Investigating Chemistry

Notes for Teachers

Davies Denial Locke Reay

Second Edition

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Introduction

The general aims of *Investigating Chemistry* are described in the introduction to the main text. It is particularly important to note the comments on safety (page vi) and to ensure that eye protection is worn for *all* practical work. These *Notes for Teachers* include further hints on safety and information about additional experiments and methods of approach. They also provide answers to the numerical problems in the *Check your understanding*, *Points for discussion*, and end-of-chapter *Questions* sections.

We should perhaps emphasize that the main text covers the three years up to O level and C.S.E. We envisage that most of the pupils starting to use the book will be about thirteen years old and that they will already have some knowledge of chemistry.

The degree of difficulty of the questions and points for discussion varies. There is material for the average and weak candidates, and also some which is intended to stimulate only the most able. The teacher can thus decide which questions are appropriate for a particular class, or even a particular pupil. Similarly, subject matter which is intended mainly for the more able has been placed under separate headings and is removed, wherever possible, from the *basic* arguments under discussion. Some experiments are intended only for the more able pupils.

Note that the abbreviation S.S.R. refers to the *The School Science Review*, published by The Association for Science Education. A comment about the Association and a list of useful addresses is included in the appendix on page 88.

In the chapters of the main text which contain much factual information (e.g. Chapters 19, 21, and 22) it has not been possible to re-state all of the facts in the summaries given at the ends of the chapters. These particular summaries consist largely of a list of 'revision headings', which are intended to break down the subject matter for revision purposes and to act as a 'check list' for the student. They are not traditional summaries, and students may need guidance about making maximum use of them. Some other summaries also contain 'headings' of this kind where facts are already summarized adequately in tables in the text.

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1 The particles which make up matter
(atoms, molecules, ions)

The pupils will already know something about atoms, so there may be little point in introducing the 'continuous theory'. With able classes, however, it can be worth-while for the teacher to argue for this theory against the particulate theory. The class is usually surprised to find how difficult it is to prove that matter *does* consist of particles. The argument makes a useful lead-in to Experiment 1.1.

An excellent introduction to the idea of very small particles, and one which helps to stimulate the imagination of the pupils, is to be found in Theme 7 of *Nuffield Secondary Science*. In this investigation the pupils are taken in a series of step-by-step observations on progressively smaller but visible particles such as dried peas, soil, icing sugar particles, etc., onto gelatine and water where the particles are too small to be seen.

Guessing the objects in a sealed box makes an interesting class exercise. Different objects, e.g. a pencil, a pen-knife, a ping-pong ball, a marble, are sealed in separate boxes. The pupils are allowed to use aids such as magnets, balances, etc., and often display considerable ingenuity in their attempts to name the objects correctly.

Points for discussion numbers 2 and 3 on page 2 can form the basis of demonstration experiments. For number 2, a burette (with bung to fit) may be used for the demonstration, and pupils can help to read the volumes. For number 3, a suitable liquid would be ethoxyethane (diethyl ether) as long as there are no naked flames in the laboratory. If the pupils vacate the room for a few minutes, the odour of the ethoxyethane is usually instantly noticeable on their return unless the room is well ventilated. This can be done in a more 'quantitative' way with able pupils by calculating the volume (of the room) into which, say, 1 cm^3 of the liquid has evaporated, which in turn gives an indication of how much a substance can be 'diluted' and still be detected.

In order to provoke class discussion on experiments like these, it is useful to point out that nobody warmed the ethoxyethane or broke it up in any way; it spread throughout the room of its own accord. Could this be because it was already in the form of particles which separated from each other when they were given more space? The results of experiments such as these *can* be explained if the various substances are made up of particles. Can any pupil think of an alternative explanation?

We try to make it clear to the pupils that no individual experiment has proved anything about the make-up of the various materials, but that all of the evidence so far produced (and there are many more similar experiments) can be explained by the particulate theory. We point out that it is still a theory and would have to be abandoned or modified if some unexplainable fact were to be produced.

How small are the particles?

The following experiment may be useful with more able classes.

Place a tiny crystal of potassium manganate(VII) on a piece of filter paper and ask the class how many particles they think it can be broken down into. Then using a small measuring cylinder, find out how many similar crystals occupy 1 cm^3 (usually about 500). Crush the original crystal and dissolve it in 1 cm^3 of water. This 'divides' it into 500 parts. Dilute by making 1 cm^3 of this solution up to 10 cm^3 and continue to dilute in the same proportion until the colour can no longer be seen. The final division is in the region of 5 million ($500 \times 10 \times 10 \times 10 \times 10$) and the pupils get the tangible idea that the tiny crystal, the size of a pin-head, that they saw at the beginning, has been broken down into 5 million parts.

The well-known 'oil drop experiment' can be used to calculate the approximate diameter of a molecule such as that of stearic acid. This experiment is not an easy one for pupils to understand as it includes several concepts, and the maths is difficult for some. We often leave the experiment until later in the course, and if we do use it at an earlier stage we break it up into three parts so as to separate the necessary ideas. In the first stage, we allow the pupils to do the experiment (or we demonstrate it) without making any measurements. This allows practice of the technique and it also draws attention to the contraction of the original cleared space on the water surface due to the evaporation of the ethoxyethane. We find that there are always some pupils who fail to grasp that the ethoxyethane is just a vehicle for the easy transfer of a minute volume of oil to the surface of the water, and we ask them to try to visualize what would happen if the oil was not 'diluted' with ethoxyethane but used on its own. The tiniest drop of oil we could produce would cover a very big area or, if the available space was limited, for example by the sides of the bowl, would build up into a number of particle 'layers'.

In the second stage of the experiment we pour lead shot into a small tray so that the surface of the tray is completely covered by a layer of shot just one shot deep. These are then poured into a measuring cylinder, and from the area of the tray and the volume of lead shot, it is possible to calculate the diameter of an average lead shot. This gives visual help with the idea that the oil film spreads out until one particle thick, and gives practice in the important steps in the calculation.

Finally, the pupils conduct the experiment proper, taking the appropriate measurements. The only new idea to be introduced at this stage is the fact that the 'volume' used in the calculation is only part of the volume of one drop of the mixture; the rest is ethoxyethane, which evaporates.

2 Particles in motion: the kinetic theory

In this chapter, as well as finding further evidence for the particulate theory, the pupils also enlarge their ideas about the energy possessed by all forms of matter. It is perhaps worth pointing out to them, once again, that we are not 'doing anything' to the chemicals; they behave as they do because they have their own energies. 'Liquid diffusion', S.S.R. March 1978, Vol. 59, No. 208, may be of interest.

Brownian movement

It is as well to practise setting up Experiment 2.3 several times before showing it to the class as it is not easy at first to get the right conditions.

To show Brownian movement in water, shake up a speck of Aquadag or carmine red with about 5 cm^3 of water and transfer a drop of the suspension to the microscope slide, put a cover slip on top, and view through a microscope illuminated from the side. This also needs plenty of practice beforehand and the results are not as dramatic as with the smoke.

We find that Brownian movement needs plenty of discussion before it is fully understood. Pupils are inclined to confuse the particles that they see moving under the microscope with molecules. Here again, the use of models may help to clearer understanding. Bombarding a balloon with ping-pong balls is a simple but telling demonstration and the mechanical model used to illustrate change of state can be adapted by adding one larger polystyrene sphere (or marble) and demonstrating the erratic path it takes as it is bombarded by the smaller spheres.

A simple method of illustrating pictorially the type of random movement which particles in liquids and gases undergo is given in *Activity Pack 7* of *Nuffield Combined Science*. With the aid of an eight-sided numbered spinning top, a random pencilled path is produced on a sheet of graph paper.

Comparing the movement of particles in gases

In Experiment 2.4, it is important to emphasize that it is not the liquids which are diffusing, but rather the gases which escape from them. Some pupils will persist in describing the diffusion of hydrochloric acid! Relative molecular masses can be introduced very simply in this experiment by saying, for example, that a molecule of hydrogen chloride has a mass approximately double that of the mass of a molecule of ammonia, or alternatively it can be stated that hydrogen chloride gas is about twice as dense as ammonia gas.

It is not intended that Experiment 2.5 should be done with all classes, and some teachers may feel that it is better to introduce the experiment later when the chemistry of hydrogen is considered. 'Gaseous diffusion in air and in a vacuum', S.S.R. June 1977, Vol. 58, No. 205, may be of interest.

Change of state

Mechanical models and film loops are available to reinforce the relative movement of particles in the three states of matter. It is useful to discuss, very briefly, liquid air (for example) so as to emphasize that *most* substances can be liquefied if they are cooled and/or compressed sufficiently. Many pupils will answer question 1 on page 16 incorrectly, and be quite convinced that they have seen steam. They could be asked to look more closely at the end of the spout of a kettle containing boiling water.

The effect of air pressure on the boiling point

Many pupils do not have a clear picture of what is happening when a liquid boils, and many confuse evaporation with boiling. It is useful to remind them (or to demonstrate) that once a sample of water has reached its boiling point, the temperature remains the same no matter how many Bunsen burners are used to heat it, and to ask them where all the heat energy is going when a Bunsen burner keeps water on the boil but without raising the temperature of the water. This kind of discussion helps pupils to understand how steam 'scalds twice' (page 19). It is also useful to remind pupils (or demonstrate) that some liquids have boiling points very different from 100 °C, e.g. cooking oil.

In Experiment 2.6 some pupils will fail to see the significance of the bottle acting as an air 'reservoir' and thus facilitating gradual pressure reduction. They could be asked to imagine what would happen when the pump is turned on if no such bottle were included in the apparatus. The bottle also serves as a mercury trap—very useful if the filter pump blows water! It is important not to overfill the manometer before commencing the experiment.

The flask used in Experiment 2.7 should have a thick wall. Less able pupils may have difficulty in explaining what happens in this experiment, but it can be used as a stimulating demonstration ('I am now going to boil water by cooling it . . .') and to provoke class discussion. Able classes can be asked to suggest *why* a change in pressure affects the boiling point.

Answers to numerical questions in Chapter 2

Page 16

1 373 K 546 K 273 K 173 K 0 K
2 30 °C 0 °C −173 °C −273 °C

3 Elements, compounds, and mixtures
Symbols and formulae

Elements

If the pupils have not already met the concept of an element, the introduction to the chapter will need expansion. Pupils could be asked how they might simplify copper(II) sulphate, and they could be allowed to heat samples (to the anhydrous stage) and weigh them before and after heating. Similarly, they could electrolyse a solution of copper(II) sulphate, or this could be demonstrated. It can be shown that all attempts to simplify copper (e.g. by heating, or by the conduction of electricity) either have no effect or make the copper 'more complicated'. It is perhaps easiest at this stage to develop the idea that an element is a substance which contains only one 'kind' of atom, e.g. copper atoms. Many pupils confuse the purification of a substance (e.g. copper(II) sulphate) with its 'simplification', e.g. its conversion into copper. An appreciation of this distinction will ensure that the concept of an element is properly understood at this elementary level.

Metals and non-metals

Pupils may have encountered simple physical distinctions between metals and non-metals, but if not they should be allowed to 'discover' some for themselves. Commercial apparatus (e.g. Ingenhausz apparatus) may be available in the Physics department to demonstrate heat conduction by metals and non-metals.

Compounds and mixtures

If pupils are allowed to make their own samples of iron(II) sulphide in Experiment 3.1, they should be warned about the possibility of the sulphur catching fire, and about what to do if this should happen. There are alternative solvents for sulphur, but carbon disulphide is convenient as long as it is used in very small quantities, in an efficient fume cupboard. An appropriate residues bottle should be available. It must be emphasized that carbon disulphide is toxic, readily absorbed through the skin, and very flammable, and so it must be used with great care.

In Experiment 3.1, the iron will almost certainly give off impure hydrogen when dilute acid is added, and the smell may be confused with the hydrogen sulphide given off from the compound later in the experiment. Iron(II) sulphide is slightly magnetic but it is the difference in degree of magnetism which must be pointed out.

It will help the pupils to appreciate the difference between a compound and its constituent elements if more familiar substances are used as further examples. Sodium chloride is used as such an example in the text, and its formation from sodium and chlorine, and a few of the more 'spectacular' properties of the two elements, could be demonstrated. Similarly, some of the properties of hydrogen and oxygen can be demonstrated and compared with those of water. Examples of this kind help pupils to see that two elements 'locked together' produce a substance which has entirely different properties from those of the elements themselves.

4 Purification techniques: finding out whether a substance is pure

The main aim behind the work in this chapter is to establish the fact that before attempting identification, a substance should be pure. The experiments chosen illustrate a number of fundamental techniques and the need for accurate observation. The experiments also introduce some basic chemical terms. Note that the evaporation of a solution (e.g. prior to crystallization) has frequently resulted in accidents to eyes, particularly if heating is continued after the solution has become concentrated. In these circumstances, 'spitting out' often occurs and it is important that pupils are given proper instruction in the process of crystallization.

Some teachers may introduce the idea of decolorization by allowing pupils to remove the colour from brown sugar. About 5 g of brown sugar are dissolved in 50 cm^3 of water and three spatula measures of activated charcoal are added. The mixture is boiled for a few minutes and then filtered. This is a useful example of a large scale method. It introduces the idea of adsorption and, as this principle is used later in the work on chromatography, it may be valuable to discuss here the difference between adsorption and absorption.

In the interests of safety it must be stressed that activated charcoal (or any other porous finely divided solid) should be added *only* to a *cold* solution. If addition is made to a hot liquid, vigorous frothing and expulsion of the hot liquid may occur.

If, after boiling with activated charcoal, the sugar solution is filtered and the filtrate evaporated, it will be found that crystallization is very difficult and that a thick syrup is obtained. Seeding with a crystal of cane sugar can speed up the process of crystallization, but pupils may be disappointed if they do not produce crystals of white sugar and it may be advisable to ignore this stage. The fact that they have a colourless filtrate after starting with a light brown solution is usually sufficient.

The experiment provides useful homework or discussion on the extraction of sugar and its refining. The pupils could also be asked to comment upon the fact that brown sugar is more expensive than white, even though the latter requires further processing.

It is useful to stress that this technique has general applications in chemistry and pupils could be told how and why gas masks are made containing charcoal particles.

Simple distillation

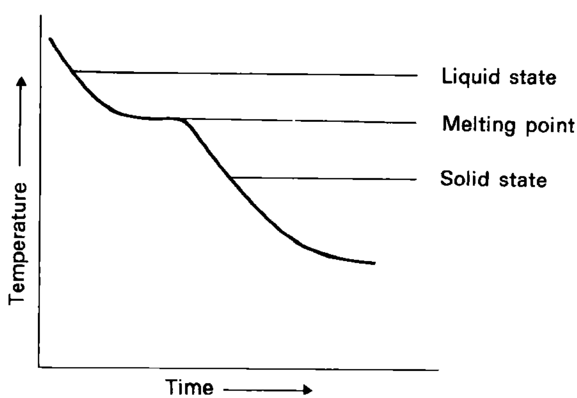
The apparatus indicated in Figure 4.3 is suitable for class sets, but care is needed not to heat too vigorously, as copper(II) sulphate solution will boil over. Young pupils with little experience of distillation are sometimes surprised that the vapour is not blue.

If teachers prefer to approach some of the topics in this chapter in an open-ended way, ink can be investigated as follows.

(a) What could ink be? Hypotheses: (i) a blue liquid, (ii) a blue solid dissolved in a liquid, (iii) a blue solid suspended in a liquid, etc. Devise experiments to test these hypotheses.
(b) What is the solvent in ink? Devise experiments to collect the pure solvent. End with a demonstration using a Liebig condenser. Prove it is water by the use of cobalt(II) chloride paper, boiling point, etc.
(c) Is the solid in ink a pure substance? Use chromatography to find out.

Fractional distillation

Teachers may prefer to illustrate the process of fractional distillation by demonstrating the distillation of a 1 : 1 (by volume) mixture of cyclohexane and methylbenzene, using a suitable fractionating column. If the column is unlagged at the beginning of the experiment, the pupils can see the column in action. It may be necessary to lag the column before the methylbenzene can distil over. If a recording of temperature against time is made, then an idealized form of the graph obtained is shown in the figure. Such a graph is particularly useful for discussion with more able pupils. Note that the boiling points of the two liquids used in the suggested mixture are quite far apart and a good separation could be achieved using simple distillation. This should not be allowed to obscure the principle illustrated by the experiment.



Distilling crude oil

The sending of crude oil by post is restricted by Post Office regulations, which do not allow any samples so carried to contain the low boiling-point fractions. A synthetic sample is easily made by mixing small, suitable volumes of petrol, paraffin, engine oil, and bitumen, or by adding petrol to purchased crude oil.

An important discussion point at this stage in the text (page 44) is that in a very complex mixture of liquids a large number of fractionations may be necessary to obtain a good separation of the components. The point that should be emphasized here is that each 'fraction' distils over a range of temperatures and that each 'fraction' itself still contains a number of components. Use can be made here of film loops, films, and the excellent booklets produced by the major oil companies. A more detailed consideration of crude oil, its processing, etc. is to be found in Chapter 22.

Chromatography

Some ball point inks give good results, especially the black ones, but it is important to test the ink before giving it to the pupils. Black or blue-black fountain pen inks can be used. Care must be taken not to make the spots too large, and it may be useful to demonstrate the process on a larger scale using a gas jar or a commercial chromatography kit.

At the start of the experiments it is important to warn the pupils to handle the paper as little as possible and not to put it down on the bench because this may introduce other impurities on to the paper. Strips of paper about 7 cm × 1.5 cm folded into two enable a group of pupils to complete a chromatogram in 15–20 minutes. We sometimes use a hand-held hair dryer for drying the strips, or alternatively hang the strips on a string line by means of paper clips. Pupils delight in sticking the chromatograms in their books.

The extraction of the colouring matter from sweets (e.g. Smarties) and subsequent chromatographing is a useful experiment (S.S.R., 1972, 53, No. 184, p. 589).

If time allows, the separation of colourless materials by chromatography may be demonstrated as follows. Solutions of lead(II) nitrate, cadmium nitrate, lead(II) ethanoate (acetate) in dilute nitric acid, and a mixture of the three solutions, are spotted separately on to chromatographic paper and dried. The chromatogram is prepared using dilute nitric acid as the solvent. After drying the chromatogram, it may be 'fumed' by holding it over a beaker containing a little ammonium sulphide solution (in a fume cupboard) or by spraying with dilute ammonium sulphide solution. The pupils should see that the distance travelled by the lead(II) ions from each salt are the same and differ from that of the cadmium ion. This also makes the point that the distance for 'each' ion is independent of the anion present.

Another alternative is to stir about half a spatula measure of washing powder containing an optical whitener with about 2 cm^3 propanone, and then to spot the mixture on chromatographic paper. After running a chromatogram with propanone as solvent, the result can be revealed by the use of an ultraviolet lamp. Poor separation of the components may result, in which case only a fluorescent streak will be seen, but it does help to emphasize that chromatography is not restricted to naturally coloured substances. Care must be taken *not* to allow pupils to look directly at the ultraviolet light source.

R_f values (page 47) are mentioned for the benefit of the more able pupils.

Sublimation

In Experiment 4.6, if heating is continued for too long the sublimate does give a faint sulphate test. Note that it is *particularly* important that goggles should be worn when warming sodium hydroxide solution in the test for ammonium ions.

Criteria of purity

This section demonstrates that precise measurements of various physical properties are required to determine the degree of purity of a substance. Note that the determination of melting point by means of a cooling curve requires discussion and explanation in terms of the latent heat of fusion. A full explanation should be discussed with able pupils, for whom it provides a useful link with the work on kinetic theory.

General

At the end of the topic it is useful to give the pupils a test which might incorporate both practical and theoretical questions. One example is given on the next page.