Mastering Chemistry

- Book 4A
- Topic 10 Rate of Reaction

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- Key terms
- Summary
- Unit Exercise

36.1 Rate of reaction (p.2)

- Some chemical reactions happen in an instant: explosion.
- Other reactions take seonds, minutes, hours or even years: rusting or rotting of food.

36.1 Rate of reaction (p.2)

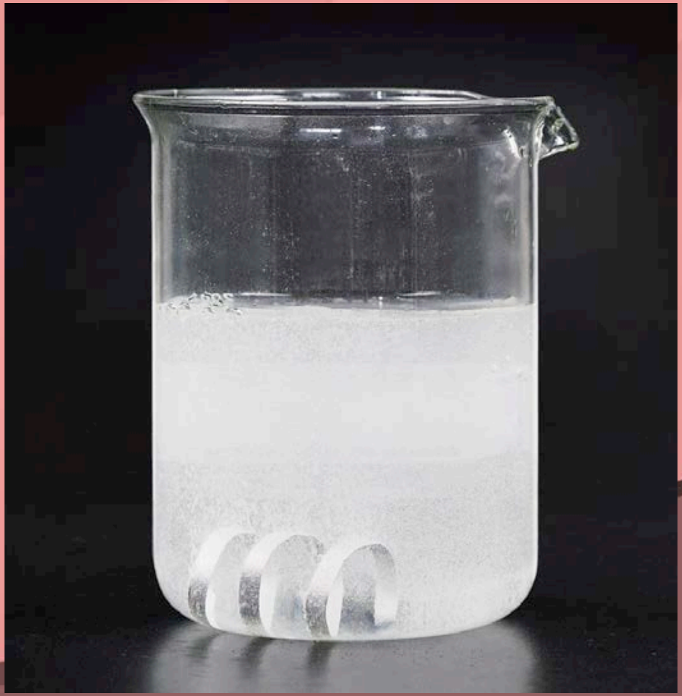
- Your pulse rate is the number of times your heart beats every minute.
- You can measure the rate of a reaction by finding the amount of a reactant used up or the amount of a product produced per unit time.
- **Chemical kinetics (化學動力學)** is the branch of chemistry that measures the rates of chemical reactions, studies the factors that influence the rates, and interprets the results at the molecular level.
- It is important because industrial chemists need to know how fast a reaction goes. They have to find out exactly how much of their products they can make each hour, day or week.

36.2 Measuring the rate of reaction (p.3)

- When magnesium is added to dilute sulphuric acid, they react to give magnesium sulphate and hydrogen:

$$Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$$

- Both magnesium and sulphuric acid get used up in the reaction. At the same time, magnesium sulphate and hydrogen form.

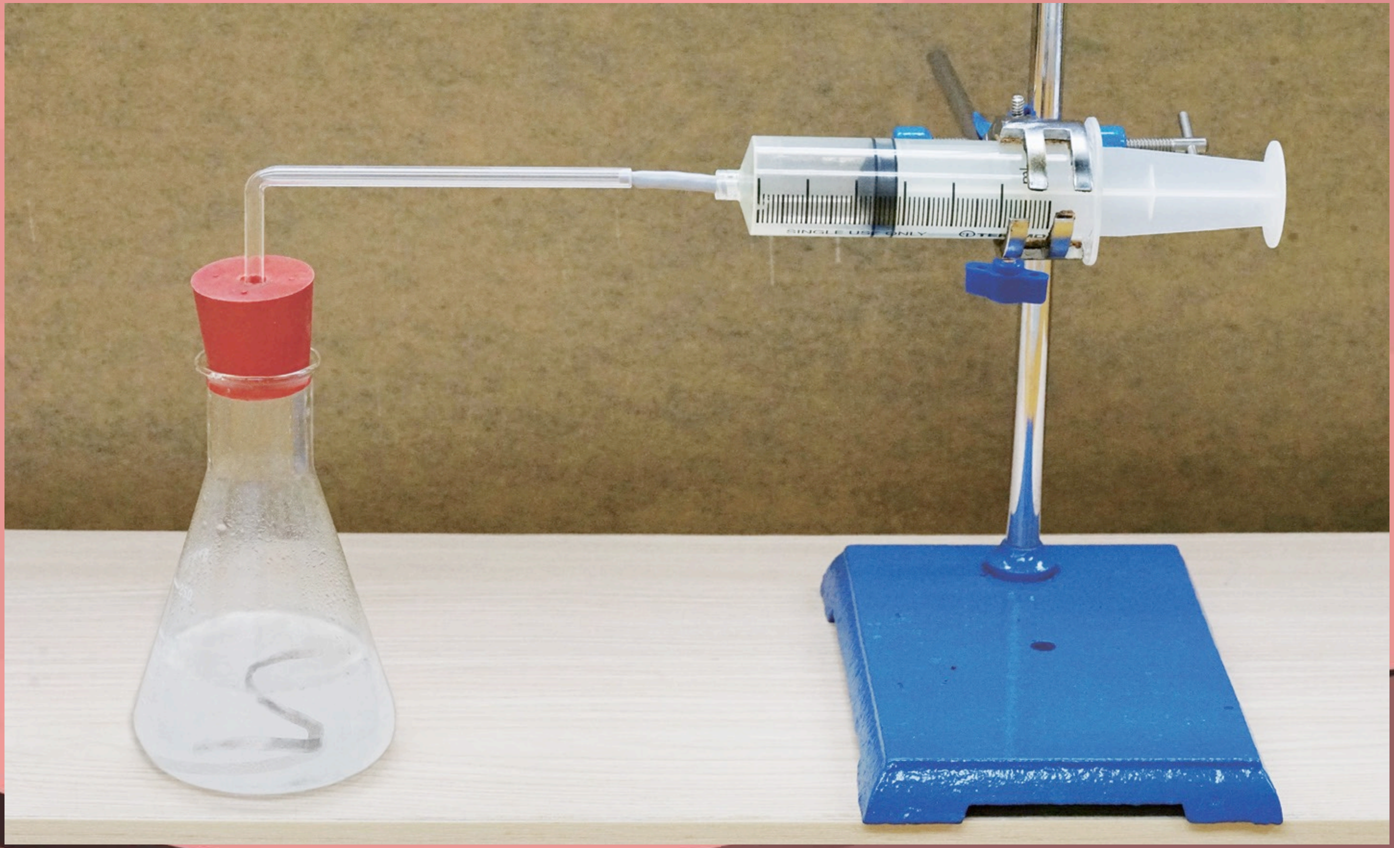


36.2 Measuring the rate of reaction (p.3)

- The rate of the reaction can be measured by measuring:
  - the amount of magnesium used up per second; or
  - the amount of sulphuric acid used up per second; or
  - the amount of magnesium sulphate formed per second; or
  - the amount of hydrogen formed per second.
- For this reaction, it is easier to measure the amount of hydrogen formed per second, since it is the only gas that forms. It can be collected as it bubbles off, and its volume can be measured.

36.2 Measuring the rate of reaction (p.3)

- The total volume of gas in the gas syringe is measured every 10 seconds. Suppose excess dilute sulphuric acid is used. The reaction ends when all the magnesium is used up.



36.2 Measuring the rate of reaction (p.3)

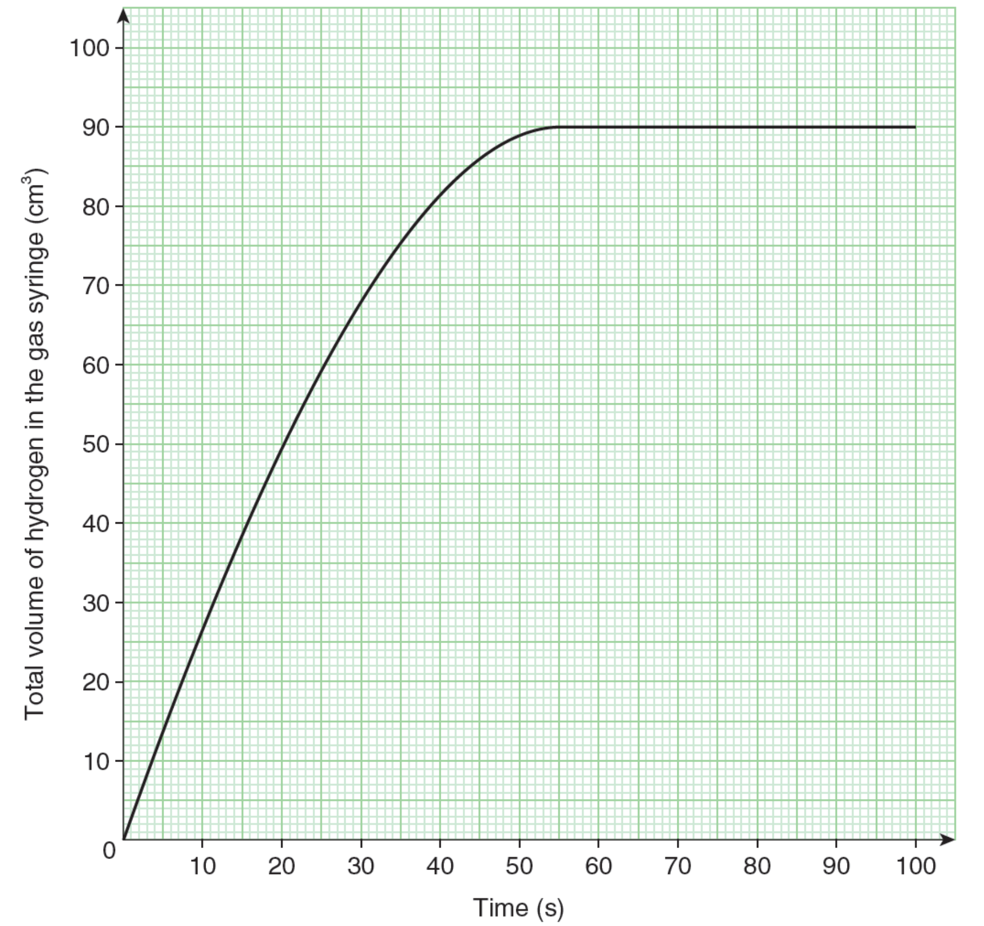
- Sample data for this experiment are shown.

Table 36.1 Sample data for the reaction between magnesium and dilute sulphuric acid

Time (s)	0	10	20	30	40	50	60	70	80	90	100
Total volume of H_2 (cm^3)	0.0	26.0	50.0	68.0	81.0	89.0	90.0	90.0	90.0	90.0	90.0

36.2 Measuring the rate of reaction (p.3)

- The reaction finishes at 60 s because no more gas is produced after that. The **average rate (平均速率)** of reaction during the first 60 s can be worked out as:



Average rate

$$= \frac{change\ in\ volume}{time} = \frac{90.0\ cm^3}{60\ s}$$

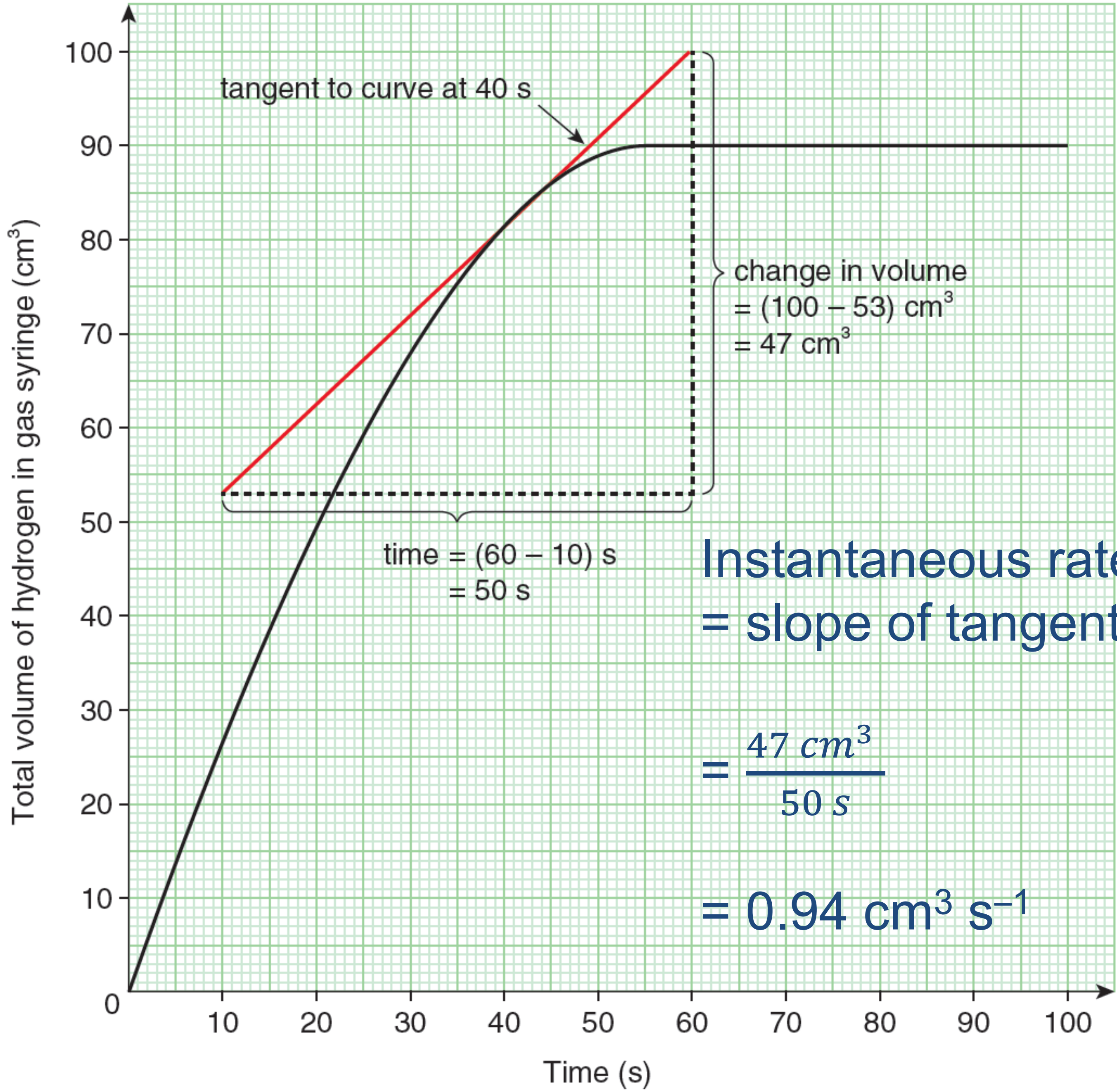
$= 1.5\ cm^3\ s^{-1}$

36.2 Measuring the rate of reaction (p.3)

Instantaneous rate of reaction

- The rate of a reaction at a particular time is called the **instantaneous rate (瞬間速率)**. Graphically, the instantaneous rate of reaction at a particular time equals the **slope of the tangent (切線的斜率)** to the curve at that time.

- You can work out the instantaneous rate at 40 s by determining the slope of the tangent to the curve at that time.



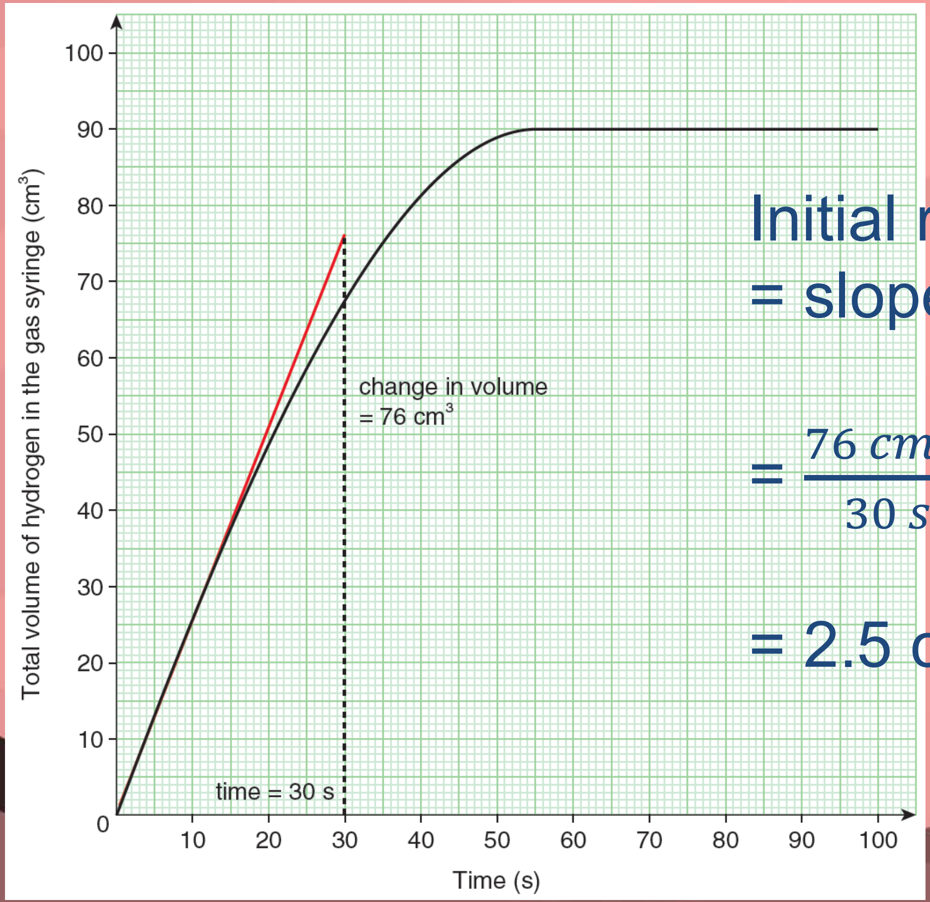
Instantaneous rate at 40 s
= slope of tangent to curve at 40 s

$$= \frac{47\ cm^3}{50\ s}$$

$= 0.94\ cm^3\ s^{-1}$

36.2 Measuring the rate of reaction (p.3)

- The **initial rate (初速)** is the instantaneous rate at time = 0 s. You can work this out by determining the slope of the tangent to the curve at time = 0 s.



Initial rate

= slope of tangent to curve at 0 s

$= \frac{76\ cm^3}{30\ s}$

$= 2.5\ cm^3\ s^{-1}$

36.2 Measuring the rate of reaction (p.3)

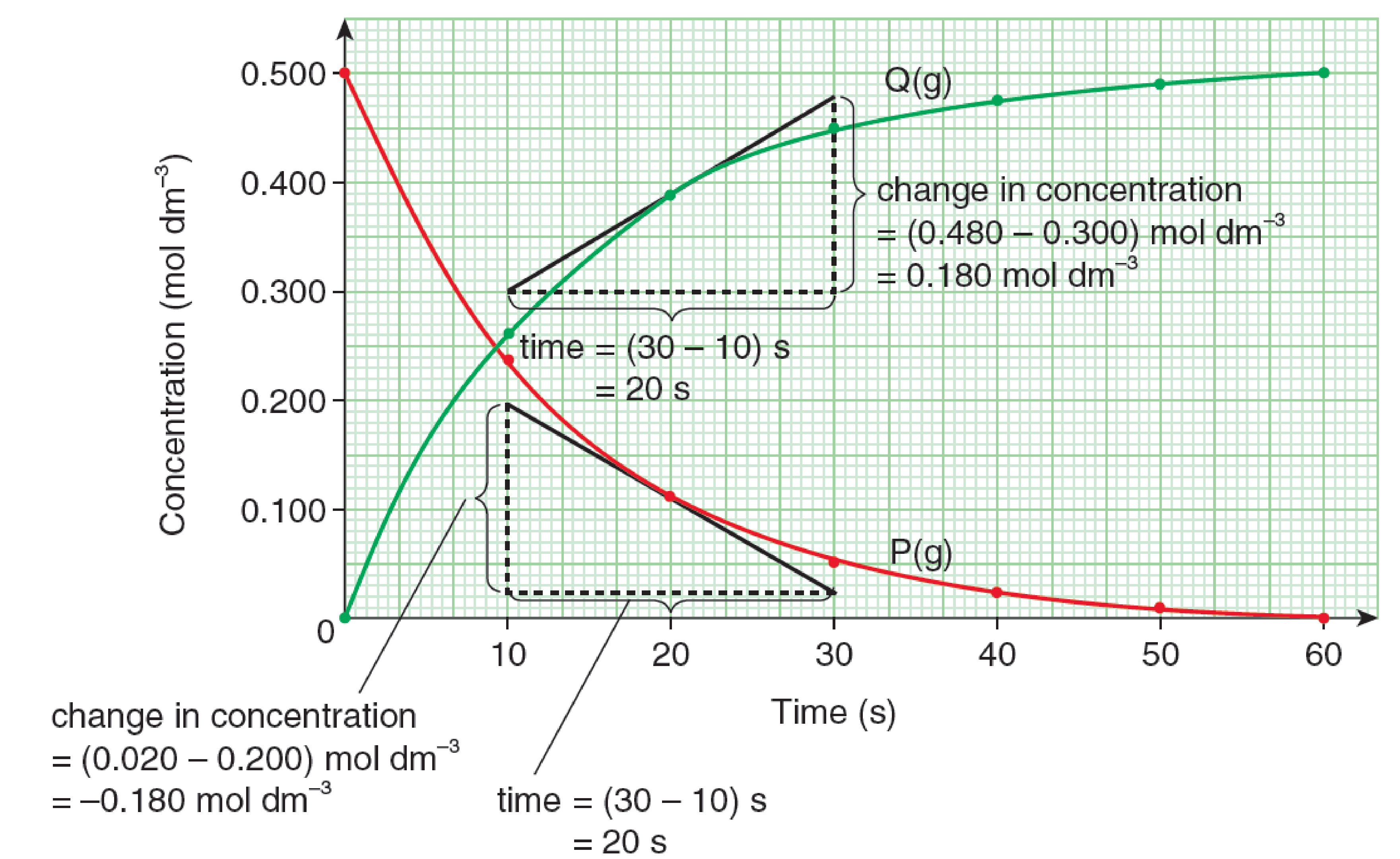
- Although the rate of the above reaction is calculated by using change in volume, rates are most often considered in terms of changing concentrations.
- Rate of reaction is the change in concentration (or amount) of a reactant or a product per unit time.

$$\text{Rate} = \frac{\textit{change in concentration (or amount) of a reactant or a product}}{\textit{time}}$$

36.2 Measuring the rate of reaction (p.3)

- Units for rate of reaction are
  mol dm^{-3} s^{-1}, mol dm^{-3} min^{-1}, mol s^{-1}, cm^3 s^{-1}, etc.
- Consider P(g) → Q(g) in a closed container.
- The rate at which P(g) is consumed is equal to the rate at which Q is formed.

36.2 Measuring the rate of reaction (p.3)



36.2 Measuring the rate of reaction (p.3)

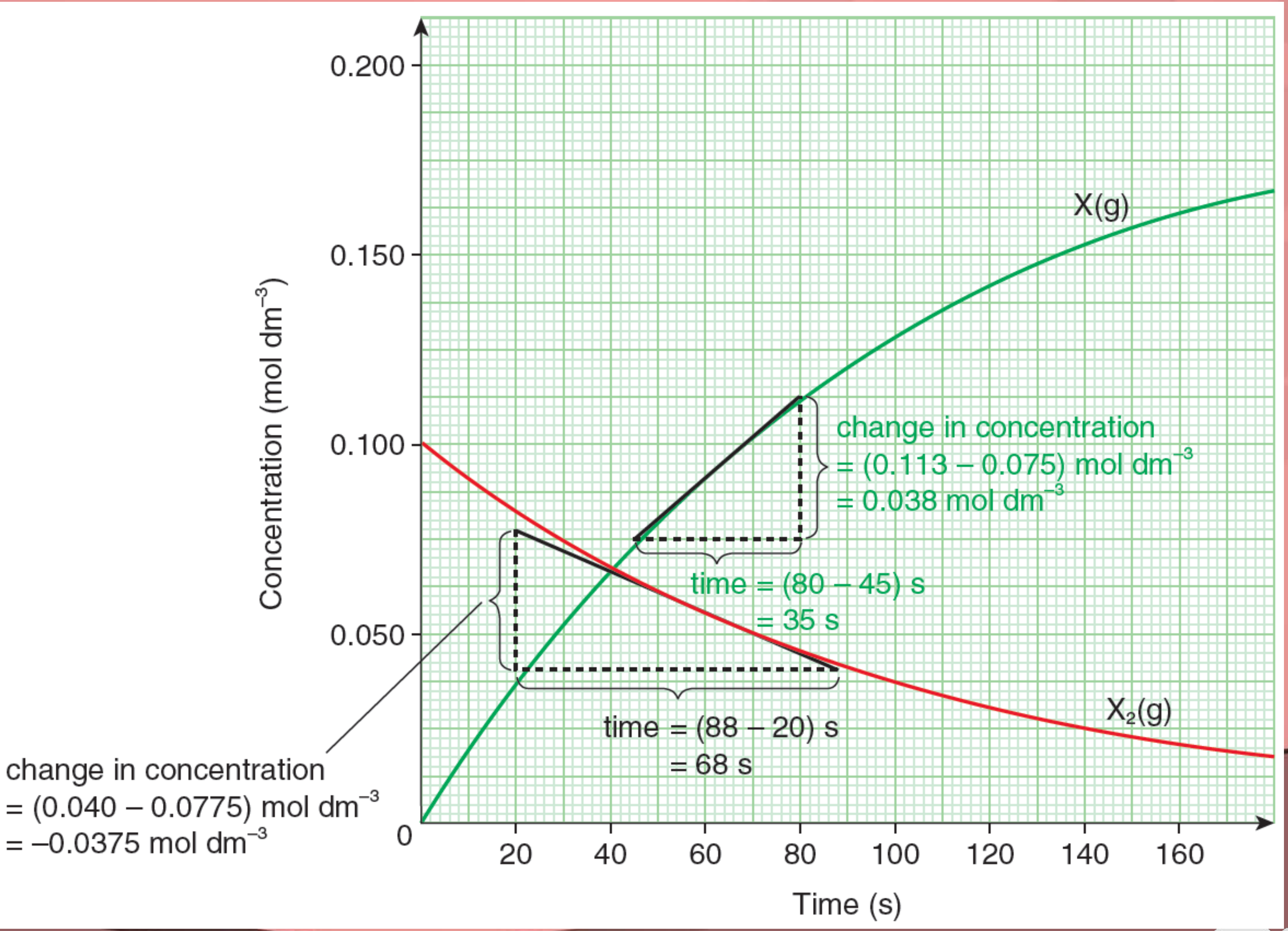
- instantaneous rate of consumption of P(g) at 20 s
  = –(slope of tangent to curve for P(g) (in red) at 20 s)
  $= -\dfrac{(-0.180\ mol\ dm^{-3})}{20\ s}$ = 0.0090 mol dm^{-3} s^{-1}

- The concentration of reactant P(g) decreases with time. Thus, the change in concentration of P(g) within a given time period is a negative value. As it is usual to work with positive reaction rates, a negative sign is introduced in the above expression so as to make the rate a positive value.

- instantaneous rate of formation of Q(g) at 20 s
  = slope of tangent to curve for Q(g) (in green) at 20 s
  $= \dfrac{0.180\ mol\ dm^{-3}}{20\ s}$ = 0.0090 mol dm^{-3} s^{-1}

36.2 Measuring the rate of reaction (p.3)

- Consider $X_2(g) \rightarrow 2X(g)$ in a closed container.



36.2 Measuring the rate of reaction (p.3)

- instantaneous rate of decomposition of $X_2(g)$ at 60 s
  = –(slope of tangent to curve for $X_2(g)$ (in red) at 60 s)
  $= -\frac{(-0.0375\ mol\ dm^{-3})}{68\ s}$ = 5.5×10^{-4} mol dm^{-3} s^{-1}

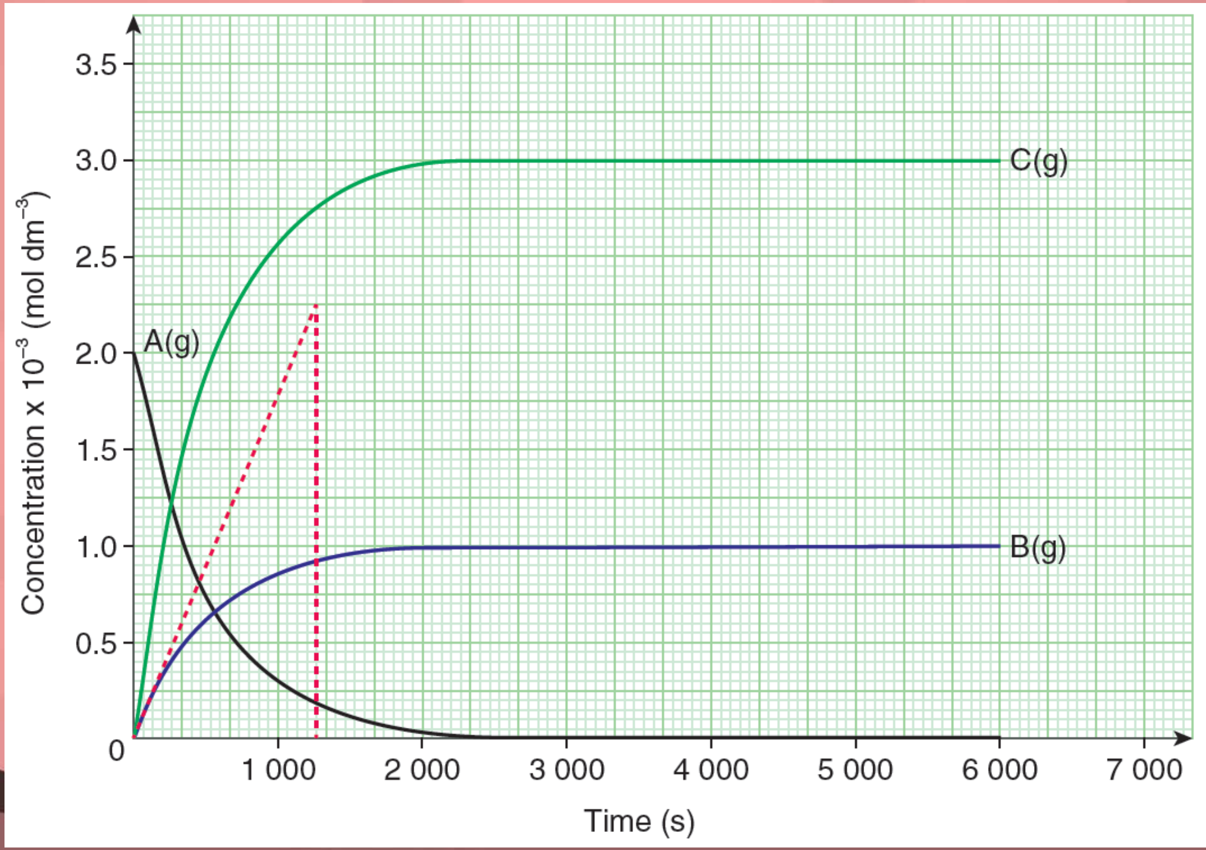
- instantaneous rate of formation of X(g) at 60 s
  = slope of tangent to curve for X(g) (in green) at 60 s
  $= \frac{0.038\ mol\ dm^{-3}}{35\ s}$ = 1.1×10^{-3} mol dm^{-3} s^{-1}

- The rate of formation of X(g) is twice the rate of decomposition of $X_2(g)$ because one mole of $X_2(g)$ decomposes to form two moles of X(g).

36.2 Measuring the rate of reaction (p.3)

Practice 36.1

A(g) decomposes to form B(g) and C(g). A(g) is allowed to decompose in a closed container at constant temperature. The graph below shows the variations of concentrations of the three gases in the container with time.



36.2 Measuring the rate of reaction (p.3)

a) Write a chemical equation for the reaction.

$2A(g) \rightarrow B(g) + 3C(g)$

b) Determine the average rate of consumption of A(g) in the first 1 000 s.

average rate of consumption of A(g) in the first 1 000 s

$$= -\frac{(-0.3 - 2.0) \times 10^{-3}\ mol\ dm^{-3}}{1\,000\ s} = 1.7 \times 10^{-6}\ \text{mol dm}^{-3}\ \text{s}^{-1}$$

c) Determine the initial rate of formation of B(g).

initial rate of formation of B(g)

$$= \frac{2.25 \times 10^{-3}\ mol\ dm^{-3}}{1\,270\ s} = 1.77 \times 10^{-6}\ \text{mol dm}^{-3}\ \text{s}^{-1}$$

36.2 Measuring the rate of reaction (p.3)

2 Ammonia can react with oxygen according to the equation below:

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$$

$NH_3(g)$ and $O_2(g)$ are allowed to react in a closed container. Find the instantaneous rate of consumption of $O_2(g)$ if the instantaneous rate of formation of NO(g) is 1.32×10^{-4} mol dm^{-3} s^{-1}.

instantaneous rate of consumption of $O_2(g)$

$= \frac{5}{4}(1.32 \times 10^{-4})$ mol dm^{-3} s^{-1} $= 1.65 \times 10^{-4}$ mol dm^{-3} s^{-1}

36.3 Methods for following the progress of a reaction (p.10)

- To measure the rate of a reaction, it is necessary to find out how fast one of the products is being formed or how fast one of the reactants is being used up.
- This can be achieved by using a physical method. A physical method depends on a change in physical property during the course of the reaction, such as:
  - change in the volume of a gaseous product;
  - change in the mass of the reaction mixture;
  - change in the pressure of the reaction mixture;
  - change in the colour intensity of the reaction mixture.

36.4 Following the progress of a reaction by measuring the change in volume of a gaseous product (p.10)

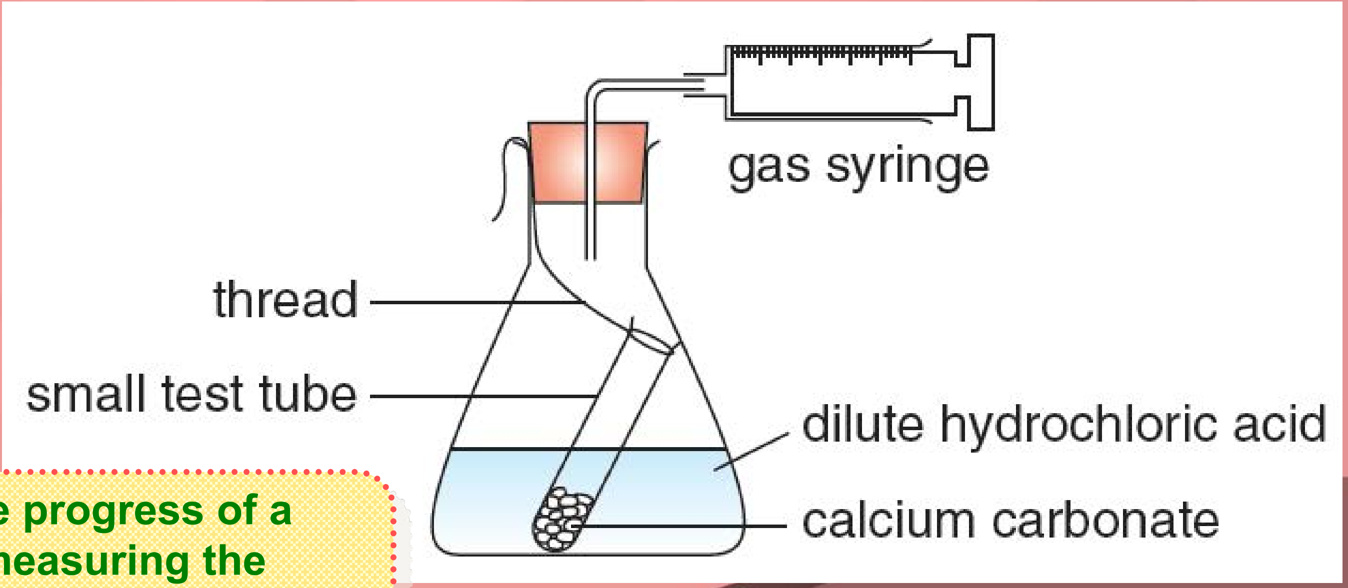
- Consider this reaction:

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

- One way of following the progress of this reaction is by measuring the volume of carbon dioxide released at regular time intervals.

36.4 Following the progress of a reaction by measuring the change in volume of a gaseous product (p.10)

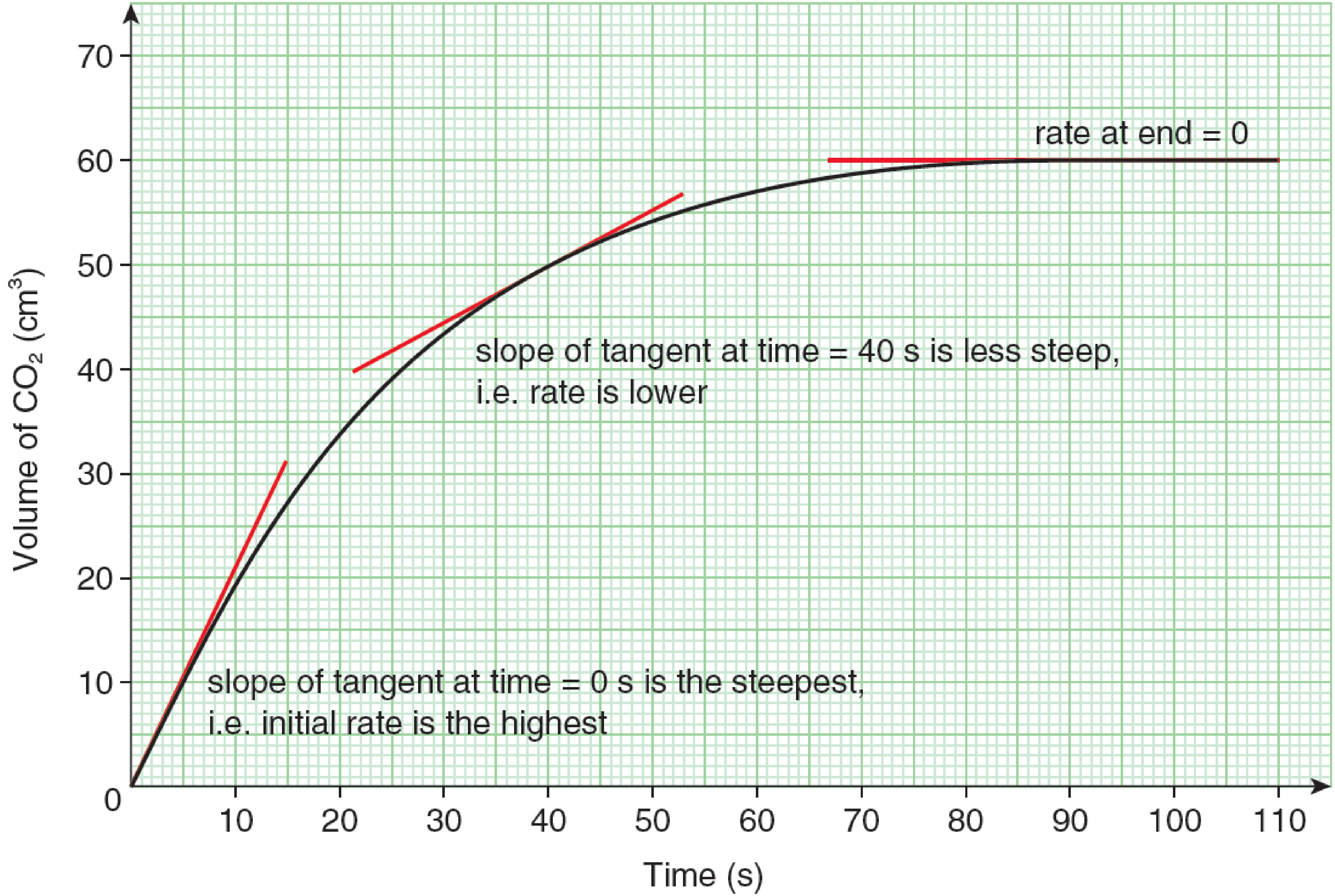
- This arrangement ensures that the two reactants are kept separate while the apparatus is set up so that the start time can be accurately recorded.



Following the progress of a reaction by measuring the change in volume of a gaseous product

36.4 Following the progress of a reaction by measuring the change in volume of a gaseous product (p.10)

- Mix the reactants and start the stopwatch at the same time. Record the volume of carbon dioxide released every 10 seconds until the reaction finishes.


rate at end = 0
slope of tangent at time = 40 s is less steep,
i.e. rate is lower
slope of tangent at time = 0 s is the steepest,
i.e. initial rate is the highest
Volume of CO_2 (cm^3)
Time (s)
0
10
20
30
40
50
60
70
80
90
100
110

36.4 Following the progress of a reaction by measuring the change in volume of a gaseous product (p.10)

Notice:

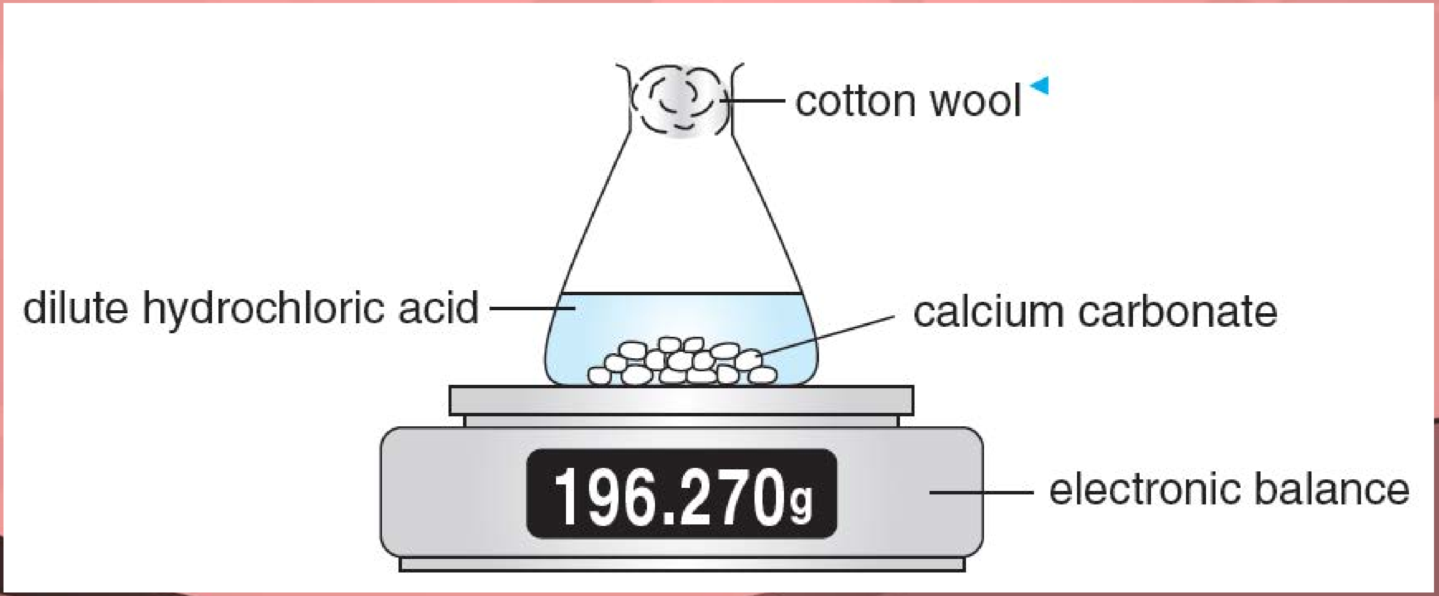
- The rate of reaction changes during the course of the reaction.
- The slope of the tangent to the curve at time = 0 s is the steepest. So the initial rate is the highest.
- The slope of the tangent to the curve at time = 40 s is less steep. So the rate at this point is lower.
- The reaction finishes at 90 s because no more gas is produced after that. When the reaction is over, the curve goes flat.

36.4 Following the progress of a reaction by measuring the change in volume of a gaseous product (p.10)

- Suppose excess dilute hydrochloric acid is used, the reaction finishes when all the calcium carbonate is used up.
- Notice that this method can be used to follow the progress of any reaction with one gaseous product.

36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)

- An alternative method of following the progress of the reaction between calcium carbonate and dilute hydrochloric acid involves weighing the reaction mixture using the experimental set-up shown:



36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)

Follow the procedure below:

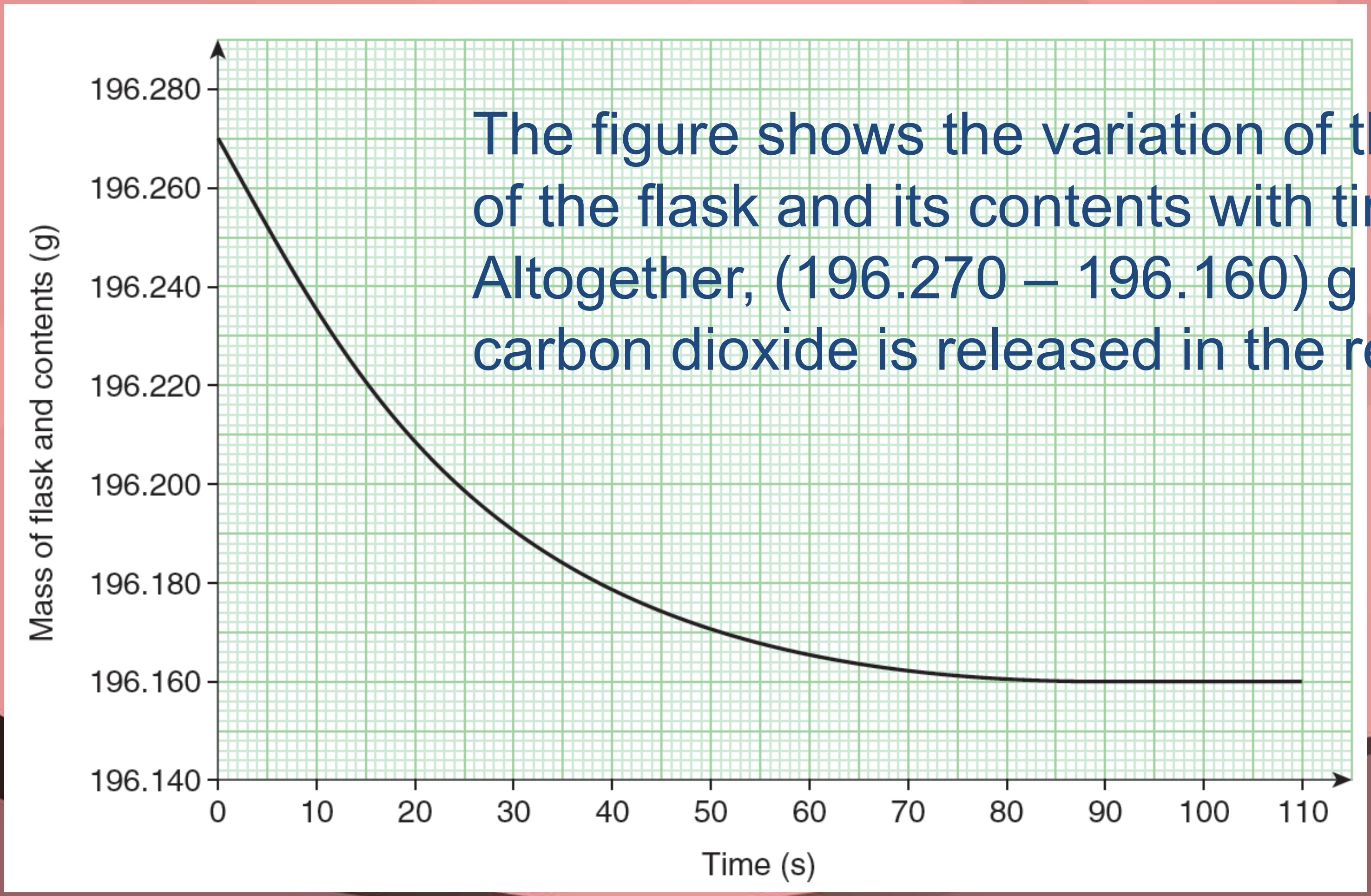
Step 1 Place dilute hydrochloric acid in a conical flask. Stopper the flask with cotton wool.

Step 2 Place the flask on an electronic balance.

Step 3 Remove the cotton wool, drop the calcium carbonate into the flask. Start a stopwatch at the same time. Replace the cotton wool.

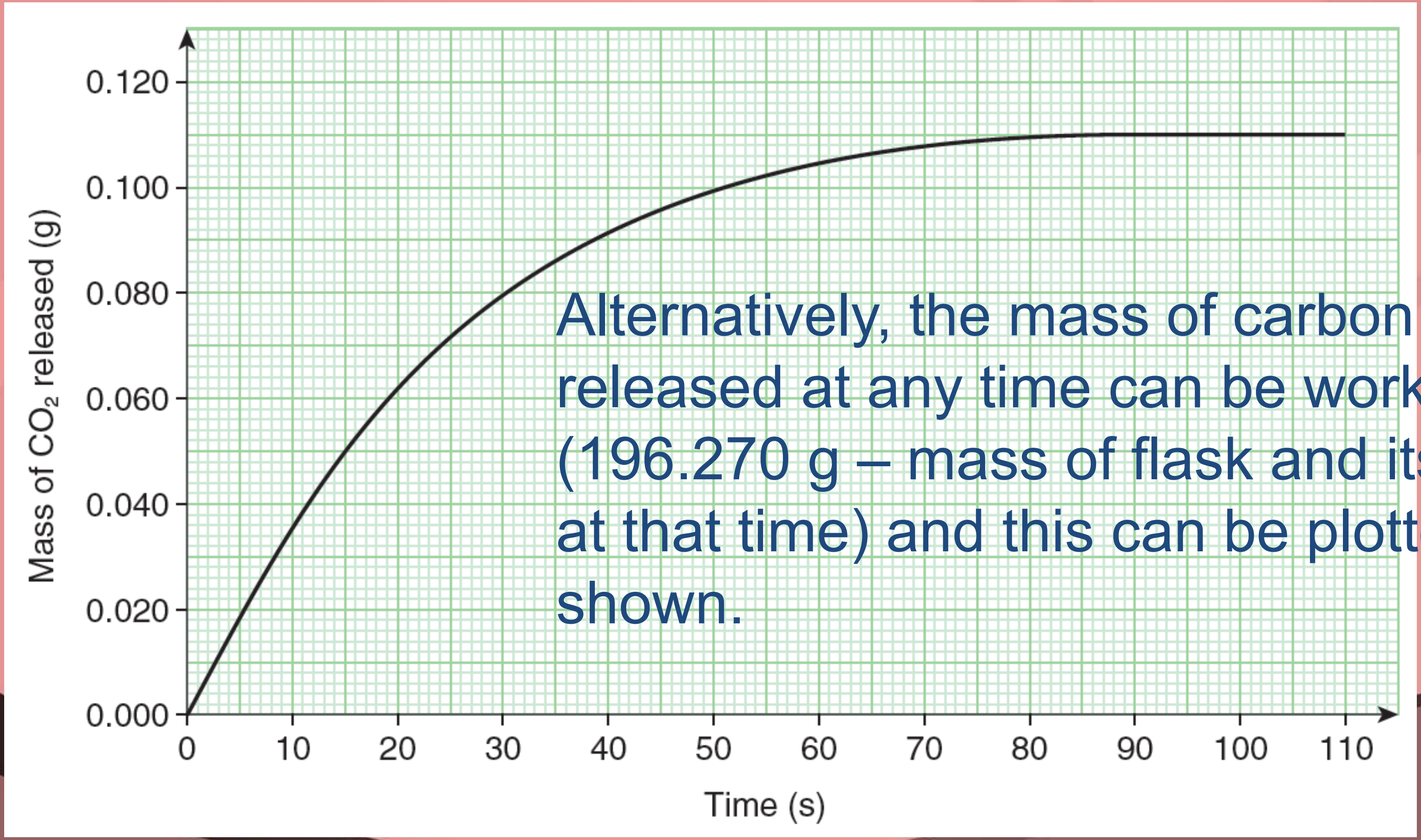
Step 4 Record the balance reading every 10 seconds until the reaction finishes.

36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)



The figure shows the variation of the mass of the flask and its contents with time. Altogether, (196.270 – 196.160) g of carbon dioxide is released in the reaction.

36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)



Alternatively, the mass of carbon dioxide released at any time can be worked out (196.270 g – mass of flask and its contents at that time) and this can be plotted as shown.

36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)

Practice 36.2

Consider the reaction below:

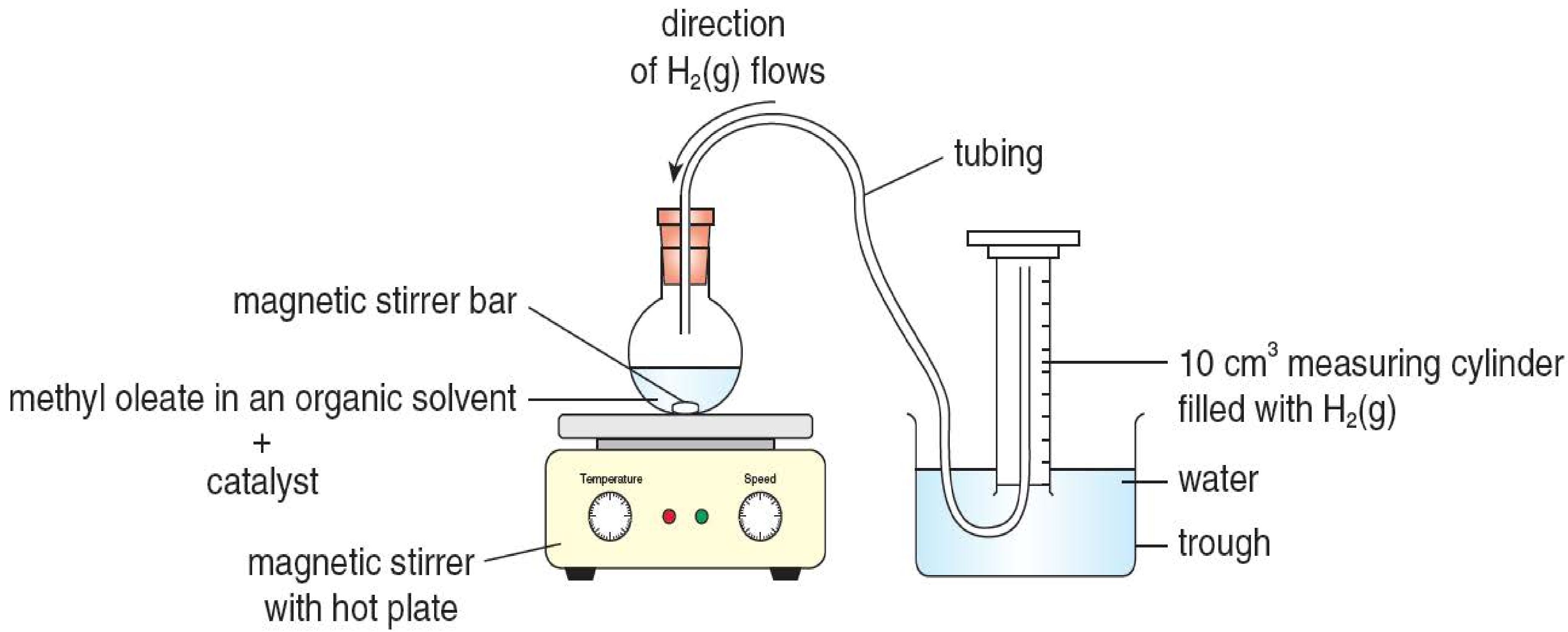
$$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOCH_3(l) + H_2(g) \rightarrow CH_3(CH_2)_7CH_2CH_2(CH_2)_7COOCH_3(l)$$

methyl oleate

At room temperature and pressure, methyl oleate is allowed to react with excess $H_2(g)$ in the set-up shown below. The $H_2(g)$ flows from the inverted measuring cylinder to the reacting flask through the tubing.

36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)

a) Explain why the right end of the tubing is placed at the uppermost position of the inverted measuring cylinder. Prevent sucking back of water.

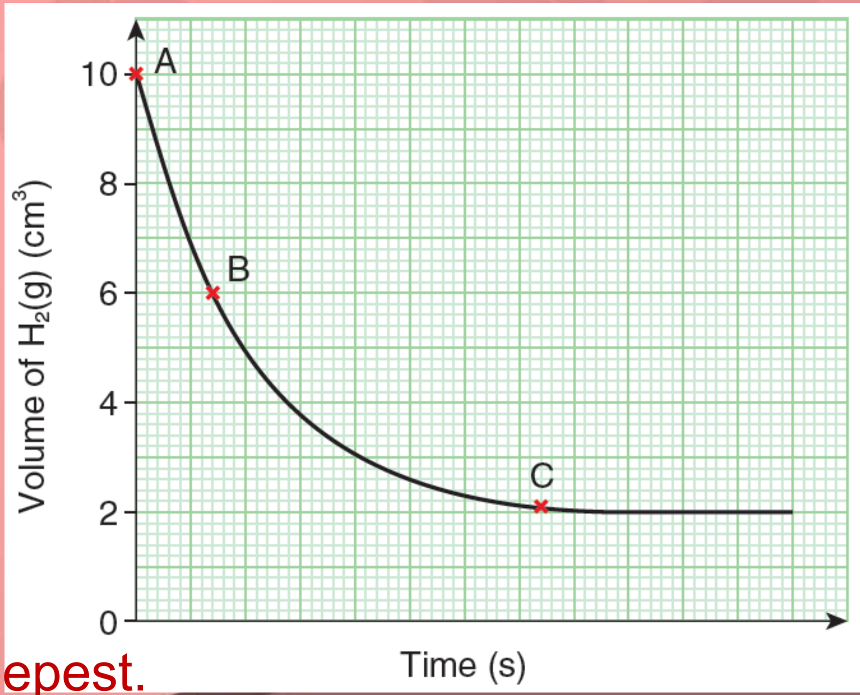


36.5 Following the progress of a reaction by measuring the change in mass of the reaction mixture (p.12)

b) The curve below shows the variation of the volume of $H_2(g)$ in the measuring cylinder with time. (The measuring cylinder initially contains 10.0 cm^3 of $H_2(g)$.)

i) Suggest what would happen to the water level inside the measuring cylinder during the reaction.

The water level rises.



ii) Referring to the curve, which point (A, B or C) represents the most rapid reaction? Explain your answer.

Point A

The tangent to the curve at A is the steepest.

36.6 Following the progress of a reaction by measuring the change in pressure (p.15)

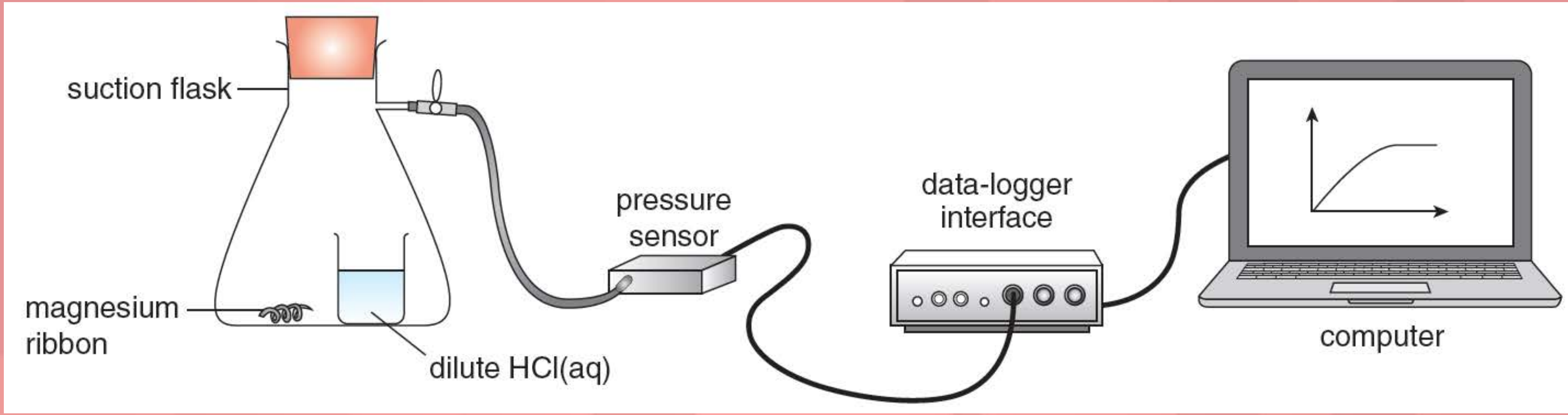
- Consider the reaction in a closed container:

  $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

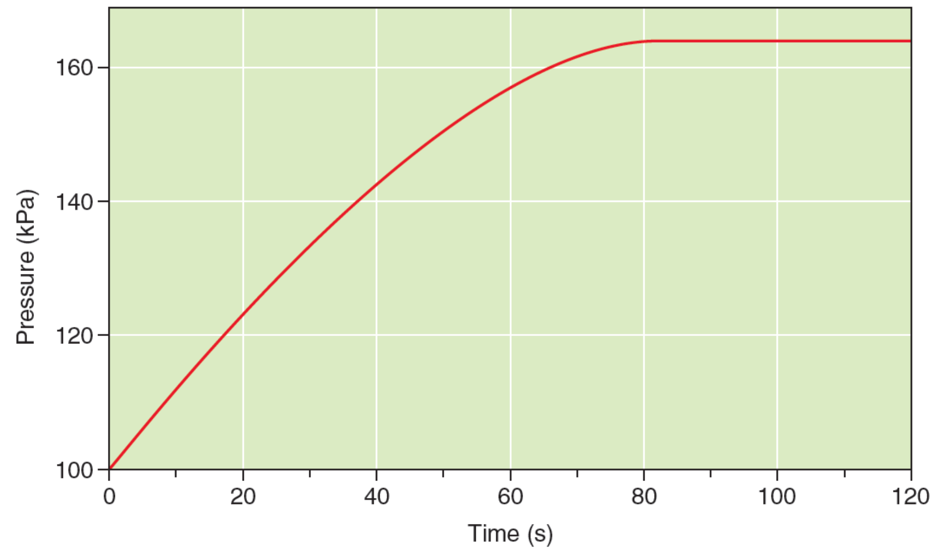
- The pressure inside the container will increase as $H_2(g)$ is formed.

- The progress of the reaction can be followed by measuring the pressure change using a **pressure sensor (壓強感應器)** connected to a **data-logger interface (數據收集儀介面)** and a computer. Tilt the beaker containing the acid to mix the reactants. Immediately start recording for 2 minutes.

36.6 Following the progress of a reaction by measuring the change in pressure (p.15)



The variation of the pressure inside the closed container with time



36.6 Following the progress of a reaction by measuring the change in pressure (p.15)

- The pressure increases as the reaction proceeds. The more the gas formed, the higher is the pressure measured. The pressure no longer changes when the reaction finishes. The curve goes flat.
- The use of a data-logger allows continuous pressure readings. The curve of the variation of pressure with time can be plotted automatically.

36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)

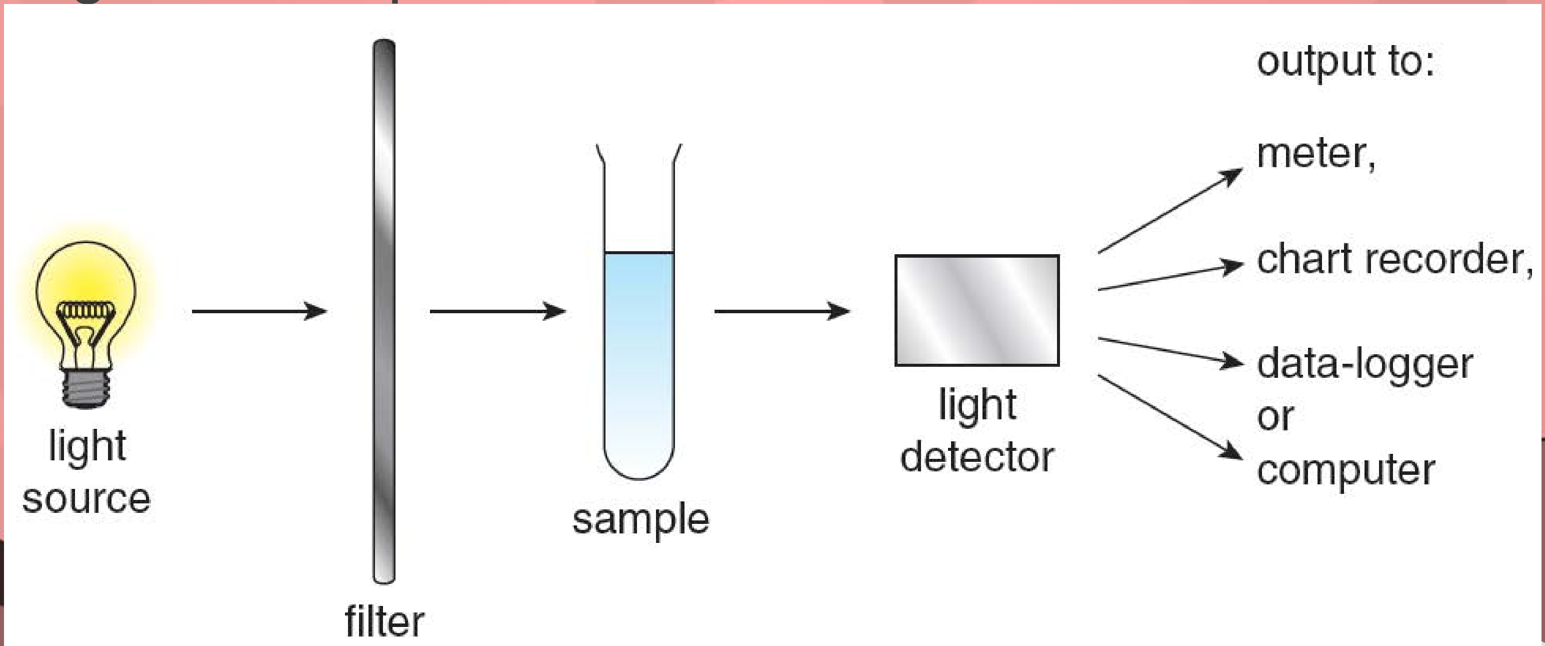
- In acidic solution, propanone and iodine react according to the equation below:

$$\underset{\text{colourless}}{CH_3COCH_3(aq)} + \underset{\text{brown}}{I_2(aq)} \longrightarrow \underbrace{CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)}_{\text{colourless}}$$

- As the reaction proceeds, the brown colour of the reaction mixture becomes less intense as the concentration of iodine decreases.This change in colour intensity allows the progress of the reaction to be followed by using a **colorimeter (比色計)**.

36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)

- A colorimeter consists of a light source with filters to select a suitable colour of light which is absorbed most by the coloured chemical species in the sample. The light passes through the sample onto a detector.



36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)

- The transmitted light is detected and the **absorbance (吸光度)** is shown on the meter. The darker the colour of the sample, the higher is the absorbance.

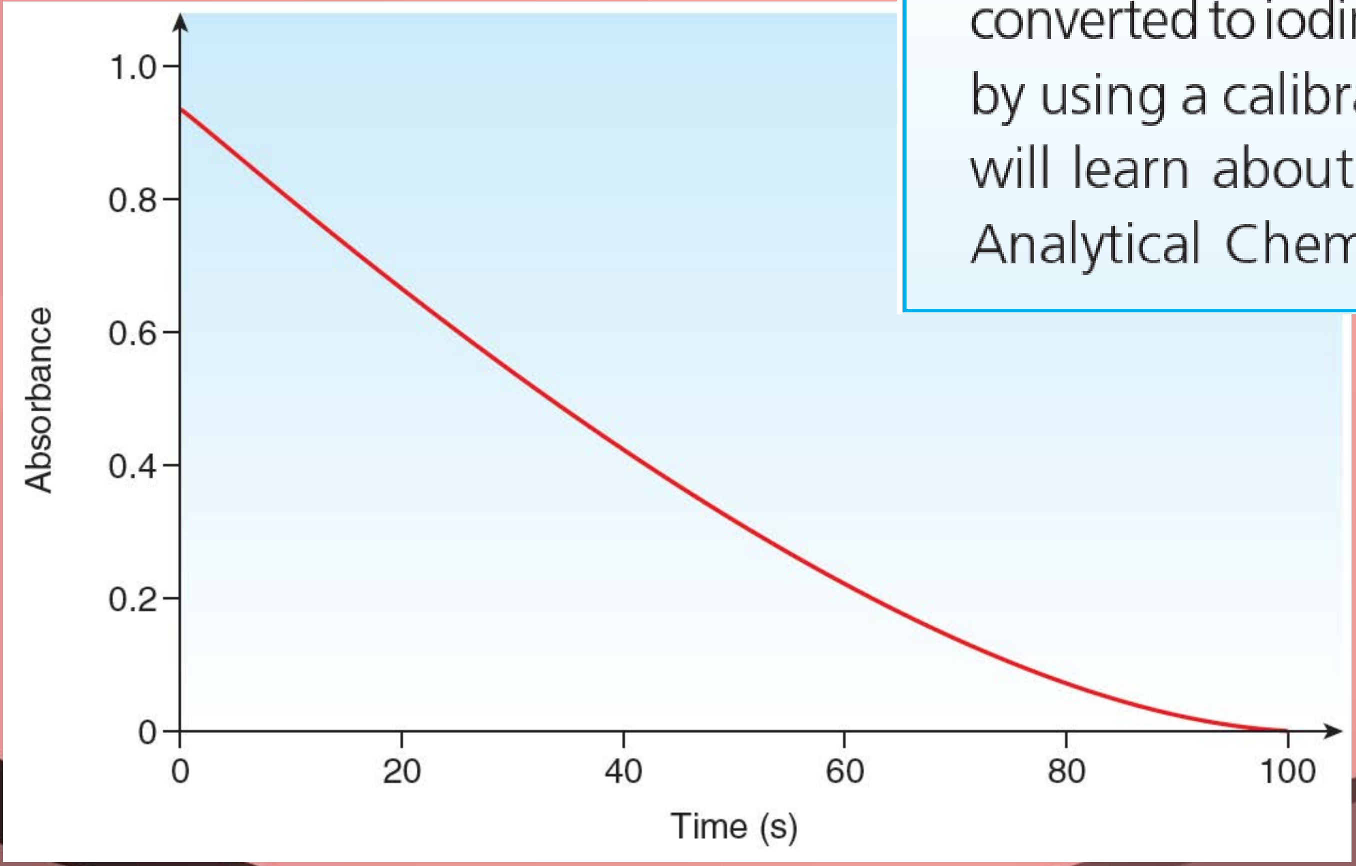
Absorbance (A) is determined by comparing the intensity of the incident light (I_o) to the intensity of light after it has passed through the sample (I_s) using the following equation:

$$A = \log\left(\frac{I_o}{I_s}\right)$$

36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)

- The reaction mixture of propanone and iodine is initially brown, and then fades through orange to yellow to colourless as the iodine is consumed.
- A colorimeter measures the absorbance of the reaction mixture. The absorbance of the reaction mixture decreases as the colour intensity of the reaction mixture and the concentration of iodine decreases.

36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)



The absorbance readings can be converted to iodine concentrations by using a calibration graph. You will learn about this in Topic 15 Analytical Chemistry.

36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)

- Notice that this method can be used to follow the progress of a reaction with one coloured reactant or product.

$$\underbrace{2MnO_4^-(aq)}_{\text{purple}} + \underbrace{5C_2O_4^{2-}(aq) + 16H^+(aq)}_{\text{colourless}} \longrightarrow \underbrace{2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)}_{\text{colourless}}$$

- The absorbance of the reaction mixture falls with time as the purple permanganate ions are consumed.

36.7 Following the progress of a reaction by measuring the change in colour intensity (p.16)

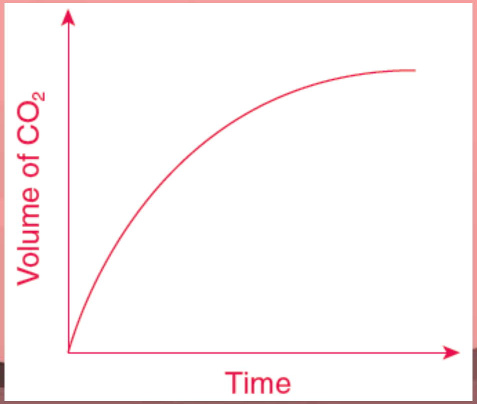
Practice 36.3

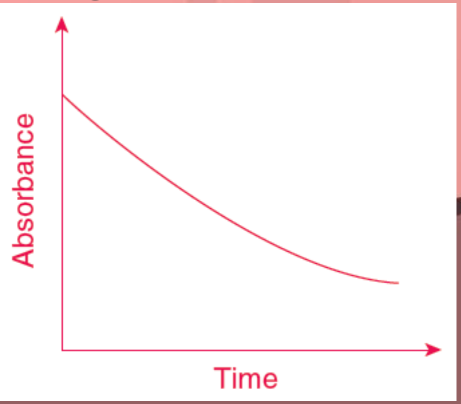
Br_2(aq) reacts with HCOOH(aq) according to the equation below:

$$Br_2(aq) + HCOOH(aq) \rightarrow CO_2(g) + 2HBr(aq)$$

a) Suggest TWO physical methods for following the progress of this reaction.
Volume of gas formed.
Colour intensity of the reaction mixture

b) For each method suggested in (a), sketch a curve to show how the measured physical parameter would change with time.





36.8 Studying the reaction between sodium thiosulphate solution and dilute hydrochloric acid (p.18)

- $Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + SO_2(aq) + S(s) + H_2O(l)$
  Sulphur forms and changes the turbidity of the mixture.

Follow the procedure below:

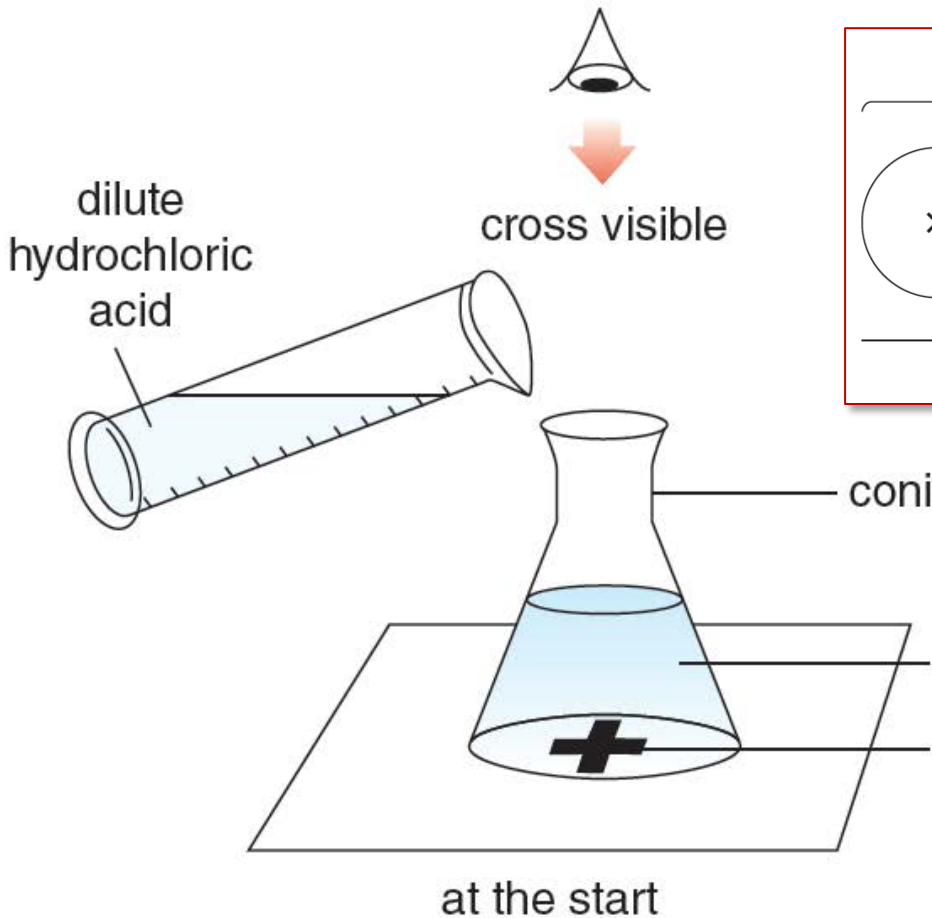
Step 1 Place the sodium thiosulphate solution in a conical flask and put the flask on a cross drawn on a piece of white paper.

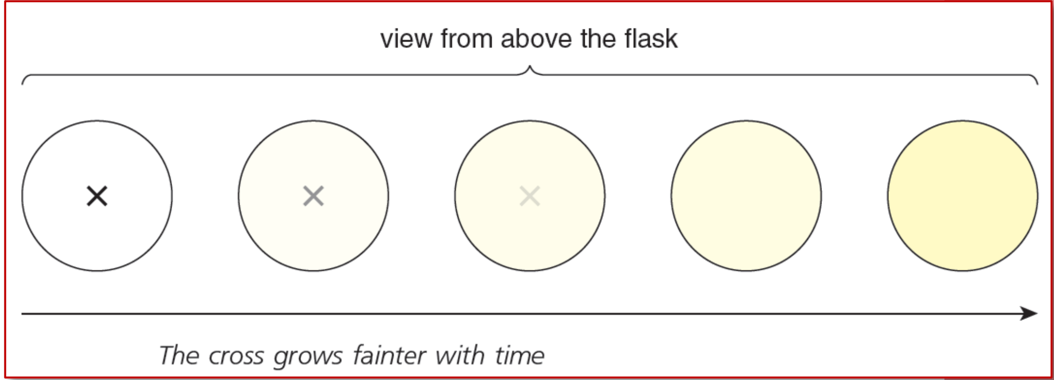
Step 2 Quickly add hydrochloric acid to the flask. Start the stopwatch at the same time.

Step 3 Look at the cross from above. The cross grows fainter as the precipitate forms.

Step 4 Stop the stopwatch when the cross becomes invisible. Note the time.

36.8 Studying the reaction between sodium thiosulphate solution and dilute hydrochloric acid (p.18)





36.8 Studying the reaction between sodium thiosulphate solution and dilute hydrochloric acid (p.18)

- When enough sulphur has formed, the reaction mixture would become so turbid that the cross is obscured.
- Average rate of reaction from start to turbid stage

$$= \frac{amount\ of\ sulphur\ needed\ to\ obscure\ the\ cross}{time\ to\ reach\ this\ turbid\ stage}$$

- The shorter the time taken to reach this turbid stage, the faster is the reaction.

36.9 Following the progress of a reaction by titimetric analysis (p.20)

- All the methods described so far have not interfered with the progress of the reaction. However, **titrimetric analysis (滴定分析)** involves taking small samples of the reaction mixture at regular intervals, and stopping the reaction in the sample before analysis, by a process known as **quenching (猝滅)**.

- You may quench a reaction by:
  - cooling the sample in ice rapidly; or
  - diluting the sample with a large volume of ice-cold water to lower the temperature and concentrations of the reactants.

36.9 Following the progress of a reaction by titimetric analysis (p.20)

- Titrimetric analysis suffers from being a destructive technique, which consumes some of the reaction mixture during the analysis.

- The progress of the below reaction can be followed by monitoring the concentration of NaOH as it is consumed during the course of the reaction:

$$CH_3COOCH_3(l) + NaOH(aq) \rightarrow CH_3COONa(aq) + CH_3OH(aq)$$

36.9 Following the progress of a reaction by titimetric analysis (p.20)

Follow the procedure below:

Step 1 Take a small sample of known volume from the reaction mixture quickly after the reaction has started.

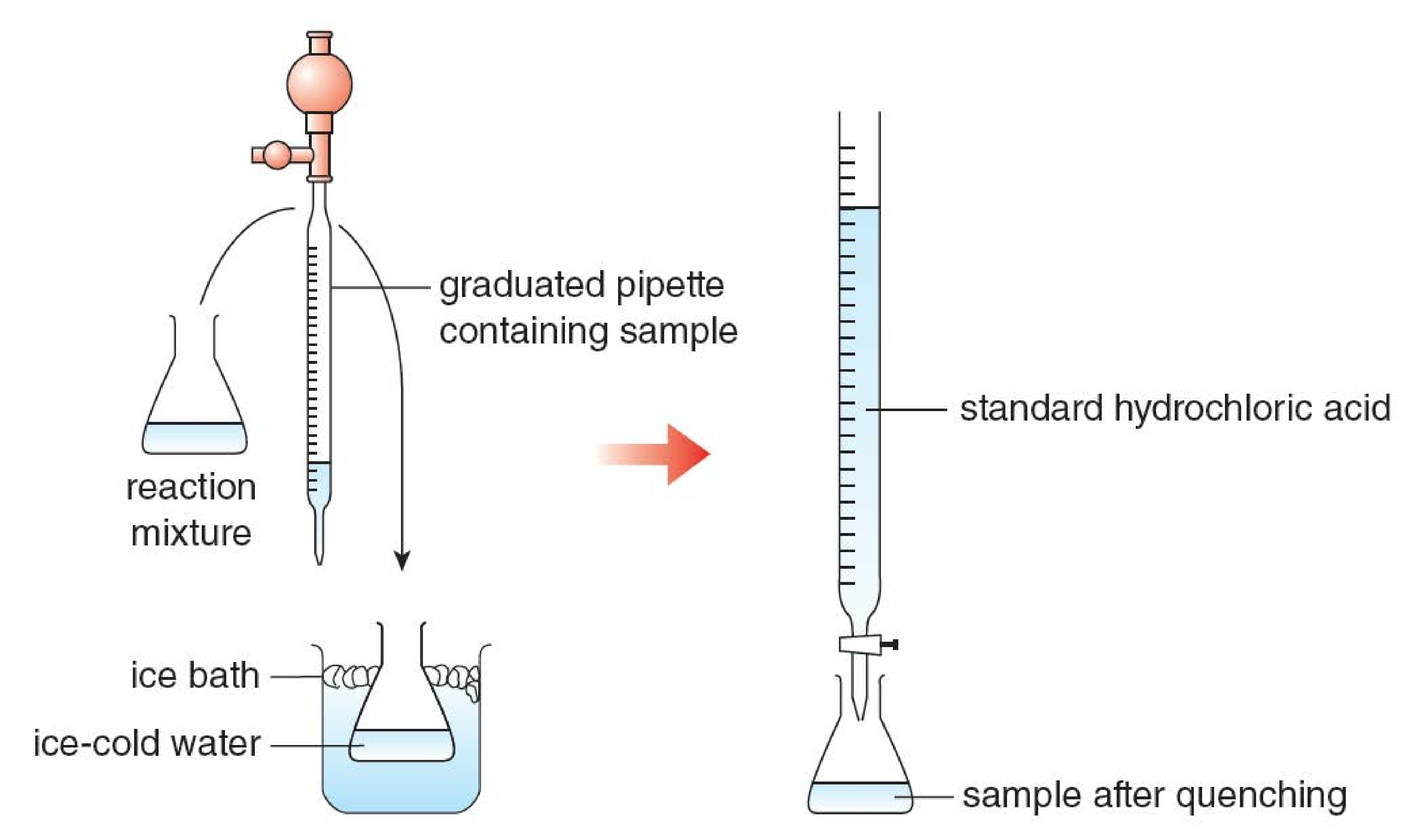
Step 2 Quench the sample by dilution with a known volume of icecold water and immediately record the time.

Step 3 Repeat *Steps 1* and *2* at regular intervals.

Step 4 Determine the concentration of sodium hydroxide remaining in each sample by titrating it with standard hydrochloric acid.

Titrimetric analysis would be suitable for following the progress of a reaction which takes over an hour to go to completion, but not for one which is over in a few seconds.

36.9 Following the progress of a reaction by titimetric analysis (p.20)



36.9 Following the progress of a reaction by titimetric analysis (p.20)

Practice 36.4

1 Why is it better to select a method which avoids sampling for following the progress of a reaction?

Sampling is slow.

It is possible to contaminate the reaction mixture while taking samples.

2 Propanone and iodine react according to the equation below:

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$$

a) Suggest how the reaction could be 'quenched'.

Add the sample to excess / large amount of water.

b) Describe how you could follow the progress of the reaction by an acid-alkali titration.

Take samples of known volume at regular time intervals.

Quench the reactions.

Titrate each sample with a standard alkali.

Determine the concentration of hydrogen ions in each sample.

Key terms (p.22)

chemical kinetics	化學動力學	pressure sensor	壓強感應器
average rate	平均速率	data-logger interface	數據收集儀界面
instantaneous rate	瞬間速率	colorimeter	比色計
slope of the tangent	切線的斜率	absorbance	吸光度
initial rate	初速	titrimetric analysis	滴定分析
rate of reaction	反應速率	quenching	猝滅

Summary (p.23)

1 Rate of reaction is the change in concentration (or amount) of a reactant or a product per unit time.

$$\text{Rate} = \frac{\textit{change in concentration (or amount) of a reactant or a product}}{\textit{time}}$$

2 Graphically, the instantaneous rate of a reaction at a particular time equals the slope of the tangent to the concentration-time curve of the reaction at that time.

3 The initial rate of reaction is the instantaneous rate at time $t = 0$.

Summary (p.23)

4 The following table summarises the methods used to follow the progress of different reactions.

Method	Example
Measuring the change in volume of a gaseous product	$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
Measuring the change in mass of a reaction mixture	$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
Measuring the change in pressure of a reaction mixture	$Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$
Measuring the change in colour intensity of a reaction mixture	$CH_3COCH_3(aq) + I_2(aq) \longrightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$
Titrimetric analysis	$CH_3COOCH_3(l) + NaOH(aq) \longrightarrow CH_3COONa(aq) + CH_3OH(aq)$

Unit Exercise (p.24)

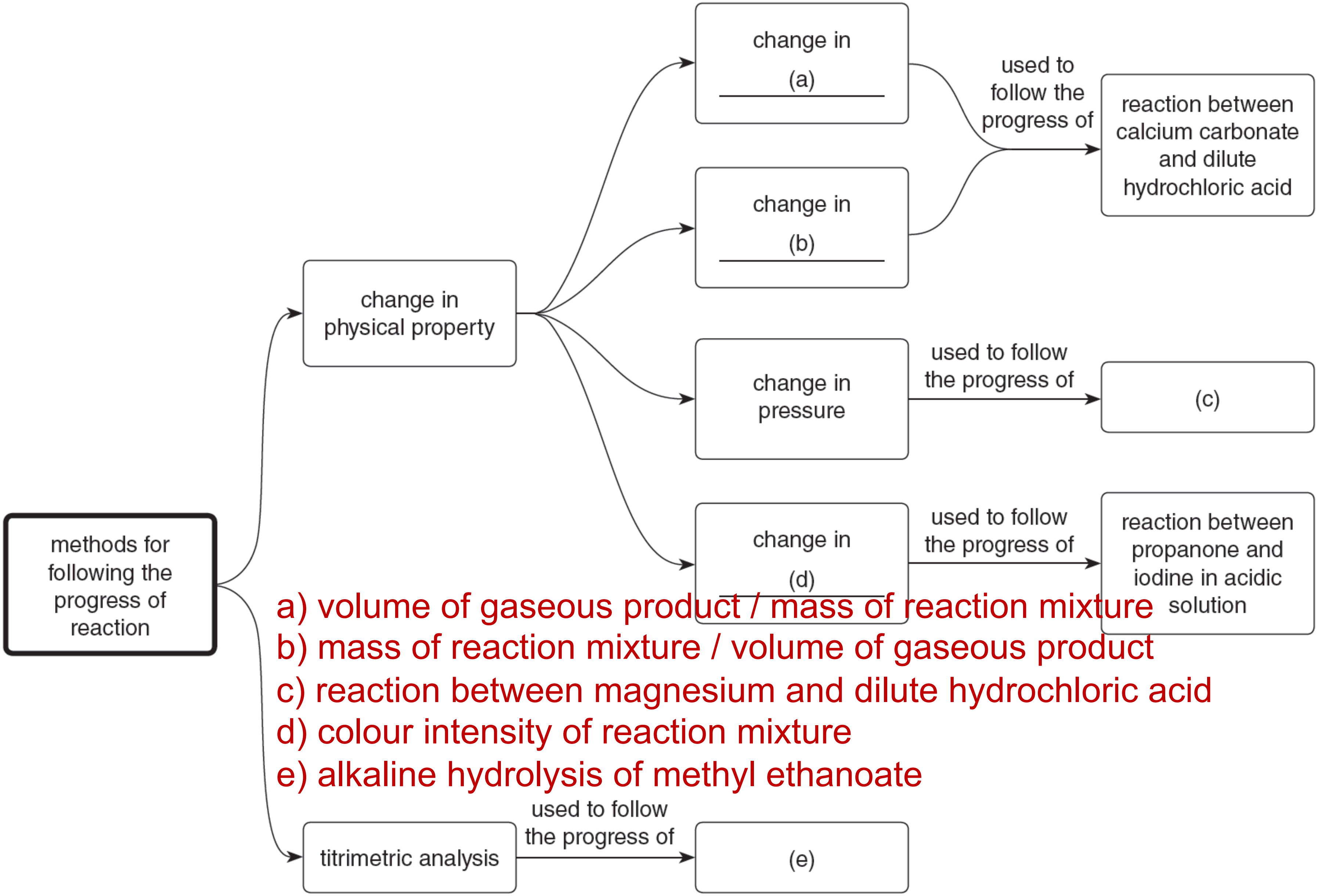
Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

👍 **question targeted at level 3 and above;**
👍👍 **question targeted at level 4 and above;**
👍👍👍 **question targeted at level 5.**
‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.24)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



a) volume of gaseous product / mass of reaction mixture
b) mass of reaction mixture / volume of gaseous product
c) reaction between magnesium and dilute hydrochloric acid
d) colour intensity of reaction mixture
e) alkaline hydrolysis of methyl ethanoate

Unit Exercise (p.24)

PART II MULTIPLE CHOICE QUESTIONS

Directions: Questions 2 and 3 refer to the following methods for following the progress of reactions:

A Colorimetry
B Collecting and measuring the volume of a gas
C Measuring the mass of the reaction mixture
D Quenching, followed by titration with a standard alkali

2 Which method would be the most suitable for following the progress of the reaction below?

Answer: D

$HCOOCH_3(aq) + H_2O(l) \rightarrow HCOOH(aq) + CH_3OH(aq)$

3 Which method would be the most suitable for following the progress of the reaction below?

Answer: A

$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$

Unit Exercise (p.24)

4 Which of the following is most likely to have the HIGHEST reaction rate at room temperature?

A $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
B $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
C $Pb(s) + 2HCl(aq) \rightarrow PbCl_2(s) + H_2(g)$
D $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

Answer: B

Explanation:
$Ag^+(aq)$ ions and $Cl^-(aq)$ ions exist in solution.

Unit Exercise (p.24)

5 Which of the following could be the units of reaction rate?

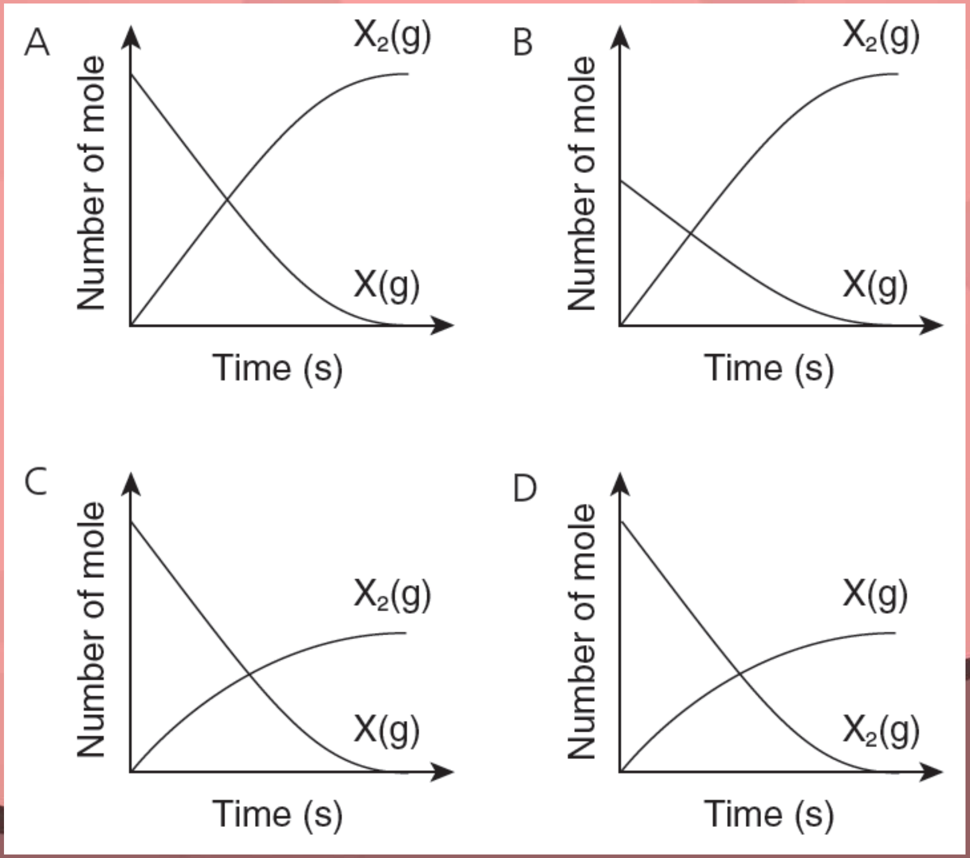
A g cm^{-3}
B g min^{-1}
C g mol^{-1}
D mol dm^{-3}

Answer: B

Unit Exercise (p.24)

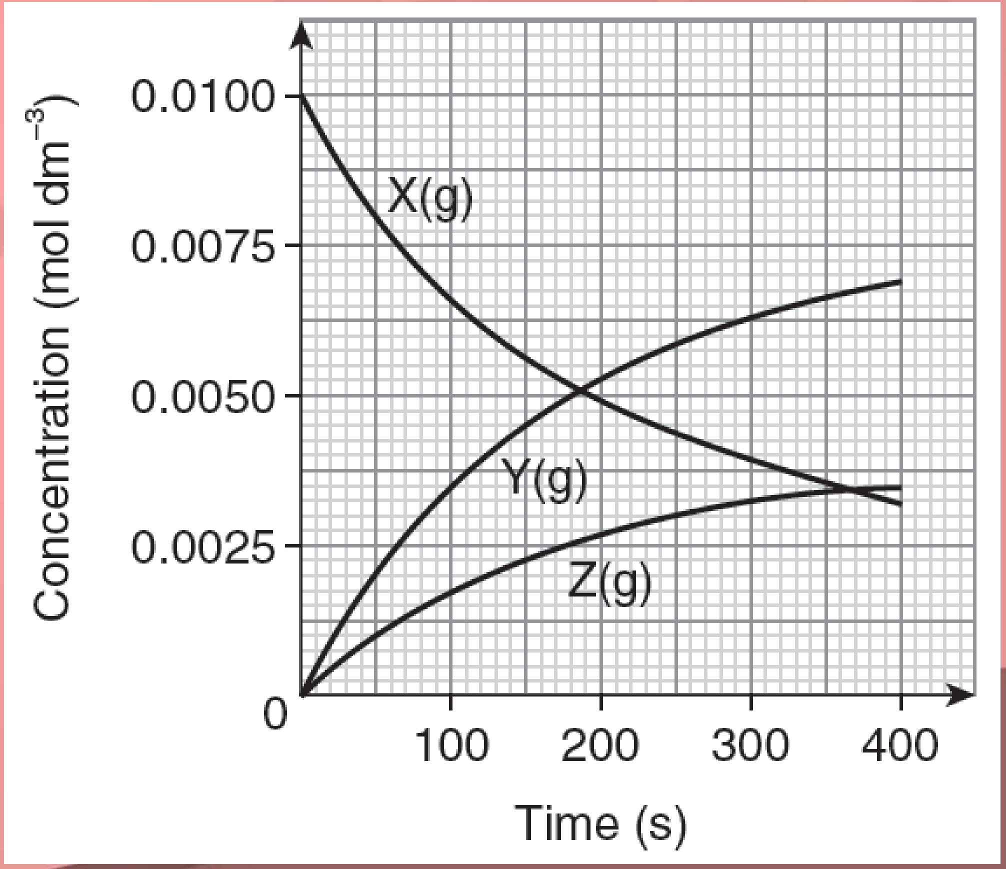
6 Consider the reaction shown below: $2X(g) \rightarrow X_2(g)$
X(g) was contained in a gas syringe during the reaction.
Which of the following graphs correctly shows the variation of the numbers of mole of X(g) and X_2(g) with time during the reaction?

Answer: C



Unit Exercise (p.24)

7 The concentration-time graph for a certain chemical reaction in a closed vessel of fixed volume is shown below.
Which of the following chemical equations correctly represents the reaction?



A $X(g) \rightarrow Y(g) + Z(g)$
B $Y(g) + Z(g) \rightarrow X(g)$
C $2X(g) \rightarrow 2Y(g) + Z(g)$
D $2Y(g) + Z(g) \rightarrow 2X(g)$

Answer: C

Unit Exercise (p.24)

8 A pressure sensor is used to follow the progress of a certain reaction that occurs in a closed reaction vessel of a fixed volume. The graph shows the results obtained.

Answer: C

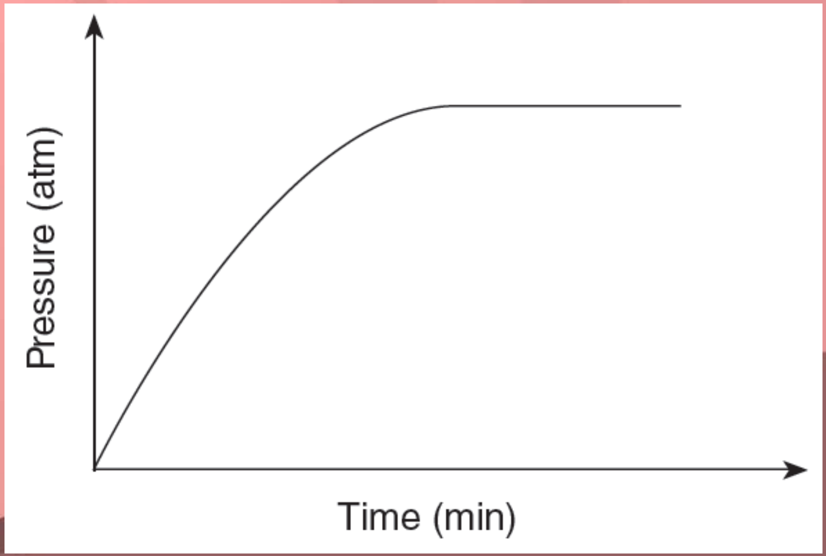
Which of the following reactions might the graph represent?

A $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$

B $H_2(g) + I_2(g) \rightarrow 2HI(g)$

C $2SO_3(g) \rightarrow 2SO_2(g) + O_2(g)$

D $HCl(aq) + NaOH(aq)\ NaCl(aq) + H_2O(l)$



Explanation:

Two moles of $SO_3(g)$ decompose to give three moles of gases.

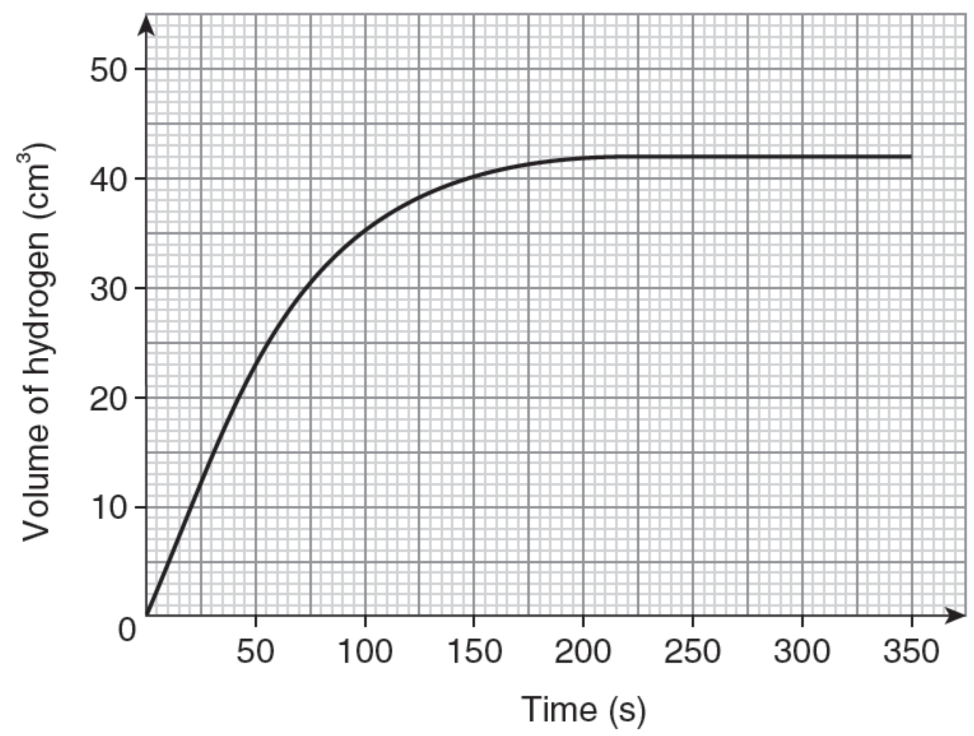
Thus, the pressure in the closed reaction vessel increases.

Unit Exercise (p.24)

9 A student investigated the reaction between magnesium and hydrochloric acid. He measured the volume of gas released every minute. The results he obtained are shown in the graph below.
What was the average rate of reaction between 0 and 100 s?

A 0.44 $cm^3\ s^{-1}$
B 0.35 $cm^3\ s^{-1}$
C 0.28 $cm^3\ s^{-1}$
D 0.24 $cm^3\ s^{-1}$

Answer: B



Explanation:
average rate of reaction between 0 and 100 s

$$= \frac{35\ cm^3}{100\ s} = 0.35\ cm^3\ s^{-1}$$

Unit Exercise (p.24)

10 Consider the reaction below:

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

Suppose the rate of consumption of $H_2(g)$ is 0.090 mol dm^{-3} s^{-1}. What is the rate of formation of $NH_3(g)$?

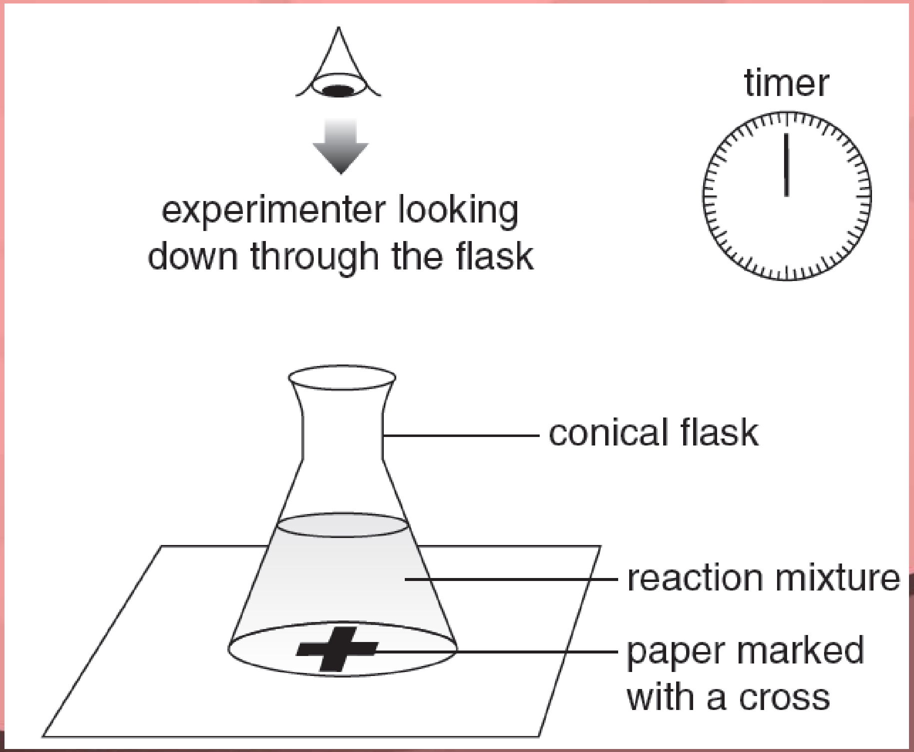
Answer: C

A 0.020 mol dm^{-3} s^{-1}
B 0.040 mol dm^{-3} s^{-1}
C 0.060 mol dm^{-3} s^{-1}
D 0.080 mol dm^{-3} s^{-1}

Explanation:
Rate of formation of $NH_3(g)$
$= \frac{2}{3}(0.090)$ mol dm^{-3} s^{-1} = 0.060 mol dm^{-3} s^{-1}

Unit Exercise (p.24)

11 The apparatus below was set up to measure the time taken for 20.0 cm^3 of sodium thiosulphate solution to react with 5.0 cm^3 of hydrochloric acid in a 100 cm^3 conical flask at 20 °C. The timer was started when the sodium thiosulphate solution was added to the acid in the flask. The timer was stopped when it was no longer possible to see the cross on the paper.



Unit Exercise (p.24)

Which of the following is likely to decrease the accuracy of the experiment?

A Rinsing the flask with acid before each new experiment
B Stirring the solution throughout each experiment
C Using the same piece of paper for each experiment
D Using different measuring cylinders to measure the volumes of acid and sodium thiosulphate

(AQA Advanced Subsidiary, Paper 2, 7404/2, Specimen v0.5, 2015, 21)

Answer: A

Unit Exercise (p.24)

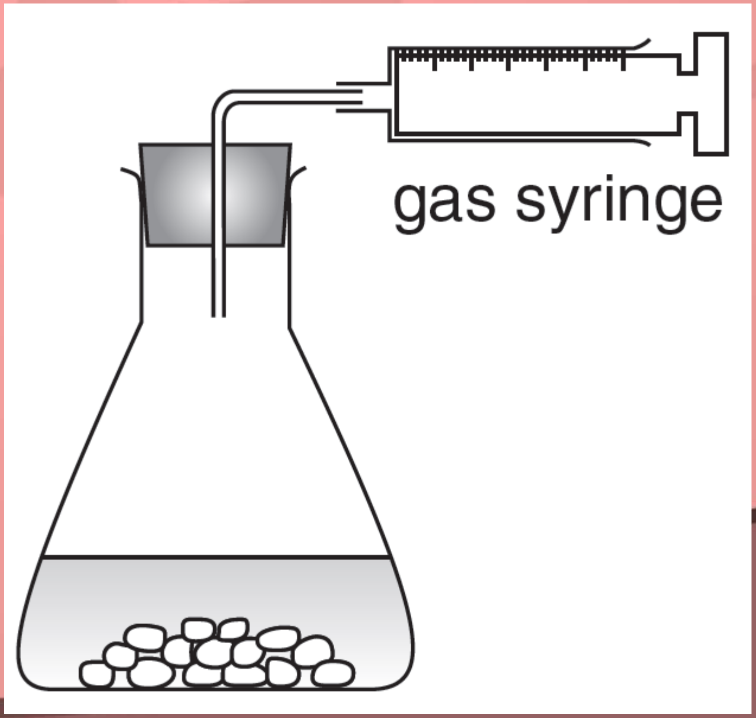
12 The apparatus shown can be used to follow the progress of some chemical reactions. For which of the following reactions would the apparatus be suitable?

(1) $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

(2) $MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$

(3) $ZnCO_3(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + CO_2(g) + H_2O(l)$

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)



Answer: B

Explanation:
(2) NO gas is produced in this reaction.

Unit Exercise (p.24)

13 Consider the reaction between permanganate ions and ethanedioate ions.

$$2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) + 16H^+(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

Which of the following methods can be used to follow the progress of the reaction?

(1) Measuring the colour intensity of the reaction mixture
(2) Weighing the mass of the reaction mixture
(3) Measuring the pH of the reaction mixture

Answer: D

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Explanation:
(2) The mass of the reaction mixture decreases as carbon dioxide gas is released in the reaction.
(3) The pH of the reaction mixture increases as $H^+(aq)$ ions are consumed in the reaction.

Unit Exercise (p.24)

PART III STRUCTURED QUESTIONS

14 For each of the following reactions, suggest with reason(s) ONE method that can be used to follow the progress of the reaction.

a) $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

Colorimetry (1)

because the blue colour of $CuSO_4(aq)$ decreases as the reaction proceeds. (1)

b) $2NaOCl(aq) \rightarrow 2NaCl(aq) + O_2(g)$

Any one of the following:

- Measure the volume of oxygen gas collected (1)
  because oxygen gas is produced as the reaction proceeds. (1)
- Measure the pressure of the reaction mixture in a closed vessel (1)
  because oxygen gas is produced and the pressure increases as the reaction proceeds. (1)
- Measure the mass of the reaction mixture (1)
  because oxygen gas produced escapes as the reaction proceeds. (1)

Unit Exercise (p.24)

c) $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

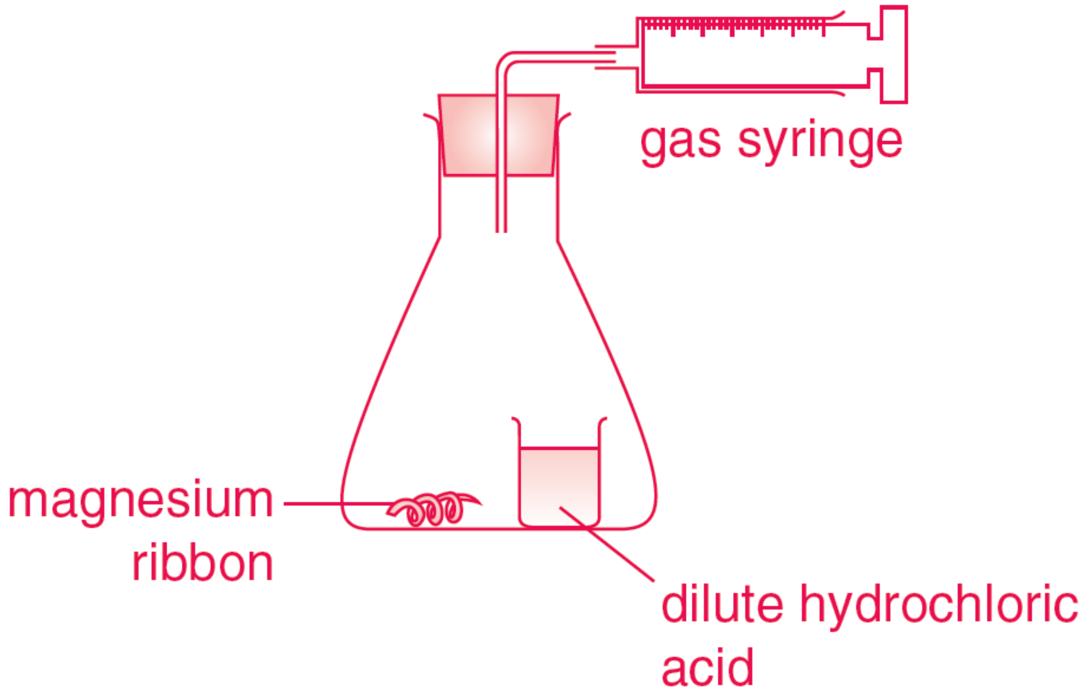
Any one of the following:

- Measure the pressure of the reaction mixture in a closed vessel (1) because 3 moles of gas react to give 2 moles of gas, and the pressure decreases as the reaction proceeds. (1)
- Measure the brown colour intensity of the reaction mixture (1) because NO_2(g) is brown in colour while the other gases are colourless. (1)

Unit Exercise (p.24)

15 Zinc reacts with dilute sulphuric acid to form hydrogen gas. The progress of the reaction is followed by monitoring how the volume of gas released changes with time.

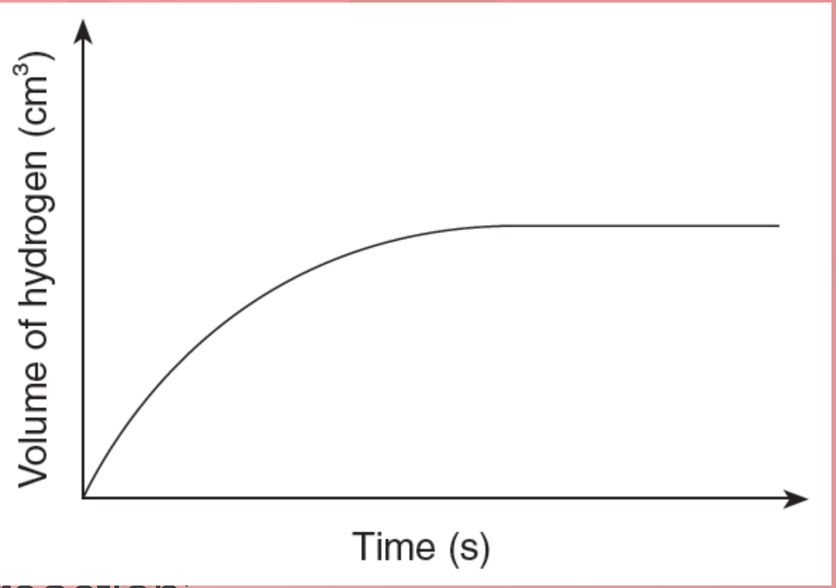
a) Draw an experimental set-up for monitoring the progress of the reaction.



(2)

Unit Exercise (p.24)

b) The curve below shows how the volume of hydrogen released changes with time.



i) State the meaning of the term 'rate of reaction'.

Any one of the following:

- Change in concentration of a reactant / product per unit time (1)
- Amount of a substance formed / consumed per unit time (1)

ii) Describe how the rate of formation of hydrogen changes with time.

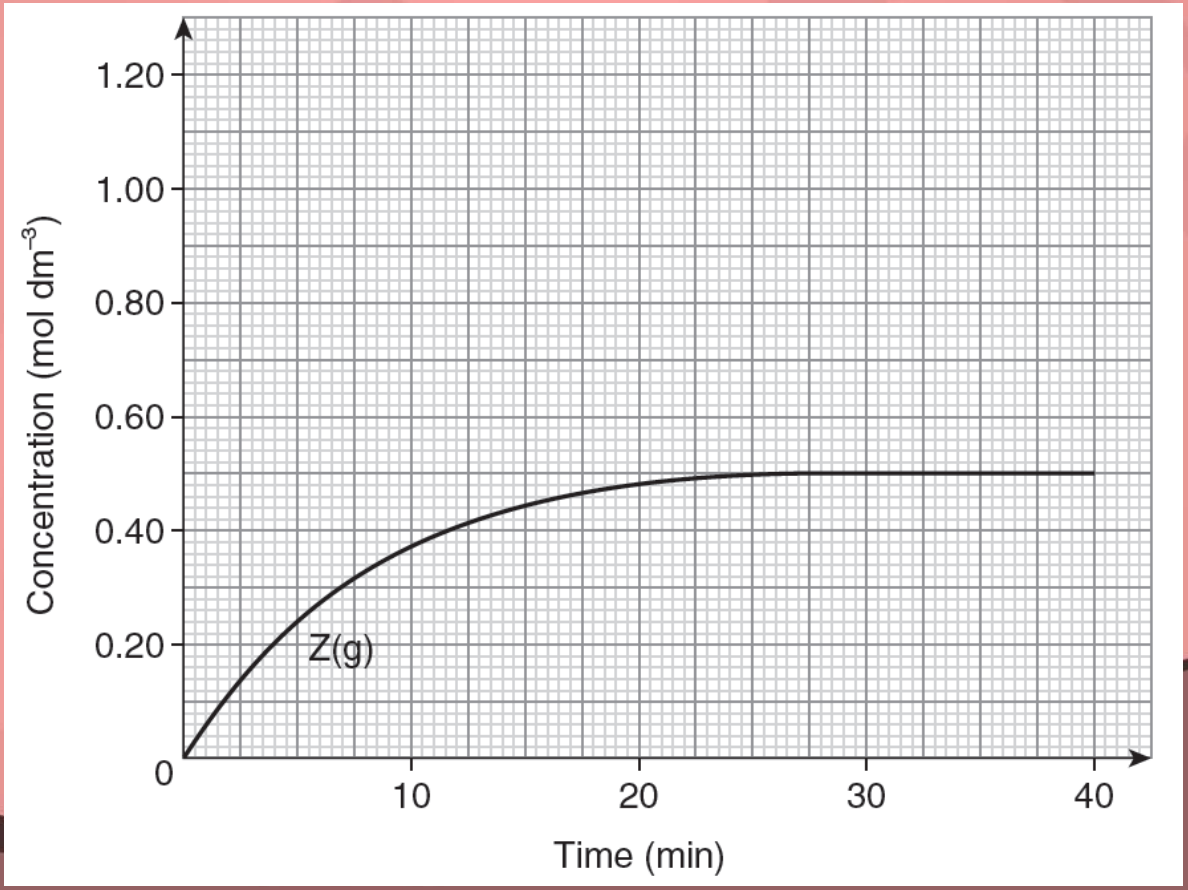
The initial rate is the highest. (1)

The rate decreases with time and becomes zero when the reaction completes. (1)

Unit Exercise (p.24)

16 In an experiment, gas X reacted completely with solid Y to form gas Z as shown in the equation below: $2X(g) + Y(s) \rightarrow Z(g)$

The graph below shows how the concentration of Z varied with time at constant temperature. (X, Y and Z do NOT represent symbols of elements.)



Unit Exercise (p.24)

a) Calculate the average rate of formation of Z(g) in the first 10 minutes.

Average rate of formation of Z(g) in the first 10 minutes

$= \dfrac{0.38\ mol\ dm^{-3}}{10\ min}$ = 0.038 mol dm^{-3} min^{-1} (1)

b) Base on the answer in (a), deduce the average rate of consumption of X(g) in the first 10 minutes.

According to the equation, 2 moles of X(g) react with Y(s) to form 1 mole of Z(g).
Average rate of consumption of X(g) in the first 10 minutes
= 2 x 0.038 mol dm^{-3} min^{-1}
= 0.076 mol dm^{-3} min^{-1} (1)

Unit Exercise (p.24)

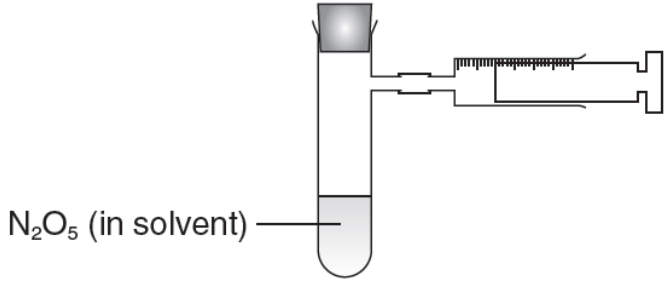
17 The decomposition of dinitrogen pentoxide in a suitable solvent produces nitrogen dioxide, which remains in solution, and oxygen gas which is given off. The equation for the reaction is shown below:

$$2N_2O_5\text{ (in solvent)} \rightarrow 4NO_2\text{ (in solvent)} + O_2(g)$$

a) Draw a labelled diagram of the experimental set-up you would use to follow the progress of this reaction and give the measurement you would make.

Any one of the following:

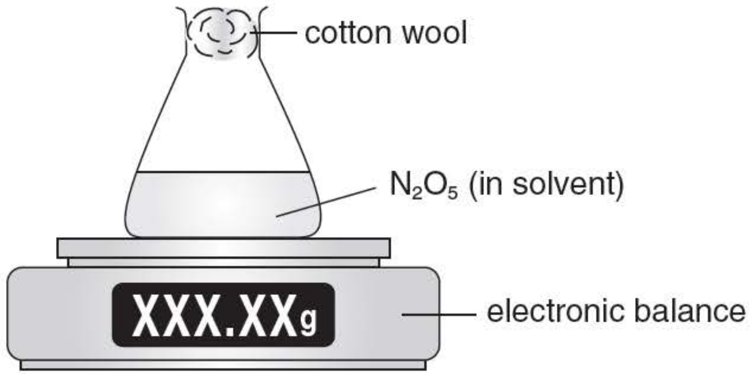
- Gas collection



(2)

Measurements: volume of gas and time (1)

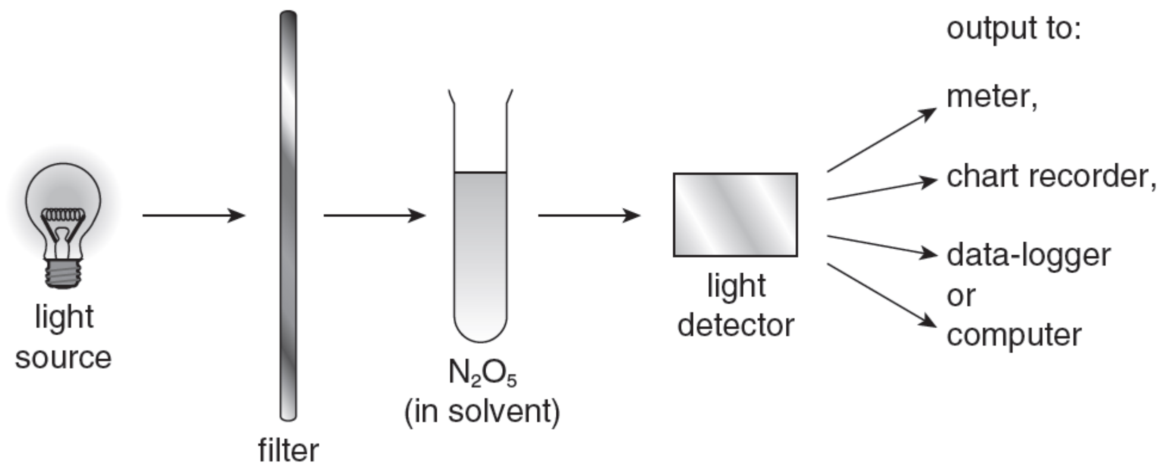
- Mass loss



(2)

Measurements: mass loss and time (1)

- Colour change

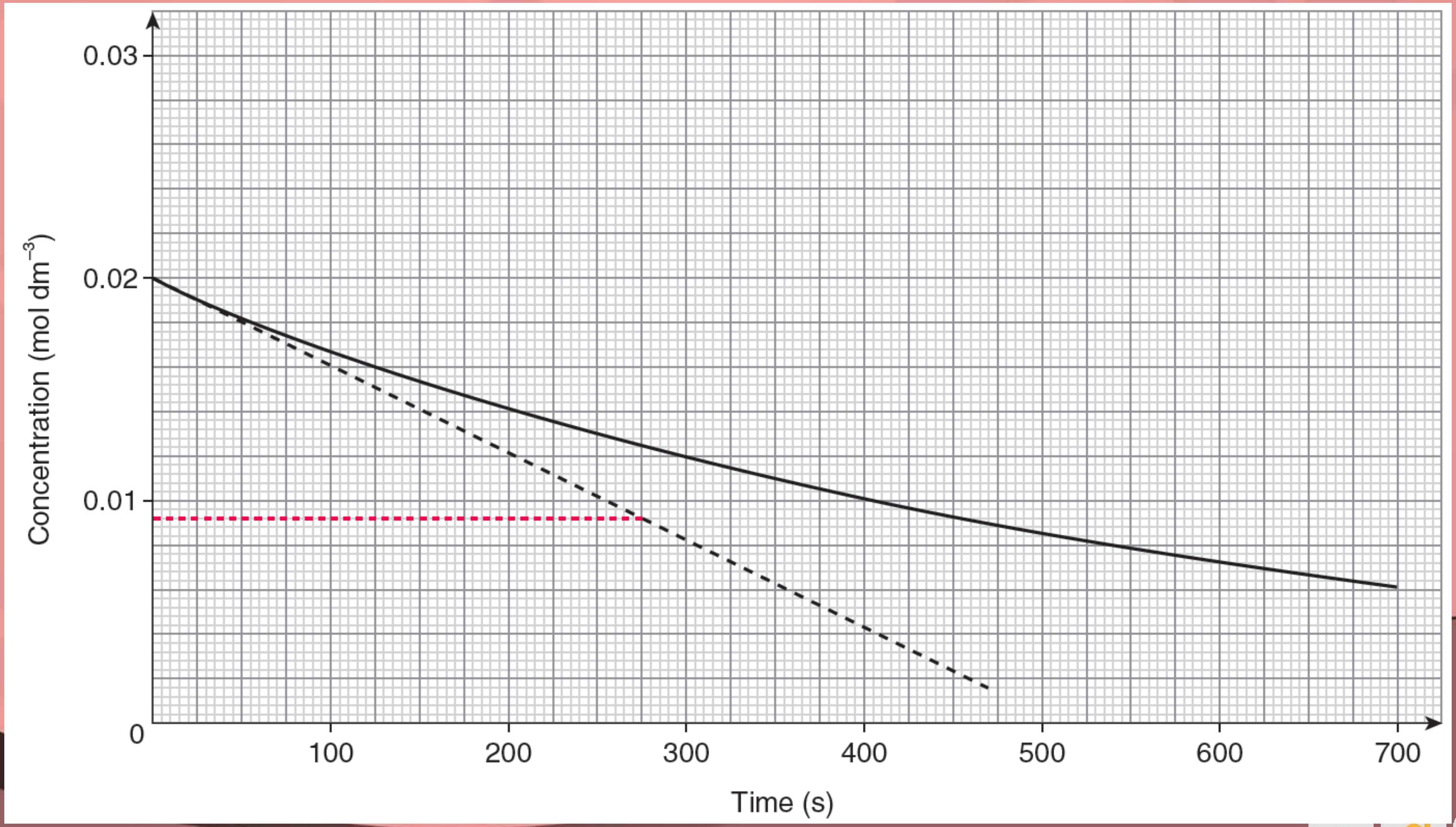


(2)

Measurements: absorbance and time (1)

Unit Exercise (p.24)

b) A sample of dinitrogen pentoxide in a suitable solvent is allowed to decompose. The curve below shows how the concentration of dinitrogen pentoxide varies with time. The dotted line is the tangent to the curve at the start of the decomposition.



Unit Exercise (p.24)

Calculate

i) the average rate of decomposition in the first 300 s;

Average rate of decomposition of N_2O_5 in the first 300 s

$$= \frac{(0.012 - 0.020)\ mol\ dm^{-3}}{300\ s} = 2.7 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1} \qquad (1)$$

ii) the initial rate of consumption of dinitrogen pentoxide.

Initital rate of consumption of N_2O_5

$$= \frac{(0.0092 - 0.020)\ mol\ dm^{-3}}{275\ s} = 3.9 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1} \qquad (1)$$

Unit Exercise (p.24)

18 Potassium peroxodisulphate ($K_2S_2O_8$) is made by the electrolysis of a saturated solution of potassium hydrogensulphate.
Peroxodisulphate ions oxidise iodide ions according to the equation below:

$$S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow 2SO_4^{2-}(aq) + I_2(aq)$$

A colorimeter was used to follow the change in concentration of iodine in the reaction mixture. The absorbance readings were converted to iodine concentrations.

a) Explain why a colorimeter could be used in this experiment.

I_2(aq) has a brown colour.
As the reaction proceeds, the reaction mixture changes from colourless to brown due to I_2(aq) formation. (1)

b) Suggest how the initial rate of formation of iodine can be determined from a concentration-time graph.

Determine the slope of the tangent to the curve at time = 0. (1)

Unit Exercise (p.24)

19 Sodium thiosulphate solution reacts slowly with dilute hydrochloric acid to form a precipitate. The chemical kinetics of this reaction can be studied by measuring the time (*t*) it takes for a small fixed amount of precipitate to form under different conditions.

a) Write an equation for the reaction between sodium thiosulphate solution and dilute hydrochloric acid.

$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + SO_2(aq) + S(s) + H_2O(l)$ (1)

b) Identify the product of this reaction which forms the precipitate.

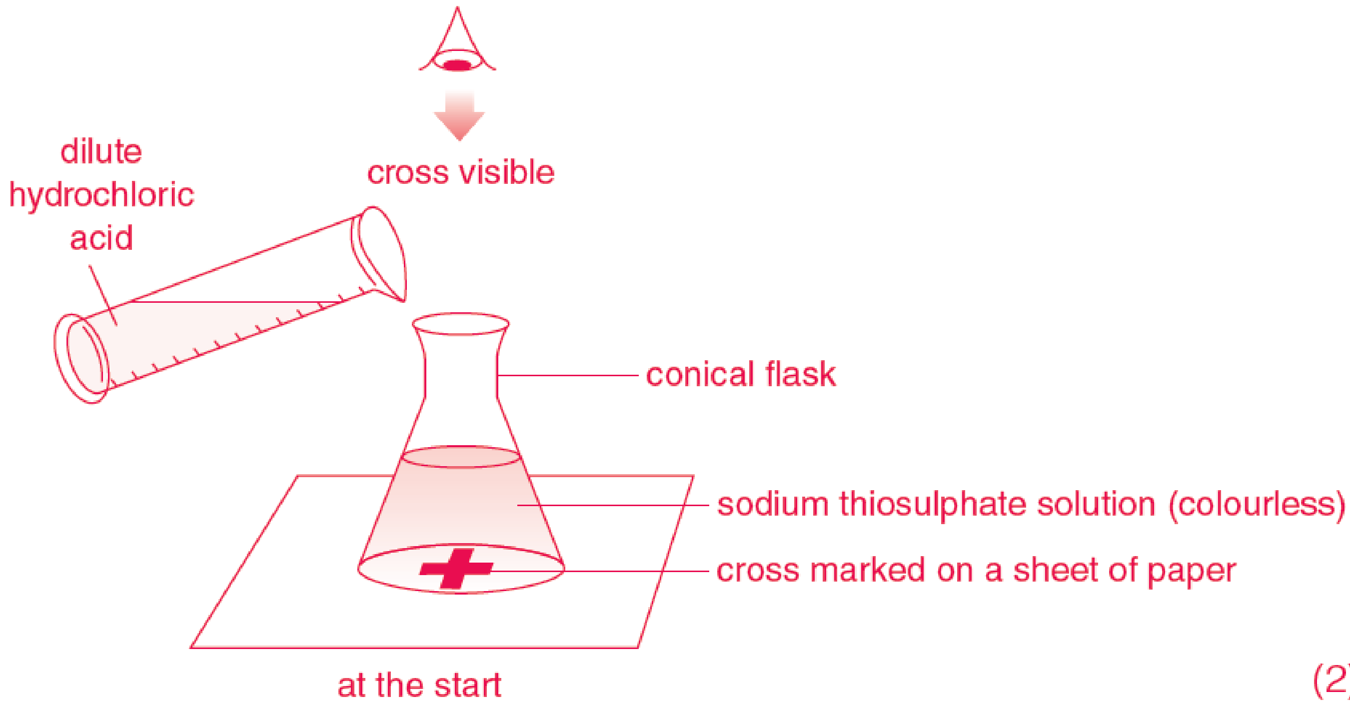
Sulphur (1)

Unit Exercise (p.24)

c) You are provided with common laboratory apparatus. Describe how you could measure the time (*t*) taken for a small fixed amount of precipitate to form.

Measure the time for the cross to become invisible when viewed from above the flask. (1)

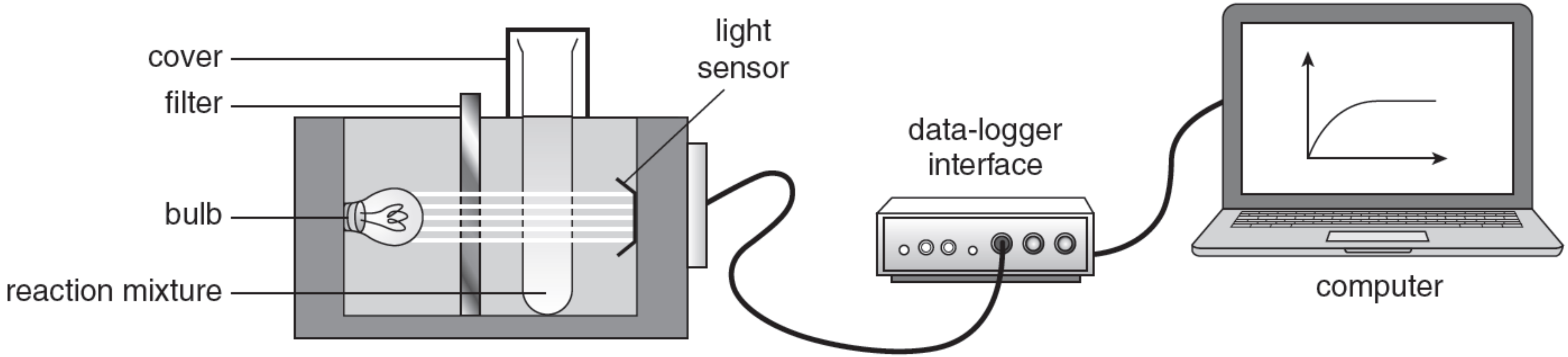
Draw a labelled diagram of the experimental set-up you would use.



(2)

Unit Exercise (p.24)

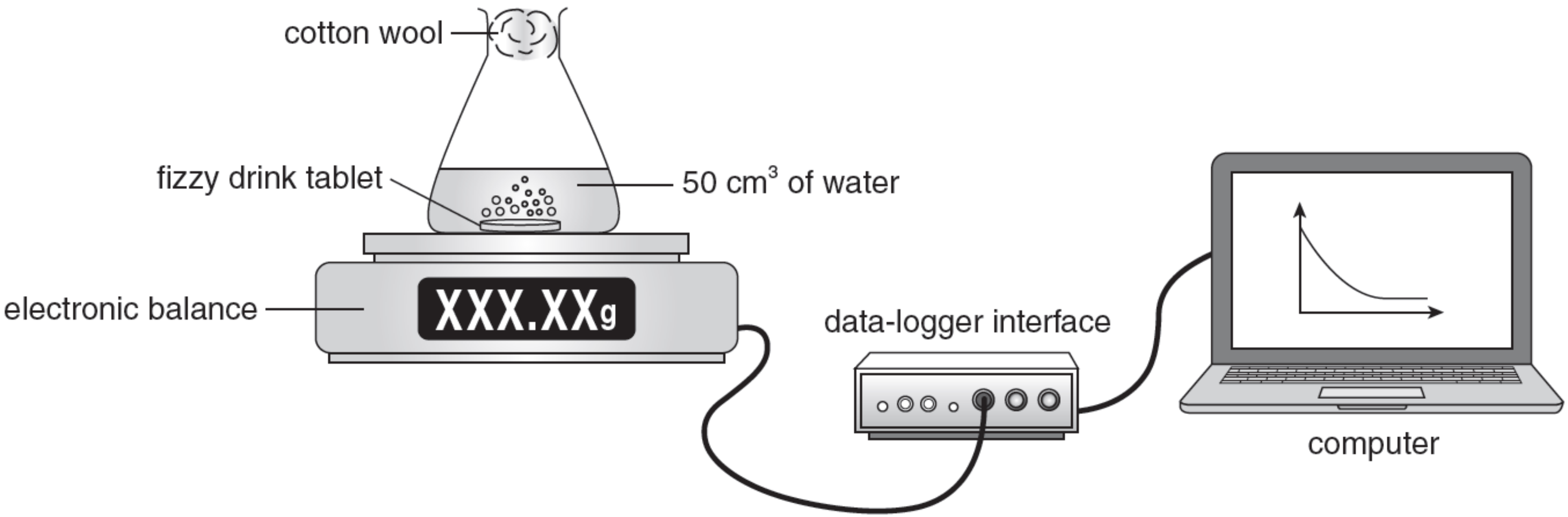
d) The turbidity of the reaction mixture increases as the reaction proceeds. The amount of light that can pass through the reaction mixture (i.e. the light transmittance) gets less.
A technician studied the chemical kinetics of this reaction by using a light sensor connected to a data-logger interface and a computer. Give ONE advantage of using a data-logger with a light sensor.



Continous readings / graph of light transmittance of reaction mixture against time plotted automatically. (1)

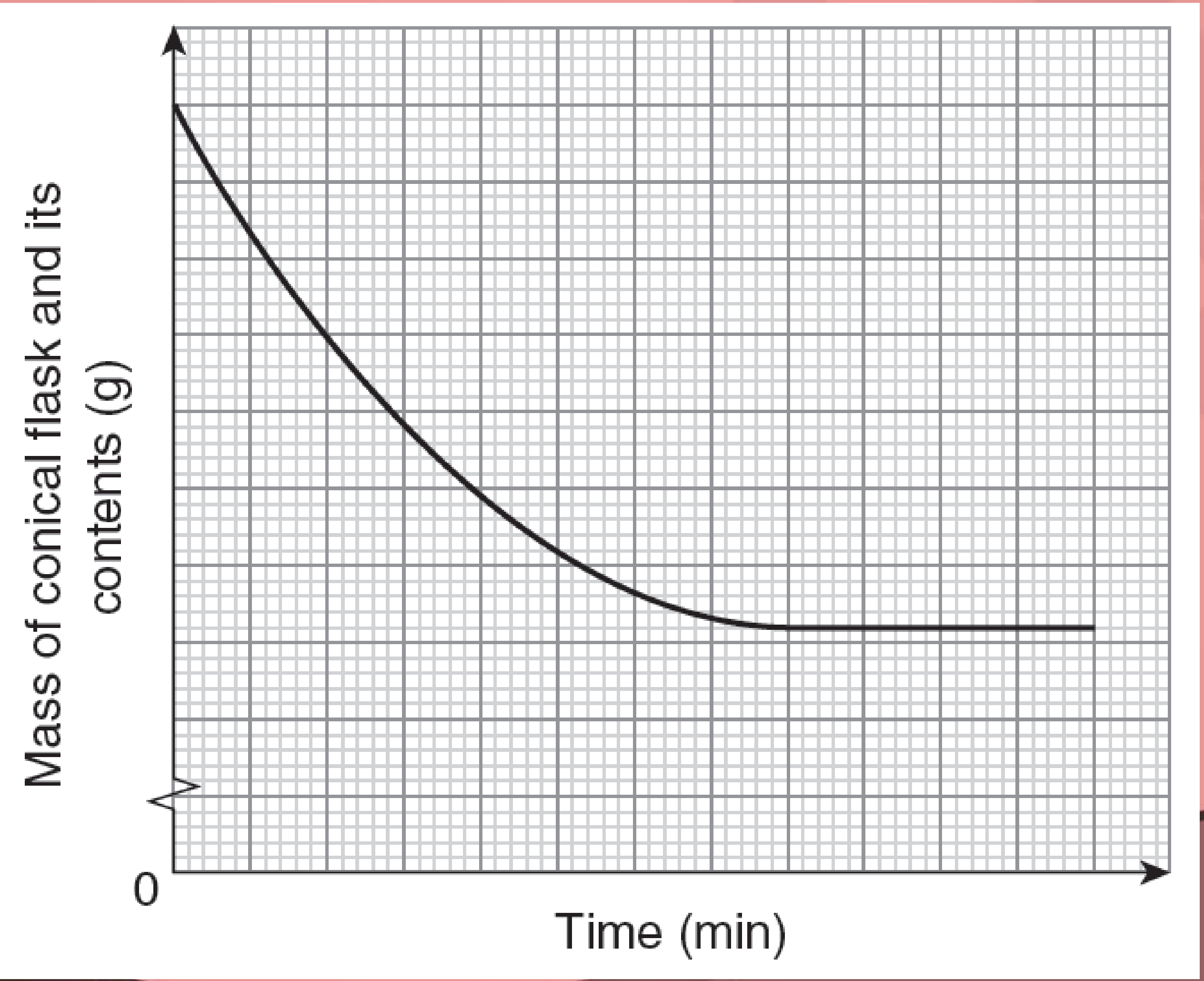
Unit Exercise (p.24)

20 An experiment was designed to investigate the rate at which a certain brand of fizzy drink tablet, which contained sodium hydrogencarbonate, dissolved in water at 25 °C. Carbon dioxide was released in the experiment. The set-up shown below was used.



Unit Exercise (p.24)

The graph below shows the results obtained in the experiment.



Unit Exercise (p.24)

a) Explain why effervescence occurs when a fizzy drink tablet is added to water. Write the ionic equation for the reaction involved.

The fizzy drink tablet contains a solid acid and sodium hydrogencarbonate. The solid acid gives hydrogen ions when dissolved in water. (1)
The hydrogen ions react with sodium hydrogencarbonate to give carbon dioxide gas. This gives rise to the effervescence that occurs. (1)
$HCO_3^-(aq) + H^+(aq) \rightarrow CO_2(g) + H_2O(l)$ (1)

Unit Exercise (p.24)

b) The mass of sodium hydrogencarbonate in one fizzy drink tablet was 1.25 g. What was the mass of carbon dioxide given off?
(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0, Na = 23.0)

Number of moles of $NaHCO_3$ in one tablet $= \dfrac{1.25 \text{ g}}{84.0 \text{ g mol}^{-1}}$

$= 0.0149$ mol (1)

According to the equation, 1 mole of $NaHCO_3$ gives 1 mole of CO_2.

i.e. number of moles of CO_2 given off from one tablet
= 0.0149 mol (1)

$\therefore$ mass of CO_2 given off = 0.0149 mol x 44.0 g mol^{-1}
= 0.656 g (1)

c) Suggest ONE advantage of using a data-logger in this experiment.

As the change in mass is very small in this experiment, the use of data-logger can give more accurate results. (1)

Unit Exercise (p.24)

21 The kinetics of the fast reaction below were investigated in a series of experiments.

$$A + B \xrightarrow{\text{catalyst X}} C + D \qquad \Delta H \text{ is negative}$$

Outline a titrimetric method that could be used to measure the change in concentration of compound A with time.

Compound A is an alkali, whereas compounds B, C and D are neutral.

(Edexcel Advanced GCE, Unit 4, Jun. 2015, 14(a))

Take samples of known volume at regular time intervals. (1)
Quench the reactions by cooling in ice / removing the catalyst. (1)
Titrate each sample with a standard acid. (1)