ef: 48.4/16:24.3/32.1:21.2/14:6/1/1 = 3.03:0.76:1.51:6.1 = 4:1:2:8 so ef = $O_4SN_2H_8$; unit formula = $(NH_4)_2SO_4$

*Lesson 9 – What are chemical equations and why are they useful?*

### Test your knowledge 9.1: Using equations to calculate numbers of moles

(a) (i) 0.01/2 = 0.005; (ii) 0.01/2 = 0.005

(b) (i) 0.5 x 3/2 = 0.75; (ii) 0.5 x 1 = 0.5

(c) (i) 0.05/4 = 0.0125; (ii) 0.05/2 = 0.025

### Online task 9.2: Illustrating the law of conservation of mass

### Test your knowledge 9.3: Balancing Chemical Equations

a) $N_2 + 3H_2 \rightarrow 2NH_3$

b) $4Na + O_2 \rightarrow 2Na_2O$

c) $2Al + 3Cl_2 \rightarrow 2AlCl_3$

d) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

e) $4HCl + O_2 \rightarrow 2Cl_2 + 2H_2O$

***Lesson 10 – How can we use chemical equations to predict reacting quantities?***

**Test your knowledge 10.1: Calculating Reacting Quantities**

a) moles of Mg = 1.94/24.3 = 0.08; moles of HCl = 0.16; volume of HCl = 0.16/0.5 = 0.32 $dm^3$ = 320 $cm^3$

b) moles of $H_2S$ = 8.5/34.1 = 0.25; moles of $O_2$ = 0.375;
volume of $O_2$ = 0.375 x 8.31 x 298/100000 = 9.3 x $10^{-3}$ $m^3$ = 9.3 $dm^3$

c) moles of K = 7.8/39.1 = 0.2; moles of $K_2O$ = 0.1; mass of $K_2O$ = 0.1 x 94.2 = 9.4 g

d) moles of $NH_3$ = 10/17 = 0.588; moles of $O_2$ = 0.588 x 5/4 = 0.735;
volume of $O_2$ = 0.735 x 8.31 x 298/100000 = 0.018 $m^3$ = 18 $dm^3$

e) moles of Al = 135/27 = 5; moles of $Al_2O_3$ = 2.5; mass of $Al_2O_3$ = 2.5 x 102 = 255 g

f) moles of $Cl_2$ = 100000 x 0.0024 /(8.31 x 298) = 0.097; moles of $I_2$ = 0.097; mass of $I_2$ = 0.097 x 253.8 = 25 g

g) moles of CuO = 32/79.5 = 0.4; moles of $H_2$ = 0.4;
volume of $H_2$ = 0.4 x 8.31 x 298 / 1000000 = 10 x $10^{-3}$ $m^3$ = 10 $dm^3$

h) moles of $KClO_3$ = 735/122.6 = 6; moles of $O_2$ = 9;
volume of $O_2$ = 9 x 8.31 x 298 / 1000000 = 0.222 $m^3$ = 222 $dm^3$

i) moles of K = 195/39.1 = 5; moles of $H_2$ = 2.5; volume of $H_2$ = 2.5 x 8.31 x 298 / 1000000 = 0.062 $m^3$ = 62 $dm^3$

j) moles of $CO_2$ = 100000 x 0.0012 /(8.31 x 298) = 0.048; moles of $CaCO_3$ = 0.048;
mass of $CaCO_3$ = 0.048 x 100.1 = 4.9 g

k) moles of $O_2$ = 0.006 x 100000 / (8.31 x 298) = 0.24; moles of MgO = 0.48; mass of MgO = 0.48 x 40.3 = 20 g

l) moles of $C_4H_8$ = 5.6/56 = 0.1; moles of $CO_2$ = 0.4;
volume of $CO_2$ = 0.4 x 8.31 x 298 / 100000 = 9.9 x $10^{-3}$ $m^3$ = 9.9 $dm^3$

m) moles of $SO_2$ = 100000 x 0.48 / (8.31 x 298) = 19.4; moles of $CaCO_3$ = 19.4;
mass of $CaCO_3$ = 19.4 x 100.1 = 1940 g = 19 kg

n) moles of HCl = 0.015 x 0.1 = 0.0015; moles of NaOH = 0.0015;
molarity of NaOH = 0.0015/0.025 = 0.06 $moldm^{-3}$

o) moles of $SiCl_4$ = 5/170.1 = 0.029; moles of $H_2O$ = 0.059; mass of $H_2O$ = 0.059 x 18 = 1.06 g

p) moles of $PH_3$ = 200/34 = 5.88; moles of $P_4$ = 5.88; mass of $P_4$ = 5.88 x 124 = 729 g

q) moles of $PbO_2$ = 37/2/239.2 = 0.156; moles of $PbCl_2$ = 0.156; mass of $PbCl_2$ = 0.167 x 278.2 = 43.3 g

r) moles of $Cu(NO_3)_2$ = 20/187.5 = 0.107; moles of CuO = 0.107; mass of CuO = 0.107 x 79.5 = 8.5 g

s) moles of NaOH = 0.025 x 0.1 = 0.0025; moles of HCl = 0.0025; molarity of HCl = 0.0025/0.05 = 0.05 $moldm^{-3}$

t) moles of NaOH = 0.025 x 0.1 = 0.0025; moles of HCl = 0.0025;
molarity of HCl = 0.0025/0.0273 = 0.092 $moldm^{-3}$

**Extension 10.2: Calculating Reacting Quantities**

a) moles of $AgNO_3$ = 0.015 x 0.02 = 3 x $10^{-4}$; moles of NaCl = 3 x $10^{-4}$; molarity of NaCl = 3 x $10^{-4}$ /0.01 = 0.03 $moldm^{-3}$; mass concentration = 0.03 x 58.5 = 1.8 $gdm^{-3}$

b) moles of $H_xA$ = 0.025 x 0.1 = 0.0025; moles of NaOH = 0.075 x 0.1 = 0.0075; 1:x = 0.0025:0.0075 so x = 0.0075/0.0025 = 3

c) moles of $CaCO_3$ = 1.3/100.1 = 0.013; moles of HCl = 0.026; molarity of acid = 0.026/0.025 = 1.0 $moldm^{-3}$

d) moles of $CaCO_3$ = 2.3/100.1 = 0.023; moles of HCl = 0.046; Volume of HCl = 0.046/0.1 = 0.46 $dm^3$ = 460 $cm^3$

e) moles of HCl = 0.0089 x 2 = 0.0178; moles of $X_2CO_3$ = 0.0089; Molar mass of $X_2CO_3$ = 2.05/0.0089 = 225 so ram of X = (225 – 60)/2 = 82.6 so X = Rb

f) (Moles of $Ca(NO_3)_2$ = 10/164.1 = 0.061; moles of $NO_2$ = 0.122; moles of $O_2$ = 0.030; (i) Volume of $NO_2$ = 0.122 x 8.31 x 298/100000 = 3.0 x $10^{-3}$ $m^3$ = 3.0 $dm^3$; (ii) volume of $O_2$ = 0.030 x 8.31 x 298/100000 = 7.5 x $10^{-4}$ $m^3$ = 0.75 $dm^3$; (iii) Total volume of gas = 3.8 $dm^3$

g) Moles of $H_2O_2$ = 0.1 x 0.03 = 0.003 so moles of $O_2$ = 0.003/2 = 0.0015; Volume of $O_2$ = 0.0015 x 8.31 x 298 / 100000 = 3.7 x $10^{-3}$ $m^3$ = 37 $cm^3$

h) moles of $PbO_2$ = 37.2/239.2 = 0.156; moles of HCl = 0.311; moles of $Cl_2$ = 0.156; moles of $PbCl_2$ = 0.156; (i) volume of HCl = 0.311/12 = 0.026 $dm^3$ = 26 $cm^3$; (ii) mass of $PbCl_2$ = 278.2 x 0.156 = 43 g; (iii) volume of $Cl_2$ = 0.156 x 8.31 x 298/100000 = 3.9 x $10^{-3}$ $m^3$ = 3.9 $dm^3$

i) Moles of $H_2$ = 100 x $10^{-6}$ x 100000 /(298 x 8.31) = 0.0040; moles of Mg = 0.0040; moles of HCl = 0.0081; Mass of Mg = 0.04 x 24.3 = 0.098 g; volume of HCl = 0.0081/2 = 0.004 $dm^3$ = 4 $cm^3$

j) Moles of Na = 0.52/23 = 0.023; moles of $H_2$ = 0.011; moles of NaOH = 0.023; (ii) Volume of $H_2$ = 0.011 x 8.31 x 298 / 100000 = 2.8 x $10^{-4}$ $m^3$ = 0.28 $dm^3$ = 280 $cm^3$; (ii) Molarity of NaOH = 0.023/0.1 = 0.23 $moldm^{-3}$

k) Moles of Ti = 2.5/47.9 = 0.0522; moles of $Cl_2$ = PV/RT = (100000 x 0.00194)/(8.31 x 298) = 0.0783; mole ratio $Cl_2$: Ti = 0.0783/0.0522 = 1.5:1 so Ti + 1.5$Cl_2$ → $TiCl_3$

***Lesson 11 – What have I understood about Amount of Substance and Measurement?***

**11.1 END-OF-TOPIC QUIZ**
**UNIT 3 – AMOUNT OF SUBSTANCE AND MEASUREMENT**

1. Mass (kg); temperature (K); time (s); amount (mol)
2. Volume ($m^3$, $m^3$); molarity ($molm^{-3}$, $molm^{-3}$); pressure (Pa, $kgm^{-1}s^{-2}$)
3. Temperature – thermometer; time – stopclock; gas volume – gas syringe
4. ef = $C_2H_5$; mf = $C_4H_{10}$
5. ef = $MgO_2H_2$; mf = $Mg(OH)_2$
6. Mass required = 100/65 x 63 x 0.25 x 0.1 = 2.42 g
   Weigh out 2.42 g of the acid and add to 100 $cm^3$ of water in a beaker, stir well, transfer into a volumetric flask, make up to 250 $cm^3$ using washings from beaker
7. Dilution factor = 6/0.5 = 12 so volume needed = 250/12 = 20.8 $cm^3$
8. $N_2 + 3H_2 \rightarrow 2NH_3$
9. 3 moles of $H_2$ makes 2 moles of $NH_3$ so 0.06 moles of $H_2$ makes 0.04 moles of $NH_3$
10. 1.08 $dm^3$
11. 53.3 $cm^3$
12. 1.49 $dm^3$