

UNIT 3

AMOUNT OF SUBSTANCE AND MEASUREMENT

Answers

Lesson 1 – Why are practicals important?



Activity 1.1: Understanding 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) $2.5 \times 10^{-5} \text{ m}^3$; (ii) $3.2 \times 10^{-3} \text{ m}^3$; (iii) $3.4 \times 10^{-4} \text{ m}^3$, (d) $1.5 \times 10^{-4} \text{ m}^3$, (e) 0.12 m^3
(c) (i) 250 dm³; (ii) 3200 dm³; (iii) 0.025 dm³; (iv) 0.15 dm³; (v) $6.2 \times 10^{-3} \text{ dm}^3$
(d) (i) $2.5 \times 10^5 \text{ cm}^3$, (b) $3.2 \times 10^6 \text{ cm}^3$, (c) 400 cm³, (d) 15 cm³, (e) 6200 cm³

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) kgm²s⁻²
(c) Power (= voltage x current) kgm²s⁻³
(d) Momentum (= mass x velocity) kgms⁻¹
(e) Rate of reaction (= concentration / time) molm⁻³s⁻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

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



Practical 3.1: Comparing the densities of pure water and salt water

Equipment needed per group: 100 cm³ measuring cylinder, funnel, access to a mass balance, access to tap water, access to brine (50 cm³ 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: Measuring the density of sand

Equipment needed per group: 2 x 100 cm³ measuring cylinders, access to a mass balance, access to tap water, access to sand, 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 x 10⁻³ (b) 1.5 x 10²³ (c) 0.05 (d) 1.2 x 10²² (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) (i) 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



Practical 5.2: Preparing 250 cm³ of 0.1 mol dm⁻³ standard solutions of sodium chloride (NaCl) and sugar (C₁₂H₂₂O₁₁)

Equipment needed per group: 250 cm³ beaker, distilled water bottle, spatula, stirring rod, funnel, 250 cm³ volumetric flask, weighing boat, access to 2 dp mass balance, access to NaCl, access to sugar

- Mass of salt needed = $58.5 \times 0.25 \times 0.1 = 1.46 \text{ g}$
- Mass of sugar needed = $342 \times 0.25 \times 0.1 = 8.55 \text{ g}$

It may 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: Preparing 250 cm³ of a 0.1 mol dm⁻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 cm³), one dropping pipette; one mass balance (2dp); one 250 cm³ volumetric flask, one funnel

- 1) Weigh out 2.53 g of concentrated HCl (put one of the small beakers onto the mass 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 cm³ 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 cm³ of a 0.1 mol dm⁻³ solution of hydrogen peroxide by diluting a 2.0 mol dm⁻³ solution

Equipment needed per group: around 20 cm³ 2.0 mol dm⁻³ H₂O₂ or closest concentration available; one 25 cm³ measuring cylinder, one dropping pipette, beaker (250 cm³), one 250 cm³ volumetric flask, one funnel

- 1) dilution factor = $2/0.1 = 20$ so volume needed = $250/20 = 12.5 \text{ cm}^3$
- 2) Use a dropping pipette for the final 2 – 3 cm³ of H₂O₂
- 3) Use washings from the measuring cylinder



Test your knowledge 6.3: Preparing standard solutions by dilution

- (a) Moles needed = $250/1000 \times 0.1 = 0.025$; mass of pure HNO₃ = $0.025 \times 63 = 1.58 \text{ g}$; mass of conc. HNO₃ = $100/65 \times 1.58 = 2.42 \text{ g}$
- (b) Moles of NaOH = $5/1000 \times 6 = 0.03$; total volume of diluted solution = $0.03/0.1 = 0.3 \text{ dm}^3 = 300 \text{ cm}^3$; So $300 - 5 = 295 \text{ cm}^3$ of water must be added

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's 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 dm³, (b) 7.2 dm³, (c) 24 dm³, (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: Measuring 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 measuring cylinder), thermometer 50 cm³ measuring cylinder, access to mass balance, access to 2.0 moldm⁻³ HCl and marble chips

Using the measuring cylinder, pour around 50 cm³ 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 cm³ 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 cm³ = $6.5 \times 10^{-5} \text{ m}^3$ (use class measurement); number of moles of gas produced = $(100,000 \times 6.5 \times 10^{-5}) / (8.31 \times 293) = 2.7 \times 10^{-3}$ moles (this is an example using V = 65 cm³ 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 dm³, (ii) 6.2 dm³, (iii) 9.1 dm³, (iv) 2.5 dm³, (v) 11 dm³

(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 C₆H₁₂O₆ or CO₂
- 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) $0.5 \times 3/2 = 0.75$; (ii) $0.5 \times 1 = 0.5$
- (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) $4HCl + O_2 \rightarrow 2Cl_2 + 2H_2O$



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 = $0.16/0.5 = 0.32 \text{ dm}^3 = 320 \text{ cm}^3$
- b) moles of H₂S = $8.5/34.1 = 0.25$; moles of O₂ = 0.375;
volume of O₂ = $0.375 \times 8.31 \times 298/100000 = 9.3 \times 10^{-3} \text{ m}^3 = 9.3 \text{ dm}^3$
- c) moles of K = $7.8/39.1 = 0.2$; moles of K₂O = 0.1; mass of K₂O = $0.1 \times 94.2 = 9.4 \text{ g}$
- d) moles of NH₃ = $10/17 = 0.588$; moles of O₂ = $0.588 \times 5/4 = 0.735$;
volume of O₂ = $0.735 \times 8.31 \times 298/100000 = 0.018 \text{ m}^3 = 18 \text{ dm}^3$
- e) moles of Al = $135/27 = 5$; moles of Al₂O₃ = 2.5; mass of Al₂O₃ = $2.5 \times 102 = 255 \text{ g}$
- f) moles of Cl₂ = $100000 \times 0.0024 / (8.31 \times 298) = 0.097$; moles of I₂ = 0.097; mass of I₂ = $0.097 \times 253.8 = 25 \text{ g}$
- g) moles of CuO = $32/79.5 = 0.4$; moles of H₂ = 0.4;
volume of H₂ = $0.4 \times 8.31 \times 298 / 1000000 = 10 \times 10^{-3} \text{ m}^3 = 10 \text{ dm}^3$
- h) moles of KClO₃ = $735/122.6 = 6$; moles of O₂ = 9;
volume of O₂ = $9 \times 8.31 \times 298 / 1000000 = 0.222 \text{ m}^3 = 222 \text{ dm}^3$
- i) moles of K = $195/39.1 = 5$; moles of H₂ = 2.5; volume of H₂ = $2.5 \times 8.31 \times 298 / 1000000 = 0.062 \text{ m}^3 = 62 \text{ dm}^3$
- j) moles of CO₂ = $100000 \times 0.0012 / (8.31 \times 298) = 0.048$; moles of CaCO₃ = 0.048;
mass of CaCO₃ = $0.048 \times 100.1 = 4.9 \text{ g}$
- k) moles of O₂ = $0.006 \times 100000 / (8.31 \times 298) = 0.24$; moles of MgO = 0.48; mass of MgO = $0.48 \times 40.3 = 20 \text{ g}$
- l) moles of C₄H₈ = $5.6/56 = 0.1$; moles of CO₂ = 0.4;
volume of CO₂ = $0.4 \times 8.31 \times 298 / 100000 = 9.9 \times 10^{-3} \text{ m}^3 = 9.9 \text{ dm}^3$
- m) moles of SO₂ = $100000 \times 0.48 / (8.31 \times 298) = 19.4$; moles of CaCO₃ = 19.4;
mass of CaCO₃ = $19.4 \times 100.1 = 1940 \text{ g} = 19 \text{ kg}$
- n) moles of HCl = $0.015 \times 0.1 = 0.0015$; moles of NaOH = 0.0015;
molarity of NaOH = $0.0015/0.025 = 0.06 \text{ moldm}^{-3}$
- o) moles of SiCl₄ = $5/170.1 = 0.029$; moles of H₂O = 0.059; mass of H₂O = $0.059 \times 18 = 1.06 \text{ g}$
- p) moles of PH₃ = $200/34 = 5.88$; moles of P₄ = 5.88; mass of P₄ = $5.88 \times 124 = 729 \text{ g}$
- q) moles of PbO₂ = $37/2/239.2 = 0.156$; moles of PbCl₂ = 0.156; mass of PbCl₂ = $0.167 \times 278.2 = 43.3 \text{ g}$
- r) moles of Cu(NO₃)₂ = $20/187.5 = 0.107$; moles of CuO = 0.107; mass of CuO = $0.107 \times 79.5 = 8.5 \text{ g}$
- s) moles of NaOH = $0.025 \times 0.1 = 0.0025$; moles of HCl = 0.0025; molarity of HCl = $0.0025/0.05 = 0.05 \text{ moldm}^{-3}$
- t) moles of NaOH = $0.025 \times 0.1 = 0.0025$; moles of HCl = 0.0025;
molarity of HCl = $0.0025/0.0273 = 0.092 \text{ moldm}^{-3}$



Extension 10.2: Calculating Reacting Quantities

- a) moles of $\text{AgNO}_3 = 0.015 \times 0.02 = 3 \times 10^{-4}$; moles of $\text{NaCl} = 3 \times 10^{-4}$; molarity of $\text{NaCl} = 3 \times 10^{-4} / 0.01 = 0.03 \text{ mol dm}^{-3}$; mass concentration = $0.03 \times 58.5 = 1.8 \text{ g dm}^{-3}$
- b) moles of $\text{H}_2\text{A} = 0.025 \times 0.1 = 0.0025$; moles of $\text{NaOH} = 0.075 \times 0.1 = 0.0075$; $1:x = 0.0025:0.0075$ so $x = 0.0075/0.0025 = 3$
- c) moles of $\text{CaCO}_3 = 1.3/100.1 = 0.013$; moles of $\text{HCl} = 0.026$; molarity of acid = $0.026/0.025 = 1.0 \text{ mol dm}^{-3}$
- d) moles of $\text{CaCO}_3 = 2.3/100.1 = 0.023$; moles of $\text{HCl} = 0.046$; Volume of $\text{HCl} = 0.046/0.1 = 0.46 \text{ dm}^3 = 460 \text{ cm}^3$
- e) moles of $\text{HCl} = 0.0089 \times 2 = 0.0178$; moles of $\text{X}_2\text{CO}_3 = 0.0089$; Molar mass of $\text{X}_2\text{CO}_3 = 2.05/0.0089 = 225$ so $\text{ram of X} = (225 - 60)/2 = 82.6$ so $\text{X} = \text{Rb}$
- f) (Moles of $\text{Ca}(\text{NO}_3)_2 = 10/164.1 = 0.061$; moles of $\text{NO}_2 = 0.122$; moles of $\text{O}_2 = 0.030$; (i) Volume of $\text{NO}_2 = 0.122 \times 8.31 \times 298/100000 = 3.0 \times 10^{-3} \text{ m}^3 = 3.0 \text{ dm}^3$; (ii) volume of $\text{O}_2 = 0.030 \times 8.31 \times 298/100000 = 7.5 \times 10^{-4} \text{ m}^3 = 0.75 \text{ dm}^3$; (iii) Total volume of gas = 3.8 dm^3
- g) Moles of $\text{H}_2\text{O}_2 = 0.1 \times 0.03 = 0.003$ so moles of $\text{O}_2 = 0.003/2 = 0.0015$; Volume of $\text{O}_2 = 0.0015 \times 8.31 \times 298 / 100000 = 3.7 \times 10^{-3} \text{ m}^3 = 37 \text{ cm}^3$
- h) moles of $\text{PbO}_2 = 37.2/239.2 = 0.156$; moles of $\text{HCl} = 0.311$; moles of $\text{Cl}_2 = 0.156$; moles of $\text{PbCl}_2 = 0.156$; (i) volume of $\text{HCl} = 0.311/12 = 0.026 \text{ dm}^3 = 26 \text{ cm}^3$; (ii) mass of $\text{PbCl}_2 = 278.2 \times 0.156 = 43 \text{ g}$; (iii) volume of $\text{Cl}_2 = 0.156 \times 8.31 \times 298/100000 = 3.9 \times 10^{-3} \text{ m}^3 = 3.9 \text{ dm}^3$
- i) Moles of $\text{H}_2 = 100 \times 10^{-6} \times 100000 / (298 \times 8.31) = 0.0040$; moles of $\text{Mg} = 0.0040$; moles of $\text{HCl} = 0.0081$; Mass of $\text{Mg} = 0.04 \times 24.3 = 0.98 \text{ g}$; volume of $\text{HCl} = 0.0081/2 = 0.004 \text{ dm}^3 = 4 \text{ cm}^3$
- j) Moles of $\text{Na} = 0.52/23 = 0.023$; moles of $\text{H}_2 = 0.011$; moles of $\text{NaOH} = 0.023$; (i) Volume of $\text{H}_2 = 0.011 \times 8.31 \times 298 / 100000 = 2.8 \times 10^{-4} \text{ m}^3 = 0.28 \text{ dm}^3 = 280 \text{ cm}^3$; (ii) Molarity of $\text{NaOH} = 0.023/0.1 = 0.23 \text{ mol dm}^{-3}$

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



- Mass (kg); temperature (K); time (s); amount (mol)
- Volume (m^3 , m^3); molarity (mol m^{-3} , mol m^{-3}); pressure (Pa, $\text{kg m}^{-1} \text{s}^{-2}$)
- Temperature – thermometer; time – stopclock; gas volume – gas syringe
- $e_f = \text{C}_2\text{H}_5$; $m_f = \text{C}_4\text{H}_{10}$
- $e_f = \text{MgO}_2\text{H}_2$; $m_f = \text{Mg}(\text{OH})_2$
- Mass required = $100/65 \times 63 \times 0.25 \times 0.1 = 2.42 \text{ g}$
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
- Dilution factor = $6/0.5 = 12$ so volume needed = $250/12 = 20.8 \text{ cm}^3$
- $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$
- 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
- 1.08 dm^3
- 53.3 cm^3
- 1.49 dm^3