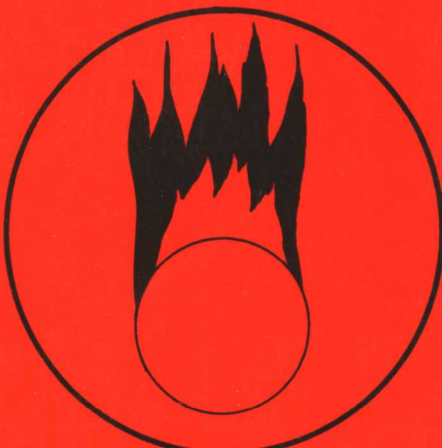
Laboratory Safety

A Science Teachers' Source Book



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Preface

Every responsible teacher and technician wants to feel that their laboratory is as safe as it is possible to make it. This has, in the past, meant having at hand a large number of Government memoranda as well as copies of the invaluable, non-statutory publications by organizations such as the Association for Science Education, The Royal Society for the Prevention of Accidents, The Chemical Society, etc. The purpose of this book is to provide a concise summary of as much of the currently available safety information as is relevant to science teachers and technicians in schools and colleges.

For the book to have maximum effect, 'safety' must be seen as the foundation stone of science work. The first question to be asked about a procedure is not 'Is this better done as a demonstration?' but 'Is it safe?' It is too late to ask that question once work is underway, so discussions about safety should be a regular item in science department meetings.

There is currently a great deal of discussion about the effects of science on the environment and science teachers, more than any others, are faced with the task of educating – changing the attitudes of – pupils. Part of this education must involve the reasoned consideration of hazardous chemicals, procedures, etc., and the best ways of minimizing their potential hazards.

This book should help in achieving this but no matter how detailed it is, it will inevitably be incomplete for each reader by virtue of any special Regional, County Council or Governors' rules relating to a particular geographic area or an individual school. All teachers should acquaint themselves with local regulations as well as with the steps that must be taken in the event of an accident, no matter how small. For example, most teachers in State schools and colleges are expected to complete a standard 'accident report form' should an accident occur (see Appendix A, page 53).

In case of an accident, one rule outweighs all others – the priority is to save lives and, in the case of fire, to give adequate warning to others working in the same building complex.

The book is aimed at science teachers in 'developed' countries as well as those faced with the exciting prospect of teaching in a 'developing' nation. Individual teachers may thus find certain areas of the book not immediately relevant to them, but all readers should find that the information contained in this slim work will serve as the foundation for a school (or area) based science safety policy.

The final section of the book (after the index) comprises a set of 'hazard cards' which correspond to the best industrial procedures. These 16 pages may be detached from the body of the book and reproduced by any commercial duplicating system. They can then be pasted on to cards, or displayed on laboratory walls. Staff should use these hazard cards as a convenient but succinct reference for safety points whenever they are involved with the twenty-five or so activities or materials listed.

P.A. and J.F.
July 1977

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Chapter 1

General Laboratory Safety and Techniques

Systems Checking

The Head of Department in a school or college has the responsibility to see that the laboratories are safe for his staff and students. Nothing should be taken for granted in this respect and schools and college staff should, on a regular and methodical basis, check all laboratory services – gas, power, water, drainage, and fume extraction, where appropriate.

These items should only be *checked.* Any faults which are found should then be reported to the appropriate authority for correction.

Staff and Students Involvement in Safety

How should one deal with the all important problem of involving both staff *and* students in considerations of safety? Rules and regulations imposed from above rarely have the effects on users which occur if the latter have had a hand in deciding policy.

Involving staff is very easy. Not only can staff, through consultation, have a hand in planning a safety policy for a particular institution, but this involvement can be on-going through science staff meetings, where each year (or each term initially) one item on the agenda could be a discussion of any serious accidents (or avoidable accidents) which have occurred in the school or college laboratories.

Involving students in a meaningful way is not so easy but one possible way is to ask students, at the end of their first year of laboratory work to design a safety poster for use the following year. The whole process can be done as a competition and the best posters retained and displayed.

Use of Posters

Published posters, aimed at drawing people's attention to unsafe practices, are frequently grossly misused. If you are lucky enough to have a set of such posters, do not make the mistake of exhibiting them all at once. Instead, show only two or three at any one time, change them regularly, and also change their siting. If a poster remains fixed in one place too long, students (and staff, for that matter) soon 'look but do not see'.

Publications

Every science department should keep on hand, and in a clearly identified position, a comprehensive list of current safety publications. A fairly comprehensive list of available material is given in Appendix C, on pages 57–58. Schools and colleges can draw from that list those items which they feel are most appropriate to their needs.

Techniques and Habits

There are certain ways of working in a laboratory, which are used as a matter of course by experienced staff, and, are quite simply, the safest methods of carrying out everyday activities. It will surprise few people to know that the most serious accidents in laboratories are those that affect the eyes. In the U.K., the Department of Education and Science (D.E.S.) has recently taken steps to limit hazards to the eyes by re-issuing its *Safety in Science Laboratories* booklet (*see* Appendix C, page 57). All staff can help themselves, school technicians, and students by adopting any of the following techniques which may be new to them.

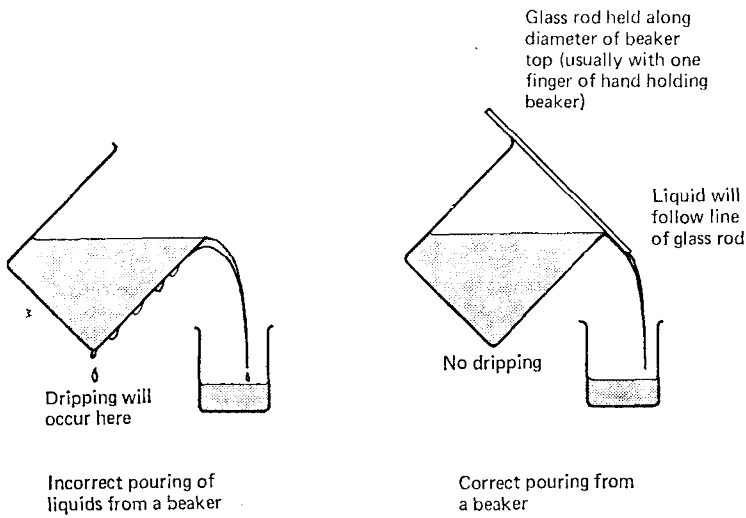

Figure 1.1

Transference of Liquids – 1

Many teachers and technicians suffer accidents to their eyes not only because adequate eye (or face) protection is not used but because staff overlook the fact that liquids being transferred from bulk containers, such as Winchester Quart bottles, invariably 'splash'. Also, in the case of hygroscopic liquids (such as concentrated sulphuric acid), a small drop left on the lip of a bottle soon absorbs moisture and runs down the side of the bottle, making it slippery.

Whenever staff are transferring liquids from bulk containers (something pupils should never be asked to do) eye protection should always be worn and the neck of the container cleaned carefully afterwards.

Transference of Liquids – 2

Pouring liquids from one container to another sometimes leads to a dangerous situation, again as a result of dripping, etc. The safest way of pouring any liquid (on a small scale) is to make use of the fact that liquids 'run' along a glass surface whenever possible. A glass rod, used as shown in Figure 1.1, prevents dripping. Students should be encouraged to practice this technique, using water.

Manoeuvring Cork and Rubber Bungs

Far too many staff and students ignore the generally accepted ways of handling even simple equipment such as cork and rubber bungs. As with all processes, there are at least two ways of connecting or disconnecting bungs and glass tubing – one is safe and, possibly, slow and the other is convenient, quick, and dangerous.

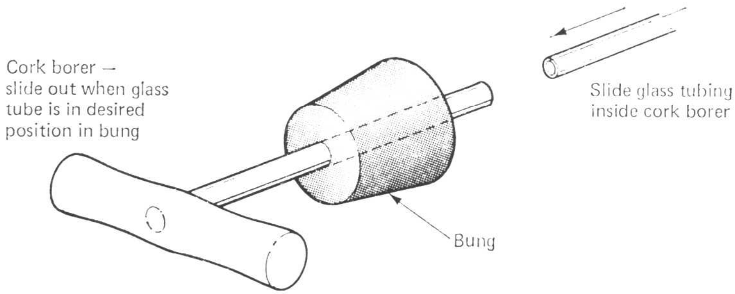

Figure 1.2

The safe way, and the way that should be adopted for the movement of glass rod or tubing into or out of cork or rubber bungs, is as follows. It is even more desirable to use this technique in cases where the cork or rubber has become 'aged', which happens once the two have been left in contact for a week or so. All that is required is the appropriate size of cork borer, which should be used, as shown in Figure 1.2, to prevent sliding contact between the glass and the bung.

Students should be shown this simple technique and be encouraged to use it whenever the need arises.

Storage

Glassware

A hidden (and expensive) danger particularly in biology and chemistry laboratories is the common practice of storing certain items of glassware – pipettes, thermometers, condensers, etc. – in drawers without protective padding. If they are stored loose, there is the constant risk of any small movement causing damage ('It wasn't broken when it was put in, sir!'). If a drawer holds a number of such items, a broken one, which will not be easy to see, can cause a bad cut.

Whenever possible, drawers holding fragile glassware should be lined in such a way as to prevent movement and contact of the contents. Any soft material will do – expanded polystyrene is ideal (*see* Figure 1.3).

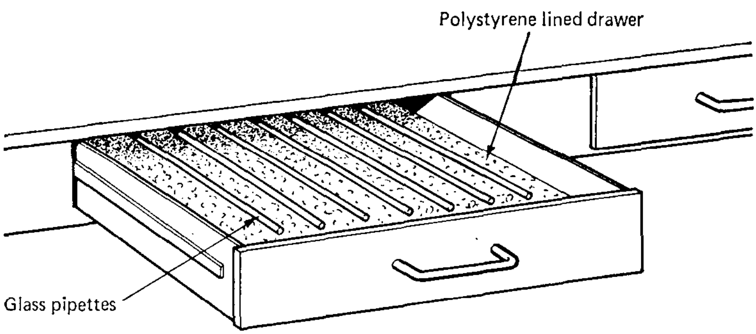

Figure 1.3 Storage of glassware

General

Quite often, staff store items of equipment in such a way that 'frequently used' items are in the most convenient position for regular access. This has a number of advantages but one hazard can result if staff are not on their guard. When storing items on shelving, etc., always make sure that heavy items are at ground level, or very close to it. Each year, staff and students have accidents as a result of lifting rarely used, but heavy, items from a high shelf which they have reached by standing on a stool. In addition, a shelf holding more than one line of bottles is dangerous when items are lifted from the back line.

Chapter 2

Chemical Hazards

This area is dealt with first because, design considerations apart (these are dealt with in Chapter 7 – Designing for Safety), a chemistry laboratory presents the greatest combination of potential hazards. However, careful attention to techniques and the avoidance of known dangers can help to make this area as safe as any other.

Storage

Flammable Chemicals

Details for the provision of storage areas in new laboratory buildings are given in Chapter 7, pages 35–42. What can be done in an existing chemistry laboratory or even in a laboratory that has had to be adapted to teach chemistry?

First, thought must be given to the storage of flammables – not only *how* they are to be stored but also *what* and *how much* is to be kept in storage at any one time.

The very minimum safety provision that is acceptable is to fit, in place of a normal underbench unit, a proprietary steel underbench fire cupboard. These are available (*see* Appendix C, page 58) and provide a storage unit capable of withstanding one hours fire.

The normally accepted limit in terms of *quantity* of flammable liquid in store is 50 litres (but see also Chapter 8 – Legal Liabilities). That is, no school, or college, unless it has a special permit to do so, should hold more than 50 litres of flammable liquid on the premises. If, in addition to any such bulk store, smaller quantities are held in laboratory reagent bottles, these should never have a capacity greater than 500 cm^3.

Checking Stock

No matter how careful laboratory staff are, it is inevitable that chemistry laboratories gradually accumulate a varied stock of materials that are best disposed of. A quick examination of a chemical store will undoubtedly uncover one or more of the following:

(a) reagents without labels or with unreadable (faded) labels;
(b) the presence of materials that are now recognized as hazardous and whose use in a teaching situation is either banned or at least inadvisable;

(c) stocks of materials held in unnecessarily large quantities;
(d) materials that have deteriorated with keeping.

None of the above should be tolerated.

(a) Represents a hazard in all cases and any such reagent containers should be cleaned out.

(b) Covers such materials as those substances now recognized as carcinogenic (cancer-forming) and other materials once commonly used, such as hydrogen sulphide. Materials whose use is banned in the U.K. under the carcinogenic substances regulations include $4,4^1$-biphenyldiamine (benzidine), naphthalen-2-amine (β-naphthylamine) and naphthalen-1-amine (α- naphthylamine) as the 2 (β)- form is nearly always present as an impurity), all nitrosoamines, all nitrosophenols, all nitronaphthalenes, and many substituted biphenyls.

(c) Covers materials such as metallic sodium and potassium, elementary bromine, white phosphorus, etc. In the past, laboratory suppliers have always supplied these materials in large quantities – 2 kg (5 lb) cans were once quite common. Such a bulk is quite unnecessary and excess of such dangerous materials should be disposed of (see page 15, 'Disposal').

(d) Materials that deteriorate on keeping include particularly those materials unstable in the presence of moisture – non-metallic chlorides, phosphorus oxides, calcium (II) dicarbide (calcium carbide), etc. Once a stock of these is found to be deteriorating, it should be destroyed.

A stock check should be undertaken *each term* by a *senior* member of staff who knows the properties of, and, therefore, the hazards presented by, each material held in stock.

Incompatibles

One thing that should be avoided is the storage system that places incompatible materials in close proximity. The commonly used, and very helpful 'alphabetical storage system', where each substance is stored in alphabetical order has its dangers unless modified to overcome them. One can, for example, have phosphorus (white) close to potassium (metal), which is safe until either the labels are lost or fade, or there is a fire. Another combination that has obvious dangers is to store a material such as bromine in the vicinity of any metal container, such as those used to hold metallic sodium.

The alphabetical system is quite satisfactory, so long as separate provision is made for the storage of bulk liquids, flammables, and poisons. If flammable materials are put in a separate room, it should be a room free of any source of flame or electric spark, such as a room holding fuse boxes or switch gear, and should be one that has forced ventilation through an external wall.

Practical Work

General

First and foremost, all staff should appreciate that in any laboratory where chemicals are being used there is a constant hazard from splashes or irritant dust particles entering the eye. Steps should be taken to ensure that everyone in the laboratory – student, technician, teacher *or visitor* – wears eye protection while the practical work is being carried out.

Other than the two practical-work hazards already mentioned (bung/glass movement (page 3) and carcinogenic substances (page 6)) the following should be noted:

(a) Large bottles – particularly Winchester Quarts ($2\frac{1}{2}$ litres) – should *never* be lifted by the neck. Small baskets, that hold two Winchester bottles, are available and facilitate their movement and use.

(b) Gas cylinders must always be kept strapped in a trolley or provided with some means of stability and the valves should never be subject to any sudden mechanical shock (such as being knocked over or struck by a hammer).

(c) Wherever possible, loose asbestos products should no longer be used. This includes 'soft asbestos' tiles; asbestos paper, wool, tape and string; and asbestos-centred gauzes. Although the asbestos normally met with in these items is not the very dangerous 'blue' form, the materials mentioned, when subjected to heating (as they nearly always are), tend to create airborne asbestos fibres whose long-term effect is known to be hazardous.

Various alternative materials are now coming on to the market that avoid the use of asbestos. No list of materials can hope to remain up-to-date for long, but the following should be helpful.

Gauzes (*Asbestos-centred*). Schools normally use squares of mild-steel mesh with a central area that may hold an asbestos filler. Possible alternatives are:

1. Similar gauzes made with a central *ceramic* filler. The few tests on these to date seem to indicate extreme brittleness, particularly after the gauze has been heated;
2. Plain stainless steel gauzes, without a central filler. Two varieties are available in the U.K. – wire gauzes, usually of 0·457 mm diameter (26 SWG) wire, and gauzes made from expanded stainless-steel mesh. Both of these seem to give satisfaction but

schools should be wary of choosing gauzes made from wire any finer than 0·457 mm diameter (26 SWG).

Asbestos Wool and Paper. The only really acceptable substitute for asbestos wool and paper-type products are the ceramic alternatives (schools should avoid using glass wool), though some schools find the increased brittleness of ceramic paper to be a major disadvantage to its use.

Asbestos Boards. These are used to protect benching when using heated experiments and many cheap (but perishable) alternative materials are available, for example, hardboard squares, etc. The best heat-resistant product available at present would appear to be 'Supalux' – a calcium silicate(IV) (calcium silicate) matrix material which is available from a number of suppliers.

Specific Cases

Twenty-two specific materials or activities are given below that each present a hazard to the unknowing. As time passes, additional hazards will become evident and careful note should be made of these, and circulated to as wide an audience as possible, via local and national teachers organizations and publications.

1. *Benzene.* This liquid presents a wide range of unacceptable hazards to the user. It has a low flashpoint (–11 °C) and so can be rated as highly flammable. Far more serious, however, are the dangers of inhalation of the vapour and absorption of the liquid through the skin. Not only can skin absorption give rise to narcosis and dermatitis, but repeated inhalation of the vapour has been shown to give rise to bone marrow damage. This material should be phased out of teaching laboratories as quickly as possible.

2. *Boiling Liquids.* When a small quantity of a solution is to be boiled, this should always be done in a large ('boiling tube') test-tube containing, if appropriate, fragments of porcelain. (Collect all old broken porcelain dishes, etc. and keep them for this purpose.) These two steps should prevent hasty heating causing 'bumping' of the liquid, but even if it does occur, the hot liquid stands less chance of spurting out of the tube.

3. *Broken Glass.* It is inevitable that some glassware will get broken in the course of experimental work. Once large pieces have been carefully picked or swept up, a safe way of ensuring that *small* slivers of glass are collected is to use a small lump of plasticine, a proprietory material (such as 'Blu-Tack'), or even moist clay to wipe over the area suspected of harbouring

glass fragments. Once the material has been used in this way, it must, of course, be discarded.

4. *Tetrachloromethane (Carbon Tetrachloride).* Although limited exposure to this material is not dangerous, the long-term effects of high-level exposure include liver and kidney damage as well as a more immediate narcosis and irritation. Laboratories should hold only small quantities of the material which should be used only with adequate ventilation.
   Note. Some forms of fire extinguisher use tetrachloromethane (carbon tetrachloride) as the active principle. Such extinguishers should never be used on a fire in an enclosed area.

5. *Charcoal Blocks.* Although work with charcoal blocks, for example, when used for 'blowpipe reduction' experiments, etc., is now less frequent, they regularly cause fires after use. Charcoal blocks retain their heat for a long period and, when stacked in an enclosed space (such as a drawer) can be subject to spontaneous combustion. When finished with, the blocks should be stacked loosely on a metal tray and left in the open laboratory overnight.

6. *Chlorine.* Although this gas is not now produced experimentally in the same quantity as previously, its preparation presents two hazards. First, from the gas itself, which is a well-known vesicant and respiratory irritant. Second, from the usual method of preparation in which concentrated hydrochloric acid is reacted with *dry* potassium manganate(VII) (potassium permanganate) crystals. These two reagents have been known to explode on contact, presumably due to an impurity in one or other of them. This problem can be overcome by covering the crystals with cold water *prior* to running in the hydrochloric acid.

7. *Chromate(VI) (Chromates).* Salts of chromium(VI) – chromates and dichromates – should always be handled with care. Both the dry chemicals and their solutions can cause dermatitis and non-malignant skin cancers. Users should always wash their hands immediately after using any of these compounds.

8. *Hydrogen.* Explosions occur regularly when experiments are performed in which hydrogen is passed over a heated material, usually a metal oxide. Two precautions need to be taken to minimize this risk. First, the experiment must be carried out behind a safety screen. Second, the material under test must *not be heated* until hydrogen has been flowing through the test apparatus for at least five minutes and all air has been flushed out.

9. *Hydrogen Sulphide.* This is another gas which is not now prepared as frequently as it has been in the past. It is as poisonous as hydrogen cyanide and causes irritation to the eyes and mucous membranes even at very low concentrations. Its preparation should be avoided. Work with sulphides should be limited to situations where accidental formation of the gas is vented from the laboratory.

10. *Mercury and its Compounds.* Not only should great care be taken to avoid spillages of metallic mercury (stand equipment in a plastic tray to retain any globules which are spilt) but schools and colleges should avoid heating mercury compounds in the open. All mercury compounds are poisonous and the majority are volatile or decompose on heating to yield the volatile metal. Experiments in which materials such as mercury oxide are heated to yield oxygen and the metal do, in fact, fill the room with an unacceptably high level of mercury vapour, far higher than the recommended threshold limit value (T.L.V.) (see Appendix D, page 59).

11. *Ninhydrin.* This material is being increasingly used to 'develop' chromatograms of amino acids etc. In these experiments it is frequently used as a spray. Such use must be confined either to a fume cupboard giving a good rate of extraction or, better still, be carried out outside in the fresh air. Ninhydrin is a respiratory poison and is easily absorbed into the system, especially if present in the form of a fine mist.

12. *Nitrogen Oxide or Nitrogen Dioxide (Nitrous Fumes).* Thankfully, nitric(V) acid is not now used as widely as it has been in the past. Reactions of this acid with metals and other reducing agents produce copious fumes of nitrogen oxide (nitric oxide) or nitrogen dioxide which can give rise to pulmonary oedema. Reactions which might produce these fumes should either be avoided or carried out in such a way as to localize the fumes.

13. *Phosphorus Residues.* In any experiment in which white phosphorus is used (or where red phosphorus has been subjected to heat and would, therefore, probably contain white phosphorus), all residues from the experiment must be collected and burnt off by a responsible member of staff. Residues washed down the sink constitute a very real fire hazard.

14. *Pipetting.* Mouth-pipettes are still in common use, even to transfer dangerous liquids and solutions. Whenever possible this form of pipette should be replaced by the slightly more

expensive safety pipettes, a number of varieties of which are available from suppliers catalogues. Even if all mouth pipettes are not replaced, each chemistry laboratory should have two or three of the safety variety for operations involving the more hazardous liquids.

15. *Plastics.* Many establishments are now experimenting with plastics, and rightly so. However, these substances present a new range of hazards in the laboratory, from the solvents used, from the organic peroxide catalysts, and, at a simpler level, from the combustion products formed when pupils experiment on different kinds of plastic materials. Staff should ensure that work with materials of this kind are done on a very small scale and always under well-ventilated conditions.

16. *Potassium.* Mention has already been made of the hazard presented by large stocks of this and similar materials. Potassium affords another hazard due to ageing. Old stocks of potassium that have discoloured (the sticks develop a greasy yellow colour) have passed the stage when they may be considered safe. Well-documented cases are recorded where 'old' potassium has exploded on being cut by a knife, probably due to the formation of the unstable peroxo compound (peroxide), a powerful oxidizing agent, and its being brought into contact with the fresh metal, a powerful reducing agent, in the cutting process. Old stocks should be destroyed, see page 15.

17. *Scheduled Poisons.* The U.K., in common with most developed countries, operates a system of control over the sale and use of poisonous materials. These substances appear on a 'schedule' and those that fall into category 1, i.e. Schedule 1 ('S1') poisons, are subject to rules of both use and storage. A list of the more common scheduled poisons is given in Appendix B, pages 55–56, and these materials should not be available to pupils (except possibly sixth formers) in the solid or pure form except under strict control. Some scheduled poisons, barium chloride, for example, are common laboratory reagents and whereas *solutions* of them may be on laboratory shelves or benches, the solid reagents should be kept under lock and key in a 'poisons cupboard'.

18. *Sucking Back.* There are a whole range of experiments in which a substance or mixture of substances are heated to prepare a sample of a gas which is then collected over water. The reagents and the gas collected may themselves present no hazard, but the design of the experiment may do so. The equipment should be so arranged as to prevent cold water being drawn back into the reaction chamber when heating has

stopped. The cold water will soon fracture the hot glass. In such an experiment, once heating has stopped, the line of glass must be 'broken' so as to allow air to enter the apparatus, either by uncorking at A or at B (Figure 2.1).

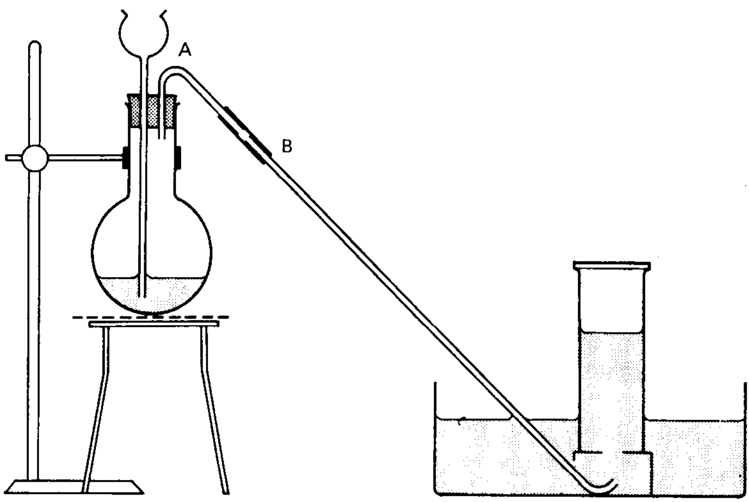

Figure 2.1 Typical layout which could cause suck-back when heating is stopped

19. *Sulphuric Acid/Water Mixtures.* Although the vast majority of staff must be aware of the dangers of incorrectly mixing concentrated sulphuric acid and water, details of the correct method always bear repeating. If water is simply added to concentrated acid, the less dense water will form a separate phase and a violently exothermic reaction will occur at the interface. The generation of heat is minimized by:
(a) adding acid to water;
(b) stirring continuously.

20. *Urea-methanal Resin (Urea-formaldehyde Resin).* The preparation of urea-methanal resin, as usually performed, involves the reaction of hydrochloric acid and methanal (formaldehyde). These two materials undergo a secondary reaction in which bis-chloromethyl ether is produced. This is a member of a family of chemicals, all of which are known to give rise to carcinomas (cancers). Schools and colleges are advised not only to cease preparation of this particular resin using hydrochloric acid, but to take steps to see that methanal (formaldehyde) has no chance of reacting with either hydrochloric acid or metal chlorides in any other preparation.

21. *Venting of Reagents.* Certain compounds and solutions must have their containers checked regularly to prevent a build-up of internal pressure. Reagents that have given rise to explosions because of lack of venting include solutions of hydrogen peroxide, sodium chlorate(I), (sodium hypochlorite), and silicon or titanium tetrachloride. In the case of these latter materials, their reaction with moisture forms the solid dioxide in each case, which often seals the bottle, especially if this is fitted with a ground-glass stopper. In all cases of seized stoppers in reagent bottles, great care must be taken on opening, which should be done remotely, if this can be arranged.

22. *Violent Reactions.* Any list under this heading *must* be selective and incomplete and staff will undoubtedly wish to add to it. Reactions between the following pairs of chemicals should be avoided at all costs as they are unpredictable and often extremely violent.

(a)	concentrated acids	:	concentrated alkalies.
(b)	concentrated acids	:	alkali or alkali earth metals.
(c)	oxidizing agents	:	metal powders.
(d)	oxidizing agents	:	powerful reducing agents.
(e)	oxidizing agents	:	organic liquids.
(f)	alkali metals	:	hot water.
(g)	alkali metals	:	organic chlorinated compounds.
(h)	alkali metals	:	non-metallic chlorides.
(i)	metal hydrides	:	water.
(j)	heavy metal nitrates	:	heated with organic acids or their salts.
(k)	heavy metal nitrates	:	any powerful reducing agent.

Dealing with Spillages

Spillages of *solid* materials should rarely present any hazard. Only in the case of white phosphorus could delay cause serious harm and, so long as the lumps of phosphorus are regularly dowsed with cold water, they can quickly be returned to their container and immersed in water.

Liquids, however, present an unusual array of hazard and are best dealt with in groups.

Organic Liquids

As soon as any organic liquid has been spilt, *extinguish all flames* and remove all sources of heat. Even if tetrachloromethane (carbon tetrachloride) is spilt, it would be unwise to leave flames burning, as in the presence of heat and moisture, tetrachloromethane (carbon tetrachloride) can form carbon dichloride oxide (phosgene), $COCl_2$, which is very poisonous. If the spillage is at bench level, it should be washed into a sink and followed by a copious flow of water. Spillages