

SYSTEMATIC ORGANIC CHEMISTRY

PART I

CHAPTER I

INTRODUCTORY

Cautions

1. **Fire.**—(a) Fire extinguishers should always be at hand in the laboratory, and should be applied *at once*.

(b) Great care is necessary in the use of ether, light petroleum, carbon disulphide, acetone, alcohol, benzene, etc., as the vapours of these are highly inflammable. They should always be distilled from a water bath and be collected in the apparatus shown on p. 20. Special care is necessary with carbon disulphide, as its vapour inflames in contact with a warm surface, even in the absence of a flame.

(c) If the liquid in a beaker or flask catches fire, the source of heat should be removed, and the flame extinguished by placing a watch-glass on the opening of the vessel.

(d) A blanket should be at hand in case the clothes catch fire.

2. **Poison.**—(a) All operations in which fumes or noxious vapours are evolved must be carried out in a good fume cupboard.

(b) Special care must be taken not to breathe vapours of strong or fuming acids, cyanogen, hydrogen cyanide, carbon monoxide, halogens, phosgene, alkyl sulphates, acyl chlorides, nitro compounds, aniline, etc.

(c) The hands should be immediately washed after using poisonous substances such as alkaloids, potassium or sodium cyanide, arsenious oxide, phosphorus. This precaution could be extended to the majority of organic compounds.

3. **Accidents.**—(a) A First-Aid outfit should be kept in each laboratory.

(b) For burns by heat, cover with a freshly prepared 20% aqueous solution of tannic acid containing 1 in 1,000 of acriflavine.

(c) For acid burns (1) on the skin; wash with much water and with dilute ammonia, or bicarbonate solution. (2) In the eye; use much saturated solution of borax.

(d) For alkalis (1) on the skin; wash with much water, then with 1% acetic acid. (2) In the eye; use much saturated boric acid solution and then drop in castor oil.

(e) For acid on the clothes; wash with ammonium carbonate solution.

(f) For alkali on the clothes ; wash with dilute acetic or boric acid, and remove remaining acid with ammonium carbonate solution.

(g) For bromine on the skin ; wash with alcohol, then with carron oil.

(h) For phenol burns ; treat with dilute bromine water in glycerol.

All these remedies *should be kept* on a special shelf in the laboratory.

Sodium Residues.—These should not be dropped into the sink or waste box, but should be added in small portions to alcohol, and, when all action has ceased, the solution poured into the sink.

Gas Masks.—Students should acquaint themselves with gas masks for use in case of fire, explosion, or other emergency.

Scheme of Arrangement of Reactions

The reactions in this book are grouped in sections determined by the linking of elements that occurs in the reaction to form the product. The order of the sections depends on the Richter alphabet—**C, H, O, N, Cl, Br, I, S**, etc. A complete classification by this method would take the form :—

I. Reactions in which **C,**
H,
O,
N,
Cl, Br, I, S, etc., } are linked to **C.**

II. Reactions in which **H,**
O,
N,
Cl, Br, I, S, etc. } are linked to **O.**

III. Reactions in which **H,**
O,
N,
Cl, Br, I, S, etc. } are linked to **N.**

Small sections as III. are not further subdivided in practice. Large sections are subdivided to give a separate subsection for the linking of each separate element to the main one, so to speak, of the section ; and each subsection is further subdivided according to the type of compounds necessarily obtained in the various reactions. An examination of the table of contents and of the **C** to **C** section will make all the details clear. In the various sections the reactions follow one another so that related reactions come together as much as possible.

Of course, in practice, points arise which have to be settled arbitrarily. Some reactions can be placed under two or more headings, *e.g.*, $C_6H_5SH \rightarrow C_6H_5SO_3H$ might be put under **S** to **O** or **O** to **S**. In this case it is more natural to put it in the latter section, but in analogous cases the reaction in question is classified under the section first occurring. No linkings to **H** are considered, **H** is always supposed to be linked to the

other element. Some sections do not appear in the book because so few reactions fall within them.

Decomposition reactions in which links are broken rather than made, electrolytic preparations and some others are placed in a separate section.

Hints to Students

1. Before commencing a course on practical organic chemistry, become familiar with the chapter on apparatus and methods. This chapter must be continually referred to as the course proceeds, so that facility in manipulative detail may be gained.

2. Before beginning any individual preparation read carefully the entire method and also obtain a clear idea of the theory as well as the practice of the operation. Know the reason for every step in the process.

3. Work on a definite plan, never omitting anything essential for the sake of speed.

4. Procure *suitable and sufficient* apparatus. This applies especially to the use of vessels appropriate to the quantities to be used.

5. Clean and, if necessary, dry all apparatus before use.

6. Fit up the apparatus carefully and compactly, paying particular attention to the boring and fitting of corks.

7. Follow exactly the instructions given. Definite times, temperatures and weights are not specified for nothing.

8. Cultivate a habit of observation; observe all changes and record them. This is one of the essentials of successful research.

9. Whenever possible, control the course of the reaction by testing samples. This will in many cases enable the end point to be determined exactly (see Acetanilide, Benzenesulphonic Acid).

10. Remember that the criterion of practical work is the yield of *pure* substance obtained, and if this differs by more than 10% from the yield stated, seek the cause of this difference, and then *repeat* the experiment.

11. After the experiment expand the notes already taken, giving particulars of the yield, physical characteristics (M.P., B.P., D., and microscopic examination for crystalline form) of the product. The ratio of the yield obtained to the theoretical yield also should be recorded as a percentage.

12. Cost the preparation (see p. 6) and compare the price with the current value if quoted.

13. A sample of each stable product should be kept in a specimen bottle, and details of physical characteristics and yield placed on the label.

14. Above all, keep the bench neat and clean. Use separate dusters for it and for the apparatus.

The Use of the Library

The references given in this book to the reactions and preparations should be consulted where possible by the student.

A knowledge of the literature is of fundamental importance. Richter's *Lexicon* must be used where a reference for a preparation is not given. The method of using this lexicon is fully described in the preface to that book. To facilitate the use of this lexicon, molecular formulæ have been given in this book.

Richter also gives references to Beilstein which should afterwards be consulted, and the latter book always gives an indication of the scope of the reference. "A Brief Introduction to the Use of Beilstein's *Handbuch der Organischen Chemie*" (Huntress) has been published in English (Chapman & Hall, 1930).

The *Lexicon* of Stelzner should be consulted for references from 1910—1921, while the formula register of *Chemisches Zentralblatt*, based on the same plan as Richter and Stelzner, continues the index. Volumes 1922—1930 of this index have appeared and Volume 1930—1934 is appearing in parts. A general register is also supplied by the *Chemisches Zentralblatt* from 1925 onwards.

British Chemical Abstracts (Sections A and B) issued by the Bureau of Chemical Abstracts, and *Chemical Abstracts* of the American Chemical Society, should also be consulted for recent references.

Cultivate a habit of reading the current journals, especially *J. C. S.*, *J. S. C. I.*, *Berichte* and *Am. Soc.* Do not forget that organic chemistry is not the only branch of the subject. Pay particular attention to the Annual Reports issued by the Chemical Society and the Society of Chemical Industry.

Nomenclature

The nomenclature used in this book is that according to The Chemical Society.

Alternative names are given in preparations to assist the student in looking up the literature in Richter and in Beilstein. There are also appended in some cases, in square brackets, the names according to the Geneva Commission of 1892. Although the latter has not been uniformly adopted in different countries, it is well that the student should become acquainted with this type of nomenclature, in which the name is derived, in general, from the parent hydrocarbon, and which is sometimes adopted, perhaps with slight modification, to designate a compound of complex structure.

Suggested Lists of Preparations

Before commencing a course in practical organic chemistry, the student should have a definite list of preparations to follow. These should be arranged in increasing order of difficulty, and in such a way that, as far as possible, each preparation leads naturally to the next. Where several students are working in the laboratory, the best results are obtained when each works through a different list and compares notes with his neighbour.

The following lists are suggested :—

	I.	II.	III.	IV.
1	No. 199	No. 143	No. 321	No. 478
2	„ 266, 269	„ 321	„ 184	„ 311
3	„ 34, 37	„ 218	„ 195	„ 218
4	„ 409, 479	„ 198, 200	„ 160	„ 441
5	„ 75	„ 101	„ 482	„ 226
6	„ 184	„ 375	„ 337	„ 360
7	„ 249	„ 426	„ 274	„ 385
8	„ 228	„ 224	„ 230	„ 187
9	„ 361	„ 359	„ 288	„ 217
10	„ 293	„ 292	„ 364	„ 271
11	„ 384	„ 386	„ 278	„ 189, 265
12	„ 225	„ 284	„ 243	„ 486
13	„ 371	„ 140	„ 292	„ 376
14	„ 369	„ 241	„ 383	„ 457
15	„ 131	„ 338	„ 109	„ 289
16	„ 245	„ 29, 36	„ 46	„ 398
17	„ 248	„ 294	„ 25, 166	„ 138
18	„ 342	„ 345	„ 207	„ 272
19	„ 391	„ 278	„ 344	„ 43
20	„ 390	„ 21, 57	„ 157	„ 442
21	„ 20, 56	„ 393	„ 21	„ 51, 52

More advanced students should work through a synthesis involving several steps, *e.g.*, Collidine, and should also attempt the preparation of homologues of some of the substances given in detail. In the lists given above, several preparations of industrial importance are included.

These preparations should be prefaced by exercises in fractional crystallisation and fractional distillation (pp. 13, 22, 24).

Tests on groups of organic compounds, such as those outlined in Chapter XLIII, should be interspersed during the preparation exercises.

Note on Costing

The student should always acquaint himself with the cost of the materials he uses in a preparation. He should therefore consult the price list of some well-known manufacturer or retailer. Such a list should be available in every laboratory. Having ascertained such prices, he should always, after completing his preparation, calculate the cost of his final product, and compare with the price in the price list. Many factors control the market prices, such as labour, recovery of by-products, etc.; it is, nevertheless, a good exercise to make this comparison. In deciding which particular method of preparation should be adopted in a particular case, the student should consider the question of cost, weighing up the cost of starting materials, reagents, solvents, with yield. For example, there is a well-known reaction by which aromatic amines are converted into the corresponding hydrocarbons. It would be little short of a crime, however, except in order to confirm the reaction, to attempt to prepare toluene from toluidine in this way, since the value of the final product is only a fraction of that of the starting material, apart altogether from the cost of the reagents required; often such reactions can well be studied in a test-tube.

Such evaluation should be adopted in all the simpler preparations. In this way the student will become acquainted with the elements of costing which play such an important part in his later life in the factory. He should hardly wait until he enters the factory to appreciate the cost of such common substances as sulphuric acid, benzene, aniline, naphthalene; he should be able to estimate roughly the cost of derivatives such as dinitrobenzene, *p*-nitroaniline, etc. Even should he not take up the industrial side of his profession, he should be acquainted with the relative value of the more common products, and trained to decide for himself whether, for example, it would be more economical to extract with ether or benzene, taking into consideration the relative efficiencies of the two processes.

Moreover, he should not use chemically pure products for his preparations, unless for research purposes. The ordinary technical qualities supplied by the well-known manufacturers are quite suitable for most preparations, and are, of course, much cheaper. It should be remembered that the facilities for the purification of many organic products are much greater on the large scale than in the laboratory, and that these technical products are often therefore of remarkable purity. It is a valuable

exercise to purify some technical product of poor quality and again to estimate the cost of such purification (see Purification of Crude Anthracene).

The authors would not stress the point further in a book of this kind. Their experience teaches them that too often do students look upon such things as gas and power, bench reagents, and the commoner organic chemicals supplied from the departmental store, as commodities which have no actual value. It is a moot point as to whether educational authorities would not render much greater service to the student by charging more moderate fees for instruction, and thereafter charging for all materials used in the course of his work.

CHAPTER II

APPARATUS AND METHODS

Practical Hints

Softening of Corks.—Corks should always be softened before inserting in any flask and the boring performed after softening. Several methods are available. The cork may be softened in the ordinary eccentric iron press between the two rollers. It may also be rolled on the floor underneath the foot. A convenient way is to place the cork in hot or boiling water; the cork swells somewhat and becomes quite soft so that it can be made to fit various tubes or flasks. An excellent method of reducing the size of a cork is to rotate it in a flame until the outer coating has charred; it is then rolled and cleaned: a cork thus treated may be used for vacuum distillations as the layer of carbon forms a good seal.

Corks impregnated with sodium silicate solution resist attack by hydrochloric acid and chlorine.

Rubber stoppers should be occasionally rubbed with a little toluene, which prevents hardening and keeps them clean. A trace of vaseline smeared on a rubber stopper affords considerable protection from the actions of halogens. Rubber stoppers should always be removed from vessels while the latter are still warm, to prevent sticking to the glass.

Boring of Corks.—Sharp borers should always be used. The end of the cork is placed against some solid object and bored half-way through from one end. The boring should then be completed from the other end. The boring of rubber stoppers may be greatly facilitated by moistening the borer with caustic soda. Mechanical borers are now available.

Removing Fixed Stoppers.—Hot water should be run on to the neck of the bottle and the stopper gently tapped with another glass stopper. The neck of the bottle may be inverted in hot water for a minute and afterwards gently tapped. If these methods fail, and if the contents of the bottle are not easily inflammable, the neck of the bottle may be rotated in a flame prior to tapping. Similar methods may be applied to fixed stop-cocks.

Ground-glass Joints.—Apparatus provided with ground-glass joints for attachment to other pieces are available for most of the common operations and should be employed for the sake of convenience and of avoiding the introduction of impurities from corks.

Crystallisation

The solid product obtained from a chemical reaction is seldom pure, being contaminated with various impurities and by-products. For

purification, the process of crystallisation is generally employed. As the process is of such frequent occurrence, the student should early in his course acquire proficiency in it. When dealing with products obtained in plenty, the utmost care should be taken to obtain the maximum yield of pure crystallised compound, as only by doing so can the manipulative skill be acquired which is necessary to obtain a satisfactory yield of pure compound from a product obtained in meagre quantities.

Crystallisation by Cooling.—The ideal solvent is one in which the compound to be obtained in pure crystalline form is insoluble in the cold, but readily soluble in the hot. Further, the impurities should either be insoluble or else very soluble. In practice such a solvent is seldom obtained, but the nearest approach to it should be selected.

The solvents most commonly employed are: water, alcohol, ether, benzene, petroleum ether, acetone, glacial acetic acid; or mixtures of water and alcohol, water and acetic acid, ether and petroleum ether, benzene and petroleum ether.

The following are frequently used: chloroform, carbon disulphide, carbon tetrachloride, ethyl acetate, pyridine, hydrochloric acid, sulphuric acid, nitrobenzene, aniline, phenol, epichlorohydrin.

The following solvents are now manufactured on the large scale for industrial purposes: ethylene dichloride, di-, tri-, and tetra-chloroethylene, tetrachloroethane, dichloroethyl ether, hexahydrobenzene, cyclohexanol, tetra- and deca-hydronaphthalene (tetralin and dekalin), triacetin, ethylene glycol, butyl alcohol, diacetone alcohol, ethyl lactate, isopropyl ether, etc.

Selection of Solvent.—In order to select a suitable solvent small quantities (each about 0.1 gm.) of the finely pulverised product are placed in several test tubes and treated with a few drops of single solvents of the above class. Where the substance dissolves easily in the cold on shaking, or does not dissolve appreciably on boiling, the solvents in question may be regarded as unsuitable. Where the substance dissolves on heating or boiling, and separates out again on cooling, the solvents are suitable; that solvent should be selected which gives good crystals in the greatest abundance. At times crystallisation does not take place owing to supercooling; in such cases the side of the test tube should be rubbed with a glass rod, or the solution should be "seeded" by the addition of a small portion of the crude product, since such operations frequently induce crystallisation. If necessary, the solution should also be cooled in ice or in a freezing mixture. With substances which are sparingly soluble in the common solvents, solvents of high boiling points such as toluene, nitrobenzene, etc., should be used.

Where no single solvent is found suitable, a mixture of two miscible solvents in one of which the product is soluble and in the other insoluble may be employed with advantage. Substances which are very soluble in cold alcohol or cold acetic acid are frequently but slightly soluble in water, and many substances which are very soluble in benzene are sparingly soluble in petroleum ether. From the preliminary investigation with

single solvents it can generally be deduced which are suitable to serve as mixed solvents. The substance is dissolved in a small quantity of one solvent and heated; the second solvent is then gradually added to the hot solution until a turbidity appears; heat is again applied until complete solution takes place, and the solution is set aside to cool. Many substances separate in an amorphous or sticky form from an alcohol-water solvent. It is important that the crystals should be sufficiently well defined that their crystalline form as well as the presence of other crystals or impurities can be detected with the aid of a lens. The crystals obtained from these preliminary tests should be preserved, to serve, if needed, to "seed" the solution containing the main bulk of the substance.

Preparation of Solution.—If the substance is readily soluble the heating is generally carried out in a flask (conical or ordinary) on a water bath. If considerable heating is necessary, a reflux condenser should be provided to avoid loss of solvent or danger of fire. A convenient type of reflux condenser when small quantities of liquid are being dealt with is an ordinary glass filter funnel placed stem-wise in the mouth of the flask. Should the vapour catch fire, the flame should be withdrawn and the mouth of the vessel covered with a damp cloth or with a watch-glass. When the solvent is neither very volatile nor easily inflammable (*i.e.*, water or acetic acid), the heating may be performed in a beaker over a flame. Small quantities of such liquids as alcohol or benzene may be heated in a similar manner by an experienced operator. Where the resulting solution does not require filtration, a conical flask should always be used (see next section). During the heating, the contents of the vessel should be frequently shaken or stirred, since crystals, especially when they melt to a heavy oil on the bottom of the vessel, render the latter liable to crack.

In preparing the solution an excessive amount of solvent should not be employed at first; successive small quantities should be added to the boiling or nearly boiling solution until the substance just completely dissolves, or until nothing but impurity remains undissolved. With substances of low melting point care should be taken that concentrated solutions from which the substance commences to separate at temperatures above its melting point are not used. When using mixed solvents, the procedure is similar to that described for the preliminary tests; if on the addition of the second liquid (*i.e.*, water or petroleum ether) resinous impurities separate, these should be filtered off before proceeding further.

Filtration of Hot Solution (see also **Filtration**).—This operation is usually necessary in order to remove insoluble impurities, filter fibres, etc. When the substance does not separate rapidly from the hot solution, and the liquid filters quickly, the solution may be filtered through an ordinary funnel with a short stem, fitted with a folded filter paper (Fig. 1). Both funnel and paper should previously be warmed in a steam bath. Or, the solution may be filtered with suction, using suitable types of apparatus (Figs. 27, 28). The funnel and filtering medium should be previously warmed. When the filtrate is collected in a thick glass suction flask,

the latter should be warmed beforehand by immersion in warm water. The bell-jar form of filtering apparatus (Fig. 29) is recommended, as the hot solution can be collected in a conical flask of suitable size. For "crystallisation by cooling" a rather *wide-mouthed conical flask* should be used to contain the hot filtered solution—a filter flask serves equally well for large volumes; with *vessels of this conical type* the crystals *do not creep up the sides*, as may occur when beakers or the so-called "crystallisation dishes" are used; after separation, the crystals can easily be removed with the aid of a glass rod over the end of which a short piece of rubber tube has been drawn.

If the substance crystallises rapidly from the hot solution, a hot filter should be used. Figs. 2 and 3 show steam jacketed and hot-water jacketed filters. With a volatile and easily inflammable solvent the flame should be removed from the jacket immediately before filtering, danger of fire being

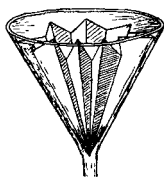


FIG. 1.

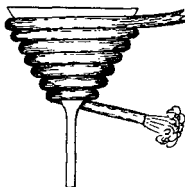


FIG. 2.

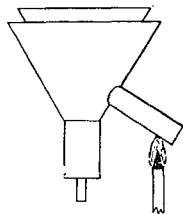


FIG. 3.

thereby avoided; in such an instance the steam funnel is preferable when the steam is generated at a safe distance.

After filtration the conical flask is covered with a watch-glass and set aside. If large crystals are required, the rate of cooling should be as slow as possible, and the flask should not be disturbed. The rate of cooling may be lessened by immersing the flask in a bath of warm water and allowing the bath and its contents to cool. If the substance separates in large coarse crystals on slow cooling, or if small pure crystals are required, it is expedient to cool quickly in cold water or in ice water, and to stir or agitate the solution at the same time. Small crystals are generally free from mother liquor, which is liable to be occluded in large crystals. When the substance is very soluble at ordinary temperature, the cooling should be continued in a freezing mixture.

The list on p. 12 gives some useful freezing mixtures, the most convenient for many purposes being a mixture of conc. hydrochloric acid and ice, or sodium chloride and ice.

Separation of Crystals.—This is generally effected by filtration with suction, vessels of size suitable to the quantities dealt with being selected. The crystals left on the funnel should be well pressed down and then washed a few times with small quantities of the pure solvent in order to remove the last traces of mother liquor. If the substance is easily soluble, too large quantities of solvent must not be employed for washing. When

a solvent which is not readily volatile has been used (*e.g.*, nitrobenzene, acetic acid, etc.), it must be removed from the crystals by washing with an easily volatile solvent with which it is miscible. After being thoroughly drained on the funnel, the crystals are dried (see also p. 36). They

Mixture in gms.	Temp. falls from 15° to
250 calcium chloride cryst. + 100 aq.	-8°
8 sod. sulphate + 5 conc. HCl	-12°
25 amm. chloride + 100 ice	-15°
45 amm. nitrate + 100 ice	-17°
50 conc. HCl + 100 ice	-18°
33 sod. chloride + 100 ice	-20°
1 pot. thiocyanate + 1 aq.	-24°
100 dil. H ₂ SO ₄ 66% + 100 ice	-31°
3 calcium chloride cryst. + 2 ice	-49°
Solid CO ₂ + ether	-100°

may be placed on filter paper or porous plate, covered to protect from dust, and allowed to dry in the air, or left in a desiccator over a suitable substance to absorb the solvent; the operation may be hastened by evacuating the desiccator. If the crystals have a high melting point, the drying may be effected in a bath at temperatures below the fusion point. In this connection it should be noted that the presence of small quantities of solvent may produce a considerable lowering of the melting point. A test portion should therefore first be dried.

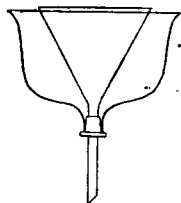


FIG. 4.

Often further crops of crystals can be obtained by concentrating the mother liquor; generally these are less pure and require to be recrystallised. In some cases the first crop has to be recrystallised before the crystals are pure (determined by M.P.). It is often convenient, in order to separate a second crop, to dilute the mother liquor with a liquid in which the

dissolved substance is sparingly soluble. Crops separated in this way generally require recrystallisation.

Crystals which are very soluble in the solvent at laboratory temperature, and which have been obtained by cooling the solution in a freezing mixture, should be filtered through an ice-jacketed funnel (Fig. 4).

In all cases the process of crystallisation must be continued until no change in melting point occurs on further crystallisation, or until the product obtained by evaporating a sample of the mother liquor has the same melting point as the crystals separated from it.

On the larger laboratory scale centrifuges may be used for separating and draining crystals.

Crystallisation by Evaporation.—This method is employed when the substance is so easily soluble in all solvents (hot and cold) that it will only separate after partial evaporation. The solvent is allowed to evaporate spontaneously in the air or in a desiccator; if in the latter the evaporation is greatly hastened by using a suitable absorbent as well as evacuating the desiccator. The type of vessel employed depends on the volatility of the solvent; obviously the conical flask already recommended for “crystallisation by cooling” is not suitable for spontaneous evaporation, while a beaker or shallow “crystallising dish” is. When the latter type of vessel is used, “crusts” often form on the sides above the surface of the liquid. Such crusts seldom consist of pure substance, and they should be carefully removed with a spatula before attempting to filter off the crystals.

Since the purifying effect of crystallisation depends on the fact that the impurities remain dissolved in the mother liquor—except in cases where the impurities being insoluble are first filtered off—the solvent should never be completely evaporated, but the crystals should be filtered off while still covered with mother liquor.

Special Methods.—With some substances it is difficult to obtain good crystals by the methods already described. A method which frequently gives excellent results consists in dissolving the substance in some solvent, then adding a second solvent miscible with the first, but in which the substance is sparingly soluble. The first solvent is then gradually removed and the substance separates out—usually in the crystalline form. If the first solvent is the more volatile in air, spontaneous evaporation in air may diminish its concentration in the solution. The solution may be placed in a desiccator over some substance which absorbs the first solvent but not the second; in this way water may be removed from a water-alcohol solution by solid caustic potash or quicklime.

Another method—applicable when the substance is soluble in alcohol and in ether, but insoluble in water—consists in making a saturated solution in cold alcohol, adding water until considerable precipitation has taken place, then adding ether until the precipitate has redissolved, and finally allowing the ether to diminish by spontaneous evaporation.

When a substance is soluble without change in concentrated sulphuric acid, but insoluble in water, a saturated solution in the former medium when left exposed to water-vapour—say, side by side with a vessel of water under a bell-jar—gradually absorbs water, and the substance frequently separates out in crystalline form.

The purification of many products can be facilitated by distillation, prior to crystallisation, provided they distil without decomposition. Generally it is preferable to conduct the distillation under reduced pressure (p. 26).

Fractional Crystallisation

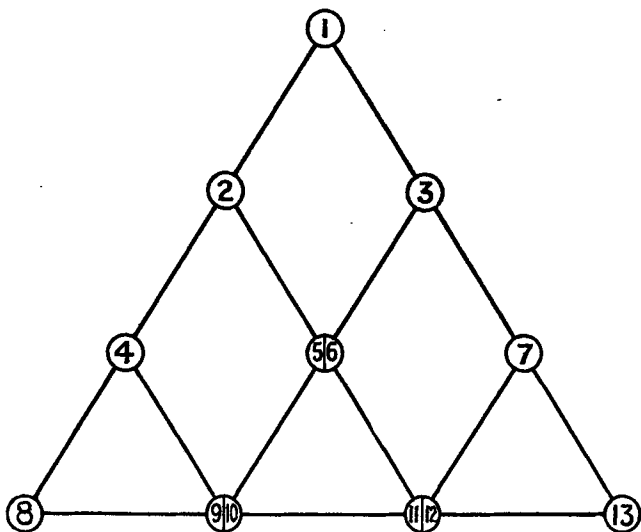
The process of fractional crystallisation is employed to separate two or more substances, all of which are soluble in the solvent used. When only two substances are present, it is often possible to find, by preliminary tests, a solvent which, when used in suitable quantity, will dissolve the whole of

the more soluble compound, but only a small quantity of the less soluble. In such a case, a preliminary separation may be effected by shaking the mixture with a quantity of solvent (hot or cold—as found suitable by trial), and filtering the solution from the residue remaining undissolved. For extracting a mixture of this nature with a hot solvent the Soxhlet apparatus (Fig. 30) is specially useful; in fact this apparatus should be employed for all extractions where a residue remains undissolved, since filtration as well as extraction is accomplished; also, only a relatively small quantity of solvent is required (see p. 34).

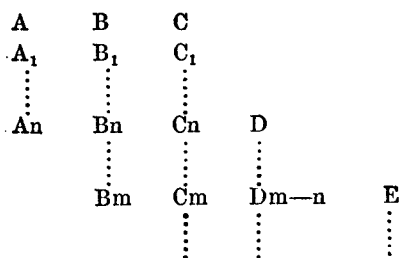
When commencing a fractional crystallisation, preliminary tests similar to those described under "Crystallisation" are first carried out, and the crystals which separate during such tests examined with a lens. The crystals which form first are either the least soluble or most abundant constituent of the mixture. If a second or further type of crystal appears, its shape and time of formation relative to cooling should be noted; it is often necessary to filter off the first crop while the mixture is still warm.

When dealing with a finely powdered or amorphous mixture, it is often useful to examine a small portion placed on a watch-glass under the microscope. The action of a few drops of various solvents (hot or cold) can be examined in this position, and valuable information—which might not be obvious to the naked eye—perhaps gained concerning the solubility or insolubility of some constituent in a particular solvent.

No definite plan can be given which will suit all examples of fractional crystallisation. The scheme outlined in "Text-book of Inorganic Chemistry," Vol. IV., p. 324 (J. Newton Friend), when applicable, affords a convenient method of marking and recording the various fractions involved in a fractional crystallisation; it also avoids the accumulation of a vast number of small crops and mother liquors:—



The mixture is dissolved with the aid of heat in a solvent to give solution (1). From this solution on cooling, crystals separate which are filtered off, and solution (1) is thereby divided into crop (2) and mother liquor (3). Crop (2) is dissolved in the minimum quantity of hot solvent, and from the resulting solution after cooling, crop (4) and mother liquor (5) are obtained. Mother liquor (3) is concentrated, and from the concentrated solution after cooling, crop (6) and mother liquor (7) are obtained. Crop (6) and mother liquor (5) are united to form a single fraction, and after being heated to dissolve and subsequently cooled give rise to crop (10) and mother liquor (11). Crop (4) is dissolved in a small portion of pure solvent by heating and after cooling is divided into crop (8) and mother liquor (9). Mother liquor (7) after concentration and cooling yields crop (12) and mother liquor (13). (9) and (10), likewise (11) and (12), are united to give single fractions. Proceeding in this way, the least soluble compound goes to the left in the diagram, while the most soluble goes to the right, and compounds of intermediate solubility lie between these extremes. Each crop should be tested for purity. If, when examined with the aid of a lens, two or more types of crystals are present, the crop must be recrystallised. When a crop appears uniform, a small portion should be withdrawn, dried by exposure on porous porcelain or on filter paper, and its melting point taken. In the above scheme if crop (2), say, is pure it takes no further part in the recrystallisation; mother liquor (3) is then worked up. When the principal product is moderately soluble in the hot solvent, but not very soluble in the cold solvent, the following method might be serviceable. The product is divided into three (say) equal portions, A, B and C. A is recrystallised from the minimum quantity of pure solvent, yielding crop A_1 . The mother liquor from A_1 and small quantity of washings are used to recrystallise B, yielding crop B_1 . The mother liquor from B_1 is similarly used to recrystallise C. In this way the mother liquor from C_1 should be more or less saturated with the impurities present, while it contains but little more of the principal product than was contained in the mother liquor from A_1 . If crop A_1 is impure, it is recrystallised from fresh solvent yielding crop A_2 . Crops B_1 and C_1 are recrystallised from mother liquors A_2 and B_2 , and mother liquors C_1 and C_2 are united. The process is continued after this fashion until the crop under A is pure. The crop under B then becomes the first fraction, and the mother liquors from the C's are combined and evaporated, so as to give a crop D, which becomes the new end-fraction and enters into the recrystallisations.



This method was found very useful for the purification of *d*- α -phenylethylamine *l*-malate (p. 408).

When the product separates from the solvent in compact crystalline masses, the mother liquor may be decanted on to the next fraction, and thus filtration, which is always attended with some slight loss of material, is avoided.

It sometimes happens that after a fractional crystallisation has been continued for some time, a solution is obtained from which two products crystallise side by side, the solution being apparently saturated with regard to each product. In such a case a separation might be effected by evaporating off the solvent and proceeding with a different solvent in which the ratio of the solubilities of the two compounds differs from the corresponding ratio in the first solvent. In some such cases mechanical means of separation might be effective; if one set of crystals is heavier than the other, the lighter set may be separated by stirring the supernatant liquor (or by rotating the vessel) and rapidly decanting. The mother liquor after filtration from the lighter crystals may be agitated a second time over the heavier crystals in order to remove any of the lighter which still remain. If one or both sets of crystals separate in fairly large form, a separation may be effected by hand picking.

Determination of Melting Point

In order to identify a substance, or to test its purity, the melting point of the substance is determined, a process which can be rapidly carried out. If a substance does melt at all, it should, if pure, melt sharply at a definite temperature. This figure should agree with the figure given in the literature, and is valuable in the identification of a compound. If the figure is considerably lower than the one given, one must suspect impurity or else a different compound from that stated. In every case, however, the melting point should be verified by reference to Beilstein or Richter's Lexicon or Stelzner. If the melting point is higher than the figure given, the compound may be a different one, or the melting point may have been carelessly taken, for example, by heating too quickly. In general, a pure substance melts within 1° of the figure given. If the melting point is not sharp, the substance should be recrystallised from a suitable solvent before a further determination is made. From this it is obvious that great care should be observed in making this simple determination, and the following points should be carefully observed.

The choice of a thermometer is an important one. In the first place it should have a small bulb, and the range should be suitably chosen. For example, if it is known that a substance has a low melting point, a thermometer of range 0° — 100° should be used. If the substance has a high melting point, a range of say 200° — 300° should be chosen, and so on. All thermometers used for the determination of melting points should be standardised against a standard thermometer.

The preparation of the capillary tube requires a little practice. A piece

of thin-walled glass tubing or a test tube is heated in an ordinary Bunsen flame or blowpipe until it softens, when it is withdrawn from the flame and carefully drawn out for 2 or 3 feet. Draw slowly at first, then quicker as the glass cools and hardens. The central part, consisting of the capillary tube, is then cut into sections of about 8—10 cms. in length, and one end of each section fused in the flame. A supply of melting-point tubes should always be in readiness.

The substance of which the melting point has to be taken should be perfectly dry. A sample is ground to a fine powder on a watch-glass with a clean glass rod, introduced into the capillary tube and shaken to the

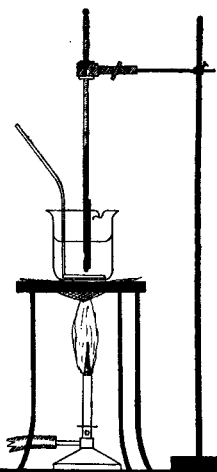


FIG. 5.

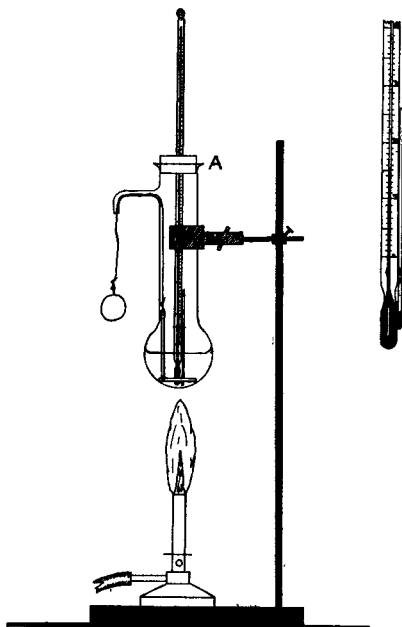


FIG. 6.

bottom; light scratching of the tube with a file often brings this about. The tube is then ready for fixing to the thermometer. The liquid used in the melting-point apparatus is usually concentrated sulphuric acid (vaseline may also be used). After being reheated several times, sulphuric acid is apt to become discoloured. It may be rendered water-white again by adding a crystal of potassium nitrate and heating. Above 250° sulphuric acid should not be employed alone, but should be mixed with 30% or more of potassium sulphate. As this mixture is solid at ordinary temperature it should be poured out while hot. For higher temperatures fused zinc chloride or an electrically heated apparatus may be used. (J. S. C. I., 44, 577).

The melting-point apparatus consists of a small beaker or a large-sized test tube containing sulphuric acid up to a convenient level. The ther-

momometer can be held in position with its bulb well immersed in the acid by means of a clamp in the former case, or by means of a cork in the latter. It is advisable to have some kind of mechanical agitation in the sulphuric acid (see sketch) although if the heating is carefully done this may be dispensed with.

Figs. 5 and 6 show the arrangement in the two cases where a glass rod is used as a stirrer, the stirring being maintained while the acid is slowly heated. The cork at A in Fig. 6 should be as thin as possible so as to obscure the minimum amount of the scale, and if no agitator is used passing through the cork, then a slit should be made in the cork to allow exit to the vapours on heating.

The thermometer is first dipped in the sulphuric acid, and then the drop of acid which clings to the bulb is smeared on the side of the capillary tube containing the substance. The capillary tube is then made to adhere to the thermometer (Fig. 6) by capillary attraction, so that the substance in the tube is just opposite the bulb of the thermometer. This method is much better than using a rubber band, which is apt to perish in the sulphuric acid fumes, and gives rise generally to a speedy discoloration of the acid.

A cloth should be placed on the bench below the apparatus when heating is commenced, to protect the observer should an accident occur. The Bunsen burner should be held in the left hand and the stirrer worked with the right. The heating should be moderated on approaching the melting point, and the Bunsen lowered to give a flame about 2 cms. in length. The range of temperature over which the substance melts is recorded.

Correction.—Melting points are usually given as “uncorrected”; for correction the following formula is employed:—

$$T_c = T_o + 0.000156l(T_o - T_m)$$

T_c = corrected temperature.

T_o = observed temperature.

0.000156 = apparent coefficient of expansion of mercury in glass.

l = length of mercury column in degrees above surface of liquid.

T_m = mean temperature of mercury column, *i.e.*, the temperature of the middle point of the mercury column, taken by another thermometer.

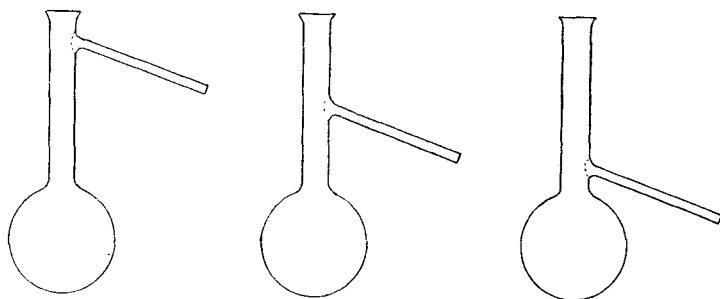
Some Corrected Melting Points for Standardising Thermometers.—

<i>p</i> -Toluidine	45°	Salicylic acid	159.8°
α -Naphthylamine	50°	Anthracene	216°
Naphthalene	80.8°	Carbazole	246°
Benzoic acid	122.5°	Anthraquinone	285°

“Mixed” Melting Points.—Impurities generally lower the melting point of a substance. To determine whether two substances of the same melting point are one and the same, a convenient method is to mix equal quantities of the two and take a melting point of the mixture. If the melting point is lowered the two substances are not identical.

Setting Point.—When a large quantity of the substance is available a very speedy determination of its setting point (freezing point) may be made as follows. The method is used largely on the technical scale, and is specially suitable for controlling chemical operations.

The substance is placed in a large test tube and melted. A thermometer reading fifths or tenths of a degree is used, and is placed in the melted substance which is stirred by means of the thermometer. The mercury in the thermometer gradually falls as the liquid cools, until it reaches a point when it jumps up suddenly (due to the heat liberated on the appearance of the solid phase). The stirring is continued, and the highest temperature to which it reaches after this upthrust is taken as the setting



(a) For low B.P. liquids. (b) For medium B.P. liquids. (c) For high B.P. liquids.

FIG. 7.

point or freezing point. This figure should, of course, agree with the melting point.

Distillation and Determination of Boiling Point

The same apparatus (Fig. 8) is used for the distillation of a liquid and for determining its boiling point. A pure liquid should boil at a constant temperature, and the whole should pass over within a very small range.

The liquid to be distilled, or of which the boiling point is required, is placed in a suitable round-bottomed flask, fitted with a side tube. The flask chosen should be of suitable capacity, *e.g.*, one should not use a 500-c.c. distilling flask to distil 10 c.c.s. of a liquid. The liquid should half fill the bulb of the distilling flask. Figure 7 above shows the position of the side tube for particular boiling ranges. This is important, and a proper choice will well repay the trouble taken.

Determination of Boiling Point.—After the liquid has been placed in the distilling flask, the thermometer which is chosen to suit the substance, as in the determination of melting points, is fixed in the neck of the flask by means of a thin cork, so that the bulb of the thermometer is opposite the exit tube.

The flask is then fixed to a Liebig or air condenser by means of a cork placed near to the neck of the flask. The condenser is attached to an

adapter at its lower end to deliver the condensed liquid into a receiver. The cork should be placed reasonably far from the end of the condenser tube. The sketch (Fig. 8) shows how the complete apparatus should

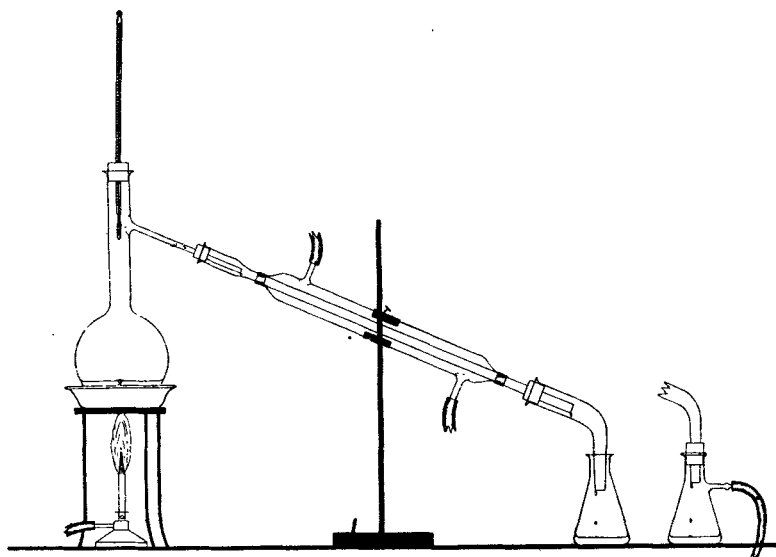


FIG. 8.

appear. The ordinary Liebig condenser should be replaced by an air condenser for liquids boiling over 160° (see Fig. 9).

When inflammable liquids are distilled, the receiver, as shown, should take the form of a Buchner flask, with a rubber tube connected to the

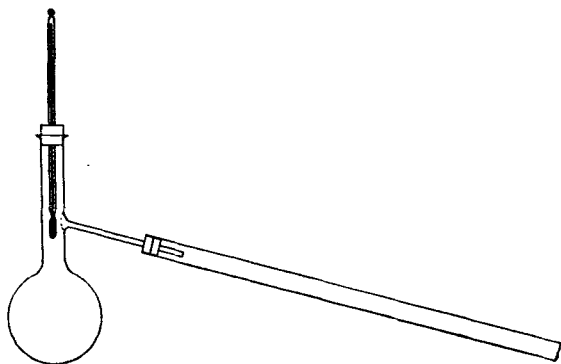


FIG. 9.

side tube, and dipping over the side of the bench. In this way inflammable vapours are removed from the region of the Bunsen burner.

Before heating is commenced, a small piece of unglazed porcelain or magnesite is introduced into the flask in order to prevent "bumping"