Lesson Seven

Investigative Skills A: Design

Aims

By the end of this lesson you should:

- understand the principles of experimental design in Chemistry
- be able to apply these in new situations
- know and understand some new technical vocabulary.

Context

Investigative skills are not given a separate section in the "Qualification Content" section of the Specification. However, you will see from the "Assessment Objectives and Weightings" section on pages 20-21 that these form the whole of the third assessment objective, called AO3. These skills will be tested in your exam papers and carry 20-25% of the total marks.

In this lesson we look at how to design investigations. In the next two lessons we then look at how to carry them out and interpret them. All of these skills receive further practice in other lessons throughout the course.

Edexcel IGCSE Chemistry Appendix A, page 218.

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Introduction

A Chemistry **investigation**, or experiment, or practical, is a piece of practical work done to find something out. However, it will only achieve this aim if it is designed correctly before starting work. This lesson looks at the various components of a good design.

Rather than talking in general, we will examine how to design an investigation into a particular problem:

“How does the concentration of hydrochloric acid affect its rate of reaction with magnesium?"

This investigation is related to the work on rates of reaction that we did in Lesson Six.

The Reaction under Investigation

Magnesium and hydrochloric acid react together as follows:

magnesium + hydrochloric acid ---> magnesium chloride + hydrogen

$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$

Magnesium is a silvery metal. In schools it is used as rolls of **magnesium ribbon** that have a uniform thickness and width and can be cut into lengths using scissors. It reacts briskly with acid, producing bubbles of hydrogen gas. Provided an excess of acid is used, the magnesium ribbon will eventually disappear completely leaving just a colourless solution of magnesium chloride.

Activity 1

(a) See several pictures of rolls of magnesium ribbon at www.google.co.uk . Press the "Images" tab, then enter "magnesium ribbon" in the search box.

(b) See several videos of this reaction at www.youtube.com . Enter "magnesium ribbon and hydrochloric acid" in the search box.

Hypothesis and Prediction

Any good investigation starts with an idea of what *might* be going on, based on scientific understanding, called a **hypothesis**. In this investigation, a good hypothesis might be:

> The rate of reaction will increase as the acid concentration increases, because the collisions between the magnesium and acid particles will become more frequent.

Notice that the hypothesis is not just a blind guess; it is developed from relevant scientific knowledge.

A hypothesis can be used to generate a **prediction** of what will happen in a specific situation. Here we might predict that:

> If we double the concentration of the acid, we halve the time taken for the reaction to finish.

A prediction is something that we can verify or disprove by carrying out a practical procedure. Remember that rate = 1 / time (the rate of the reaction equals 1 divided by the time taken for it to finish), so as the time taken goes up the rate of the reaction goes down.

Note that the prediction does not have to be *right*, but it does have to be *sensible* given the scientific knowledge that we have.

Activity 2

Fred takes four spoonfuls of sugar in his tea. He has noticed that the sugar seems to disappear faster if he stirs it in.

(a) Formulate (make) a hypothesis to account for this fact.
(b) Make a prediction, based on this hypothesis, which could be used to test it.

Method

The next thing needed is an outline plan of how to do the practical work. This is called the **method**.

Our method will be:

- Cut several pieces of magnesium ribbon.
- Dilute down the laboratory acid with water (one part acid to one, two, four, etc, parts water) to produce different concentrations of acid.
- Drop a piece of magnesium ribbon into one of the acid concentrations in a test tube.
- Time how long it takes for the effervescence to stop and the magnesium to disappear.
- Repeat for the different concentrations of acid.

Apparatus

Any equipment or materials used in an investigation is called the **apparatus**. It is useful to write a list of this, specifying the number or quantity of each item needed if appropriate.

In this experiment we need:

- standard laboratory dilute hydrochloric acid
- measuring cylinder
- test tubes (6)
- test tube rack
- roll of magnesium ribbon
- scissors
- stopclock
- safety goggles/glasses

Safety

You need to specify any important hazards involved in the practical work and how you would minimize the risk involved with each. Doing this process is known as undertaking a **risk assessment**.

In our investigation:

- wear safety goggles/glasses (the acid is corrosive)
- wash any acid off your skin promptly with cold water (ditto)
- keep windows open for ventilation, and do not have any naked flames present (hydrogen gas is explosive)

Activity 3

(a) How would you adapt the method to investigate the effect of temperature on the rate of reaction?

(b) What extra apparatus would you need for your investigation?

(c) Carry out a risk assessment for your new investigation.

Variables

Things which can change during the course of an investigation are called **variables**. We want to find out the effect of acid concentration on rate of reaction, so both acid concentration and rate of reaction are variables in our investigation.

In any investigation there is one variable you change deliberately so you can observe the effect of doing so. This is called the **independent variable**. There is also another variable whose changes you want to discover. This is called the **dependent variable**. In our investigation, acid concentration is the independent variable and time taken (or rate of reaction) is the dependent variable.

Variables can be **categoric** or **continuous**. A categoric variable is one that is best described by a label, like blue or brown eyes in humans. A continuous variable is one that can be measured by an instrument and described using numbers, like the speed of a moving car.

In our investigation, acid concentration and time taken (or rate of reaction) could both be categoric or continuous variables:

- If we predict that 'concentrated acid will produce a fast rate of reaction; dilute acid will produce a slow rate of reaction' we are using categoric variables.

- If we predict that ‘if we double the acid concentration we double the rate of reaction’ we are using continuous variables.

In general, an investigation that uses continuous variables is more informative than one using categoric variables, and should be chosen if possible.

Validity

The concentration of the acid is not the only factor which will affect the rate of the reaction. Four other factors that might well also affect the time taken for the reaction to finish are:

- the length of the piece of magnesium ribbon

- the volume of acid solution used
- the temperature of the acid
- the extent to which the mixture is stirred or agitated

We will need to keep these other factors **constant** so they do not also affect the rate of the reaction. Only in this way can we be sure that the variation in the rate we observe is due to the concentration of the acid, not to some other factor.

Keeping other relevant factors, or potential variables, constant is to carry out a **fair test.** It would be unfair to handicap our dilute solution by making it react with a longer piece of magnesium ribbon! Potential variables which we deliberately keep constant in this way are called **control variables**. Relevant variables which we fail to keep constant are called **uncontrolled variables**.

Our investigation will only be **valid** if we design it as a fair test, eliminating all relevant uncontrolled variables. Otherwise we may unwittingly be measuring the effect of something else, not the concentration of the acid, on the rate of reaction.

Activity 4

Return to the sugar in tea investigation in Activity 2. Assume that you are going to investigate the effect of rate of stirring on time taken for all the sugar to dissolve.

(a) What are the dependent and independent variables in your investigation?

(b) Think of any other variables which might affect the time taken for the sugar to dissolve.

(c) To what extent could you control these variables in your investigation?

Activity 5	A student made the following prediction: "The final grade that a student gets in their IGCSE Chemistry examination will be determined by the number of hours of study that they undertake". What are the potentially uncontrolled variables in this student's investigation?

Reliability

Once we have completed our investigation, we want to be *sure* that we have discovered the right answer - that our conclusion is **reliable**. The best way to ensure this is to repeat all of our readings several times. This is known as doing **replicates**.

One reason is: it is so easy to make a mistake while carrying out practical work. We could misread a scale, for example, or press the wrong button on a stopwatch. If we only do the procedure once, we will not spot this. But if we do it several times, the problem will show up immediately.

For example, if we had six readings of the time taken for the reaction to finish using the same acid concentration:

25.2 24.7 26.3 35.9 25.0 24.8 (all in seconds)

we could straight away see that the fourth reading was suspect. A reading like this is called an **anomalous result** – one that is an exception to the pattern shown by the rest of the readings. Such a reading should be repeated, or ignored when interpreting our data later on.

The other advantage of doing replicates is that we can take an **average** of our readings (eliminating any anomalous results first). The average of the five good readings above comes to 25.2 seconds, which a more reliable answer than any of the individual readings.

Accuracy and Precision

An **accurate** measurement is one which is close to the true value. A **precise** measurement is one which is quoted to a lot of significant figures.

For example, let's say a student doing our investigation used a stopwatch that measured to the nearest $1/1000^{th}$ of a second. If she recorded a time reading as 25.731s, that would be a very precise measurement of the time taken for the reaction to finish. It might, however, be hopelessly inaccurate. If the true value for the time was 17.2s, a reading of 24s would be much more *accurate* (closer to the true value) even though much less *precise*.

In Chemistry, accuracy is more important than precision. In general you should only quote your readings with the degree of precision you feel your investigation is achieving. In our case, this will definitely not be better than the nearest whole second for the reaction to finish.

Tables

Measurements taken during an investigation are recorded in a **table**.

When you draw up a table it should have gridlines as shown below. The column headings should always state what is being measured and the units used.

Get it right! Units should never be written against each reading – only in the column heading.

The following table shows how to set out your data:

Concentration of acid (% of standard laboratory concentration)	time for reaction to finish (s)
100.0	4
50.0	9
25.0	21
12.5	52

It is important to keep the precision of the measurements consistent.

Keywords

Investigation

Dependent variable

Hypothesis

Prediction

Method

Apparatus

Variables

Valid

Accurate

Replicates

Table

Continuous variable

Control variable

Uncontrolled variable

Fair test

Reliable

Precise

Anomalous result

Magnesium ribbon

Summary

Hypothesis → prediction

Method and apparatus

Risk assessment

Variables - independent and dependent

- controlled and uncontrolled

Accuracy, precision, validity and reliability

Tables

What you need to know

- the meaning of the technical terms in **bold** print in this lesson

What you might be asked to do

- design an investigation using the principles described in this lesson
- identify different types of variable
- criticise inadequately designed investigations
- construct a table given a list of data

Self-Assessment Test: Lesson Seven

1. A student was measuring the effect of surface colour on the rate of cooling of hot water in metal cans. She predicted that dark coloured cans would cool faster than light coloured cans. She measured the time taken for the water in each can to cool down to 50^0C.

   (a) What was her independent variable?

   (b) What was her dependent variable?

   (c) Suggest important control variables she needs to keep the same to make her investigation a fair test.

   (d) Her thermometer measures temperatures to the nearest degree Celsius. Suggest and explain how she should record a time of 4:23.27 displayed on her stopclock.

   (e) When writing up her experiment, she says that she repeated each colour three times to make her results more precise. Is this correct?

2. Look at the following table of experimental data. List all of the mistakes that have been made in drawing and completing the table.

Temperature (°F)	Weight (g)	Time (min + s)	Length
36.8	156g	3.25	17
37	158g	3.33	18
39.25	163g	3.45	19
40	165g	3.56	20

Suggested Answers to Activities

Activity 2

(a) The sugar dissolves faster when the tea is stirred, because this keeps fresh supplies of sugar-poor water in contact with the solid sugar.

(b) If you double the rate of stirring, the time taken for the sugar to dissolve will halve. (Not true, but sensible!)

Activity 3

(a) Warm the test tubes of acid up in a water-bath before adding the magnesium ribbon. Measure the temperature of the acid using a thermometer.

(b) Thermometer; electrical water-bath (or Bunsen burner, tripod, gauze and beaker)

(c) If using a Bunsen burner, extinguish flame before adding magnesium to acid (hydrogen is explosive); hot acid is more corrosive: consider wearing gloves.

Activity 4

(a) Independent: rate of stirring

Dependent: time taken for all the sugar to dissolve

(b) Temperature of the tea, volume of liquid, shape of the container

(c) Volume and shape are easily standardised. Use a thermometer to monitor the temperature of the liquid, and add hot and cold water to adjust as necessary.

Activity 5

Potentially uncontrolled variables include: age of student, sex of student, motivation of student, health of student, when the study time was used, other IGCSEs studied at the same time, quality of teaching – and many more!

Answers to Self-Assessment Test: Lesson Seven

1. (a) The surface colour of the cans.

   (b) The time taken OR the rate of cooling.

   (c) The starting temperature of the hot water; the size and shape of the cans; the volume of hot water in each can; the temperature of the room, the material the cans are made of.

   (d) The display reads 4 minutes and 23.27 seconds. She should convert this into seconds, and only record her answer to the nearest second i.e. as 263s. The temperature readings are not precise enough to justify great precision in her time readings.

   (e) No. It is to make her results more accurate and therefore more reliable.

2. Temperature should be in °C, not °F.

   It should be mass, not weight, that is measured in grams.

The times should be in seconds or (less good) minutes. It is unclear what the figures mean. For example, does 3.25 mean 3.25 minutes (3 minutes and 15 seconds) or 3 minutes and 25 seconds?

Lengths should have units. Is it miles or millimetres?!

There should be a line ruled across under the column headings before the first set of numbers.

The temperatures should all be expressed to the same number of decimal places.

The units ("g") should not be written in after the numbers in the second column.

How many did you spot?