CHAPTER XI

QUALITATIVE ORGANIC ANALYSIS

XI,1. BASIS OF QUALITATIVE ORGANIC ANALYSIS

MANY of the organic compounds normally encountered may be regarded as derived from the paraffin hydrocarbons either by the substitution of one or more inorganic atoms or radicals for hydrogen *or* by the insertion of one or more inorganic atoms or radicals between the carbon atoms constituting the carbon chain, *i.e.*, by the attachment of inorganic atoms or radicals to paraffin hydrocarbon residues. Thus, by the introduction of halogen atoms, of oxygen as hydroxyl (OH), of oxygen as carbonyl (C=O), of nitrogen, of the ammonia residue (NH_2), of sulphur as sulphydryl (SH), etc. one may arrive at the homologous series of halogen compounds, alcohols, aldehydes, ketones, nitriles, amines, thiols, etc. Likewise, if an oxygen atom, sulphur atom or ammonia residue (NH) etc. is coupled with paraffin hydrocarbon residues, the homologous series of ethers, thio-ethers, or secondary amines, etc. is obtained. Both the chemical and physical properties of the paraffin hydrocarbons are fundamentally changed by the introduction of these inorganic substituents; they are, indeed, essentially dependent upon them. It is known, however, that members of any homologous series exhibit similar chemical reactions, which are markedly different from those members of another homologous series. Certain physical properties, such as melting point, volatility and solubility, on the other hand, depend upon the size of the paraffin hydrocarbon residue and thus undergo considerable change, within each series, with increasing molecular weight. It is usually possible to separate the components of a mixture of organic compounds into members of different homologous series as a result of their differing chemical reactions or more obvious physical differences. Mixtures of various members of a homologous series can frequently be separated by physical methods : in some cases the separation may be extremely difficult (necessitating the use of precision physical methods, *e.g.*, of fractional distillation) or be almost impossible.

In addition to inorganic radicals, which profoundly modify the properties of a paraffin hydrocarbon residue, there is a whole series of organic groupings which are distinguished by exceptional reactivity, for example, the ethylene and acetylene groupings, and the phenyl and naphthyl radicals. Thus the characterisation of unsaturated hydrocarbons and their derivatives, *e.g.*, the aromatic compounds, becomes possible.

Although more than 400,000 organic compounds have been recorded in the literature, most of these may be grouped into a comparatively small number of homologous series or of classes of organic substances. By identifying the class to which an organic compound belongs, the problem of characterisation is enormously simplified. For purposes of qualitative organic analysis, the following admittedly incomplete scheme will be adopted in this book. It must be emphasised, however, that, unlike systematic inorganic analysis,* the scheme is merely intended as a rough guide to the method of attack of the problem ; the student must be prepared to apply his knowledge of organic chemistry at all points, and must be alert at all times to the significance of any observations which may throw light on the analysis.

1. **Determination of the physical constants and the establishment of the purity of the compound.** For a solid, the melting point is of great importance : if recrystallisation does not alter it, the compound may be regarded as pure. For a liquid, the boiling point is first determined : if most of it distils over a narrow range (say, 1–2°), it is reasonably pure. (Constant boiling point mixtures, compare Section **I,4**, are, however known.) The refractive index and the density, from which the molecular refractivity may be calculated, are also valuable constants for liquids.

2. **Qualitative analysis for the elements.** This includes an examination of the effect of heat upon the substance—a test which *inter alia* will indicate the presence of inorganic elements—and qualitative analysis for nitrogen, halogens and sulphur and, if necessary, other inorganic elements. It is clear that the presence or absence of any or all of these elements would immediately exclude from consideration certain classes of organic compounds.

3. **Study of the solubility behaviour of the compound.** A semi-quantitative study of the solubility of the substance in a limited number of solvents (water, ether, dilute sodium hydroxide solution, dilute hydrochloric acid, sodium bicarbonate solution, concentrated sulphuric and phosphoric acid) will, if intelligently applied, provide valuable information as to the presence or absence of certain classes of organic compounds.

4. **Application of class reactions.** The application of selected reactions that indicate the presence or absence of certain functional groups, with due regard to the indications provided by tests **1**, **2** and **3**, will locate the class (or classes) to which the compound belongs or will, at least, serve to eliminate all but a few classes to which the compound can be assigned.

5. **Location of the compound within a class (or homologous series) of compounds.** Reference to the literature or to tables of the physical properties of the class (or classes) of organic compounds to which the substance has been assigned, will generally locate a number of compounds which boil or melt within 5° of the value observed for the unknown. If other physical properties (*e.g.*, refractive index and density for a liquid) are available, these will assist in deciding whether the unknown is identical with one of the known compounds. In general, however, it is more convenient in practice to prepare one, but preferably two, crystalline derivatives of the substance.

6. **Preparation of derivatives.** If two distinct crystalline derivatives of the unknown have the same melting point (or other physical properties) as those of the compound described in the literature (or in the tables), the identity of the two compounds may be assumed. Further

---

* See, for example, the author's *Text Book of Macro and Semimicro Qualitative Inorganic Analysis*, Fourth Edition, 1954 (Longmans, Green and Co. Ltd.).

confirmation may be obtained, if desired, by mixed melting point determinations (see Section **I,17**)

XI,2. DETERMINATION OF PHYSICAL CONSTANTS

The most widely used physical constants in the characterisation of organic compounds are melting points and boiling points. The technique of the **determination of melting points** is discussed in detail in Section **II,10.** For routine use in the laboratory the apparatus shown in Fig. *II, 10,* 2, *a* is satisfactory. The melting point of a solid which melts slightly above or below room temperature is determined with the aid of the apparatus depicted in Fig. *II, 10,* 4. For compounds which melt above 250°, the electrically-heated melting point apparatus of Fig. *II, 11,* 1 should be used. The latter apparatus is suitable for melting point determinations from just above room temperature to about 400°; it is recommended that at least one such apparatus be available in every laboratory.

In general, a sharp melting point (say, within 0·5°) is one of the most characteristic properties of a pure organic compound. The purity should not, however, be assumed but must be established by observation of any changes in the melting point (or in the melting range) when the compound is subjected to purification by recrystallisation (the technique of recrystallisation is discussed fully in Sections **II,27–II,31**). If the melting point is unaffected by at least one recrystallisation, then the purity of the substance may be regarded as established. In rare cases purification may be effected by sublimation at atmospheric or under reduced pressure (see Section **II,45**).

The experimental **determination of the boiling point** of a liquid is dealt with in Section **II,12.** Since only small quantities are generally supplied for qualitative analysis, the boiling point determination is usually made with a volume of 5–10 ml. and the apparatus of Fig. *II, 12,* 1 is proportionally reduced, using a distilling flask of 10–15 ml. capacity. It is convenient to use a set-up such as is shown in Fig. *II, 19,* 1, which dispenses with the Liebig's condenser; the neck of the flask is closed by a cork for distillation at atmospheric pressure and a few small pieces of porous porcelain are placed in the flask to ensure smooth boiling. The small (10–15 ml.) Claisen flask may be replaced by a distilling flask, but it is better, if possible, to use the former. Heating is best conducted in an air bath (Fig. *II, 5,* 3). The distillation is carried out at a slow steady rate; it is advisable to collect the first portion of the distillate separately, since this will contain any water present in the sample. If the boiling point range does not exceed 1–3° for the main bulk of the sample (there is usually some superheating towards the end of the distillation), it is reasonably safe to assume that the liquid is pure. The possibility that it may be a constant boiling point mixture (compare Section **I,4**) should be borne in mind.

When the volume of the liquid available is less than 1 ml. or is limited owing to consideration of cost, etc., the boiling point may be determined by the Siwoloboff method (see Fig. *II, 12,* 2). It should, however, be remembered that the Siwoloboff method gives trustworthy results only for comparatively pure liquids; small amounts of volatile impurities, such as ether and water, may lead to boiling points which approximate to those of the volatile component.

If the liquid is shown by distillation to have a wide boiling range (10–30°), it may be necessary to subject it to fractional distillation in order to obtain a reasonably pure sample of the compound. The simple Hempel column, filled with glass or porcelain rings, shown in Fig. *II*, *16*, 1 may be used. Alternatively a Claisen flask with fractionating side arm (Figs. *II*, *24*, 2–5) will be found satisfactory. When the boiling points of the components of the mixture are quite close to each other (5–10°), a more efficient type of fractionating column (see Section **II,17**) will be required.

DETERMINATION OF DENSITY AND OF REFRACTIVE INDEX

The density and the refractive index of a liquid will frequently be of value in assisting its characterisation.

Density. The density of a liquid is conveniently determined with the aid of a pycnometer (Fig. *XI*, *2*, 1). The bulb has a capacity of 1–2 ml. and the capillary arms have a bore of 1 mm.; a mark *A* is made with a fine file or diamond (in the position indicated) for the adjustment of the level of the liquid in the pycnometer. A thin silver wire loop is provided for supporting the pycnometer on the hook over the balance pan. This pycnometer is readily filled by means of the device shown in Fig. *XI*, *2*, 2 (colloquially known as a "snake"); it consists of a short length of narrow (about 3 mm. bore) rubber tubing into one end of which is fitted a piece of glass tubing shaped as shown in the figure. The liquid is placed in a small glazed crucible (3–5 ml. capacity) and the rubber tubing is fitted over the longer arm of the pycnometer. By holding the pycnometer vertically so that the short capillary end is below the surface of the liquid in the crucible, and applying *gentle* suction at the glass tube of the

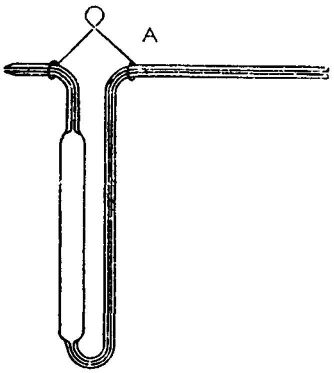


Fig. *XI*, *2*, 1.

Fig. *XI*, *2*, 2.

" snake " by means of the mouth,* the pycnometer is completely filled slightly beyond the file mark *A*. The pycnometer is then returned to the vertical position (no air bubbles should be present if the pycnometer has been carefully filled) and the short arm touched with filter paper. This will cause the liquid to move along the capillary ; immediately it reaches the mark *A*, the filter paper is sharply removed. With a little practice, no difficulty will be experienced in filling the pycnometer accurately to the mark *A*. After carefully polishing the outside with a clean linen cloth and weighing the pycnometer, the liquid is emptied into the crucible or other vessel by attaching the snake to the longer arm and blowing gently. The pycnometer is then cleaned by charging the crucible with rectified spirit and then filling the pycnometer ; the alcohol is emptied into the "ALCOHOL RESIDUES " bottle and the pycnometer is then filled again. The process is repeated with sodium-dried ether ; finally a stream of air is drawn through the pycnometer by attaching the " snake " through a filter flask trap to a water pump for 10–15 minutes. The outside of the pycnometer is again wiped with a clean linen cloth and weighed empty.

The density determination may be carried out at the temperature of the laboratory. The liquid should stand for at least one hour and a thermometer placed either in the liquid (if practicable) or in its immediate vicinity. It is usually better to conduct the measurement at a temperature of 20° or 25° ; throughout this volume a standard temperature of 20° will be adopted. To determine the density of a liquid at 20°, a clean, corked test-tube containing about 5 ml. of the liquid is immersed for about three-quarters of its length in a water thermostat at 20° for about 2 hours. An empty test-tube and a shallow beaker (*e.g.*, a " Baco " beaker) are also supported in the thermostat so that only the rims protrude above the surface of the water ; the pycnometer is supported by its capillary arms on the rim of the test-tube, and the small crucible is placed in the beaker, which is covered with a clock glass. When the liquid has acquired the temperature of the thermostat, the small crucible is removed, charged with the liquid, the pycnometer rapidly filled and adjusted to the mark. With practice, the whole operation can be completed in about half a minute. The error introduced if the temperature of the laboratory differs by as much as 10° from that of the thermostat does not exceed 1 mg. ; if the temperature of the laboratory is adjusted so that it does not differ by more than 1–2° from 20°, the error is negligible. The weight of the empty pycnometer and also filled with distilled (preferably conductivity) water at 20° should also be determined. The density of the liquid can then be computed.

The specific gravity ($d_{t°}^{t°}$) of a liquid may be defined as the ratio of the weight of the liquid to that of an equal volume of water at the same temperature. Thus :

$$\text{Specific gravity, } d_{20°}^{20°} = \frac{\text{Weight of liquid at } 20°}{\text{Weight of an equal volume of water at } 20°} = \frac{W_l^{20°}}{W_w^{20°}}$$

---

* An empty wash-bottle, equipped with a two-holed cork, may be interposed between the mouth and the pycnometer for corrosive or poisonous liquids.

The density ($d_{4°}^{20°}$) may be regarded as the specific gravity referred to an equal volume of water at 4°, *i.e.*,

$$d_{4°}^{20°} = \frac{W_l^{20°}}{W_w^{20°}} \times D^{20°} = W_l^{20°} \times \left(\frac{0 \cdot 9982}{W_w^{20°}}\right)$$

where $D^{20°}$ is the density of water at 20°, *i.e.*, 0·9982. The quantity enclosed in the bracket is the constant for the pycnometer and should be recorded permanently. In all subsequent determinations of the density, only the weight of the liquid filling the pycnometer will be required. It is advisable, however, to redetermine the constant periodically.

Notes on the construction of a thermostat. A thermostat may be easily constructed by a skilled mechanic. The essential requirements are :

(1) A large metal tank, preferably lagged to within 5 cm. of the upper rim.

(2) A motor-driven stirrer. That illustrated in Figs. *II*, *7*, 1 (see also Fig. *II*, *7*, 7) is quite satisfactory : the motor is supported on a stout metal bar fitted across the thermostat tank.

(3) A conventional type of mercury-toluene regulator.

(4) A relay : the Sunvic type F.102N hot-wire vacuum switch * with neon indicator lamp is satisfactory.

(5) A suitable heating lamp or other heating device. The author has found the 250 watts vertical pattern radiator lamp (" sausage " lamp) or, alternatively, the Santon 250 or 500 watts immersion heater † to give excellent results.

No difficulty should be experienced in constructing a thermostat with the aid of the components recommended that will maintain a temperature of 20° ± 0·01°.

For circulating water through a refractometer any commercial water circulating pump may be used.‡

Refractive index. The refractive index of a liquid is conveniently determined with an **Abbe refractometer.** This refractometer possesses the following advantages :

(*a*) The refractive index (1·3000 to 1·7000) may be read directly on a scale with accuracy of about 0·0002.

(*b*) It requires only a drop of the sample.

(*c*) A source of monochromatic light is not essential ; by means of a " compensator " the observed refractive index corresponds to that obtained with the D line of sodium even though white light is used as a source of illumination.

The principle of the instrument is the observation of the " critical angle " for total reflection between glass of high refractive index (*e.g.*, flint glass, n_D 1·75) and the substance to be examined. The glass is in the form of a right-angled prism upon the hypotenuse face *AB* of which the compound to be investigated is placed. If the compound is a solid,

---

* Supplied by Sunvic Controls Ltd.

† Manufactured by Santon Ltd.

‡ The author employs the Stuart centrifugal pump, No. 10, supplied by Stuart Turner Ltd.

optical contact with the prism is made by means of a liquid of higher refractive index than the solid (*e.g.*, methylene iodide); if it is a liquid (as is usual in qualitative organic analysis), it is enclosed as a thin film (about 0·15 mm. thick) between two similar prisms (Fig. *XI*, *2*, 4). The face *AC* of the prism plays a part in the refraction of the light, and it is the angle of emergence (α) from this face which is measured, the scale of the instrument being, however, divided to read the refractive index directly. The ray shown in Fig. *XI*, *2*, 3 and in Fig. *XI*, *2*, 4 is that which enters the face *AB* at grazing incidence, and corresponds to the edge of the dark part of the field of view of the instrument. The direction of the ray after entering the face *AB* depends upon its wave length, and thus the scale of refractive index will vary with the light employed. That selected is for sodium light, but in order to permit the use of white light, the resultant dispersion of the light emerging from the face *AC* is neutralised by means of a dispersion "compensator" situated at the base of the telescope. It consists of two direct vision prisms, made accurately direct for the D sodium line, which are capable of rotation at equal rates and in opposite directions about the axis of the telescope of the refractometer. They form a system of variable dispersion which can be made equal in amount and of opposite direction to the resultant dispersion (*D*) of the refractometer prism and the substance investigated.

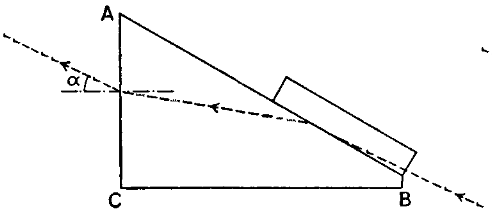


Fig. *XI*, *2*, 3.

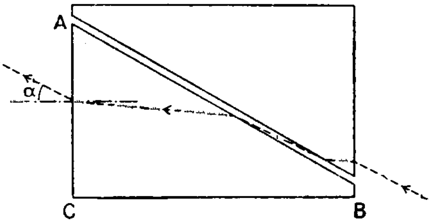


Fig. *XI*, *2*, 4.

Fig. *XI*, *2*, 5 * is a drawing of the Hilger Abbe refractometer, whilst Fig. *XI*, *2*, 6 * is a line diagram showing the essential parts of the instrument.

To determine the refractive index of a liquid at 20°, circulate water at 20° from a thermostat through the jacket surrounding the two prisms until the temperature on the thermometer has remained steady for at least 10 minutes. Separate the prism jackets by opening the clamp, and move the index arm, if necessary, until the face of the prism is horizontal. Wipe the latter with a clean linen cloth, place a drop or two of the liquid on the ground glass prism face and then clamp it to the upper polished prism. Focus the cross-wires of the telescope by rotating the eyepiece, and then adjust the mirror so as to give good illumination from a suitably placed frosted electric lamp. By means of the rack and pinion controlling the arm at the side of the apparatus, turn the prism box until the field of view becomes partly light and partly dark. When white light is used,

---

* The author is indebted to Messrs. Adam Hilger Ltd. for these two figures. A detailed description of the instrument will be found in their booklet, "*Instructions for the Use of the Abbe Refractometer*," and to which the reader is referred for further particulars.

the edge of the light band will show a coloured fringe. By means of the milled screw head at the base of the telescope, rotate the dispersion "compensator" until the coloured fringe disappears and the light (or dark) band is bounded by a sharp edge. Now rotate the prism box slowly until the sharp edge coincides with the intersection of the cross wires in the telescope, and read off directly the refractive index for the D sodium line on the divided arc by means of the magnifying lens. Immediately the determination has been completed, wipe off the organic liquid with filter paper or cotton wool, and clean the prism surfaces with cotton wool soaked in acetone. The accuracy of the instrument may be checked by measuring the refractive index of distilled water ($n_D^{10°}$ 1·3337, $n_D^{20°}$ 1·3330, $n_D^{30°}$ 1·3320, $n_D^{40°}$ 1·3307).

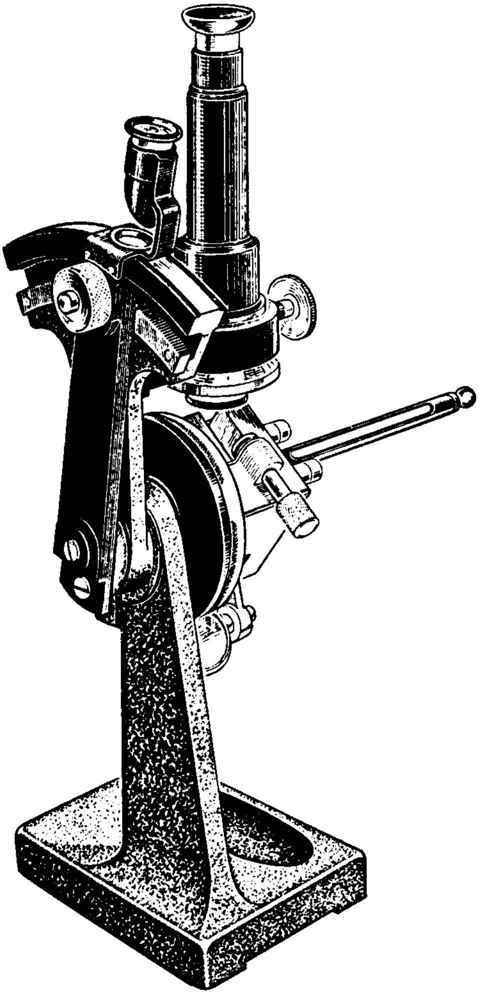


Fig. *XI*, *2*, 5.

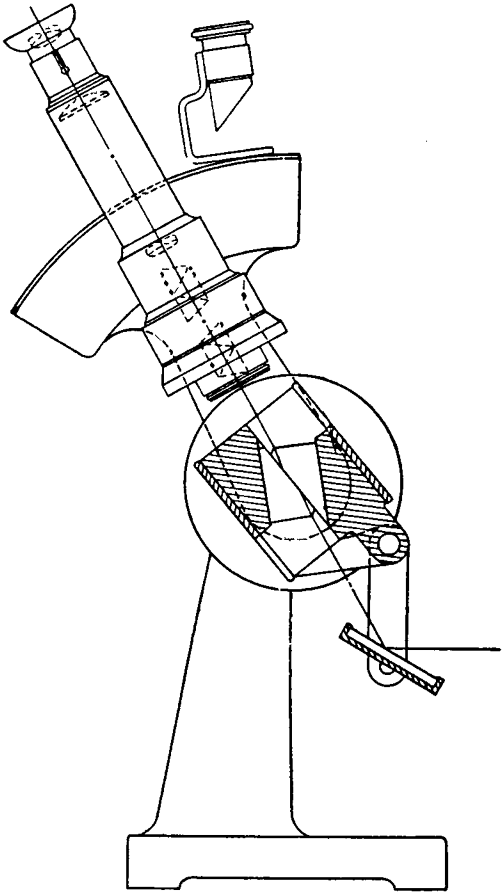


Fig. *XI*, *2*, 6.

The refractive index of a liquid is recorded as $n_D^{t°}$ where t is the temperature at which the measurement is made, and D refers to the wave length of the D line of sodium. As already pointed out, it is usual to determine both the refractive index and the density of the liquid at 20° ; in any case they should be determined at the same temperature. These two constants are useful in assisting the characterisation of a pure liquid ; they are particularly valuable for aliphatic hydrocarbons and similar compounds where the methods of characterisation by the formation of solid derivatives are not entirely satisfactory.

The **molecular refractivity** can be computed from the Lorenz and Lorentz equation :

$$[R_L]_D = \frac{n_D^2 - 1}{n_D^2 + 2} \cdot \frac{M}{d}$$

where n is the refractive index, d is the density at the same temperature, and M is the molecular weight. The molecular refractivity may also be *calculated* from the structural formula by the summation of either the atomic and structural constants or the bond refractions. Agreement between the observed and calculated values of the molecular refractivity constitutes powerful evidence for the correctness of the structural formula from which $[R_L]_D$ was calculated.

The values for the D sodium line of the atomic and structural constants and of the bond refractions, as determined by the author, are collected in Tables **XI,2A** and **XI,2B** respectively.

TABLE XI,2A. ATOMIC AND STRUCTURAL CONSTANTS (D-LINE)

CH_2	4·647	CO (methyl ketones)	4·76
H (in CH_2)	1·028	COO (esters)	6·20
C (in CH_2)	2·591	COOH	7·23
CH_3	5·65	OH (aliphatic alcohols)	2·55
C_2H_5	10·30	SH (alkyl thiols)	8·76
n-C_3H_7	14·97	S (dialkyl sulphides)	7·92
iso-C_3H_7	14·98	S_2 (dialkyl disulphides)	16·05
n-C_4H_9	19·59	Double bond ($C=C$)	1·58
iso-C_4H_9	19·62	Triple bond ($C\equiv C$), terminal	1·98
sec.-C_4H_9	19·42	Triple bond ($C\equiv C$), non-terminal	2·35
tert.-C_4H_9	19·85	3-membered carbon ring	0·61
n-C_5H_{11}	24·25	4-membered carbon ring	0·32
iso-C_5H_{11}*	24·20	NH_2 (primary aliphatic amines)	4·44
iso-C_5H_{11}†	24·28	NH (secondary aliphatic amines)	3·61
n-C_6H_{13}	28·86	NH (secondary aromatic amines)	4·68
n-C_7H_{15}	33·55	N (tertiary aliphatic amines)	2·74
n-C_8H_{17}	38·14	$N=N$ (azo)	6·19
C_3H_5 (allyl)	14·52	CN (aliphatic nitriles)	5·46
C_6H_5	25·36	NO_2 (aliphatic nitro compounds)	6·71
Cl	5·84	O.NO (aliphatic nitrites)	7·24
Br	8·74	NO (nitroso)	5·20
I	13·95	SCN (aliphatic thiocyanates)	13·40
F	0·81	NCS (aliphatic *iso*-thiocyanates)	15·62
O (ethers)	1·76	CO_3 (dialkyl carbonates)	7·70
O (acetals)	1·61	SO_3 (dialkyl sulphites)	11·34
CO (ketones)	4·60	PO_4 (trialkyl phosphates)	10·77

* From synthetic *iso*-amyl alcohol.

† From fermentation *iso*-amyl alcohol.

TABLE XI,2B. BOND REFRACTIONS AT 20° (D-LINE)

C—H	1·676	C=S	11·91
C—C	1·296	C—N	1·57
C=C	4·17	C=N	3·76
C≡C (terminal)	5·87	C≡N	4·82
C≡C (non-terminal)	6·24	O—H (alcohols)	1·66
C—C (3-ring)	1·49	O—H (acids)	1·80
C—C (4-ring)	1·37	S—H	4·80
C—C (5-ring)	1·26	S—S	8·11
C—C (6-ring)	1·27	S—O	4·94
C—F	1·55	S→O	−0·20
C—Cl	6·51	N—H	1·76
C—Br	9·39	N—O	2·43
C—I	14·61	N→O	1·78
C—O (ethers)	1·54	N=O	4·00
C—O (acetals)	1·46	N—N	1·99
C=O	3·32	N=N	4·12
C=O (methyl ketones)	3·49	$\mathrm{C_{ar}}$—$\mathrm{C_{ar}}$	2·69
C—S	4·61		

Note.

In the calculation of the molecular refractivity of esters, the C—O value for acetals is employed.

DETERMINATION OF MOLECULAR WEIGHT

The determination of the molecular weight of a compound is rarely necessary in qualitative organic analysis. Occasionally a knowledge of the molecular weight may be useful, particularly in those cases where a derivative cannot easily be prepared or is unknown. The usual methods of determining molecular weights are too cumbersome and too time-consuming for characterisation work. The high freezing point depression of camphor permits the use of an ordinary melting point apparatus, thus enabling the molecular weight to be determined rapidly (**Rast's camphor method**).

Support a small clean test-tube (*e.g.*, 75 × 10 mm.) in a hole bored in a cork so that it will stand conveniently on the pan of a balance. Weigh the tube. Introduce about 50 mg. of the compound of which the molecular weight is to be determined, and weigh again. Then add 500–600 mg. of pure, resublimed camphor (*e.g.*, the micro-analytical reagent, B.D.H.) and weigh again. Stopper the test-tube loosely and melt the contents by placing it in an oil bath previously heated to about 180° * ; stir the liquid with a platinum wire, but do not heat the liquid for more than one minute or camphor will sublime from the solution. Allow to cool, transfer the solid to a clean watch glass and powder the solid. Introduce some of the powder into a thin capillary tube of which the closed end is carefully rounded : press the solid down into the closed end with the aid of a platinum wire or with a closed capillary tube of smaller diameter. The height of the solid should not exceed 2 mm. Determine the melting point of the mixture (Fig. *II*, *10*, 2, *a* or *II*, *10*, 3) using, preferably, a 100–200° thermometer graduated in 0·1° or 0·2°; good illumination is essential. The melting point is taken as that temperature at which the last fragment of solid disappears. To make sure that the mixture is homogeneous, repeat the melting point determination with a second sample ; if the two differ appreciably, prepare a new mixture. Then determine the melting point of the original camphor. The difference in melting points gives the depression of the melting point of camphor caused by the addition of the compound. The molecular weight M can then be calculated from the formula :

$$M = \frac{K \times w \times 1000}{\Delta T \times W}$$

where K is the molecular depression constant of camphor (39·7)
w is the weight of the compound
W is the weight of the camphor
and ΔT is the depression of the melting point.

Note

The solute concentration should be above $0 \cdot 2M$; in dilute solution K increases from 39·7 to about 50.

---

* If very great care is taken, the mixture may be melted by heating over a *very small* flame for about 30 seconds ; the technique described in the text is to be preferred.

XI,3. QUALITATIVE ANALYSIS FOR THE ELEMENTS

The most commonly occurring elements in organic compounds are carbon, hydrogen, oxygen, nitrogen, sulphur and the halogen elements; less common elements are phosphorus, arsenic, antimony, mercury, or other metals which may be present as salts of organic acids. There is no direct method for the detection of oxygen.

It is usually advisable to carry out the ignition test first. This will provide useful information as to the general properties of the compound and, in particular, the residue may be employed for the detection of any inorganic elements which may be present.

IGNITION TEST

Place about 0·1 g. of the compound in a porcelain crucible or crucible cover. Heat it gently at first and finally to dull redness. Observe:

(*a*) Whether the substance melts, is explosive, or is inflammable and the nature of the flame.

(*b*) Whether gases or vapour are evolved and their odour (*CAUTION!*)

(*c*) Whether the residue fuses.

If an appreciable amount of residue remains, note its colour. Add a few drops of water and test the solution (or suspension) with litmus or with Universal indicator paper. Then add a little dilute hydrochloric acid and observe whether effervescence occurs and the residue dissolves. Apply a flame test with a platinum wire on the hydrochloric acid solution to determine the metal present. (In rare cases, it may be necessary to subject a solution of the residue to the methods of qualitative inorganic analysis to identify the metal or metals present.) If the flame test indicates sodium, repeat the ignition of the substance on platinum foil.

Heating with soda lime is often a useful preliminary test. Mix thoroughly about 0·2 g. of the substance with about 1 g. of powdered soda lime. Place the mixture in a Pyrex test-tube; close the tube by a cork and delivery tube. Incline the test-tube so that any liquid formed in the reaction cannot run back on the hot part of the tube. Heat the test-tube gently at first and then more strongly. Collect any condensate produced in a test-tube containing 2–3 ml. of water. Nitrogenous compounds will usually evolve ammonia or vapours alkaline to litmus and possessing characteristic odours; hydroxybenzoic acids yield phenols; formates and acetates yield hydrogen; simple carboxylic acids yield hydrocarbons (methane from acetic acid, benzene from benzoic or phthalic acid, etc.); amine salts and aromatic amino carboxylic acids yield aromatic amines; etc.

CARBON AND HYDROGEN

Evidence of the organic nature of the substance may be provided by the behaviour of the compound when heated on porcelain or platinum or other comparatively inert metal (*e.g.*, nickel): the substance is inflammable, burns with a more or less smoky flame, chars and leaves a black residue consisting largely of carbon (compare *Ignition Test* above).

If it is desired to test directly for the presence of carbon and hydrogen in a compound, mix 0·1 g. of the substance with 1–2 g. of ignited, fine copper oxide powder * in a dry test-tube, and fit the latter with a cork carrying a tube bent at an angle so that the escaping gases can be bubbled below the surface of lime water contained in a second test-tube. Clamp the test-tube containing the mixture near the cork. Heat the mixture gradually. If carbon is present, carbon dioxide will be evolved which will produce a turbidity in the lime water. If hydrogen is present, small drops of water will collect in the cooler part of the tube.

NITROGEN, SULPHUR AND HALOGENS

In order to detect these elements in organic compounds, it is necessary to convert them into ionisable inorganic substances so that the ionic tests of inorganic qualitative analysis may be applied. This conversion may be accomplished by several methods, but the best procedure is to fuse the organic compound with metallic sodium (**Lassaigne's test**). In this way sodium cyanide, sodium sulphide and sodium halides are formed, which are readily identified. Thus :

$$\text{Organic compound containing C,H,O,N,S,Hal.} + \text{Na} \xrightarrow{\text{Heat}} \text{NaCN} + \text{Na}_2\text{S} + \text{NaHal.} + \text{NaOH}$$

It is essential to use an excess of sodium, otherwise if sulphur and nitrogen are both present sodium thiocyanate, NaCNS, may be produced ; in the test for nitrogen it may give a red coloration with ferric iron but no Prussian blue since there will be no free cyanide ions. With excess of sodium the thiocyanate, if formed, will be decomposed :

$$\text{NaCNS} + 2\text{Na} \longrightarrow \text{NaCN} + \text{Na}_2\text{S}$$

The filtered alkaline solution, resulting from the action of water upon the sodium fusion, is treated with ferrous sulphate and thus forms sodium ferrocyanide :

$$\text{FeSO}_4 + 6\text{NaCN} \longrightarrow \text{Na}_4[\text{Fe(CN)}_6] + \text{Na}_2\text{SO}_4$$

Upon boiling the alkaline ferrous salt solution, some ferric ions are inevitably produced by the action of the air ; upon the addition of dilute sulphuric acid, thus dissolving the ferrous and ferric hydroxides, the ferrocyanides reacts with the ferric salt producing ferric ferrocyanide (Prussian blue) :

$$3\text{Na}_4[\text{Fe(CN)}_6] + 2\text{Fe}_2(\text{SO}_4)_3 \longrightarrow \text{Fe}_4[\text{Fe(CN)}_6]_3 + 6\text{Na}_2\text{SO}_4$$

Hydrochloric acid should not be used for acidifying the alkaline solution since the yellow colour, due to the ferric chloride formed, causes the Prussian blue to appear greenish. For the same reason, ferric chloride should not be added—as is frequently recommended : a sufficient concentration of ferric ions is produced by atmospheric oxidation of the hot alkaline solution. The addition of a little dilute potassium fluoride solution may be advantageous in assisting the formation of Prussian blue in a readily filterable form.

Sulphur, as sulphide ion, is detected by precipitation as black lead sulphide with lead acetate solution and acetic acid or with sodium plumbite solution (an alkaline solution of lead acetate). Halogens are detected as the characteristic silver halides by the addition of silver nitrate solution and dilute nitric acid : the interfering influence of sulphide and cyanide ions in the latter tests are discussed under the individual elements.

---

* Copper oxide powder, prepared by grinding copper oxide (wire form), is heated to dull redness in a porcelain basin, allowed to cool partially in the air and finally in a desiccator.

Support a small, soft glass test-tube (50 × 12 mm.)* in a clamp or insert the tube through a small hole in a piece of abestos board (or of "uralite") so that the tube is supported by the rim. Place a cube (*ca.* 4 mm. side = 0·04 g.) of freshly cut sodium † in the tube. Have in readiness about 0·05 g. of the compound on a spatula or the tip of a knife blade; if the compound is a liquid, charge a capillary dropper or a melting point capillary with about three drops of the liquid. Heat the ignition tube, gently at first to prevent cracking, until the sodium melts and the vapour rises 1–2 cm. in the tube. Drop the substance, preferably portionwise, directly on to the molten sodium (*CAUTION:* there may be a slight explosion, particularly with chloroform, carbon tetrachloride, nitroalkanes and azo compounds.) Remove the tube from its support and hold it by means of a pair of tongs. Heat it carefully at first, then strongly until the entire end of the tube is red hot and maintain it at this temperature for a minute or two. Plunge the tube while still hot into an evaporating basin ‡ containing about 10 ml. of distilled water, and cover the dish *immediately* with a clean wire gauze. The tube will be shattered and the residual sodium will react with the water. When the reaction is over, heat to boiling, and filter. The filtrate should be water-clear and alkaline. If it is dark coloured, decomposition was probably incomplete: repeat the entire sodium fusion.

The following *alternative procedure* is recommended and it possesses the advantage that the same tube may be used for many sodium fusions. Support a Pyrex test-tube (150 × 12 mm.) vertically in a clamp lined with asbestos cloth or with sheet cork. Place a cube (*ca.* 4 mm. side = 0·04 g.) of freshly cut sodium in the tube and heat the latter until the sodium vapour rises 4–5 cm. in the test-tube. Drop a small amount (about 0·05 g.) of the substance, preferably portionwise, directly into the sodium vapour (*CAUTION:* there may be a slight explosion); then heat the tube to redness for about 1 minute. Allow the test-tube to cool, add 3–4 ml. of methyl alcohol to decompose any unreacted sodium, then half-fill the tube with distilled water and boil gently for a few minutes. Filter and use the clear, colourless filtrate for the various tests detailed below. Keep the test-tube for sodium fusions; it will usually become discoloured and should be cleaned from time to time with a little scouring powder.

Nitrogen. Pour 2–3 ml. of the filtered "fusion" solution into a test-tube containing 0·1–0·2 g. of powdered ferrous sulphate crystals. Heat

---

* If preferred, suitable ignition tubes may be prepared by the student from soft glass tubing: it is important that the thickness of the glass at the closed end be uniform, otherwise the tube is likely to crack when heated. The simplest procedure is to blow a small bulb of uniform wall thickness at the end of the tube. The small test-tubes are available from all laboratory supply dealers.

† *CAUTION :* Handle sodium with great care. Small pieces for sodium fusions may be kept in a small dry bottle. Larger quantities and pieces are better kept under solvent naphtha or xylene. Do not handle the metal with the fingers: use tongs or pincers or a penknife. If the sodium is stored under naphtha or xylene, dry it quickly with filter paper immediately before use. Any residual sodium should be placed in the bottle for "*Sodium Residues.*" Never throw small pieces of residual sodium in the sink or into water; if you wish to destroy sodium residues, use methylated spirit.

‡ An alternative technique is as follows. Plunge the hot tube into about 10 ml. of water contained in a small, clean mortar and cover the latter immediately with a clean wire gauze. When the reaction is over, grind the mixture of solution and broken glass to ensure thorough extraction of the sodium salts. Transfer with the aid of a little water to a porcelain basin, heat to boiling, and filter.

the mixture gently with shaking until it boils, then, without cooling, add just sufficient dilute sulphuric acid to dissolve the iron hydroxides and give the solution an acid reaction. {The addition of 1 ml. of 5 per cent. potassium fluoride solution is beneficial (possibly owing to the formation of potassium ferrifluoride $K_3[FeF_6]$) and usually leads to a purer Prussian blue.} A Prussian blue precipitate or coloration indicates that nitrogen is present. If no blue precipitate appears at once, allow to stand for 15 minutes, filter through a small filter and wash the paper with water to remove all traces of coloured solution : any Prussian blue present will then become perceptible in the cone of the filter paper. If in doubt, repeat the sodium fusion, preferably using a mixture of the compound with pure sucrose or naphthalene. In the absence of nitrogen, the solution should have a pale yellow colour due to iron salts.

If sulphur is present, a *black* precipitate of ferrous sulphide is obtained when the ferrous sulphate crystals dissolve. Boil the mixture for about 30 seconds, and acidify with dilute sulphuric acid ; the ferrous sulphide dissolves and a precipitate of Prussian blue forms if nitrogen is present.

Sulphur. This element may be tested for by any one of the following three methods :

(*a*) Prepare a **solution of sodium plumbite** by adding 10 per cent. sodium hydroxide solution to a few drops of about *N* lead acetate solution until the white precipitate of lead hydroxide initially formed just redissolves to a clear solution. Add 1 ml. of the " fusion " solution : the presence of sulphur is indicated by a black precipitate of lead sulphide.

(*b*) Acidify 2 ml. of the " fusion " solution with dilute acetic acid, and add a few drops of lead acetate solution. A black precipitate of lead sulphide indicates the presence of sulphur.

(*c*) To 2 ml. of the " fusion " solution add 2–3 drops of a freshly-prepared dilute solution (*ca.* 0·1 per cent.) of sodium nitroprusside $Na_2[Fe(CN)_5NO]$. (The latter may be prepared by adding a minute crystal of the solid to about 2 ml. of water.) A purple coloration indicates sulphur ; the coloration slowly fades on standing.

Halogens. If nitrogen and/or sulphur are present, the addition of silver nitrate to the acidified " fusion " solution will precipitate silver cyanide and/or silver sulphide in addition to the silver halides. The removal of hydrogen cyanide and/or hydrogen sulphide before precipitation of the silver halides is effected by boiling the " fusion " solution, just acidified with dilute nitric acid, in an evaporating basin until it has been reduced to half its original volume. Cool, dilute with an equal volume of water and add a few drops of silver nitrate solution. A white or pale yellow precipitate, which darkens rapidly upon exposure to light, indicates the presence of halogen.

Nitrogen and sulphur absent. (i) *If only one halogen is present*, acidify with dilute nitric acid and add excess of silver nitrate solution. A precipitate indicates the presence of a halogen. Decant the mother liquor and treat the precipitate with dilute aqueous ammonia solution. If the precipitate is white and readily soluble in the ammonia solution, chlorine is present ; if it is pale yellow and difficultly soluble, bromine is present ; if it is yellow and insoluble, then iodine is indicated. Iodine and bromine should be confirmed by the tests given below.

If one or more halogens may be present, proceed as follows :

(ii) Acidify 1–2 ml. of the " fusion " solution with a moderate excess of glacial acetic acid and add 1 ml. of carbon tetrachloride. Then introduce 20 per cent. sodium nitrite solution drop by drop with constant shaking. A purple or violet colour in the organic layer indicates the presence of iodine. The reaction is :

$$2NaI + 2NaNO_2 + 4CH_3COOH \longrightarrow I_2 + 2NO + 4CH_3COONa + 2H_2O$$

This solution may also be employed in the test for bromine. If iodine has been found, add small amounts of sodium nitrite solution, warm slightly and shake with fresh 1 ml. portions of carbon tetrachloride until the last extract is colourless ; boil the acid solution until no more nitrous fumes are evolved and cool. If iodine is absent, use 1 ml. of the " fusion " solution which has been strongly acidified with glacial acetic acid. Add a small amount of lead dioxide, place a strip of fluorescein paper across the mouth of the tube, and warm the solution. If bromine is present, it will colour the test paper rose-pink (eosin).

Fluorescein test paper is prepared by dipping filter paper into a dilute solution of fluorescein in ethyl alcohol ; it dries rapidly and is then ready for use. The test paper has a lemon yellow colour.

Lead dioxide in acetic acid solution gives lead tetra-acetate which oxidises hydrogen bromide (and also hydrogen iodide), but has practically no effect under the above experimental conditions upon hydrogen chloride.

(iii) Acidify 1–2 ml. of the " fusion " solution with dilute sulphuric acid, cool, and add 1 ml. of carbon tetrachloride. Prepare the equivalent of " chlorine water " by acidifying 10 per cent. sodium hypochlorite solution with one fifth of its volume of dilute hydrochloric acid. Add this solution dropwise (use a dropper) with vigorous shaking to the mixture. If iodine is present, the organic phase first becomes purple in colour. As the addition of the " chlorine water " is continued, the purple colour disappears (owing to the oxidation of the iodine to iodate) and, if bromine is present, is replaced by a brown or reddish colour. If bromine is absent, the organic layer will be colourless. It is, of course, evident that if the carbon tetrachloride layer remains uncoloured, the halogen present is chlorine.

(iv) Acidify 1–2 ml. of the " fusion " solution with acetic acid, add a slight excess of pure lead dioxide (say, 0·5 g.) and boil gently until all the iodine and bromine are liberated. Dilute, filter off the excess of lead dioxide, and test for chloride with dilute nitric acid and silver nitrate solution.

$$2NaBr(I) + PbO_2 + 4CH_3COOH \longrightarrow$$
$$Br_2(I_2) + (CH_3COO)_2Pb + 2CH_3COONa + 2H_2O$$

Nitrogen and sulphur present. Just acidify 2–3 ml. of the " fusion " solution with dilute nitric acid, and evaporate to half the original volume in order to expel hydrogen cyanide and/or hydrogen sulphide which may be present. Dilute with an equal volume of water. If only one halogen is present, proceed as in tests (i) or (iii). If one or more halogens may be present, use tests (ii), (iii) or (iv).

Alternatively, add 1 or 2 drops of 5 per cent. nickel nitrate solution to 2–3 ml. of the " fusion " solution, filter off the nickel cyanide and/or nickel sulphide, acidify the filtrate with 2*N* nitric acid, and test for halides as above.

The detection of the following elements, which occur infrequently in organic compounds, is included here for the sake of completeness.

Fluorine. Strongly acidify 2 ml. of the " fusion " solution with glacial acetic acid, and boil until the volume is reduced by about one half. Cool. Use either of the following tests.

(*a*) Place one drop of the solution upon zirconium-alizarin-S test paper.* A yellow colour on the red paper indicates the presence of fluoride.

(*b*) Add a few drops of saturated calcium chloride solution, and allow to stand for several hours. If fluorine is present, a gelatinous precipitate of calcium fluoride will form.

Phosphorus. The presence of phosphorus may be indicated by a smell of phosphine during the sodium fusion. Treat 1 ml. of the " fusion " solution with 3 ml. of concentrated nitric acid and boil for one minute. Cool and add an equal volume of ammonium molybdate reagent. Warm the mixture to 40–50°, and allow to stand. If phosphorus is present, a yellow crystalline precipitate of ammonium phosphomolybdate will separate.

It is usually preferable to oxidise the compound directly as follows. Intimately mix 0·02–0·05 g. of the compound with 3 g. of sodium peroxide and 2 g. of anhydrous sodium carbonate in a nickel crucible. Heat the crucible and its contents with a small flame, gently at first, afterwards more strongly until the contents are fused, and continue heating for a further 10 minutes. Allow to stand, extract the contents of the crucible with water, and filter. Add excess of concentrated nitric acid to the filtrate and test with ammonium molybdate reagent as above. A yellow precipitate indicates the presence of phosphorus. It must be borne in mind that the above treatment will convert any arsenic present into arsenate.

Arsenic. The presence of arsenic in an organic compound is generally revealed by the formation of a dull grey mirror of arsenic on the walls of the test-tube when the compound is fused with sodium in the Lassaigne test. Usually sufficient arsenic is found in the " fusion " solution to give a yellow precipitate of arsenic trisulphide when the solution is acidified with hydrochloric acid and treated with hydrogen sulphide.

It is recommended that the compound be fused with a mixture of sodium carbonate (2 parts) and sodium peroxide (1 part) as in the test for *Phosphorus*. Extract the fused mass with water, filter, and acidify with dilute hydrochloric acid. Pass hydrogen sulphide through the hot solution; arsenic is precipitated as yellow arsenic sulphide. If **antimony is present**, it will be precipitated as orange antimony trisulphide.

Mercury. Upon heating a mixture of the compound with soda lime in a long test-tube, a bright metallic mirror and, finally, drops of mercury will form in the upper part of the tube if mercury is present.

THE SODIUM CARBONATE - ZINC METHOD FOR THE DETECTION OF NITROGEN, SULPHUR AND HALOGENS IN ORGANIC COMPOUNDS

The Lassaigne procedure for detecting nitrogen in organic compounds frequently gives unsatisfactory results with explosive compounds (diazonium salts, polynitro compounds and the like) and with certain volatile nitrogenous substances, such as bases, their acyl derivatives or their salts. These difficulties

---

* For further details, see A. I. Vogel, *Text-Book of Macro and Semimicro Qualitative Inorganic Analysis*, Fourth Edition, 1954, p. 363 (Longmans, Green and Co. Ltd.).

may often be surmounted either by mixing the compound with pure naphthalene or sucrose, or by mixing the substance with sodium and placing a layer of soda lime above the mixture. Difficulties are also sometimes experienced in the sodium fusion test with liquids of low boiling point, such as ethyl bromide. Satisfactory results are obtained by heating the organic compound with sodium carbonate and zinc powder (Middleton, 1935). The latter method has been proposed for the detection of the common elements in all organic compounds. It is doubtful, however, whether it is to be preferred to the sodium fusion procedure in routine testing for elements, although it may be recommended for those relatively few cases in which the Lassaigne test is not entirely satisfactory.

When an organic compound is heated with a mixture of zinc powder and sodium carbonate, the nitrogen and halogens are converted into sodium cyanide and sodium halides respectively, and the sulphur into zinc sulphide (insoluble in water). The sodium cyanide and sodium halides are extracted with water and detected as in Lassaigne's method, whilst the zinc sulphide in the residue is decomposed with dilute acid and the hydrogen sulphide is identified with sodium plumbite or lead acetate paper. The test for nitrogen is thus not affected by the presence of sulphur : this constitutes an advantage of the method.

Prepare the **zinc powder - sodium carbonate mixture** by grinding together in a dry, clean mortar 25 g. of A.R. anhydrous sodium carbonate and 50 g. of the purest obtainable zinc powder. The reagent is unlikely to contain nitrogen, but traces of sulphur and halogens may be present. It is therefore essential to carry out a blank or control test for sulphur and halogens with every fresh batch of the mixture.

Place about 0·1 g. of the powdered compound in a small dry test-tube, add sufficient of the reagent to give a column about 1 cm. high, and then shake the closed tube until the contents are well mixed. Now add more reagent, without mixing with the material already in the tube, until the total height is about 3 cm. If the compound is a liquid, introduce 2–3 drops into a small dry test-tube, add sufficient of the mixture to form a column about 1 cm. long, and allow the liquid to soak well into the reagent. Then add more reagent, without mixing, until a total height of about 3 cm. is secured. Hold the tube horizontally (use tongs or a special test-tube holder) and, by means of a *small* flame, heat a 1 cm. length of the mixture gently near the open end. Gradually increase the size of the flame until the mixture is red hot at the end. Extend the heating gradually and cautiously towards the closed end of the tube until the whole of the mixture is red hot. (The extension of the heating towards the closed end of the tube must be carried out with great care, otherwise the mixture may be projected from the tube ; if the mixture tends to be pushed out of the tube by the evolution of gas, stop the heating momentarily and rotate the tube while still in a horizontal position in order to redistribute the contents.) Finally heat the tube to redness in a vertical position for a minute or two and, while the end of the tube is still red hot, plunge the tube in about 10 ml. of water in a porcelain dish. Boil the contents of the dish gently for 1–2 minutes and filter. (If the filtrate is not colourless, repeat the whole process.) Retain the residue in the basin for the sulphur test. Divide the clear filtrate into two portions.

Nitrogen. Treat one portion with 1–2 ml. of 5 per cent. sodium hydroxide solution and 0·1 g. of powdered ferrous sulphate. Boil for 1 minute and cool. Cautiously acidify with dilute sulphuric acid (carbon dioxide is evolved). A precipitate of Prussian blue indicates that nitrogen is present.

Halogens. Proceed as described under the Lassaigne test. If nitrogen is present, the cyanide must first be eliminated.

Sulphur. Moisten the centre of a filter paper with sodium plumbite solution. Add about 10 ml. of dilute hydrochloric acid to the residue in the dish and immediately cover it with the prepared filter paper. If zinc sulphide is present in the residue, a dark brown stain, visible on the upper surface of the paper, will be obtained : frequently the presence of hydrogen sulphide can also be detected by its odour.

XI,4. THE SOLUBILITIES OF ORGANIC COMPOUNDS

When a mixture of a specified amount of a given solute and a specified amount of a given solvent forms a homogeneous liquid, the former is said to be soluble in the latter. This essentially practical definition of solubility [*] forms the basis of the various schemes which have been proposed to employ solubility as a basis for the classification of organic compounds (O. Kamm, 1922 ; H. Staudinger, 1923). A detailed discussion of the relationship between solubility and chemical constitution in organic compounds is outside the scope of this work,[†] but the following qualitative generalisations (to which numerous exceptions are known), due largely to Kamm, may be found helpful.

1. *A compound is most soluble in that solvent to which it is most closely related in structure.* Thus *n*-hexane, which is sparingly soluble in water, dissolves in three volumes of methyl alcohol, is more soluble in anhydrous ethyl alcohol, and is completely miscible with *n*-butyl and higher alcohols. As the chain length increases the compound tends to resemble the hydrocarbon more and more, and hence the solubility increases.

The mono-hydroxy and mono-carboxy derivatives of the hydrocarbons (alcohols and carboxylic acids) are soluble in ether : the lower homologues (up to about C_5—see below) are soluble in water. If two or more hydroxyl groups are present in the molecule, the compound becomes more like water in structure and less like the hydrocarbons ; consequently the solubility in water increases and the solubility in ether decreases. The following examples may be quoted : ethyl and *n*-propyl alcohol are completely miscible with ether and with water, but ethylene glycol and glycerol whilst very soluble in water are almost insoluble in ether ; the carbohydrates, which contain several hydroxyl groups, are very soluble in water but insoluble in ether ; succinic acid is sparingly soluble and malic, tartaric and citric acids are insoluble in ether, but all of these polybasic acids are soluble in water. Most salts (derived from organic acidic substances

---

[*] The arbitrary standard employed in this book is 0·1 g. of solid or 0·2 ml. of liquid to 3 ml. of solvent.

[†] See, for example, J. H Hildebrand and R. L. Scott, *The Solubility of Nonelectrolytes*, 1950 (Reinhold).

and inorganic bases, or from organic bases and mineral acids) are soluble in water but insoluble in ether.

2. *The effect of a halogen atom or of phenyl is analogous to an increase in ie number of carbon atoms.*

3. *As one ascends a given homologous series, the physical properties of the members increasingly resemble those of the hydrocarbons from which they may be regarded as derived.* Thus the solubility of alcohols in water decreases as the series is ascended and for normal alcohols, the limit of solubility lies between C_4 and C_5. Branching of the carbon chain of the alkyl group decreases the effect of this group, hence a branched-chain alcohol is usually more soluble than a straight-chain alcohol of the same carbon content. The influence of various constitutional factors upon the solubilities of alcohols at 20° will be apparent from an examination of Table XI, 4.1.

TABLE XI, 4.1. SOLUBILITIES OF ALCOHOLS IN WATER AT 20°

ALCOHOL	FORMULA	SOLUBILITY (G./100 ML. OF H_2O)
Methyl	CH_3OH	∞
Benzyl	$C_6H_5CH_2OH$	4·0
Ethyl	CH_3CH_2OH	∞
β-Chloroethyl . . .	$ClCH_2CH_2OH$	∞
n-Propyl	$CH_3CH_2CH_2OH$	∞
*iso*Propyl	$CH_3CH(OH)CH_3$	∞
γ-Chloropropyl . . .	$ClCH_2CH_2CH_2OH$	50·0
γ-Bromopropyl . . .	$BrCH_2CH_2CH_2OH$	∞
1-Chloro-2-propanol . .	$ClCH_2CH(OH)CH_3$	∞
1 : 3-Dichloro-2-propanol .	$ClCH_2CH(OH)CH_2Cl$	11·0
n-Butyl	$CH_3CH_2CH_2CH_2OH$	8·3
*iso*Butyl	$(CH_3)_2CHCH_2OH$	9·6
sec.-Butyl	$CH_3CH_2CH(OH)CH_3$	13·0
tert.-Butyl	$(CH_3)_3COH$	∞
n-Amyl	$CH_3(CH_2)_4OH$	2·0
Methyl *n*-propyl carbinol .	$CH_3CH_2CH_2CH(OH)CH_3$	6·0
Diethyl carbinol . .	$CH_3CH_2CH(OH)CH_2CH_3$	8·0
*iso*Butyl carbinol . .	$(CH_3)_2CHCH_2CH_2OH$	2·8
Dimethyl ethyl carbinol .	$(CH_3)_2C(OH)CH_2CH_3$	12
n-Hexyl alcohol . . .	$CH_3(CH_2)_5OH$	0·5
n-Heptyl alcohol . .	$CH_3(CH_2)_6OH$	0·12

The lower members of other homologous series of oxygen compounds—the acids, aldehydes, ketones, anhydrides, ethers and esters—have approximately the same limits of solubility as the alcohols and substitution and branching of the carbon chain has a similar influence. For the amines (primary, secondary and tertiary), the limit of solubility is about C_6, whilst for the amides and nitriles it is about C_4.

4. *Compounds of very high molecular weight frequently exhibit decreased solubility in inert solvents.** Thus whilst glucose ($C_6H_{10}O_6$) and methyl

---

* Inert solvents, *e.g.*, water and ether, are those solvents from solutions in which the solute may be recovered by simple evaporation.

acrylate ($CH_2{=}CHCOOCH_3$) are readily soluble in water, the polymers starch, cellulose and glycogen $(C_6H_{10}O_5)_n$ and methyl acrylate resin are insoluble in water. Some exceptions are known, for example, methyl cellulose and the polyethylene oxides $HOCH_2(CH_2{-}O{-}CH_2)_nCH_2OH$ (n up to 100) dissolve in water.

5. *The solubility of solid compounds is dependent upon the molecular aggregation in the solid state.* The molecular aggregation in the solid state finds some expression in the melting points of the compounds or, otherwise expressed, the melting point of a solid is generally a criterion of the intermolecular cohesive forces. Heat is required to overcome these forces and convert the solid into a liquid ; hence the higher the m.p., the greater is the intermolecular attraction. The solution of a solid involves a similar destruction of the intermolecular forces so that, for structurally related compounds, higher melting points are associated with lower solubilities in inert solvents.* The solubilities of some stereoisomers in water and in alcohol are collected in Table XI, 4.2.

TABLE XI, 4.2. SOLUBILITIES OF STEREOISOMERS IN WATER AND IN ALCOHOL

COMPOUND	M.P.	SOLUBILITY IN 100 G. OF SOLVENT AT 20°	
		WATER	ALCOHOL
Maleic acid (*cis*)	135° †	60 g.	51 g.
Fumaric acid (*trans*)	286°	0·6 g.	5 g.
d-Tartaric acid	170°	139 g.	27 g. (25°)
l-Tartaric acid	170°	139 g.	27 g. (25°)
dl-Tartaric acid	206°	20 g.	2 g. (25°)

† The m.p. depends upon the rate of heating: the pure acid has m.p. 143° (see Section III,143), but commercial samples usually melt at a slightly lower temperature.

Similar relationships are found among the position isomers in benzene derivatives, but some abnormal results are encountered. Among compounds of a homologous series, high melting points often correspond to lower solubilities. Thus with the aliphatic dibasic acids $HOOC(CH_2)_nCOOH$, the "even" acid has the higher melting point and lower solubility in water than the next higher homologue ("odd" acid). This can be clearly seen from an examination of Table XI, 4.3.

An interesting illustration is urea $CO(NH_2)_2$, m.p. 132°, which is very soluble in water, and oxamide $(CONH_2)_2$, m.p. 420°, which is sparingly soluble in water.

---

* This does not apply to salts; these are highly polar compounds, dissociate in solution in water, and are usually very soluble.

TABLE XI, 4.3. MELTING POINTS AND SOLUBILITIES OF DIBASIC ACIDS, $HOOC(CH_2)_nCOOH$

ACID	M.P.	SOLUBILITY (G./100 G. OF H_2O) AT 20°
Oxalic ($n = 0$) . .	189°	9·5
Malonic ($n = 1$) . .	135°	73·5
Succinic ($n = 2$) . .	185°	6·9
Glutaric ($n = 3$) . .	98°	63·9
Adipic ($n = 4$) . .	152°	1·5
Pimelic ($n = 5$) . .	105°	4·9
Suberic ($n = 6$) . .	142°	0·15
Azelaic ($n = 7$) . .	106°	0·24
Sebacic ($n = 8$) . .	134°	0·10

6. *Solvation increases solubility above predicted values.* When the components of a solution possess an abnormally large attraction for each other, " solvates " are formed. Thus certain oxygen-containing compounds have a great tendency to form hydrates, thus contributing to increased water solubility : hydrogen bonding also plays an important rôle.

SOLUBILITY IN REACTION SOLVENTS

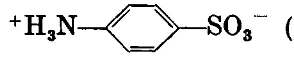
In addition to water and ether, the following reagents are employed as " solvents " for the characterisation of organic compounds : 5 per cent. aqueous solutions of hydrochloric acid and of sodium hydroxide, and also concentrated sulphuric acid.

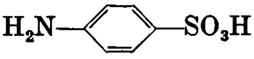
Dilute hydrochloric acid. Most compounds that are soluble in dilute hydrochloric acid contain a basic nitrogen atom in the molecule. Thus most aliphatic amines (primary, secondary and tertiary) form salts (polar, water-soluble compounds) with hydrochloric acid. Primary aromatic amines (*e.g.*, aniline) behave similarly, but in secondary and tertiary purely aromatic amines (*e.g.*, diphenylamine and triphenylamine) the basic character of the nitrogen atom has been diminished to such an extent that they do not form salts with dilute hydrochloric acid and consequently do not dissolve. Arylalkylamines and alicyclic amines, however, do dissolve. A few types of oxygen-containing compounds (such as the pyrones and the anthocyanidin pigments of certain flowers) which form oxonium salts dissolve in dilute hydrochloric acid. Amides $RCONH_2$, $RCONHR'$ and $RCONR'R''$, which are insoluble in water, are generally neutral to 5 per cent. hydrochloric acid but may dissolve in higher concentrations (10–20 per cent.) of acid : this emphasises the importance of employing the correct strength of acid in the solubility tests.

Dilute sodium hydroxide solution. Carboxylic acids (RCOOH), sulphonic acids (RSO_3H), phenols (ArOH), thiophenols (ArSH), mercaptans (RSH), imides (RCONHCOR), aryl sulphonamides ($ArSO_2NH_2$), arylsulphonyl derivatives of primary amines ($ArSO_2NHR$), oximes (RCH=NOH), primary and secondary nitro compounds (RCH=NOOH and R_2C=NOOH - *aci* forms), and some enols (*e.g.*, of 1 : 3-diketones

RCH(OH)=CHCOR or β-keto esters RCH(OH)=CHCOOR′) dissolve in dilute sodium hydroxide solution, *i.e.*, contain an acidic group of sufficient strength to react with the alkali. Carboxylic acids and sulphonic acids are soluble in dilute solutions of sodium bicarbonate : some negatively-substituted phenols, for example, picric acid, 2 : 4 : 6-tribromophenol and 2 : 4-dinitrophenol, are strongly acidic and also dissolve in dilute sodium bicarbonate solution.

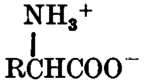
The presence of certain substituents (*e.g.*, the amino group) may markedly affect the solubility and other properties of the sulphonic acid or carboxylic acid. Thus such sulphonic acids as the aminobenzenesulphonic acids, pyridine- and quinoline-sulphonic acids exist in the form of **inner salts** or "**zwitter-ions**" that result from the interaction of the basic amino group and the acidic sulphonic acid. Sulphanilic acid, for example, is more accurately represented by formula (I) than by formula (II) :


(I)


(II)

These aminosulphonic acids possess the high melting points usually associated with salts and are sparingly soluble or insoluble in water. They all dissolve readily in dilute alkali but not in dilute acid, *i.e.*, they appear to exhibit the reactions of the sulphonic acid group but not of the amino group. The aliphatic aminocarboxylic acids, because of the presence of the strongly basic amino group, exist as inner salts :


$$\mathrm{R\overset{\overset{\displaystyle NH_2}{|}}{C}HCOOH}$$


$$\mathrm{R\overset{\overset{\displaystyle NH_3^+}{|}}{C}HCOO^-}$$

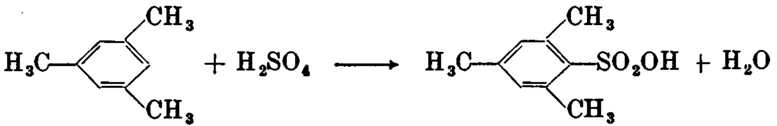
they are soluble in water but not in ether, and dissolve in both dilute acid and dilute alkali. The carboxyl derivatives of the arylamines (*e.g.*, *p*-aminobenzoic acid) are also amphoteric, but the diminution of the basic character of the amino group because of its attachment to the aryl group prevents the formation of inner salts to any degree.

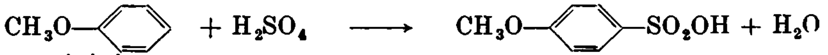
Concentrated sulphuric acid. The paraffin hydrocarbons, *cyclo*paraffins, the less readily sulphonated aromatic hydrocarbons (benzene, toluene, xylenes, etc.) and their halogen derivatives, and the diaryl ethers are generally insoluble in cold concentrated sulphuric acid. Unsaturated hydrocarbons, certain polyalkylated aromatic hydrocarbons (such as mesitylene) and most oxygen-containing compounds are soluble in the cold acid.

Unsaturated hydrocarbons dissolve through the formation of soluble alkyl hydrogen sulphates :

$$\mathrm{RCH{=}CH_2 + H_2SO_4 \longrightarrow RCH(CH_3)OSO_2OH}$$

Polyalkylated aromatic hydrocarbons and alkyl phenyl ethers are sulphonated :


Mesitylene


Anisole

Many oxygen-containing compounds dissolve because of the formation of oxonium salts; the latter are readily decomposed (hydrolysed) by pouring the acid into ice water.

The purpose of the reagent is merely to ascertain whether the substance is soluble in the concentrated acid or not. For this reason, the attendant disadvantages of the reagent—the production of more fundamental changes with certain oxygen-containing compounds than mere dissolution or oxonium salt formation—are of secondary importance provided careful distinction be made between the solubility of the original compound and the insolubility of the *products* of the reaction. Thus certain unsaturated hydrocarbons yield insoluble polymers, and benzyl alcohol affords an insoluble poly-benzyl alcohol of the average composition

$$C_6H_5CH_2(C_6H_4CH_2)_9C_6H_4CH_2OH.$$

Compounds which dissolve in concentrated sulphuric acid may be further subdivided into those which are soluble in syrupy phosphoric acid (*A*) and those which are insoluble in this solvent (*B*); in general, dissolution takes place without the production of appreciable heat or colour. Those in class *A* include alcohols, esters, aldehydes, methyl ketones and cyclic ketones provided that they contain less than nine carbon atoms. The solubility limit is somewhat lower than this for ethers: thus *n*-propyl ether dissolves in 85 per cent. phosphoric acid but *n*-butyl ether and anisole do not. Ethyl benzoate and ethyl malonate are insoluble.

XI,5. THE SOLUBILITY GROUPS

It has been found convenient (O. Kamm, 1922) to place organic compounds into seven solubility groups on the basis of:

(*a*) their solubility behaviour towards water, ether, 5 per cent. aqueous sodium hydroxide solution, 5 per cent. hydrochloric acid and cold concentrated sulphuric acid, and

(*b*) the elements, other than carbon and hydrogen, that they contain.
The resulting groups are:

Group I. Compounds soluble in both water and ether.

Group II. Compounds soluble in water, but insoluble in ether.

Group III. Compounds insoluble in water, but soluble in dilute sodium hydroxide. This group may be further subdivided into **Group IIIA**—soluble in dilute sodium hydroxide and soluble in dilute sodium bicarbonate; and **Group IIIB**—soluble in dilute sodium hydroxide and insoluble in dilute sodium bicarbonate.

Group IV. Compounds insoluble in water, but soluble in dilute hydrochloric acid.

Group V. Hydrocarbons and compounds containing C, H and O that are not in Groups I–IV and are soluble in concentrated sulphuric acid (“ indifferent compounds ”).

This group may be further subdivided into **Group VA**—soluble in concentrated sulphuric acid and soluble in 85 per cent. phosphoric acid—and **Group VB**—soluble in concentrated sulphuric acid and insoluble in 85 per cent. phosphoric acid.

Group VI. All compounds, not containing N or S, that are insoluble in concentrated sulphuric acid.

Group VII. Compounds that contain N or S which are not in Groups I–IV. Many of the compounds in this group are soluble in concentrated sulphuric acid.

It will be observed that halogen compounds are not listed separately, but appear in each of the seven groups in accordance with their solubility behaviour. Similarly, certain compounds containing N or S will fall in Groups I–IV (see preceding Section).

Table **XI,5,1** shows this grouping of organic compounds, together with the commoner classes of compounds that fall into the respective solubility groups.

TABLE XI,5,1. **DIVISION OF ORGANIC COMPOUNDS INTO SOLUBILITY GROUPS**

Group I *Soluble in Both Ether and Water*	**Group II** *Soluble in Water but Insoluble in Ether*	**Group III** *Soluble in 5 % Sodium Hydroxide Solution*	**Group IV** *Soluble in 5 % Hydrochloric Acid*	**Group V** *Not Containing N or S. Soluble only in Concentrated Sulphuric Acid*	**Group VI** *Not Containing N or S. Insoluble in Concentrated Sulphuric Acid*	**Group VII** *Containing N or S. Compounds Not in Groups I to IV*
The lower members of the homologous series of : 1. Alcohols 2. Aldehydes 3. Ketones 4. Acids 5. Esters 6. Phenols 7. Anhydrides 8. Amines 9. Nitriles 10. Polyhydroxy phenols	1. Polybasic acids and hydroxy acids. 2. Glycols, polyhydric alcohols, polyhydroxy aldehydes and ketones (sugars) 3. Some amides, amino acids, di- and polyamino compounds, amino alcohols 4. Sulphonic acids 5. Sulphinic acids 6. Salts	1. Acids 2. Phenols 3. Imides 4. Some primary and secondary nitro compounds; oximes 5. Mercaptans and thiophenols 6. Sulphonic acids, sulphinic acids, sulphuric acids, and sulphonamides 7. Some diketones and β-keto esters	1. Primary amines 2. Secondary aliphatic and aryl-alkyl amines 3. Aliphatic and some aryl-alkyl tertiary amines 4. Hydrazines	1. Unsaturated hydrocarbons 2. Some polyalkylated aromatic hydrocarbons 3. Alcohols 4. Aldehydes 5. Ketones 6. Esters 7. Anhydrides 8. Ethers and acetals 9. Lactones 10. Acyl halides	1. Saturated aliphatic hydrocarbons 2. Cyclic paraffin hydrocarbons 3. Aromatic hydrocarbons 4. Halogen derivatives of 1, 2 and 3 5. Diaryl ethers	1. Nitro compounds (tertiary) 2. Amides and derivatives of aldehydes and ketones 3. Nitriles 4. Negatively substituted amines 5. Nitroso, azo, hydrazo, and other intermediate reduction products of nitro compounds 6. Sulphones, sulphonamides of secondary amines, sulphides, sulphates and other sulphur compounds

NOTES ON TABLE XI,5,1

Group I. This includes the lower members of the various homologous series (4–5 atoms in a normal chain) that contain oxygen and/or nitrogen in their structures : they are soluble in water because of their low carbon content. If the compound is soluble in both water and ether, it would also be soluble in other solvents so that further solubility tests are generally unnecessary : the test with sodium bicarbonate solution should, however, be performed (see Section XI,6).

Group II. The classes 1 to 5 are usually soluble in dilute alkali and acid. Useful information may, however, be obtained by examining the behaviour of *Salts* to alkaline or acidic solvents. With a salt of a water-soluble base, the characteristic odour of an amine is usually apparent when it is treated with dilute alkali : likewise, the salt of a water-soluble, weak acid is decomposed by dilute hydrochloric acid or by concentrated sulphuric acid. The water-soluble salt of a water-insoluble acid or base will give a precipitate of either the free acid or the free base when treated with dilute acid or dilute alkali. The salts of sulphonic acids and of quaternary bases (R_4NOH) are unaffected by dilute sodium hydroxide or hydrochloric acid.

Group III. Carboxylic and sulphonic acids (also *sym.*-tribromophenol, 2 : 4-dinitrophenol and picric acid) are also soluble in dilute sodium bicarbonate solution.

Group IV. The student should remember that the hydrochlorides of some bases are sparingly soluble in cold water and should therefore not be misled by an apparent insolubility of a compound (containing N) in dilute hydrochloric acid. The suspension in dilute hydrochloric acid should always be filtered and the filtrate made alkaline. A precipitate will indicate that the compound should be placed in Group IV : if no precipitate is formed, the compound is relegated to Group VII.

Group V. This group includes all the water-insoluble hydrocarbons and oxygen compounds that do not contain N or S and are soluble in cold concentrated sulphuric acid. Any changes—colour, excessive charring, evolution of gases or heat, polymerisation and precipitation of an insoluble compound—attending the dissolution of the substance should be carefully noted.

Alcohols, esters (but not ethyl benzoate, ethyl malonate or ethyl oxalate), aldehydes, methyl ketones and cyclic ketones containing less than nine carbon atoms as well as ethers containing less than seven carbon atoms are soluble in 85 per cent. phosphoric acid.

Group VI. Concentrated sulphuric acid provides a simple test for the differentiation *inter alia* between (*a*) saturated paraffin and cyclic hydrocarbons and also simple aromatic hydrocarbons and (*b*) unsaturated hydrocarbons.

Group VII. This group comprises all compounds containing N or S which are insoluble in water and are indifferent (*i.e.*, insoluble in dilute acid or alkali).

An outline of the solubility classification procedure is given in Table XI,5,2, whilst the characteristic features of each of the solubility groups are summarised in Table XI,5,3.

TABLE XI,5,2. OUTLINE OF SOLUBILITY CLASSIFICATION PROCEDURE

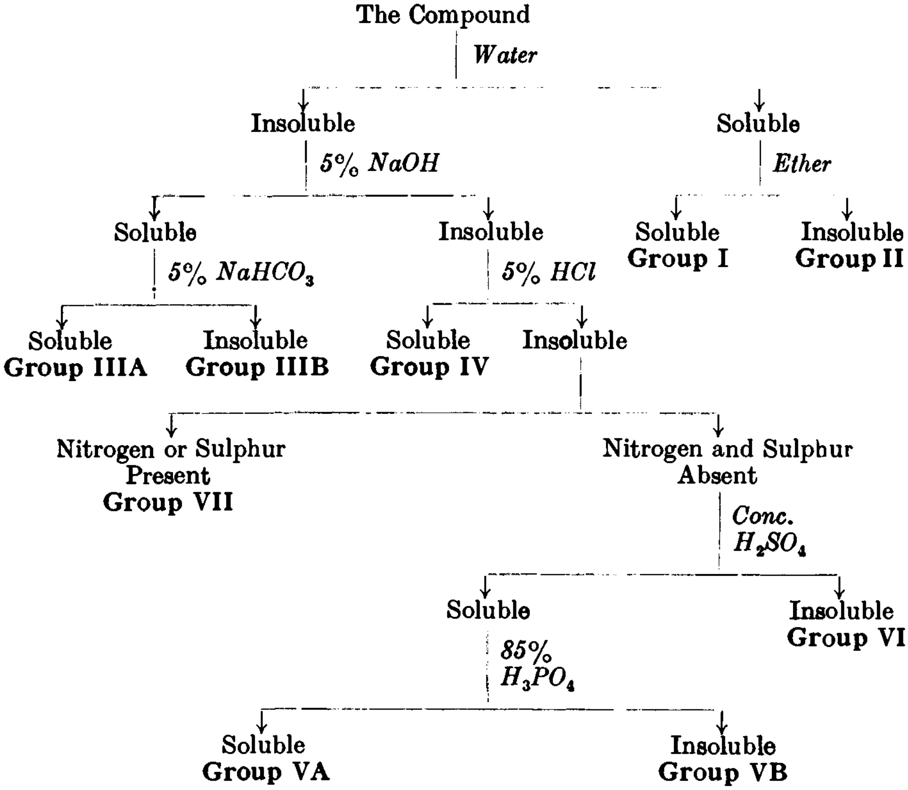


TABLE XI,5,3. CLASSIFICATION OF SOLUBILITY GROUPS

Group	Water	Ether	NaOH	$NaHCO_3$	HCl	H_2SO_4	H_3PO_4
I	+ (1)	+					
II . . .	+	—					
IIIA . . .	—		+ (2)	+			
IIIB . . .	—		+ (2)	—			
IV . . .	—		—		+		
VA (3) . . .	—		—		—	+	+
VB (3) . . .	—		—		—	+	—
VI (3) . . .	—		—		—	—	
VII (4) . . .	—		—		—		

Notes.

(1) + denotes soluble ; — denotes insoluble.

(2) If a compound contains nitrogen its solubility in dilute hydrochloric acid should be tested also to ascertain whether it is amphoteric.

(3) These are neutral compounds in which nitrogen and sulphur are *absent*.

(4) These are neutral compounds in which nitrogen or sulphur is *present*.

XI,6. DETERMINATION OF THE SOLUBILITIES OF ORGANIC COMPOUNDS (*for Group Tests*)

All solubility determinations for Group tests are carried out at the laboratory temperature in small test-tubes (*e.g.*, 100 × 12 mm.) but of sufficient size to permit of vigorous shaking of the solvent and the solute.

Amount of material required. It is convenient to employ an arbitrary ratio of 0·10 g. of solid or 0·20 ml. of liquid for 3·0 ml. of solvent. Weigh out 0·10 g. of the *finely-powdered* solid to the nearest 0·01 g.: after some experience, subsequent tests with the *same* compound may be estimated by eye. Measure out 0·20 ml. of the liquid either with a calibrated dropper (Fig. *II, 27,* 1) or a small graduated pipette. Use either a calibrated dropper or a graduated pipette to deliver 3·0 ml. of solvent. Rinse the delivery pipette with alcohol, followed by ether each time that it is used.

Much time will be saved if each of the solvents (Water, Ether, 5 per cent. Sodium Hydroxide, 5 per cent. Sodium Bicarbonate and 5 per cent. Hydrochloric Acid) be contained in a 30 or 60 ml. bottle fitted with a cork carrying a calibrated dropper.* The concentrated sulphuric acid should be kept in a glass-stoppered bottle and withdrawn with a dropper or pipette as required.

Attention is directed to the fact that if only minute amounts of material are available or if the substance is expensive, considerable economy may be effected by treating, *e.g.*, the aqueous solution or suspension with the necessary quantity of concentrated sodium hydroxide solution or concentrated hydrochloric acid.

Solubility in water. Treat a 0·10 g. portion of the solid with successive 1·0 ml. portions of water, shaking vigorously after each addition, until 3·0 ml. have been added. If the compound does not dissolve completely in 3·0 ml. of water, it may be regarded as insoluble in water. When dealing with a liquid, add 0·20 ml. of the compound to 3·0 ml. of water and shake. In either case, test the contents of the small test-tube with litmus (or with Universal indicator paper): it is best to remove a little of the solution or supernatant liquid with a dropper.

Solubility in ether. Use 0·10 g. of solid or 0·20 ml. of a liquid in a dry test-tube and proceed exactly as in testing the solubility in water, but do not employ more than 3·0 ml. of solvent.

Solubility in 5 per cent. sodium hydroxide solution. Note whether there is any rise in temperature. If the compound appears insoluble, remove some of the supernatant liquid by means of a dropper to a semimicro test-tube (75 × 10 mm.), add 5 per cent. hydrochloric acid dropwise until acid, and note whether any precipitate (or turbidity) is formed. The production of the latter will place the compound in Group III.

Solubility in 5 per cent. sodium bicarbonate solution. If the compound is soluble in 5 per cent. sodium hydroxide solution, test its solubility in a 5 per cent. solution of sodium bicarbonate. Observe

---

* See, for example, A. I. Vogel, *A Text-Book of Macro and Semimicro Qualitative Inorganic Analysis*, Fourth Edition, 1954. p. 168 (Longmans, Green and Co. Ltd.). A commercial form of the apparatus ("pipette reagent bottle") is available from Baird and Tatlock (London) Ltd. The bottle has a capacity of 250 ml. and a calibrated 5 ml. pipette is fitted into the neck with a *B*19 ground glass joint. This is recommended for large classes of students.

whether it dissolves and particularly whether carbon dioxide is evolved either immediately (carboxylic acids, sulphonic acids, negatively substituted phenols) or after a short time (some amino acids).

Solubility in 5 per cent. hydrochloric acid. Add the acid to 0·10 g. of the solid or 0·20 ml. of the liquid in quantities of 1·0 ml. until 3·0 ml. have been introduced. Some organic bases (*e.g.*, β-naphthylamine) form hydrochlorides that are soluble in water but are precipitated by an excess of acid : if solution occurs at any time, the unknown is assigned to Group IV. If the compound appears insoluble, remove some of the supernatant liquid by means of a dropper to a semimicro test-tube (75 × 10 mm.), and add 5 per cent. sodium hydroxide solution until basic and observe whether any precipitate is produced : the formation of a precipitate will place the compound in Group IV.

Solubility in concentrated sulphuric acid. Place 3·0 ml. of pure concentrated sulphuric acid in a dry test-tube and add 0·10 g. of a solid or 0·20 ml. of a liquid. If the compound does not dissolve immediately, agitate for some time but do not heat. Observe any change in colour, charring, evolution of gaseous products, polymerisation accompanied by precipitation etc.

Solubility in syrupy phosphoric acid. This test should only be applied if the compound is soluble in concentrated sulphuric acid. Place 3·0 ml. of 85 per cent. orthophosphoric acid in a dry test-tube and add 0·10 g. of a solid or 0·20 ml. of a liquid. If the compound does not dissolve immediately, agitate for some time but do not boil.

Practice in solubility determinations. It is suggested that the student should carry out solubility determinations with a selection from the following compounds :

Hydrocarbons. Hexane : Toluene : Naphthalene : *cyclo*Hexane : Amylene : *cyclo*Hexene.
Halogen compounds. *n*-Butyl bromide : Chlorobenzene : Allyl bromide : Benzoyl chloride.
Alcohols. *n*-Butyl alcohol : *n*-Hexyl alcohol : *tert.*-Butyl alcohol : Benzyl alcohol : Glycerol : Sucrose.
Aldehydes and ketones. *n*-Butyraldehyde : Acetone : Methyl *n*-amyl ketone : Benzaldehyde : Acetophenone : Benzophenone.
Ethers. Di-*n*-butyl ether : Anisole : Diphenyl ether.
Esters. *n*-Butyl acetate : Ethyl acetate : Ethyl benzoate.
Acids. Acetic acid : *n*-Caproic acid : Benzoic acid : Phenylacetic acid : Succinic acid : Adipic acid : Anthranilic acid.
Phenols. Phenol : β-Naphthol.
Anhydrides. Acetic anhydride : Benzoic anhydride.
Enols. Ethyl acetoacetate.
Nitro compounds. Nitromethane : Nitrobenzene : *m*-Dinitrobenzene.
Amides and imides. Acetamide : *n*-Caproamide : Acetanilide : Benzanilide : Phthalimide.
Amines. Aniline : Benzidine : α-Naphthylamine : *p*-Nitroaniline : Dimethylaniline.
Nitriles. *n*-Butyronitrile : Benzyl cyanide.
Salts. Sodium benzoate : Sodium benzenesulphonate : Aniline hydrochloride : Methylamine hydrochloride.

Record your results in tabular form thus:

Compound	Solubility in							Solubility Group
	Water	Ether	5% NaOH	5% $NaHCO_3$	5% HCl	Conc. H_2SO_4	85% H_3PO_4	
Phloroglucinol	+	+						I
Benzoic acid .	–		+	+				IIIA
Aniline . .	–		–		+			IV
Acetophenone	–		–		–	+	+	VA
n-Hexane .	–		–		–	–		VI
Etc. . .								

XI,7. CLASS REACTIONS (REACTIONS FOR FUNCTIONAL GROUPS)

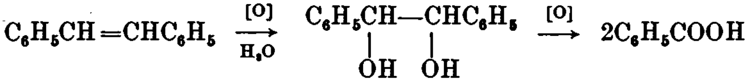
The qualitative analysis and the solubility behaviour of an unknown compound will serve to place it in one of the seven solubility groups (Table **XI,5,1**). It is then necessary to ascertain to which of the classes of the particular solubility group the compound belongs, *i.e.*, to determine the functional group (or groups) present in the substance Many of the functional groups are to be found in more than one of the solubility groups, consequently the ensuing discussion of the characteristic class reactions will, in many instances, cover several solubility groups. Where an organic compound contains more than one functional group, the classification is generally based upon the one that is most readily detected and manipulated. Thus, benzoic acid, *p*-chlorobenzoic acid, *p*-methoxybenzoic acid (anisic acid), and *p*-nitrobenzoic acid will be classified as *acids* both by the solubility tests and the class reactions, and the identification of, say, the nitrogen-containing acid *may* be completed by the preparation of derivatives of the carboxyl group without the absolute necessity of applying the class reactions that would discover the nitro group ; however, if possible, it is always advisable to establish the nature of the subsidiary functional group (or groups) since this would provide additional extremely valuable evidence for the characterisation of the unknown compound. It must also be remembered that in compounds containing two or more typical groups, the latter may influence one another so that the properties cannot easily be predicted : for example, in chlorobenzene the chlorine is not very reactive (say, towards alcoholic silver nitrate solution and to aniline), but in 1-chloro-2 : 4-dinitrobenzene the chlorine exhibits high reactivity to aniline (due to the presence of nitro groups in the *ortho* and *para* positions), but not to alcoholic silver nitrate.

1. UNSATURATED HYDROCARBONS. TESTS FOR UNSATURATION

Unsaturated hydrocarbons are found in Solubility Group V. The two reagents employed for the detection of unsaturation, not only of unsaturated hydrocarbons but of all classes of unsaturated compounds (RR′C=CR″R‴), are :

(*a*) *a dilute solution* (2–3 *per cent.*) *of bromine in carbon tetrachloride*, and
(*b*) *a dilute aqueous solution* (2 *per cent.*) *of potassium permanganate*.

It is essential to apply *both* tests, since some symmetrically substituted ethylenic compounds (*e.g.*, stilbene $C_6H_5CH{=}CHC_6H_5$) react slowly under the conditions of the bromine test. With dilute permanganate solution the double bond is readily attacked, probably through the intermediate formation of a *cis* diol :



$$C_6H_5CH{=}CHC_6H_5 \xrightarrow[H_2O]{[O]} \underset{OH\quad OH}{C_6H_5CH{-}CHC_6H_5} \xrightarrow{[O]} 2C_6H_5COOH$$

Attention is directed to the fact that other classes of organic compounds, such as phenols, aromatic amines and enols which are found in other Solubility Groups, rapidly decolourise both the bromine and permanganate reagents, but there is a fundamental difference in the reaction with the former reagent. These compounds are *substituted* by bromine and an equivalent of hydrogen bromide is evolved during the reaction white fumes when a glass stopper moistened with concentrated ammonia solution is held near the mouth of the test-tube.

Bromine test. Dissolve 0·2 g. or 0·2 ml. of the compound in 2 ml. of carbon tetrachloride, and add a 2 per cent. solution of bromine in carbon tetrachloride dropwise until the bromine colour persists for one minute. Blow across the mouth of the tube to detect any hydrogen bromide which may be evolved (compare Sections **III,6** and **III,11**).

Potassium permanganate test. Dissolve 0·2 g. or 0·2 ml. of the substance in 2 ml. of water or in 2 ml. of acetone (which gives a negative test with the reagent), and add 2 per cent. potassium permanganate solution dropwise. The test is negative if no more than 3 drops of the reagent are decolourised.

2. SATURATED HYDROCARBONS

Generally speaking the saturated aliphatic and cyclic hydrocarbons found in Solubility Group VI are inert to most simple chemical reagents.* The aromatic hydrocarbons in this Solubility Group exhibit the usual reactivity associated with the presence of the aromatic nucleus (nitration, substitutive halogenation with chlorine or bromine in the presence of catalysts, sulphonation). The most satisfactory reagent for distinguishing between paraffin and aromatic hydrocarbons is *fuming sulphuric acid* (containing 20 per cent. of free SO_3) ; only the latter react :

$$ArH + HOSO_2OH \longrightarrow ArSO_2OH + H_2O$$
$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Fuming sulphuric acid test. Place 2 ml. of 20 per cent. fuming sulphuric acid in a dry test-tube, add 0·5 ml. of the hydrocarbon and shake vigorously. Only the aromatic hydrocarbon dissolves completely : heat is evolved, but excessive charring should be absent.

Aromatic hydrocarbons also form coloured and highly characteristic picrates by interaction with a solution of picric acid (Section **IV,9,*1***).

---

* They do, however, react readily, even in the dark, with sulphuryl chloride in the presence of a trace of benzoyl peroxide as a catalyst (compare Section **IV,22**).

3. REACTIVITIES OF HALOGEN COMPOUNDS

Halogen-containing compounds may be found in each of the seven Solubility Groups. Those in Group I are of low molecular weight and owe their solubility to the presence of such groups as OH, COOH, etc. Most halogen compounds in Solubility Group II are salts in which the halogen is present as an anion; these, with the exception of quaternary ammonium salts, are converted by dilute alkali into basic compounds of Solubility Group IV. Halogen compounds may also be present in Solubility Groups III and IV, but, like those in Groups I and II, they contain other functional groups which are more easily identified. The nature of the halogen in Solubility Groups V to VII is best determined with the aid of *a 2 per cent. solution of silver nitrate in absolute alcohol*, the alcohol serving as a common solvent for the silver nitrate and the organic compound to be tested. For water-soluble compounds, aqueous silver nitrate solution should also be used after acidification with dilute nitric acid.

Organic compounds containing halogens react with silver nitrate in the following order of *decreasing* reactivity:

(i) Water-soluble compounds containing ionisable halogen or compounds such as acyl halides of low molecular weight which readily yield ionisable compounds with water, will react immediately, even with aqueous silver nitrate.

(ii) Acyl and sulphonyl halides, α-halogeno-ethers and alkyl iodides react instantly.

(iii) Alkyl chlorides and aromatic compounds containing halogen in the side chain do not usually react to any appreciable extent at room temperature, but react fairly rapidly on heating. For monohalogen-substituted compounds, the order of reactivity is

$$\text{tertiary} > \text{secondary} > \text{primary, and I} > \text{Br} > \text{Cl} > \text{F}$$

and, indeed, some tertiary halides may react in the cold.

(iv) Aromatic compounds in which the halogen is attached directly to the aromatic nucleus, polyhalogenated compounds with three or more halogens on the same carbon atom, and the α-halogenated ketones (*e.g.*, ω-chloroacetophenone or phenacyl chloride, $C_6H_5COCH_2Cl$—a powerful lachrymator) do not react even on heating. The presence of nitro groups in the *ortho* and/or *para* positions may cause increased activity of the halogen.

Reaction with alcoholic silver nitrate. To carry out the test, treat 2 ml. of a 2 per cent. solution of silver nitrate in alcohol with 1 or 2 drops (or 0·05 g.) of the compound. If no appreciable precipitate appears at the laboratory temperature, heat on a boiling water bath for several minutes. Some organic acids give insoluble silver salts, hence it is advisable to add 1 drop of *dilute* (*5 per cent.*) nitric acid at the conclusion of the test: most silver salts of organic acids are soluble in nitric acid.

Note.

If concentrated nitric acid is used, a dangerous explosion may result.

Another test, which indicates the reactivity of the halogen atom (chlorine and bromine), is based upon the fact that sodium chloride and sodium bromide are sparingly soluble in pure acetone:

$$RCl(Br) + NaI \longrightarrow RI + NaCl(Br)$$

It consists in treating a solution of sodium iodide in pure acetone with the organic compound. The reaction is probably of the S_N2 type involving a bimolecular attack of the iodide ion upon the carbon atom carrying the chlorine or bromine; the order of reactivities of halides is: primary > secondary > tertiary and Br > Cl.

Primary bromides give a precipitate of sodium bromide within 3 minutes at 25° ; chlorides react only when heated at 50° for up to 6 minutes. Secondary and tertiary bromides must be heated at 50° for up to 6 minutes, but tertiary chlorides do not react within this time.

1 : 2-Dichloro- and dibromo-compounds give a precipitate with the reagent and also liberate free iodine :

$$\begin{array}{l} \mathrm{RCHBr{-}CHBrR' + 2NaI \longrightarrow RCHI{-}CHIR' + 2NaBr} \\ \qquad\qquad\qquad\qquad\qquad\qquad\quad \Updownarrow \\ \qquad\qquad\qquad\qquad\qquad\quad \mathrm{RCH{=}CHR' + I_2} \end{array}$$

Polybromo compounds (bromoform, *s*-tetrabromoethane) react similarly at 50°, but simple polychloro compounds (chloroform, carbon tetrachloride and trichloroacetic acid) do not.

Sulphonyl chlorides give an immediate precipitate and also liberate iodine :

$$\mathrm{ArSO_2Cl + NaI \longrightarrow ArSO_2I + NaCl \xrightarrow{NaI} ArSO_2Na + I_2}$$

Acid chlorides and bromides, allyl halides, α-halo-ketones, esters, amides and nitriles react at 25° within 3 minutes. Vinyl and aryl halides are inert.

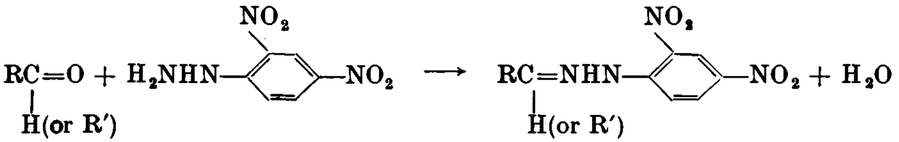
Prepare the **reagent** by dissolving 7·5 g. of sodium iodide in 50 ml. of A.R. acetone. The colourless solution gradually acquires a yellow colour. Keep it in a dark bottle. When a red-brown colour develops, it should be discarded.

Apply the test to compounds which contain chlorine or bromine. If the compound is a solid, dissolve 0·1 g. in the minimum volume of pure, dry acetone. To 1 ml. of the sodium iodide - acetone reagent add 2 drops of the compound (if a liquid) or the acetone solution (if a solid). Shake and allow to stand at room temperature for 3 minutes. Note whether a precipitate is formed and also whether the solution acquires a reddish-brown colour (liberation of iodine). If no change takes place at room temperature, place the test-tube in a beaker of water at 50°. After 5 minutes, cool to room temperature, and observe whether a reaction has occurred.

4. ALDEHYDES AND KETONES

It is convenient to consider the indifferent or neutral oxygen derivatives of the hydrocarbons—(*a*) *aldehydes and ketones*, (*b*) *esters and anhydrides*, (*c*) *alcohols and ethers*—together. All of these, with the exception of the water-soluble members of low molecular weight, are soluble only in concentrated sulphuric acid, *i.e.*, fall into Solubility Group V. The above classes of compounds must be tested for in the order in which they are listed, otherwise erroneous conclusions may be drawn from the reactions for functional groups about to be described.

Both aldehydes and ketones contain the carbonyl group, hence a general test for carbonyl compounds will immediately characterise both classes of compounds. The preferred reagent is *2 : 4-dinitrophenylhydrazine*, which gives sparingly soluble phenylhydrazones with carbonyl compounds :



Reaction with 2 : 4-dinitrophenylhydrazine. Add 2 drops (or 0·05–0·1 g.) of the substance to be tested to 3 ml. of the 2 : 4-dinitrophenylhydrazine reagent, and shake. If no precipitate forms immediately allow to stand for 5–10 minutes. A crystalline precipitate indicates the presence of a carbonyl compound. Occasionally the precipitate is oily at first, but this becomes crystalline upon standing.

2 : 4 Dinitrophenylhydrazine reagent may be prepared by either of the following methods.

Method 1. Suspend 2·0 of 2 : 4-dinitrophenylhydrazine in 100 ml. of methanol; add *cautiously* and slowly 4·0 ml. of concentrated sulphuric acid. The mixture becomes warm and the solid usually dissolves completely. Filter, if necessary.

Method 2. Dissolve 0·25 g. of 2 : 4-dinitrophenylhydrazine in a mixture of 42 ml. of concentrated hydrochloric acid and 50 ml. of water by warming on a water bath: dilute the cold solution to 250 ml. with distilled water. This reagent is more suitable for water-soluble aldehydes and ketones since alcohol is absent.

The above reagent is very dilute and is intended for qualitative reactions. It is hardly suitable for the preparation of crystalline derivatives except in very small quantities (compare Section **III,74,***1*).

The acetals $RCH(OR')_2$ are so readily hydrolysed by acids that they may give a positive result in the above test:

$$RCH(OR')_2 + H_2O \xrightarrow{H+} RCHO + 2R'OH$$

(For a more detailed discussion on *Acetals*, see Section **III,69**.)

If an unknown compound gives a positive test with the 2 : 4-dinitrophenylhydrazine reagent, it then becomes necessary to decide whether it is an aldehyde or a ketone. Although the dimedone reagent (Section **III,70,2**) reacts only with aldehydes,* it is hardly satisfactory for routine use in class reactions. It is much simpler to make use of three other reagents given below, the preparation and properties of which have already been described (Section **III,70**).

Differentiation between aldehydes and ketones.

(i) **Schiff's reagent.** Aldehydes produce a pink colour, while ketones are without effect. Use 2 drops (or 0·05 g.) of the compound and 2 ml. of Schiff's reagent and shake the mixture in the cold. A number of aromatic aldehydes (*e.g.*, vanillin) give a negative result.

(ii) **Fehling's solution.** Aldehydes alone reduce Fehling's solution to yellow or red cuprous oxide. Use 2 drops (or 0·05 g.) of the compound and 2–3 ml. of Fehling's solution: heat on a boiling water bath for 3–4 minutes. This test is positive for aliphatic aldehydes, but is usually indecisive for aromatic aldehydes.

(iii) **Ammoniacal silver nitrate solution (Tollen's solution).** Aldehydes alone reduce Tollen's reagent and produce a silver mirror on the inside of the test-tube. Add 2–3 drops (or 0·05 g.) of the compound to 2–3 ml. of Tollen's solution contained in a *clean* test-tube (the latter is preferably cleaned with hot nitric acid). If no reaction appears to take place in the cold, warm to about 35° in a beaker of warm water.

CAUTION: After the test, pour the contents of the test-tube into the sink and wash the test-tube with dilute nitric acid. Any silver fulminate present, which is highly explosive when dry, will thus be destroyed.

If the tests for an aldehyde are negative, the unknown compound is a ketone. When once the compound has been established as an aldehyde or ketone, it is permissible to refer to tables of physical constants: information thus obtained may be of value in indicating other possible groups to be tested for, with due regard to possible complications caused by the presence of these groups.

---

* The dimedone reagent may, however, be used if it is desired to detect an aldehyde in the presence of a ketone.

5. ESTERS AND ANHYDRIDES

When the compound for identification fails to respond to test *4* (aldehyde or ketone), the next class reactions to apply are the *hydroxamic acid test* and *saponification*, *i.e.*, hydrolysis in alkaline solution. These are the class reactions for **esters and anhydrides** ; the rarely-encountered **lactones** react similarly.

Esters react with hydroxylamine to form an alcohol and a hydroxamic acid, RCONHOH. All hydroxamic acids, in acid solutions, react with ferric chloride to form coloured (usually violet) complex salts :

$$RCOOR' + H_2NOH \longrightarrow RCONHOH + R'OH$$
$$3RCONHOH + FeCl_3 \longrightarrow (RCONHO)_3Fe + 3HCl$$

Lactones, which may be regarded as cyclic or inner esters, react similarly. Anhydrides of carboxylic acids also react with hydroxylamine to form hydroxamic acids :

$$RCOOCOR + NH_2OH \longrightarrow RCONHOH + RCOOH$$

It may be noted that primary aliphatic amides are readily converted by hydroxylamine hydrochloride into hydroxamic acids, which may be detected by the addition of ferric chloride solution :

$$RCONH_2 + HNHOH,HCl \longrightarrow RCONHOH + NH_4Cl$$

An ester is converted upon saponification into an alcohol and the salt of an acid, or the salts of both an acid and a phenol if it is an ester of a phenol. An anhydride upon hydrolysis yields *only* a salt of an acid.

$$\underset{\text{Ester}}{RCOOR'} + NaOH \longrightarrow R'OH + RCOONa$$

$$\underset{\text{Ester of a Phenol}}{RCOOAr} + 2NaOH \longrightarrow ArONa + RCOONa + H_2O$$

$$\underset{\text{Anhydride}}{(RCO)_2O} + 2NaOH \longrightarrow 2RCOONa + H_2O$$

Anhydrides may often be hydrolysed in the cold with dilute alkali ; they also react with primary amines (compare Section **III,94**). All anhydrides boil above 130° ; thus acetic anhydride has b.p. 140°.

Some esters (oxalates, methyl and ethyl formates and acetates, etc.) are readily hydrolysed. In general, however, esters require heating with strong aqueous alkali. If the ester is sparingly soluble or insoluble in water, hydrolysis will usually be slow : saponification may then be carried out with ethyl alcoholic sodium or potassium hydroxide (compare Section **III,106**), but difficulty will be experienced in obtaining a pure derivative of the resulting alcohol. This difficulty may be avoided by employing the inexpensive diethylene glycol (ββ'-dihydroxyethyl ether), b.p. 244°, as the solvent : potassium hydroxide dissolves readily in this solvent, hydrolysis occurs rapidly at the elevated temperature, and all but high boiling point alcohols can be distilled from the reaction mixture in a fairly pure state (*e.g.*, benzyl alcohol, b.p. 205°, can be easily isolated). If the ester yields a glycol or polyhydric alcohol on saponification, the identification of the alcohol part is not possible although identification of the acid can still be made.

Aromatic aldehydes, and also aliphatic aldehydes containing no α-hydrogen atom, undergo the Cannizzaro reaction (see Section **IV,123**) when treated with aqueous alkali, for example :

$$\underset{\text{Benzaldehyde}}{2C_6H_5CHO} + H_2O \xrightarrow[\text{aq.}]{\text{NaOH}} \underset{\text{Benzyl alcohol}}{C_6H_5CH_2OH} + \underset{\text{Sodium benzoate}}{C_6H_5COONa}$$

The production of both an alcohol and the sodium salt of an acid might easily be confused with the hydrolysis products of an ester (in the above instance benzyl benzoate). Such an error would soon be discovered (*e.g.*, by reference to the b.p. and other physical properties), but it would lead to an unnecessary expenditure of time and energy. The above example, however, emphasises the importance of conducting the class reactions of neutral oxygen-containing compounds in the proper order, *viz.*, (1) aldehydes and ketones, (2) esters and anhydrides, (3) alcohols, and (4) ethers.

Hydroxamic acid test for esters and anhydrides. *A*. Carry out the following preliminary test. Dissolve a drop or a few small crystals of the compound in 1 ml. of rectified spirit (95 per cent. ethanol) and add 1 ml. of *N* hydrochloric acid. Note the colour produced when 1 drop of 5 per cent. ferric chloride solution is added to the solution. If a pronounced violet, blue, red or orange colour is produced, the hydroxamic acid test described below is not applicable and should not be used.

B. Mix 1 drop or several small crystals (*ca.* 0·05 g.) of the compound with 1 ml. of 0·5 *N* hydroxylamine hydrochloride in 95 per cent. ethanol and add 0·2 ml of 6*N* aqueous sodium hydroxide. Heat the mixture to boiling and, after the solution has cooled slightly, add 2 ml. of *N* hydrochloric acid. If the solution is cloudy, add 2 ml. of 95 per cent. ethyl alcohol. Observe the colour produced when 1 drop of 5 per cent. ferric chloride solution is added. If the resulting colour does not persist, continue to add the reagent dropwise until the observed colour pervades the entire solution. Usually only 1 drop of the ferric chloride solution is necessary. Compare the colour with that produced in test *A*. A positive test will be a distinct burgundy or magenta colour as compared with the yellow colour observed when the original compound is tested with ferric chloride solution in the presence of acid.

Saponification of esters. *Aqueous sodium hydroxide method.* To hydrolyse an **ester of an alcohol**, reflux 5–6 g. with 50 ml. of 20 per cent. sodium hydroxide solution for 1–2 hours * or until the ester layer disappears.† Distil the alkaline mixture and collect about 6 ml. of distillate. This will contain any volatile alcohol formed in the saponification. If the alcohol does not separate, *i.e.*, is water-soluble, saturate the distillate with solid potassium carbonate : an upper layer of alcohol is then usually formed. (The alcohol may be subsequently identified as the 3 : 5-dinitrobenzoate : see Section **III,27,***1*.) Cool the residual alkaline mixture, and acidify it with dilute sulphuric acid. If no crystalline acid is precipitated, the acid may frequently be isolated by ether extraction, or it may be distilled from the acidified solution and isolated from (or investigated in) the distillate. (The acid may be subsequently identified, *e.g.*, as the S-benzyl-*iso*-thiuronium salt : see Section **III,85,***4*.)

---

* The addition of about 0·2 g. of an emulsifying agent, such as sodium lauryl or oleyl sulphate, assists in reducing the time required for complete saponification : a large flask should be used since there is usually considerable foaming.

† A water-insoluble alcohol is sometimes formed and care should be taken that this is not confused with the original ester. It usually differs in physical properties (odour, b.p., etc.) from the original ester (see Section **III,106**).

When dealing with esters of water-soluble, non steam-volatile, polyhydric alcohols (*e.g.*, ethylene glycol or glycerol), the distillate consists of water only (density 1·00). The water-soluble, non-volatile alcohol may be isolated by evaporation of the alkaline solution to a thick syrup on a water bath and extraction of the polyhydric alcohol from the salt with cold ethyl alcohol.

To hydrolyse **an ester of a phenol** * (*e.g.*, phenyl acetate), proceed as above but cool the alkaline reaction mixture and treat it with carbon dioxide until saturated (solid carbon dioxide may also be used). Whether a solid phenol separates or not, remove it by extraction with ether. Acidify the aqueous bicarbonate solution with dilute sulphuric acid and isolate the acid as detailed for the ester of an alcohol. An alternative method, which is not so time-consuming, may be employed. Cool the alkaline reaction mixture in ice water, and add dilute sulphuric acid with stirring until the solution is acidic to Congo red paper and the acid, if aromatic or otherwise insoluble in the medium, commences to separate as a faint but permanent precipitate. Now add 5 per cent. sodium carbonate solution with vigorous stirring until the solution is alkaline to litmus paper and the precipitate redissolves completely. Remove the phenol by extraction with ether. Acidify the residual aqueous solution and investigate the organic acid as above.

Diethylene glycol method. Place 0·5 g. of potassium hydroxide pellets, 3 ml. of diethylene glycol and 0·5 ml. of water in a 10 or 25 ml. distilling flask ; heat the mixture gently until the alkali has dissolved and cool. Add 1–2 g. of the ester and mix well. Fit the flask with a thermometer and a small water-cooled condenser in the usual way. Heat the flask over a small flame whilst shaking gently to mix the contents. When only one liquid phase, or one liquid phase and one solid phase, remains in the flask, heat the mixture more strongly so that the alcohol distils. Identify the alcohol in the distillate by the preparation of the 3 : 5-dinitrobenzoate (Section **III,27,***1*).

The residue in the flask is either a solution or a suspension of the potassium salt of the acid derived from the ester in diethylene glycol. Add 10 ml. of water and 10 ml. of ethyl alcohol to the residue and shake until thoroughly mixed. Then add a drop or two of phenolphthalein and dilute sulphuric acid, dropwise, until just acid. Allow the mixture to stand for about 5 minutes and then filter the potassium sulphate. Use the clear filtrate for the preparation of a solid derivative or two of the acid (see Section **III,85,***4*).

The determination of the saponification equivalent of an ester by the alcoholic potassium hydroxide method is described in Section **III,106** : an alternative procedure using diethylene glycol is given below. This constant should be determined if possible in the preliminary examination, since a knowledge of its value together with the boiling point provides a basis for a fairly good approximation of the size of the ester molecule.

---

* Preliminary indication of the presence of a phenol ester may be obtained by heating the compound with soda-lime : esters of phenols and also aromatic hydroxy-acids usually give the phenol. (Likewise amides, imides, nitriles, substituted hydrazines, urethanes, etc. afford ammonia.)

DETERMINATION OF THE SAPONIFICATION EQUIVALENT OF AN ESTER BY THE DIETHYLENE GLYCOL METHOD

The alcoholic potassium hydroxide method (Section **III,106**) has the following undesirable features :—(i) the reaction is often slow, necessitating long refluxing ; (ii) possible transposition of the unknown ester (by ethoxide ions) to the corresponding ethyl ester and consequent possible loss because of increased volatility ; and (iii) poor keeping quality of the standard solution. These disadvantages are largely overcome by using a solution of potassium hydroxide in diethylene glycol : the procedure is particularly valuable for esters which are insoluble in water.

The reagent is prepared by weighing about 6·0 g. of A.R. potassium hydroxide pellets into a 50 or 100 ml. flask, adding 25 ml. of technical diethylene glycol and heating to effect solution ; it is essential to use a thermometer for stirring and to keep the temperature below 130°, otherwise a dark yellow colour will develop. As soon as the solid has dissolved, the warm solution is poured into 75 ml. of diethylene glycol in a glass-stoppered bottle. The solution is thoroughly mixed and allowed to cool. It is *ca.* 1·0*N* and is standardised by pipetting 10 ml. into a flask, adding 15 ml. of water, and titrating with standardised 0·25*N* or 0·5*N* hydrochloric acid using phenolphthalein as indicator. (Because of the high viscosity of the solution, it is advisable to open the tip of the pipette to an internal diameter of 2–3 mm. in order to facilitate drainage ; the pipette should be recalibrated before use.)

To determine the saponification equivalent of an ester transfer 10 ml. of the reagent by means of a pipette into a 50 ml. glass-stoppered Pyrex conical flask. Place the sample of the ester in a weight burette or in a weighing bottle fitted with a cork carrying a small dropper pipette (compare Fig. *II*, *27*, 1) ; transfer about 0·5 g. of the ester, accurately weighed, into the Erlenmeyer flask and insert the ground stopper. Mix the ester with the reagent by a rotary motion of the flask. Hold the stopper firmly in place and heat the mixture in an oil bath so that a temperature of 70–80° is reached within 2–3 minutes : agitate the liquid by a whirling motion during the heating. At this point remove the flask from the heating bath, shake the flask vigorously, allow to drain and loosen the stopper *carefully* to allow air to escape. Replace the stopper and heat again in an oil bath to 120–130°. (For esters of very high boiling point, the stopper may be removed and a thermometer inserted.) After 3 minutes at this temperature, cool the flask and its contents to 80–90°, remove the stopper and wash it with distilled water so that the rinsings drain into the flask. Add about 15 ml. of distilled water and a drop or two of phenolphthalein indicator, mix well and then titrate with standard 0·25*N* or 0·5*N* hydrochloric acid. Calculate the saponification equivalent from the expression :

$$\text{Saponification Equivalent} = \frac{\text{Weight of ester} \times 1000}{\text{Ml. of } N \text{ KOH used}}.$$

6. ALCOHOLS AND ETHERS

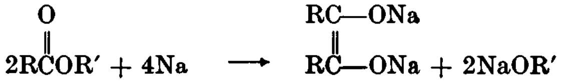
If the unknown neutral, oxygen-containing compound does not give the class reactions for aldehydes, ketones, esters and anhydrides, it is probably either an alcohol or an ether. Alcohols and ethers may be most simply distinguished by the use of two reagents—*metallic sodium and acetyl chloride.*

Metallic sodium reacts with alcohols with the evolution of hydrogen :

$$2ROH + 2Na \longrightarrow 2RONa + H_2$$

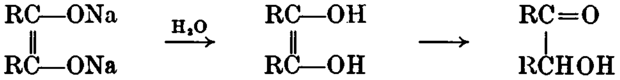
The most common interfering substance, especially with alcohols of low molecular weight, is water ; this may result in an inaccurate interpretation of the test *if applied alone.* Most of the water may usually be removed by shaking with a little anhydrous calcium sulphate. Although dry ethers (and also the saturated aliphatic and the simple aromatic hydrocarbons) do not react with sodium, many other classes of organic compounds do. Thus :

(*a*) Aliphatic esters are converted into salts of acyloins :



$$2\mathrm{R}\overset{\overset{\displaystyle O}{\|}}{\mathrm{C}}\mathrm{OR'} + 4\mathrm{Na} \longrightarrow \begin{array}{l}\mathrm{RC{-}ONa}\\ \ \ \|\\ \mathrm{RC{-}ONa}\end{array} + 2\mathrm{NaOR'}$$

Upon treatment with dilute sulphuric acid, the *acyloin* is produced :



$$\begin{array}{l}\mathrm{RC{-}ONa}\\ \ \ \|\\ \mathrm{RC{-}ONa}\end{array} \xrightarrow{H_2O} \begin{array}{l}\mathrm{RC{-}OH}\\ \ \ \|\\ \mathrm{RC{-}OH}\end{array} \longrightarrow \begin{array}{l}\mathrm{RC{=}O}\\ \ \ |\\ \mathrm{RCHOH}\end{array}$$

The term acyloin is commonly used as a class name for the symmetrical keto-alcohols RCOCH(OH)R, and the name of the individual compound is derived by adding the suffix *oin* to the stem name of the acid to which the acyloin corresponds, *e.g.*, acetoin, propionoin, butyroin, etc.

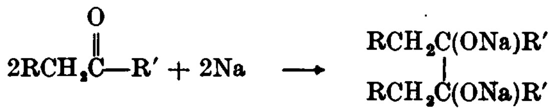
(A Note on acyloins is given at the end of this Section, *i.e.*, immediately before Section **XI,8.**)

(*b*) Simple esters (*e.g.*, ethyl acetate) undergo the acetoacetic ester condensation (compare Section **III,151**). The effective condensing agent is sodium ethoxide, produced by the action of sodium upon traces of alcohol present in the ester :

$$2CH_3COOC_2H_5 + NaOC_2H_5 \rightleftharpoons Na[CH_3COCHCOOC_2H_5] + 2C_2H_5OH$$

(*c*) Ketones containing an α-hydrogen atom may react through their enolic forms or they may be partially reduced to a sodium pinacolate (compare Section **III,77**) :

$$2\mathrm{RCH_2{-}}\overset{\overset{\displaystyle O}{\|}}{\mathrm{C}}\mathrm{R'} + 2\mathrm{Na} \longrightarrow 2\mathrm{RCH{=}}\overset{\overset{\displaystyle ONa}{|}}{\mathrm{C}}\mathrm{R'} + \mathrm{H_2}$$



$$2\mathrm{RCH_2}\overset{\overset{\displaystyle O}{\|}}{\mathrm{C}}\mathrm{{-}R'} + 2\mathrm{Na} \longrightarrow \begin{array}{l}\mathrm{RCH_2C(ONa)R'}\\ \qquad |\\ \mathrm{RCH_2C(ONa)R'}\end{array}$$

This is another reason why aldehydes, ketones and esters must be tested for in the order already given, and why it is necessary to employ *both* the sodium and acetyl chloride tests.

Acetyl chloride reacts vigorously with primary and secondary alcohols to yield esters ; it also reacts readily with any water present to form acetic acid :

$$CH_3COCl + ROH \longrightarrow CH_3COOR + HCl$$

$$CH_3COCl + HOH \longrightarrow CH_3COOH + HCl$$

The resulting esters differ sufficiently in odour and water solubility to be readily distinguished from the original alcohol. With tertiary alcohols the product is largely the alkyl chloride :

$$
\begin{array}{llrcl}
 & \text{(i)} & CH_3COCl + HOCR_3 & \longrightarrow & CH_3COOCR_3 + HCl \\
 & \text{(ii)} & R_3COH + HCl & \longrightarrow & R_3CCl + HOH \\
 & \text{(iii)} & CH_3COCl + HOH & \longrightarrow & CH_3COOH + HCl \\
\text{or} & \text{(iv)} & R_3COH + CH_3COCl & \longrightarrow & R_3CCl + CH_3COOH
\end{array}
$$

The reason for this is that reaction (i) is usually much slower than (ii) and (iii) so that the main reaction appears to be (iv) (compare the preparation of tertiary butyl chloride from tertiary butyl alcohol and concentrated hydrochloric acid, Section **III,33**). If the reaction is carried out in the presence of pyridine, the latter combines with the hydrogen chloride as it is formed, thus preventing reactions (ii) and (iii), and a good yield of the ester is generally obtained. The differentiation between primary, secondary and tertiary alcohols with the aid of the Lucas reagent is described in Section **III,27,**(vii).

Benzoyl chloride may replace acetyl chloride as a class reagent : it possesses the advantage that it is only very slowly decomposed by cold water and consequently may be employed for detecting alcohols even in aqueous solution. The reaction is usually carried out in aqueous solution containing sufficient caustic alkali to decompose any excess of benzoyl chloride into the water-soluble alkali benzoate (Schotten - Baumann reaction ; compare Section **IV,52**). The benzoyl esters formed are insoluble in water :

$$C_6H_5COCl + ROH \longrightarrow C_6H_5COOR + HCl$$

Alcohols (but not ethers) also react with phenyl *iso*cyanate or with the corresponding crystalline α-naphthyl *iso*cyanate to give carbamates or urethanes (see Section **III,27,*4***), but these substances are hardly suitable as class reagents.

Ethers are unaffected by sodium and by acetyl (or benzoyl) chloride. Both the purely aliphatic ethers {*e.g.*, di-*n*-butyl ether $(C_4H_9{}^{\alpha})_2O$} and the mixed aliphatic - aromatic ethers (*e.g.*, anisole $C_6H_5OCH_3$) are encountered in Solubility Group V : the purely aromatic ethers {*e.g.*, diphenyl ether $(C_6H_5)_2O$} are generally insoluble in concentrated sulphuric acid and are found in Solubility Group VI. The purely aliphatic ethers are very inert and their final identification may, of necessity, depend upon their physical properties (b.p., density and/or refractive index). Ethers do, however, suffer fission when heated with excess of 57 per cent. hydriodic acid, but the reaction is generally only of value for the characterisation of symmetrical ethers $(R \equiv R')$:

$$R{-}O{-}R' + 2HI \longrightarrow RI + R'I + H_2O$$

The mixed aliphatic - aromatic ethers are somewhat more reactive : in addition to cleavage by strong hydriodic acid and also by constant b.p. hydrobromic acid in acetic acid solution into phenols and alkyl halides, they may be brominated, nitrated and converted into sulphonamides (Section **IV,106,*2***).

Sodium test. Treat 1 ml. of the compound with a *small* thin slice of freshly cut sodium (handle with the tongs or with a penknife) in a small, dry test-tube (75 × 10 mm. or 100 × 12 mm.). Observe whether hydrogen is evolved and the sodium reacts. (If the compound is suspected to contain water, dry it first with a little anhydrous calcium or magnesium sulphate.)

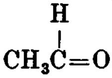
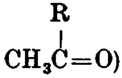
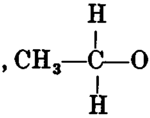
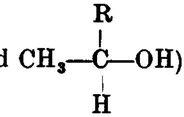
Acetyl chloride test. In a small, dry test-tube treat 0·5 ml. of the compound with 0·3–0·4 ml. of redistilled acetyl chloride and note whether reaction occurs. Add 3 ml. of water and neutralise the aqueous layer with solid sodium bicarbonate. Look for a product different from the original alcohol.

Benzoyl chloride test. (This is an alternative to the acetyl chloride test.) Place 1 ml. of the compound, 0·5 ml. of redistilled benzoyl chloride (*CAUTION* in handling) and 2·5 ml. of 10 per cent. aqueous sodium hydroxide in a small test-tube, cork the tube and shake vigorously until the odour of benzoyl chloride has disappeared. Observe the odour, density and other obvious properties of the product.

Fission of ethers with hydriodic acid. Reflux 1 ml. of the compound with 5 ml. of freshly distilled constant b.p. hydriodic acid (b.p. 126–128°) for 2–3 hours in a small flask fitted with a double surface condenser. Add 10 ml. of water, distil and collect about 7 ml. of liquid. Decolourise the distillate by the addition of a little sodium bisulphite and separate the two layers by means of a dropper pipette. If the original compound is suspected to be an aliphatic ether, determine the b.p. of the iodide by the Siwoloboff method (Section **II,12**): if the amount of product is insufficient, repeat the original experiment.

Acetals $RCH(OR')_2$ are stable in alkaline solution, but are readily hydrolysed by dilute acids to give aldehydes, which may be characterised as detailed under *4* (see Section **III,69**).

7. THE IODOFORM TEST

Neutral oxygen-containing compounds in Solubility Groups I, II and V which either contain the CH_3CO— group attached to H, alkyl, aryl, or ester $(CH_2)_nCOOR'$ (*e.g.*,  $CH_3\overset{\overset{H}{|}}{C}=O$ and  $CH_3\overset{\overset{R}{|}}{C}=O$), or are oxidised to this structure under the conditions of the experiment (*e.g.*,  $CH_3{-}\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}{-}OH$ and  $CH_3{-}\underset{\underset{H}{|}}{\overset{\overset{R}{|}}{C}}{-}OH$), give iodoform with sodium hypoiodite solution (compare Section **III,45**). The reactions which occur may be illustrated by reference to a secondary alcohol (a methyl carbinol):

$$RCH(OH)CH_3 + NaOI \longrightarrow RCOCH_3 + NaI + H_2O$$
$$RCOCH_3 + 3NaOI \longrightarrow RCOCI_3 + 3NaOH$$
$$RCOCI_3 + NaOH \longrightarrow RCOONa + CHI_3$$

If the compound to be tested is insoluble in water, it should be brought into solution by the addition of a little dioxan. Alcohols and some methyl ketones frequently react slowly: in such cases it is advisable to employ a large excess (4–5 fold) of the relatively unstable reagent ($3NaOI \rightarrow NaIO_3 + 2NaI$). Quinones and hydroquinones also give the iodoform reaction.

The iodoform test. Dissolve 0·1 g. or 5 drops of the compound in 2 ml. of water; if it is insoluble in water, add sufficient dioxan to produce a homogeneous solution. Add 2 ml. of 5 per cent. sodium hydroxide solution and then introduce a potassium iodide - iodine reagent dropwise with shaking until a definite dark colour of iodine persists. Allow to stand for 2–3 minutes : if no iodoform separates at room temperature, warm the test-tube in a beaker of water at 60°. Add a few more drops of the iodine reagent if the faint iodine colour disappears : continue the addition of the reagent until the dark colour is not discharged after 2 minutes heating at 60°. Remove the excess of iodine by the addition of a few drops of dilute sodium hydroxide solution with shaking, dilute with an equal volume of water and allow to stand for 10 minutes. The test is positive if a yellow precipitate of iodoform is deposited. Filter off the yellow precipitate, dry upon pads of filter paper and determine the m.p. : iodoform melts at 120°.

The potassium iodide - iodine reagent is prepared by dissolving 20 g. of potassium iodide and 10 g. of iodine in 100 ml. of water.

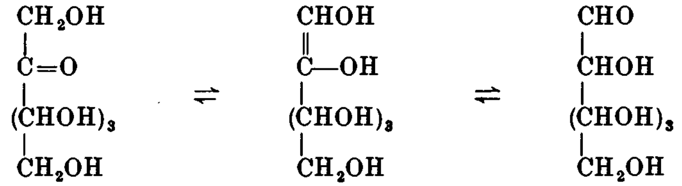
8. POLYHYDRIC ALCOHOLS AND THE POLYHYDROXY ALDEHYDES AND KETONES (SUGARS)

The polyhydric alcohols of Solubility Group II are liquids of relatively high boiling point and may be detected *inter alia* by the reactions already described for *Alcohols* (see *6*). Compounds containing two hydroxyl groups attached to adjacent carbon atoms (1 : 2-glycols), α-hydroxy aldehydes and ketones, and 1 : 2-diketones may be identified by the periodic acid test, given in reaction *9*.

The simple sugars or monosaccharides are polyhydroxy aldehydes or ketones, and belong to Solubility Group II. They are termed tetroses, pentoses, hexoses. etc. according to the number of carbon atoms in the long chain constituting the molecule, and aldoses or ketoses if they are aldehydes or ketones. Most of the monosaccharides that occur in nature are pentoses and hexoses.

All carbohydrates (mono-, di- and poly-saccharides) give the Molisch colour test {for details, see Section **III,139,(i)** }.

Both aldoses and ketoses reduce Fehling's solution (for details, see under *4*). This fact may appear surprising when it is remembered that Fehling's solution is one of the reagents for distinguishing between aldehydes and ketones (see *4*). The explanation lies in the fact that α-hydroxyketones are much more readily oxidised than simple ketones, perhaps because the hydroxy ketone allows its isomerisation, in the presence of alkali, into an aldehyde. For example, fructose, a keto-hexose, might isomerise thus :



$$\begin{array}{c} \mathrm{CH_2OH} \\ | \\ \mathrm{C{=}O} \\ | \\ \mathrm{(CHOH)_3} \\ | \\ \mathrm{CH_2OH} \end{array} \rightleftharpoons \begin{array}{c} \mathrm{CHOH} \\ \| \\ \mathrm{C{-}OH} \\ | \\ \mathrm{(CHOH)_3} \\ | \\ \mathrm{CH_2OH} \end{array} \rightleftharpoons \begin{array}{c} \mathrm{CHO} \\ | \\ \mathrm{CHOH} \\ | \\ \mathrm{(CHOH)_3} \\ | \\ \mathrm{CH_2OH} \end{array}$$

Keto-hexose Ene-diol Aldo-hexose

Positive results are given with aldoses and ketoses and with disaccharides containing potential aldehyde groups (*e.g.*, maltose). Disaccharides which do not contain potential aldehyde groups (*e.g.*, sucrose) and also polysaccharides (*e.g.*, starch and cellulose) do not reduce Fehling's solution. Non-reducing disaccharides and polysaccharides upon warming for a short time with 5 per cent. hydrochloric acid or sulphuric acid are hydrolysed to monosaccharides : upon neutralisation (to phenolphthalein) of the excess of acid with sodium hydroxide solution, a positive test is obtained with Fehling's solution.

Another reaction that is characteristic of α-hydroxy aldehydes or ketones, which has been found of value for the characterisation of sugars, is the formation of osazones with phenylhydrazine. This reagent reacts with either an aldose or a ketose to yield a phenylhydrazone, which is then oxidised and converted into a bis-phenylhydrazone or osazone by more of the phenylhydrazine (see theoretical discussion before Section **III,137**). Certain osazones also possess characteristic appearances under the microscope (see Fig. *III*, *153*, 1).

Galactose and also carbohydrates which yield galactose upon hydrolysis (*e.g.*, lactose) are oxidised to the sparingly soluble mucic acid (compare Section **III,139**).

Oxidation of galactose (or a galactose-containing sugar) to mucic acid. Dissolve 1 g. of galactose or lactose in a mixture of 10 ml. of water and 5 ml. of concentrated nitric acid contained in a small evaporating dish, and evaporate the solution to dryness on a water bath. Stir the cold residue with 10 ml. of cold water, filter off the mucic acid, wash it with cold water, dry and determine the m.p. (212–213° with decomposition).

9. THE PERIODIC ACID TEST

Periodic acid has a selective oxidising action upon compounds having two hydroxyl groups or a hydroxyl and an amino group attached to adjacent carbon atoms and is characterised by the cleavage of the carbon - carbon bond (**Malaprade reaction**) :

$$\mathrm{RCH(OH)CH(OH)R' + HIO_4 \longrightarrow RCHO + R'CHO + HIO_3 + H_2O}$$
$$\mathrm{RCH(OH)CH(NH_2)R' + HIO_4 \longrightarrow RCHO + R'CHO + HIO_3 + NH_3}$$

No oxidation occurs unless the hydroxyl groups or a hydroxyl and an amino group are attached to adjacent carbon atoms, hence the test may be employed for testing for the presence of contiguous hydroxyl groups (*e.g.*, 1,2-diols) and hydroxyl and amino groups. Carbonyl compounds in which the carbonyl group is contiguous to a hydroxyl group or a second carbonyl group are also oxidised, *e.g.*, α-hydroxy aldehydes or ketones, 1 : 2-diketones and α-hydroxy acids :

$$\mathrm{RCH(OH)COR' + HIO_4 \longrightarrow RCHO + R'COOH + HIO_3}$$
$$\mathrm{RCOCOR' + HIO_4 + H_2O \longrightarrow RCOOH + R'COOH + HIO_3}$$

The oxidation may proceed through the hydrated form of the carbonyl group $>\mathrm{CH(OH)_2}$. The rate of oxidation is 1,2-glycols > α-hydroxy aldehydes > α-hydroxy ketones > α-hydroxy acids. Under the conditions enumerated below, α-hydroxy acids usually give a negative test.

In qualitative organic analysis, use is made of the fact that silver iodate is sparingly soluble in *dilute* nitric acid whereas silver periodate is very soluble. For water-insoluble compounds solutions in ethanol or in *pure* dioxan may be employed.

The **periodic acid reagent** is prepared by dissolving 1·0 g. of paraperiodic acid H_5IO_6 in 200 ml. of distilled water.

Place 2 ml. of the periodic acid reagent in a small test-tube, add one drop (no more—otherwise the silver iodate, if formed, will fail to precipitate) of concentrated nitric acid, and shake well. Add one drop or a small crystal of the compound to be tested, shake the mixture for 15–20 seconds, and then add 1–2 drops of 3 per cent. silver nitrate solution. The instantaneous formation of a *white* precipitate of silver iodate is a positive test. Failure to form a precipitate, or the appearance of a brown precipitate which redissolves on shaking, constitutes a negative test.

10. CARBOXYLIC ACIDS AND PHENOLS

Most of the acidic compounds containing only the elements C, H and O are either carboxylic acids or phenols. They are found mainly in Solubility Group III, although the water-soluble members are in Solubility Groups I and II.

Carboxylic acids are :

(*a*) Soluble in 5 per cent. sodium hydroxide solution *and* in 5 per cent. sodium bicarbonate solution (the latter reaction is accompanied by the evolution of carbon dioxide).

(*b*) Non-reactive towards bromine water or a solution of bromine in carbon tetrachloride (unless an ethylenic or acetylenic or other unsaturated group is *also* present).

(*c*) Titratable with standard sodium hydroxide solution in aqueous or in alcoholic solution in the presence of phenolphthalein as indicator, thus enabling the equivalent weight to be determined.

Phenols (and enols), broadly speaking, give the following reactions :

(*a*) They are soluble in 5 per cent. sodium hydroxide solution and *insoluble* in 5 per cent. sodium bicarbonate solution ; they are precipitated from their solutions in aqueous sodium hydroxide by carbon dioxide. [Exceptions : the presence of certain negative groups in phenols increases the acidity to such an extent that they may dissolve in sodium bicarbonate solution, for example, 2 : 4-dinitrophenol, picric acid and *s*-tribromophenol.]

(*b*) They react with a solution of bromine in carbon tetrachloride by *substitution* and an equivalent quantity of hydrogen bromide is evolved (compare *addition* with unsaturated compounds). When the test is conducted with bromine water and a dilute aqueous solution of a phenol, the sign of reaction is the separation of a sparingly soluble bromine substitution product.

(*c*) They yield intense colorations (blue, green, red or purple) when treated with a solution of ferric chloride. Some phenols (and enols) do not give this test in aqueous solution, but react readily in alcoholic solution. [The coloration is said to be due to a complex ion $[Fe(OAr)_6]^{---}$. Some phenolic acids, such as *m*- and *p*-hydroxybenzoic acids, do not give this test, but others, such as salicylic acid (which is the enolic form of a cyclo β-keto acid), do.]

It must be borne in mind that there are many nitrogen-containing phenols and acids ; of these the nitro and amino derivatives are the most common. The aromatic nitrocarboxylic acids may usually be identified through the reactions and derivatives of the carboxyl group without recourse to the reactions of the nitro group : examination for the latter will, however, provide additional confirmation. The influence of the nitro and other groups in the *o*- and *p*-positions upon the acidity of a phenol has already been noted : such groups tend to produce a marked deepening in the colour of alkaline solutions of the phenol. Amino substituents in water-insoluble phenols and acids cause these compounds to be soluble in both dilute acid and dilute alkali, *i.e.*, to be amphoteric. Frequently it is helpful to destroy the basic character of the nitrogen by conversion of the amino group into a neutral amide group by acetylation or benzoylation in aqueous alkaline solution : the resulting compound is not amphoteric and its equivalent may be determined.

An indication whether a water-insoluble compound is an acid or a phenol (or enol) will be obtained from the Solubility Tests : water-soluble acids will liberate carbon dioxide from 5 per cent. sodium bicarbonate solution {see Section **III,85**,(i)}.

Equivalent weight of an acid. Determine the equivalent weight of the acid (use about 0·2 g.) by titration with standard *ca.* 0·1*N* alkali with phenolphthalein as indicator; if the acid is sparingly soluble in water, add alcohol to increase the solubility.

The presence of simple water-insoluble phenols (or enols) will be indicated by the insolubility in 5 per cent. sodium bicarbonate solution. Further evidence will be obtained by carrying out the following tests.

Bromine test (*cf. 1*). Dissolve 0·2 g. or 0·2 ml. of the compound in 2 ml. of carbon tetrachloride and add a 2 per cent. solution of bromine in carbon tetrachloride dropwise until the bromine colour persists for 1 minute. If no hydrogen bromide fumes are observed, blow gently across the mouth of the tube.

Dissolve 0·1 g. of the compound in 10–15 ml. of water and add bromine water until the colour of the latter persists. A white precipitate will form if a phenol is present.

Ferric chloride test. Dissolve 1 drop or 0·05 g. of the compound in 5 ml. of water and add 1 drop of ferric chloride solution: observe the colour produced. If the result is negative in aqueous solution, repeat the test in alcoholic solution.

11. AMINES (BASIC NITROGEN COMPOUNDS)

Organic compounds that dissolve in dilute hydrochloric acid and are placed in Solubility Group IV contain nitrogen: the rarely encountered pyrones and anthocyanidin pigments are exceptions. Indeed, when solubility tests have placed a compound in Solubility Group IV but elementary analysis has failed to prove the presence of nitrogen, it is advisable to repeat the test for the elements. The most important basic nitrogen compounds are the **amines**—primary, secondary and tertiary amines. The only hydrazines commonly encountered in this Group are the **monoaryl hydrazines**: they are most conveniently detected by using benzaldehyde or some other suitable carbonyl compound as a reagent. The lower aliphatic amines and diamines are soluble in water and possess characteristic ammoniacal odours which distinguish them from the water-insoluble amines of Solubility Group IV. The reactions to be described below apply to both water-soluble and water-insoluble amines.

The following reagents may be conveniently employed for the detection of amines:

(1) Acetyl chloride or acetic anhydride.

Acetyl chloride reacts immediately and often violently with primary and secondary amines, but not with tertiary amines, for example:

$$\underset{\text{Aniline}}{2C_6H_5NH_2} + CH_3COCl \longrightarrow \underset{\text{Acetanilide}}{C_6H_5NHCOCH_3} + C_6H_5NH_2{,}HCl$$

It will be observed that the reaction involves two equivalents of the amine and produces, in addition to the substituted amide, an equivalent quantity of the amine hydrochloride. Acetic anhydride, on the other hand, converts the amine quantitatively into the acyl derivative, for example:

$$C_6H_5NH_2 + (CH_3CO)_2O \longrightarrow C_6H_5NHCOCH_3 + CH_3COOH$$

For this reason, acetic anhydride is generally preferred for the preparation of acetyl derivatives, but acetyl chloride, in view of its greater reactivity, is a better diagnostic reagent for primary and secondary amines.

(2) Benzoyl chloride.

This acid chloride is much less reactive than acetyl chloride and indeed it may be employed to benzoylate a primary or secondary amine in the presence of a dilute solution of sodium hydroxide (Schotten-Baumann reaction). The resulting benzoyl derivative is insoluble in the alkaline medium and can be separated by filtration or extraction. The slight excess of benzoyl chloride which is employed is decomposed by the alkali. The reactions which occur with a typical secondary amine, monoethylaniline, are :

$$C_6H_5NHC_2H_5 + C_6H_5COCl \longrightarrow C_6H_5N(C_2H_5)COC_6H_5 + HCl$$
$$HCl + NaOH \longrightarrow NaCl + H_2O$$
$$C_6H_5COCl + 2NaOH \longrightarrow C_6H_5COONa + H_2O + NaCl$$

(3) Benzenesulphonyl chloride.

Benzenesulphonyl chloride reacts with primary and secondary, but not with tertiary, amines to yield substituted sulphonamides (for full discussion, see Section IV,100,*3*). The substituted sulphonamide formed from a primary amine dissolves in the alkaline medium, whilst that produced from a secondary amine is insoluble in alkali ; tertiary amines do not react. Upon acidifying the solution produced with a primary amine, the substituted sulphonamide is precipitated. The reactions form the basis of the Hinsberg procedure for the separation of amines {see Section IV,100,(viii) for details}. Feebly basic amines, such as *o*-nitroaniline, react slowly in the presence of alkali : in such cases it is best to carry out the reaction in pyridine solution {see Section IV,100,*3*}.

Some reference to the use of nitrous acid merits mention here. **Primary aromatic amines** yield diazonium compounds, which may be coupled with phenols to yield highly-coloured azo dyes (see Section IV,100,(iii)). **Secondary aromatic amines** afford nitroso compounds, which give Liebermann's nitroso reaction {Section IV,100,(v)}. **Tertiary aromatic amines**, of the type of dimethylaniline, yield *p*-nitroso derivatives {see Section IV,100,(vii)}.

The carbylamine or *iso*cyanide test for primary amines {Section IV,100,(i)} is so extremely delicate that it will detect traces of primary amines in secondary and tertiary amines : it must therefore be applied with due regard to this factor.

Acetyl chloride test (*for primary and secondary amines*). In a semimicro test-tube (75 × 10 mm.) treat 0·5 ml. (or 0·5 g.) of the compound with acetyl chloride drop by drop. Note whether reaction occurs. If no solid separates, pour the contents of the tube into 3 ml. of water and neutralise the aqueous layer with solid sodium bicarbonate. Observe whether a product different from the original compound is produced.

Benzoyl chloride test (*for primary and secondary amines*). Place 0·5 ml. (or 0·5 g.) of the compound, 10 ml. of 5 per cent. sodium hydroxide solution and 1 ml. of benzoyl chloride (*CAUTION*) in a test-tube, stopper the tube and shake until the odour of benzoyl chloride disappears. Examine the properties of the substance formed.

Benzenesulphonyl chloride test.* Proceed as in the benzoyl chloride test, but use 15–20 ml. of 5 per cent. sodium hydroxide solution. Examine the product when the odour of the sulphonyl chloride has disappeared. (If no reaction has occurred, the substance is probably a tertiary amine.) If a precipitate appears in the alkaline solution, dilute with about 10 ml. of water and shake ; if the precipitate does not dissolve, a secondary amine is indicated. If the solution is clear, acidify it cautiously to Congo red with dilute hydrochloric acid : a precipitate is indicative of a primary amine.

---

* *p*-Toluenesulphonyl chloride is more convenient to handle and gives similar results.

12. ACIDIC AND NEUTRAL NITROGEN COMPOUNDS

The imides, primary and secondary nitro compounds, oximes and sulphonamides of Solubility Group III are weakly acidic nitrogen compounds : they cannot be titrated satisfactorily with a standard alkali nor do they exhibit the reactions characteristic of phenols. The neutral nitrogen compounds of Solubility Group VII include : tertiary nitro compounds ; amides (simple and substituted) ; derivatives of aldehydes and ketones (hydrazones, semicarbazones, etc.) ; nitriles ; nitroso, azo, hydrazo and other intermediate reduction products of aromatic nitro compounds. All the above nitrogen compounds, and also the sulphonamides of Solubility Group VII, respond, with few exceptions, to the same classification reactions (*reduction and hydrolysis*) and hence will be considered together.

Nitro compounds and their reduction products. Tertiary nitro compounds (these are generally aromatic) * are reduced by zinc and ammonium chloride solution to the corresponding hydroxylamines, which may be detected by their reducing action upon an ammoniacal solution of silver nitrate or Tollen's reagent :

$$RNO_2 + 4H \xrightarrow[NH_4Cl\ aq.]{Zn\ and} RNHOH + H_2O$$

$$RNHOH + 2[Ag(NH_3)_2]OH \longrightarrow RNO + 2Ag + 4NH_3 + 2H_2O$$

It must be remembered, however, that nitroso, azoxy and azo compounds (which are usually more highly coloured than nitro compounds) may be reduced by zinc powder to the corresponding hydroxylamine, hydrazo and hydrazine compounds respectively, all of which reduce Tollen's reagent in the cold.

Nitro compounds are reduced in acid solution (for example, by tin and hydrochloric acid) to the corresponding primary amines, which may be detected as described under *11* :

$$RNO_2 + 6H \longrightarrow RNH_2 + 2H_2O$$

Nitrosamines are similarly reduced to secondary amines :

$$R_2N.NO + 6H \longrightarrow R_2NH + NH_3 + H_2O$$

(compare Section IV,40) ; they (and some C-nitroso compounds that yield nitrous acid when treated with concentrated sulphuric acid) may be detected by Liebermann's reaction {see Section IV,100,(v) }.

Azo compounds may be identified by examination of the amine(s) formed on reduction in acid solution (see Sections IV,76 and IV,78) :

$$RN{=}NR' + 4H \longrightarrow RNH_2 + H_2NR'$$

They are always coloured but give colourless products upon reduction. **Hydrazo and azoxy compounds** are reduced in acid solution to the parent amine.

Amides. Simple (primary) amides ($RCONH_2$) when warmed with dilute sodium hydroxide solution give ammonia readily, together with the salt of the corresponding acid :

$$RCONH_2 + HOH \longrightarrow RCOOH + NH_3$$

Complete hydrolysis may be effected by boiling either with 10 per cent. sodium hydroxide solution or with 10 per cent. sulphuric acid for 1-3 hours. It is preferable to employ the non-volatile sulphuric acid for acid hydrolysis ; this

---

* Nitro-paraffins may be primary, secondary or tertiary: $—CH_2.NO_2$, primary ; $>CH.NO_2$, secondary ; and $\gg C.NO_2$, tertiary.

acid should also be used for acidification of the solution resulting from alkaline hydrolysis since any volatile organic acid (formic acid, acetic acid, etc.) may be distilled off.

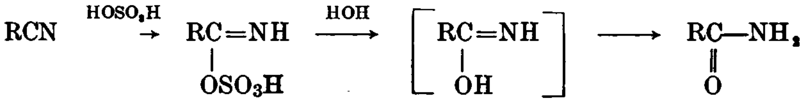
Substituted amides suffer hydrolysis with greater difficulty. The choice of an acid or an alkaline medium will depend upon (*a*) the solubility of the compound in the medium and (*b*) the effect of the reagent upon the products of hydrolysis. Substituted amides of comparatively low molecular weight (*e.g.*, acetanilide) may be hydrolysed by boiling either with 10 per cent. sodium hydroxide solution or with 10 per cent. sulphuric acid for 2–3 hours. Other substituted amides are so insoluble in water that little reaction occurs when they are refluxed with dilute acid or dilute alkali for several hours. These include such substances as benzanilide ($C_6H_5CONHC_6H_5$) and the benzoyl derivative of a naphthylamine ($C_6H_5CONHC_{10}H_7$) or a toluidine ($C_6H_5CONHC_7H_7$). For these substances satisfactory results may be obtained with 70 per cent. sulphuric acid : * this hydrolysis medium is a much better solvent for the substituted amide than is water or more dilute acid ; it also permits a higher reaction temperature (compare Section IV,192) :

$$RCONHR' + HOH \xrightarrow{H_2SO_4} RCOOH + R'NH_2,H_2SO_4$$

Nitriles. These are best hydrolysed by boiling either with 30–40 per cent. sodium hydroxide solution or with 50–70 per cent. sulphuric acid during several hours, but the reaction takes place less readily than for primary amides. Indeed the latter are intermediate products in the hydrolysis :

$$RCN + HOH \xrightarrow{NaOH} RCONH_2$$
$$RCONH_2 + HOH \xrightarrow{NaOH} RCOOH + NH_3$$

Nitriles and simple amides differ in physical properties : the former are liquids or low-melting solids, whilst the latter are generally solids. If the amide is a solid and insoluble in water, it may be readily prepared from the nitrile by dissolving in concentrated sulphuric acid and pouring the solution into water :



$$RCN \xrightarrow{HOSO_2H} \underset{OSO_3H}{\underset{|}{RC{=}NH}} \xrightarrow{HOH} \left[\underset{OH}{\underset{|}{RC{=}NH}}\right] \longrightarrow \underset{O}{\underset{\|}{RC{-}NH_2}}$$

Oximes, hydrazines and semicarbazones. The hydrolysis products of these compounds, *i.e.*, aldehydes and ketones, may be sensitive to alkali (this is particularly so for aldehydes) : it is best, therefore, to conduct the hydrolysis with strong mineral acid. After hydrolysis the aldehyde or ketone may be isolated by distillation with steam, extraction with ether or, if a solid, by filtration, and then identified. The acid solution may be examined for hydroxylamine or hydrazine or semicarbazide : substituted hydrazines of the aromatic series are precipitated as oils or solids upon the addition of alkali.

$$RR'C{=}NOH + HOH \xrightarrow[H_2SO_4]{HCl\ or} RR'C{=}O + NH_2OH,HCl$$

Imides. Imides are generally water-soluble, consequently they are much more readily hydrolysed in an alkaline medium, *e.g.*, by refluxing with 10 per cent. sodium hydroxide solution :

$$(RCO)_2NH + NaOH \longrightarrow (RCO)_2NNa \xrightarrow[[NaOH]]{HOH} 2RCOONa + NH_3$$

---

* Prepared by adding 40 ml. of concentrated sulphuric acid cautiously and with stirring and cooling to 30 ml. of water.

Sulphonamides. Sulphonamides are very resistant to the normal reagents for hydrolysis. Heating with 80 per cent. sulphuric acid at 160–170° results in rapid hydrolysis :

$$\mathrm{ArSO_2NRR' + HOH \xrightarrow{H_2SO_4} ArSO_2OH + RR'NH.H_2SO_4}$$

The reaction product may then be examined for a sulphonic acid and an amine.

Reduction of a nitro compound to a hydroxylamine. Dissolve 0·5 g. of the compound in 10 ml. of 50 per cent. alcohol, add 0·5 g. of solid ammonium chloride and about 0·5 g. of zinc powder. Heat to boiling and allow the ensuing chemical reaction to proceed for 5 minutes. Filter from the excess of zinc powder and test the filtrate with Tollen's reagent {see Section **III,70,**(i)}. An immediate black or grey precipitate or a silver mirror indicates the presence of a hydroxylamine formed by the reduction of the nitro compound. Alternatively, warm the filtrate with Fehling's solution : a hydroxylamine will precipitate red cuprous oxide. (A blank test should be performed with the original compound.)

Reduction of a nitro compound to a primary amine. In a 50 ml. round-bottomed or conical flask fitted with a reflux condenser, place 1 g. of the nitro compound and 2 g. of granulated tin. Measure out 10 ml. of concentrated hydrochloric acid and add it in three equal portions to the mixture : shake thoroughly after each addition. When the vigorous reaction subsides, heat under reflux on a water bath until the nitro compound has completely reacted (20–30 minutes). Shake the reaction mixture from time to time ; if the nitro compound appears to be very insoluble, add 5 ml. of alcohol. Cool the reaction mixture, and add 20–40 per cent. sodium hydroxide solution until the precipitate of tin hydroxide dissolves. Extract the resulting amine from the cooled solution with ether, and remove the ether by distillation. Examine the residue with regard to its solubility in 5 per cent. hydrochloric acid and its reaction with acetyl chloride or benzene-sulphonyl chloride.

Reduction of a nitrosamine to a secondary amine. Proceed as for a nitro compound. Determine the solubility of the residue after evaporation of the ether and also its behaviour towards benzenesulphonyl (or *p*-toluenesulphonyl) chloride.

Hydrolysis of simple (primary) amides in alkaline solution. Boil 0·5 g. of the compound with 5 ml. of 10 per cent. sodium hydroxide solution and observe whether ammonia is evolved.

Hydrolysis of a substituted amide. *A. With 10 per cent. sulphuric acid.* Reflux 1 g. of the compound (*e.g.*, acetanilide) with 20 ml. of 10 per cent. sulphuric acid for 1–2 hours. Distil the reaction mixture and collect 10 ml. of distillate : this will contain any volatile organic acids which may be present. Cool the residue, render it alkaline with 20 per cent. sodium hydroxide solution, cool, and extract with ether. Distil off the ether and examine the ether-soluble residue for an amine.

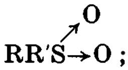
B. With 70 per cent. sulphuric acid. Reflux 1 g. of the substance (*e.g.*, benzanilide) with 10–15 ml. of 70 per cent. sulphuric acid (4 : 3 by volume) for 30 minutes. Allow to cool and wash down any acid which has sublimed into the condenser with hot water. Filter off the acid, wash it with water, and examine for solubility, etc. Render the filtrate alkaline with 10–20 per cent. sodium hydroxide solution, cool, and extract with ether. Examine the residue, after evaporation of the ether, for an amine.

Hydrolysis of a nitrile to an acid. Reflux 1 g. of the nitrile with 5 ml. of 30–40 per cent. sodium hydroxide solution until ammonia ceases to be evolved (2–3 hours). Dilute with 5 ml. of water and add, with cooling, 7 ml. of 50 per cent. sulphuric acid. Isolate the acid by ether extraction, and examine its solubility and other properties.

Hydrolysis of a nitrile to an amide. Warm a solution of 1 g. of the nitrile (*e.g.*, benzyl cyanide) in 4 ml. of concentrated sulphuric acid to 80–90°, and allow the solution to stand for 5 minutes. Cool and pour the solution cautiously into 40 ml. of cold water. Filter off the precipitate ; stir it with 20 ml. of cold 5 per cent. sodium hydroxide solution and filter again. Recrystallise the amide from dilute alcohol, and determine its m.p. Examine the solubility behaviour and also the action of warm sodium hydroxide solution upon the amide.

Hydrolysis of a sulphonamide. Mix 2 g. of the sulphonamide with 3·5 ml. of 80 per cent. sulphuric acid * in a test-tube and place a thermometer in the mixture. Heat the test-tube, with frequent stirring by means of the thermometer, at 155–165° until the solid passes into solution (2–5 minutes). Allow the acid solution to cool and pour it into 25–30 ml. of water. Render the resulting solution alkaline with 20 per cent. sodium hydroxide solution in order to liberate the free amine. Two methods may be used for isolating the base. If the amine is volatile in steam, distil the alkaline solution and collect about 20 ml. of distillate : extract the amine with ether, dry the ethereal solution with anhydrous potassium carbonate and distil off the solvent. If the amine is not appreciably steam-volatile, extract it from the alkaline solution with ether. The sulphonic acid (as sodium salt) in the residual solution may be identified as detailed under *13.*

13. SULPHUR COMPOUNDS

The following classes of sulphur compounds occur in Solubility Groups II, III and VII : sulphonic acids and derivatives, $ArSO_2OR$; sulphinic acids and derivatives, ArSOOR ; mercaptans, RSH ; thiophenols, ArSH ; sulphides or thioethers, RSR′ ; disulphides, RSSR′ ; sulphoxides, $RR'S \rightarrow O$; sulphones,  $RR'\overset{\nearrow O}{S}\rightarrow O$; esters of sulphuric acid, $ROSO_2OR'$; salts of alkyl sulphuric acids, *e.g.*, $ROSO_2ONa$; bisulphite addition products of aldehydes, methyl ketones ($RCOCH_3$) and alicyclic ketones ; *iso*thiocyanates, RN=C=S ; sulphates of amines ; and sulphonamides. The sulphonamides have already been discussed under *12.* The sulphates of amines are converted by aqueous sodium hydroxide into the free bases ; the sulphate anion can be detected in the resulting aqueous solution as barium sulphate in the usual manner.

Sulphonic acids. The aromatic sulphonic acids and their alkali-metal salts are soluble in water, but insoluble in ether (Solubility Group II). They are best characterised by conversion into crystalline S-benzyl-*iso*-thiuronium salts (see Section IV,33,*2* and III,85,*5*), which possess characteristic melting points. A more time-consuming procedure is to treat the well-dried acid or

---

* Prepared by cautiously mixing 3 volumes of concentrated sulphuric acid with 1 volume of water.

its salt with phosphorus pentachloride or with phosphorus oxychloride, and to convert the resulting sulphonyl chloride (*a*) into a sulphonamide by pouring the reaction mixture into concentrated ammonia solution or (*b*) into a substituted sulphonamide by treating it with a primary amine in the presence of aqueous sodium hydroxide (compare Section **IV,33,*1***) :

$$\begin{tikzcd}
\mathrm{ArSO_2ONa} \arrow[r, "\mathrm{PCl_5\ or}", "\mathrm{POCl_3}"'] & \mathrm{ArSO_2Cl} \arrow[r, "\mathrm{NH_3}"] \arrow[dr, "\mathrm{RNH_2}"'] & \mathrm{ArSO_2NH_2} \\
 & & \mathrm{ArSO_2NHR}
\end{tikzcd}$$

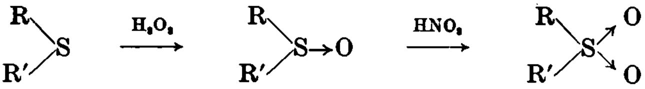
Sulphinic acids. Aromatic sulphinic acids are found in Solubility Group II. They may be detected by dissolving in cold concentrated sulphuric acid and adding one drop of phenetole or anisole when a blue colour is produced (Smiles's test), due to the formation of a *para*-substituted aromatic sulphoxide. Thus the reaction with benzenesulphinic acid is :

$$C_6H_5SOOH + C_6H_5OC_2H_5 \longrightarrow C_6H_5SOC_6H_4OC_2H_5 + H_2O$$

Aromatic sulphinic acids are oxidised by potassium permanganate to sulphonic acids and are reduced by zinc and hydrochloric acid to thiophenols.

Mercaptans and thiophenols (thiols). The thiols are generally liquids with penetrating and disagreeable odours, which persist even at extremely low concentrations in the air. They are soluble in dilute sodium hydroxide solution. Thiols are best characterised as the crystalline 2 : 4-dinitrophenyl thioethers or as the corresponding sulphones (see Section **III,168**).

Sulphides (thioethers). The organic sulphides are usually liquids with penetrating and disagreeable odours. In contrast to the oxygen analogues (ethers), they are readily oxidised; thus sulphoxides are produced with hydrogen peroxide, and sulphones with nitric acid or with potassium permanganate in glacial acetic acid solution :



Thioethers usually yield sulphonium salts when warmed with ethyl iodide and allowed to cool. The physical properties (b.p., density and refractive index) are useful for identification purposes.

Disulphides. Disulphides are liquids or low m.p. solids and have unpleasant odours, particularly if liquid. They are reduced by zinc and dilute acids to the mercaptans :

$$RSSR + 2H \longrightarrow 2RSH$$

Sulphoxides. These are usually solids of low m.p. They may be oxidised in glacial acetic acid solution by potassium permanganate to the corresponding sulphones, and reduced to the sulphides by boiling with tin or zinc and hydrochloric acid.

Sulphones. Sulphones are usually crystalline solids, and are extremely stable to most oxidising, reducing and hydrolytic reagents.

Esters of sulphuric acid. These compounds are generally water-insoluble liquids and are saponified by boiling with water or dilute alkali to the corresponding alcohols and sulphuric acid :

$$R_2SO_4 + 2H_2O \longrightarrow 2ROH + H_2SO_4$$

They are usually poisonous and can be identified by using them to alkylate β-naphthol (compare Section **IV,104**).

The **alkyl esters of sulphonic acids** exhibit properties similar to those of the alkyl sulphates, and are hydrolysed, by boiling with aqueous alkalis, to the alcohols and sulphonates. Thus with ethyl *p*-toluenesulphonate :

$$p\text{-}CH_3C_6H_4SO_2OC_2H_5 + HOH \longrightarrow p\text{-}CH_3C_6H_4SO_2OH + C_2H_5OH$$

The **salts of monoalkyl sulphates** are frequently encountered as commercial detergents (for example, " dreft," " gardinol " and " pentrone ") : they are usually sodium salts, the alkyl components contain 12 or more carbon atoms, and give colloidal solutions. They are hydrolysed by boiling with dilute sodium hydroxide solution :

$$ROSO_2ONa + NaOH \longrightarrow ROH + Na_2SO_4$$

Bisulphite compounds of aldehydes and ketones. These substances are decomposed by dilute acids into the corresponding aldehydes or ketones with the liberation of sulphur dioxide. The aldehyde or ketone may be isolated by steam distillation or by extraction with ether. Owing to the highly reactive character of aldehydes, the bisulphite addition compounds are best decomposed with saturated sodium bicarbonate solution : sodium carbonate solution is generally employed for the bisulphite compounds of ketones.

$$RCH(OH)SO_3Na + HCl \longrightarrow RCHO + NaCl + SO_2 + H_2O$$

***iso*Thiocyanates.** These compounds, also known as **mustard oils**, are oils or low melting point solids, and usually possess irritating odours. Upon boiling with acids, for example with concentrated hydrochloric acid, they are hydrolysed to the primary amines and hydrogen sulphide is evolved :

$$RN{=}C{=}S + HCl + 2H_2O \longrightarrow RNH_2{,}HCl + CO_2 + H_2S$$

They react with amines to form substituted thioureas :

$$RN{=}C{=}S + R'NH_2 \longrightarrow RNHCSNHR'$$

this reaction is also employed for the characterisation of amines (see Section **III,123**,*2*).

It is convenient to summarise the more important class reactions given in this Section.

Summary of the more important Class Reactions

Unsaturation :
- (*a*) Bromine in carbon tetrachloride.
- (*b*) Potassium permanganate solution.

Saturated hydrocarbons :
- Fuming sulphuric acid.

Halogens :
- (*a*) Alcoholic silver nitrate solution.
- (*b*) Sodium iodide in acetone.

Aldehydes and ketones :
- 2 : 4-Dinitrophenylhydrazine.

Aldehydes :
- (*a*) Schiff's reagent.
- (*b*) Fehling's solution.
- (*c*) Ammoniacal silver nitrate solution.

Esters and anhydrides :
- (*a*) Hydroxamic acid test.
- (*b*) Saponification ; saponification equivalent.

Alcohols :

(*a*) Sodium together with reaction (*b*).
(*b*) Acetyl chloride or benzoyl chloride.
(*c*) Hydrochloric acid - zinc chloride reagent.

Ethers :

(*a*) Sodium.
(*b*) Acetyl chloride.
(*c*) Hydriodic acid.

Carboxylic acids :

(*a*) Sodium bicarbonate and sodium hydroxide solution.
(*b*) Neutralisation equivalent.

Phenols :

(*a*) Sodium bicarbonate and sodium hydroxide solution.
(*b*) Bromine in carbon tetrachloride and bromine water.
(*c*) Ferric chloride solution.

Amines:

(*a*) Acetyl, benzoyl or benzenesulphonyl chloride.
(*b*) Nitrous acid.

Nitro compounds :

(*a*) Zinc and ammonium chloride solution.
(*b*) Tin and hydrochloric acid.

Amides :

(*a*) Dilute sodium hydroxide solution.
(*b*) Dilute sulphuric acid.

Nitriles :

(*a*) Dilute sodium hydroxide solution.
(*b*) Dilute sulphuric acid.

Sulphonic acids :

(*a*) Sulphur present.
(*b*) Sodium bicarbonate and sodium hydroxide solution.
(*c*) *S*-Benzyl-*iso*-thiuronium chloride.
(*d*) Neutralisation equivalent.

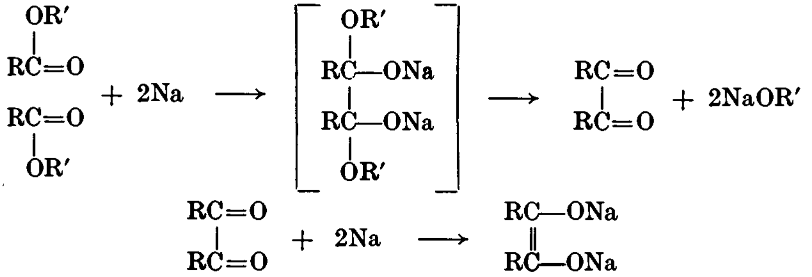
Sulphonamides :

(*a*) Sulphur and nitrogen present.
(*b*) Sodium hydroxide solution.
(*c*) Sulphuric acid (70–80 per cent.).

NOTE ON ACYLOINS

The formation of acyloins (α-hydroxyketones of the general formula RCH(OH)COR, where R is an aliphatic residue) proceeds best by reaction between finely-divided sodium (2 atoms) and esters of aliphatic acids (1 mol) in anhydrous ether or in anhydrous benzene with exclusion of oxygen : salts of enediols are produced, which are converted by hydrolysis into acyloins. The yield of acetoin from ethyl acetate is low (*ca.* 23 per cent. in ether) owing to the accompanying acetoacetic ester condensation ; the latter reaction is favoured when the ester is used as the solvent. Ethyl propionate and ethyl *n*-butyrate give yields of 52 per cent. of propionoin and 72 per cent. of butyroin respectively in ether.

The *mechanism* of the formation of an acyloin from an ester may involve the initial formation of a diketone ; the latter is reduced by the metal to give the sodium salt of the enediol form of the acyloin :



Some support for this mechanism is provided by the isolation of small amounts of 1 : 2-diketones (RCOCOR) as by-products of the reaction.

XI,8. THE PREPARATION OF DERIVATIVES

The steps so far taken in the identification of a compound, *viz.*, (i) determination of the physical constants and the establishment of the purity (Section **XI,2**), (ii) qualitative analysis for the elements (Section **XI,3**), (iii) study of the solubility behaviour towards selected solvents (Section **XI,5** and **XI,6**) and (iv) application of class reactions (Section **XI,7**), will, in general, establish the class to which the compound belongs. The next step is to prove its identity with one of the members of the class. It is at this stage that the literature is consulted. In the first instance, the appropriate table or tables in this volume are examined.* Those compounds are selected which have melting points or boiling points within about 5° of the unknown : it is assumed, of course, that the latter was supplied or subsequently obtained in a state of purity (Section **XI,2**). To distinguish between these, a suitable *derivative* is prepared and its physical properties determined ; if these agree with those of the known derivative of one of the possibilities already considered, then the identity of the compounds may be assumed. If the list of possible compounds is long, the preparation of two derivatives may be desirable. It must, however, be pointed out that in eliminating compounds from the list of possibilities, due consideration must be paid to other sufficiently characteristic properties, such as density, refractive index, neutralisation equivalent, molecular weight and optical rotation (where applicable), with adequate allowance for experimental error.

The requirements of a satisfactory derivative include :

(1) The derivative should be easily and quickly prepared in good yield by an unambiguous reaction, and be easily purified. In practice, this generally means that the derivative must be a solid, because of the

---

* It will be observed that these tables have not been arranged in the order of increasing melting or boiling points to facilitate quick reference : in the author's view it is far more satisfactory to group analogous compounds together so that variations of the physical properties of the actual compounds and their derivatives may be seen at a glance. The student is recommended to rearrange the compounds constituting the various classes in order of increasing melting points and/or boiling points, and to add a column for the formulae of the individual compounds ; these modified tables should be preserved in a stiff-covered folder for reference. This task will serve to familiarise the student with the individual members of the different classes of organic compounds.

greater ease of manipulation of small quantities of solids and the fact that melting points are more accurate and more easily determined than boiling points. The melting point should preferably be above 50°, but below 250° ; compounds which melt below 50° are frequently difficult to crystallise.

(2) The derivative should be prepared preferably by a general reaction, which under the same experimental conditions would yield a definite derivative with the other individual possibilities. Rearrangements and side reactions should be avoided.

(3) The properties (physical and chemical) of the derivatives should be markedly different from those of the original compound.

(4) The derivative selected in any particular instance should be one which clearly singles out one compound from among all the possibilities and thus enables an unequivocal choice to be made. The melting points of the derivatives to be compared should differ by at least 5–10°. Whenever possible, a derivative should be selected which has a neutralisation equivalent as well as a melting point (*e.g.*, an aryloxyacetic acid derivative of a phenol, Section **IV,114,*4***, or a hydrogen 3-nitrophthalate of an alcohol, Section **III,25,*5***).

The above considerations will assist the student in the selection of a derivative. It should also be borne in mind that when a compound has several functional groups, that functional group should be chosen for the preparation of a derivative which gives the least ambiguous reaction.

The methods of preparation of some of the more important derivatives of a number of classes of organic compounds are described in the various Sections dealing with their reactions and characterisation. These Sections conclude with tables incorporating the melting points and boiling points of the compounds themselves, and also the melting points of selected derivatives. For convenience, the references to the various tables are collected below.

Saturated Aliphatic Hydrocarbons, **Table III, 6.**
Unsaturated Aliphatic Hydrocarbons, **Table III, 11.**
Aromatic Hydrocarbons, **Table IV, 9.**
Aliphatic Alcohols, **Table III, 27.**
Polyhydric Alcohols, **Table III, 136.**
Sugars, **Table III, 139.**
Aromatic Alcohols, **Table IV, 205.**
Phenols, **Table IV, 114.**
Enols, **Table IV, 114A.**
Aliphatic Halogen Compounds, **Table III, 42**
Aromatic Halogen Compounds, **Table IV, 28.**
Aliphatic Ethers, **Table III, 60.**
Aromatic Ethers, **Table IV, 106.**
Acetals, **Table III, 69.**
Aliphatic Aldehydes, **Table III, 70.**
Aromatic Aldehydes, **Table IV, 135.**
Aliphatic Ketones, **Table III, 74.**
Aromatic Ketones, **Table IV, 148.**
Aliphatic Carboxylic Acids, **Table III, 85.**

Aromatic Carboxylic Acids, **Table IV, 175.**
Aliphatic Acid Chlorides, **Table III, 88.**
Aliphatic Acid Anhydrides, **Table III, 94.**
Acid Chlorides and Acid Anhydrides of Aromatic Acids, **Table IV, 187.**
Aliphatic Esters, **Table III, 106.**
Aromatic Esters, **Table IV, 183.**
Primary Aliphatic Amides, **Table III, 110.**
Primary Aromatic Amides, **Table IV, 191.**
Substituted Aromatic Amides, **Table IV, 192.**
Aliphatic Nitriles, **Table III, 115.**
Aromatic Nitriles, **Table IV, 195.**
Primary and Secondary Aliphatic Amines, **Table III, 123.**
Primary Aromatic Amines, **Table IV, 100A.**
Secondary Aromatic Amines, **Table IV, 100B.**
Tertiary Aliphatic and Aromatic Amines, **Table IV, 100C.**
Amino Acids, **Table III, 132.**
Mercaptans (Thiols), **Table III, 168.**
Aromatic Nitro Compounds, **Table IV, 16A.**
Aliphatic Nitro Compounds, **Table IV, 16B.**
Aromatic Sulphonic Acids, **Table IV, 33.**
Aromatic Sulphonamides, **Table IV, 33A.**
Quinones, **Table IV, 152.**

For the sake of completeness, the following Tables are included in this Chapter :

Imides, **Table XI, 8,1.**
Nitroso, Azo, Azoxy and Hydrazo Compounds, **Table XI, 8,2.**
Oximes, **Table XI, 8,3.**
Miscellaneous Sulphur Compounds, **Table XI, 8,4.**

TABLE XI,8,1. **IMIDES**

Compound	*M.P.*
Succinimide	125°
N-Phenylsuccinimide	156
Maleimide	93
N-Phenylmaleimide	91
Phthalimide	233
N-Phenylphthalimide	205
3-Nitrophthalimide	216
β-Bromoethylphthalimide	82
β-Hydroxyethylphthalimide	128
Naphthalimide	300
Alloxan ($4H_2O$)	170d
o-Benzoic sulphimide (saccharin)	226d
Barbituric acid	245d
Diethylbarbituric acid (*Veronal*)	190
Diallylbarbituric acid (*Dial*)	173
Ethyl-*n*-butyl-barbituric acid (*Neonal*)	128
Ethyl-(1-methylbutyl)-barbituric acid (*Pentobarbital*)	130
Ethyl-*n*-hexyl-barbituric acid (*Ortal*)	126
Ethyl-*iso*propyl-barbituric acid (*Ipral*)	201
Ethyl-*iso*amyl-barbituric acid (*Amytal*)	155
Ethyl-phenyl-barbituric acid (*Phenobarbital*)	171

TABLE XI,8,2. NITROSO, AZO, AZOXY AND HYDRAZO COMPOUNDS

Compound		*M.P.*
Nitroso Compounds :		
Methylphenylnitrosoamine	B.P. 120°/13	—
Ethylphenylnitrosoamine	B.P. 134°/16	—
Nitrosobenzene		68°
o-Nitrosotoluene		72
m-Nitrosotoluene		53
p-Nitrosotoluene		48
α-Nitrosonaphthalene		98
p-Nitrosophenol		125d
α-Nitroso-β-naphthol		109
4-Nitroso-α-naphthol		198
p-Nitroso-*NN*-dimethylaniline		87
p-Nitroso-*NN*-diethylaniline		84
p-Nitroso-*N*-methylaniline		118
p-Nitroso-*N*-ethylaniline		78
p-Nitrosodiphenylamine		144
Azo Compounds :		
Azobenzene		68°
o-Azotoluene		55
m-Azotoluene		55
p-Azotoluene		144
o-Azophenetole		131
p-Azophenetole		160
Benzeneazo-*o*-cresol		128
α-Benzeneazo-β-naphthol		134
β-Benzeneazo-α-naphthol		138
4-Benzeneazo-α-naphthol		206d
Benzeneazodiphenylamine		82
α-Benzeneazo-β-naphthylamine		104
4-Benzeneazo-α-naphthylamine		123
p-Aminoazobenzene		126
p-Dimethylaminoazobenzene		117
p-Hydroxyazobenzene		152
2 : 2′-Dichloroazobenzene		137
3 : 3′-Dichloroazobenzene		101
4 : 4′-Dichloroazobenzene		188
Azoxy Compounds :		
Azoxybenzene		36°
o-Azoxytoluene		60
m-Azoxytoluene		39
p-Azoxytoluene		70
o-Azoxyanisole		81
m-Azoxyanisole		52

TABLE XI,8,2. NITROSO, AZO, AZOXY AND HYDRAZO COMPOUNDS (*continued*)

Compound	*M.P.*
Azoxy Compounds (*continued*) :	
p-Azoxyanisole	119°
o-Azoxyphenetole	102
m-Azoxyphenetole	50
p-Azoxyphenetole	138
1 : 1′-Azoxynaphthalene	127
2 : 2′-Azoxynaphthalene	168
2 : 2′-Dichloroazoxybenzene	56
3 : 3′-Dichloroazoxybenzene	97
4 : 4′-Dichloroazoxybenzene	158
Hydrazo Compounds :	
Hydrazobenzene	126°
o-Hydrazotoluene	165
m-Hydrazotoluene	38
p-Hydrazotoluene	134
o-Hydrazophenol	148
o-Hydrazoanisole	102
o-Hydrazophenetole	89
m-Hydrazophenetole	119
p-Hydrazophenetole	86
1 : 1′-Hydrazonaphthalene	153
2 : 2′-Hydrazonaphthalene	141

TABLE XI,8,3. OXIMES

Compound	*B.P.*	*M.P.*
α-Acetaldoxime	—	47°
α-Propionaldoxime	—	40
α-*n*-Butyraldoxime	153°	—
α-*iso*-Butyraldoxime	140	—
α-*n*-Valeraldoxime	—	52
α-*iso*-Valeraldoxime	—	49
α-*n*-Hexaldoxime	—	51
α-*n*-Heptaldoxime	—	54
α-Benzaldoxime	—	33
β-Benzaldoxime	—	128
α-Furfuraldoxime	—	76
β-Furfuraldoxime	—	92
Salicylaldoxime	—	59
Acetoxime	—	61
Methyl ethyl ketoxime	152	—
Diethyl ketoxime	165	—
Di-*n*-propyl ketoxime	195	—
Di-*n*-butyl ketoxime	124°/15 mm.	—
Acetophenone oxime	—	60
Benzophenone oxime	—	142
Benzil monoxime	—	137
α-Benzil dioxime	—	237
Diacetyl monoxime	—	75
Dimethyl glyoxime	—	237
Carvoxime	—	71
d-Camphor oxime	—	116

TABLE XI,8,4. MISCELLANEOUS SULPHUR COMPOUNDS

Compound	*B.P.*	*M.P.*	$d_{4°}^{20°}$	$n_D^{20°}$
Dimethyl sulphide	38°	—	0·849	1·436
Methyl ethyl sulphide	66	—	0·846	1·440
Diethyl sulphide	92	—	0·837	1·442
Di-*n*-propyl sulphide	142	—	0·839	1·449
Di-*iso*-propyl sulphide	119	—	0·817	1·440
Di-*n*-butyl sulphide	187	—	0·840	1·453
D-*iso*-butyl sulphide	169	—	0·826	1·447
Di-*sec.*-butyl sulphide	165	—	0·835	1·451
Di-*n*-amyl sulphide	85°/4	—	0·841	1·456
Di-*iso*-amyl sulphide	86°/5	—	0·834	1·453
Di-*n*-hexyl sulphide	114°/4	—	0·841	1·459
Di-*n*-heptyl sulphide	142°/4	—	0·842	1·461
Di-*n*-octyl sulphide	162°/4	—	0·845	1·469
Di-allyl sulphide	140	—	—	—
Diphenyl sulphide	145°/8	—	1·114	1·633
Di-*p*-tolyl sulphide	—	57°	—	—
Dibenzyl sulphide	—	50	—	—
Dimethyl disulphide	109	—	1·065	1·526
Diethyl disulphide	153	—	0·992	1·507
Di-*n*-propyl disulphide	194	—	0·960	1·498
Di-*iso*-propyl disulphide	176	—	0·944	1·492
Di-*n*-butyl disulphide	231	—	0·938	1·493
Di-*iso*-butyl disulphide	215	—	0·928	1·487
Di-*tert.*-butyl disulphide	65°/5	—	0·923	1·490
Di-*n*-amyl disulphide	119°/7	—	0·922	1·489
Di-*iso*-amyl disulphide	115°/9	—	0·919	1·486
Di-allyl disulphide	100°/48	—	—	—
Diphenyl disulphide	—	60	—	—
Di-*p*-tolyl disulphide	—	48	—	—
Dibenzyl disulphide	—	73	—	—
Diphenyl sulphoxide	—	70	—	—
Di-*p*-tolyl sulphoxide	—	95	—	—
Dibenzyl sulphoxide	—	134	—	—
Dimethyl sulphone	238	109	—	—
Diethyl sulphone	248	74	—	—
Di-*n*-propyl sulphone	—	29	—	—
Di-*n*-butyl sulphone	—	44	—	—
Sulphonal	—	126	—	—
Trional	—	76	—	—
Diphenyl sulphone	—	128	—	—
Di-*p*-tolyl sulphone	—	159	—	—
Dibenzyl sulphone	—	150	—	—
Methyl thiocyanate	131	—	1·082	—
Ethyl thiocyanate	147	—	1·024	1·465
iso-Propyl thiocyanate	151	—	—	—
n-Propyl thiocyanate	165	—	0·981	1·463
n-Butyl thiocyanate	184	—	0·961	1·464
Benzyl thiocyanate	—	38	—	—

TABLE XI,8,4. MISCELLANEOUS SULPHUR COMPOUNDS (*continued*)

Compound	*B.P.*	*M.P.*	$d_{4^\circ}^{20^\circ}$	$n_D^{20^\circ}$
Allyl *iso*-thiocyanate . . .	152°	—	1·010	1·524
Phenyl *iso*-thiocyanate . . .	221	—	1·134	1·651
Thiophene	84	—	1·062	1·525
Methyl *p*-toluenesulphonate . .	—	28°	—	—
Ethyl *p*-toluenesulphonate . .	173°/15	33	—	—
n-Propyl *p*-toluenesulphonate . .	165°/10	—	—	—
n-Butyl *p*-toluenesulphonate . .	175°/10	—	—	—
Phenyl *p*-toluenesulphonate . .	—	96	—	—
Thiourea	—	180	—	—
Allyl thiourea	—	78	—	—
Phenyl thiourea	—	154	—	—
sym.-Diphenylthiourea (thiocarbanilide)	—	154	—	—
sym.-Di-*o*-tolyl thiourea . .	—	166	—	—
sym.-Di-*m*-tolyl thiourea . . .	—	112	—	—
sym.-Di-*p*-tolyl thiourea . . .	—	178	—	—
Thiosemicarbazide	—	182	—	—

Suggestions as to the methods for identifying the above classes of compounds will be found under *Class Reactions* in Section **XI,7.** Some further remarks upon enolic compounds (see Table **IV,114A**) may be made here. Enols may be divided into (*a*) β-keto esters and (*b*) 1 : 3-diketones. With 5 per cent. sodium hydroxide solution, a β-keto ester yields the salt of the corresponding acid, which when heated with dilute hydrochloric acid is decarboxylated to a ketone :

$$\mathrm{RCOCHR'COOR'' + NaOH \longrightarrow R''OH + RCOCHR'COONa}$$

$$\mathrm{RCOCHR'COONa + HCl \xrightarrow{Heat} RCOCH_2R' + CO_2 + NaCl}$$

A 1 : 3-diketone, under similar conditions, affords a ketone and the salt of an acid :

$$\mathrm{RCOCH_2COR' + NaOH \longrightarrow RCOCH_3 + R'COONa}$$

Two simple **tests for enols** may be given here :

(i) *Ferric chloride solution.* Add a few drops of neutral aqueous ferric chloride to a solution of 0·1 g. of the compound in water or in methanol. Most enols give a red colouration.

Prepare the **neutral ferric chloride solution** (*i.e.*, free from hydrochloric acid) by adding dilute sodium hydroxide solution dropwise to the bench reagent until a slight precipitate of ferric hydroxide is formed. Filter off the precipitate and use the clear filtrate for the test.

(ii) *Copper derivative.* Shake 0·2 g. of the substance vigorously with a little cold, saturated, aqueous copper acetate solution. Many enols give a solid, green or blue, copper derivative, which can be crystallised from alcohol and often has a definite m.p.

An enol is usually characterised by treatment with ketonic reagents or with phenylhydrazine (compare Section **IV,114** and Table **IV,114A**), or by hydrolysis with acid, followed by the identification of the ketone.

It will be appreciated that the Tables are far from complete, but they do contain most of the common organic compounds which the student is likely to encounter in the course of his work in the laboratory. For compounds which are not listed in the Tables, reference should be made to larger treatises. These include :

Mulliken, *Identification of Pure Organic Compounds*, Volumes I–IV, 1904–1922 (J. Wiley : this work is difficult to obtain in Great Britain).

Huntress - Mulliken, *Identification of Pure Organic Compounds*, Order I, 1941 (J. Wiley : Chapman and Hall).

Huntress, *Organic Chlorine Compounds*, Order III, 1948 (J. Wiley; Chapman and Hall).

Heilbron and Bunbury, *Dictionary of Organic Compounds*, Revised Edition, Four Volumes, 1953 (Eyre and Spottiswoode).

Beilstein, *Handbuch der Organischen Chemie*, Fourth Edition, 1919–1955, 84 Volumes (J. Springer, Berlin).

Elsevier's Encyclopaedia of Organic Chemistry, Edited by F. Radt, 1946–1955, 14 Volumes (Elsevier Press ; Cleaver-Hume Press).

" Beilstein " is the most comprehensive list of organic compounds. The main series, volumes 1–27, 30 and 31, part I, covers the literature up to 1910. The first supplement, volumes 1–27, and the subject and formulae indexes constituting volumes 28 and 29, survey the literature up to 1919. The second supplement, volumes 1–27, and the subject and formulae indexes constituting volumes 28 and 29, covers the period 1920–1929. For compounds not listed in " Beilstein ", *i.e.*, for those which first appear in the literature after 1929, the indexes of the Abstract Journals {Chemical Abstracts, Chemisches Zentralblatt or British Chemical Abstracts (to 1953)} should be consulted. The Collective Formula Index to Chemical Abstracts, 1920–1946, is extremely useful. For general reference work " Heilbron " will be found less cumbersome than " Beilstein ", although of necessity not so comprehensive.

XI,9. QUALITATIVE ANALYSIS OF MIXTURES OF ORGANIC COMPOUNDS

The general method to be adopted for the analysis of mixtures of organic compounds is to separate them into their components and to identify each component as previously described. It is impossible, however, to give a set of procedures which will be applicable, without modification, to the great variety of combinations which may be encountered. The student will be expected to take advantage of any facts which have emerged in the preliminary examination and to adapt, if necessary, the general schemes given below to the mixture under examination. The preliminary examination is therefore of fundamental importance.

Broadly speaking, the separation of the components of mixtures may be divided into three main groups.

(1) **Separations based upon differences in the chemical properties of the components.** Thus a mixture of toluene and aniline may be separated by extraction with dilute hydrochloric acid : the aniline passes into the aqueous layer in the form of the salt, aniline hydrochloride, and may be recovered by neutralisation. Similarly, a mixture of phenol and toluene may be separated by treatment with dilute sodium hydroxide. The above examples are, of course, simple applications of the fact that the various components fall into different solubility groups (compare Section XI,5). Another example is the separation of a mixture of di-*n*-butyl ether and chlorobenzene : concentrated sulphuric acid dissolves only the *n*-butyl ether and it may be recovered from solution by dilution with water. With some classes of compounds, *e.g.*, unsaturated compounds, concentrated sulphuric acid leads to polymerisation, sulphonation, etc., so that the original component cannot be recovered unchanged : this solvent, therefore, possesses limited application. Phenols may be separated from acids (for example, *o*-cresol from benzoic acid) by a dilute solution of sodium bicarbonate : the weakly acidic phenols (and also enols) are not converted into salts by this reagent and may be removed by ether extraction or by other means; the acids pass into solution as the sodium salts and may be recovered after acidification. Aldehydes, *e.g.*, benzaldehyde, may be separated from liquid hydrocarbons and other neutral, water-insoluble liquid compounds by shaking with a solution of sodium bisulphite : the aldehyde forms a solid bisulphite compound, which may be filtered off and decomposed with dilute acid or with sodium bicarbonate solution in order to recover the aldehyde.

In connexion with the above " chemical " methods of separation, it is important to note that sufficient of the extracting reagent must be used to remove *completely* the component which it dissolves or with which it reacts.

(2) **Separations based upon differences in the volatilities of the components in aqueous solution.** This procedure is generally employed for the water-soluble compounds listed in Solubility Table **XI,5**, and may also be applied to mixtures in which one of the components is slightly soluble in water. The water-soluble compounds include the lower members of the homologous series of alcohols, aldehydes, ketones, acids, esters, amines and nitriles ; compounds containing two or more hydroxyl or amino groups, hydroxy-, amino-, di- and polybasic acids, sulphonic acids and salts. The compounds with one functional group are usually volatile in steam and distil with the water : compounds with two or more functional groups (amino, hydroxyl or

carboxyl) are not generally steam-volatile. The stable salts of steam-volatile bases and acids may be decomposed by a stronger non-volatile mineral acid (sulphuric acid or phosphoric acid) or base (sodium or potassium hydroxide), and the organic base or acid separated by steam distillation from the aqueous solution or suspension. The salts of weaker bases and acids (*e.g.*, the amine or ammonium salts of carboxylic acids and the alkali metal salts of some phenols) are sufficiently hydrolysed by boiling water to permit the basic or acidic compound to distil with the water. It should be noted that sulphonic acids and their salts are not volatile in steam. The only disadvantage of this procedure is that certain compounds may decompose or polymerise or otherwise undergo change under the influence of aqueous alkali or acid at 100°, and this fact must be borne in mind when the method is employed. Thus sugars are decomposed by alkali; these may sometimes be isolated by evaporation of the solvent at *p*H 7. preferably under diminished pressure.

The essential basis of the scheme for the separation of water-soluble compounds is, therefore, distillation of (*a*) an aqueous solution of the mixture, (*b*) an alkaline (with sodium hydroxide) solution of the mixture, and (*c*) an acidic (with sulphuric or phosphoric acid) solution of the mixture. The residue will contain the non-volatile components, which must be separated from inorganic salts and from each other by any suitable process.

The following are examples of the above procedure. A mixture of diethylamine and *n*-butyl alcohol may be separated by adding sufficient dilute sulphuric acid to neutralise the base: steam distillation will remove the alcohol. The amine can be recovered by adding sodium hydroxide to the residue and repeating the distillation. A mixture of diethyl ketone and acetic acid may be treated with sufficient dilute sodium hydroxide solution to transform the acid into sodium acetate and distilling the aqueous mixture. The ketone will pass over in the steam and the non-volatile, stable salt will remain in the flask. Acidification with dilute sulphuric acid liberates acetic acid, which can be isolated by steam distillation or by extraction.

(3) **Separations based upon differences in the physical properties of the components.** When procedures (1) or (2) are unsatisfactory for the separation of a mixture of organic compounds, purely physical methods may be employed. Thus a mixture of volatile liquids may be fractionally distilled (compare Sections **II,15** and **II,17**): the degree of separation may be determined by the range of boiling points and/or the refractive indices and densities of the different fractions that are collected. A mixture of non-volatile solids may frequently be separated by making use of the differences in solubilities in inert solvents: the separation is usually controlled by m.p. determinations. Sometimes one of the components of the mixture is volatile and can be separated by sublimation (see Section **II,45**).

1. PRELIMINARY EXAMINATION OF A MIXTURE

A. Liquid Mixtures

(i) **Physical properties.** Examine the mixture with regard to odour, viscosity and colour.

(ii) **Solubility in water.** Transfer 1·0 ml. of the mixture by means of a calibrated dropper or a small pipette into a small graduated test-tube : add 1 ml. of water and shake. Observe whether there is complete or partial solution and if there is any sign of chemical reaction. If solution is not complete, add more water (in 1 ml. portions) and note (*a*) if the mixture dissolves completely, and (*b*) if a portion is insoluble and, if so, whether it is heavier or lighter than the aqueous layer. If an emulsion is formed, it may be assumed that at least one component of the mixture is insoluble in water and at least one component is soluble. Test the aqueous layer obtained with litmus and with phenolphthalein : if there is an acid reaction, test also with 5 per cent. sodium bicarbonate solution.

(iii) **Presence or absence of water.** Determine the absence or presence of water in the solution by one or more of the following tests :

(*a*) Investigate its miscibility with ether or with benzene.

(*b*) Observe its action upon anhydrous copper sulphate.

(*c*) Distil a small portion and note the b.p. and properties of the distillate.

(*d*) Distil 3 ml. of the mixture with 3 ml. of dry toluene from a dry 10 ml. distilling flask. Collect 2 ml. of the distillate and dilute it with 5 ml. of dry toluene ; the formation of two layers or of distinct drops suspended in the toluene indicates the presence of water.

(iv) **Behaviour upon distillation.** If the original mixture is not an aqueous solution, place 5 ml. (or 10 ml.) of it in a 10 ml. (or 25·ml.) distilling flask, immerse the latter in a small beaker of cold water, and gradually heat to boiling. Observe the b.p. of any liquid which passes over and set it aside for subsequent examination. Determine the water solubility of any residue. If it dissolves in water, examine it by Table **XI,9,2** ; if it is insoluble in water, apply Table **XI,9,1.**

(v) **Test for elements.** If the mixture is an aqueous solution, evaporate a small portion (*ca.* 1 ml.) to dryness upon platinum foil or in a small crucible. Use a portion of the residue to test for elements (Section **XI,3**) and another portion for the *Ignition Test* (vi).

If no water is present in the mixture, use it directly in the tests for elements.

(vi) **Ignition test.** Place 0·1–0·2 g. of the mixture on a porcelain crucible cover : heat gently at first over a small flame and finally ignite strongly. Observe :

(*a*) The inflammability and nature of the flame (*e.g.*, smoky or otherwise).

(*b*) Odour of gases or vapours evolved (*CAUTION !*).

(*c*) Whether a residue is left after ignition ; moisten with hydrochloric acid and test with a platinum wire.

(vii) **Miscellaneous solubility tests.** If water is absent, carry out the following tests. Treat 1 ml. of the mixture with 5 per cent. sodium hydroxide solution until strongly alkaline : note whether an oil or solid separates, whether any ammonia is evolved, and any colour changes which occur. Heat to boiling and cool: compare odour with that of the original mixture (a change in odour may indicate the presence of esters). Add dilute hydrochloric acid and observe the result.

Treat 1 ml. of the mixture with dilute hydrochloric acid until strongly acid. Note any evolution of gas or the separation of a solid. Add dilute sodium hydroxide solution and observe the effect.

(viii) **Miscellaneous class reactions.** Determine the effect of the following class reagents upon small portions of the original mixture: (*a*) bromine in carbon tetrachloride solution, (*b*) potassium permanganate solution, (*c*) alcoholic silver nitrate solution, (*d*) 2 : 4-dinitrophenylhydrazine reagent, (*e*) Schiff's reagent, (*f*) acetyl chloride, (*g*) benzoyl chloride (in the presence of aqueous sodium hydroxide), (*h*) sodium (only if water is absent), (*i*) ferric chloride solution, and (*j*) bromine water.

B. SOLID MIXTURES

(i) **Physical properties.** Observe the colour, odour and crystalline form. Examine with a lens or a microscope, if available.

(ii) **Solubility in water.** Determine the solubility of 1·0 g. of the sample in water. If in doubt as to whether a portion of the mixture dissolves, remove the supernatant liquid with a dropper and evaporate to dryness on a water bath. Determine the reaction of the aqueous solution or suspension to litmus and to phenolphthalein.

(iii) **Test for elements.** See Section **XI,3.**

(iv) **Ignition test.** Place 0·1–0·2 g. of the mixture upon a porcelain crucible cover or upon a piece of platinum foil; heat gently at first and finally ignite strongly. Note:

(*a*) Whether the mixture melts and if decomposition occurs.

(*b*) The inflammability and the nature of the flame (*e.g.*, if smoky or otherwise).

(*c*) Whether a residue is obtained after ignition (moisten with hydrochloric acid and test with a platinum wire).

(v) **Miscellaneous solubility tests.** Test the solubility behaviour of 0·5–1 g. of the mixture to 5 per cent. sodium hydroxide solution, 5 per cent. sodium bicarbonate solution and to 5 per cent. hydrochloric acid (for details, see under *Liquid Mixtures*).

(vi) **Miscellaneous class reactions.** Determine the effect of the following class reagents upon small portions of the original mixture (for some of the tests an aqueous solution or suspension may be used): (*a*) bromine in carbon tetrachloride solution, (*b*) potassium permanganate solution, (*c*) alcoholic silver nitrate solution, (*d*) 2 : 4-dinitrophenylhydrazine reagent, (*e*) Schiff's reagent, (*f*) acetyl chloride, (*g*) benzoyl chloride (in the presence of aqueous sodium hydroxide), (*h*) ferric chloride solution and (*i*) bromine water.

A careful consideration of the results of the above tests will provide much useful information and will indicate which of the following general procedures should be applied and the modifications which are necessary. Thus if nitrogen is absent, it is doubtful whether the separation for bases would be necessary.

2. SEPARATION OF WATER-INSOLUBLE MIXTURES

If the water-insoluble mixture is a liquid, evaporate a small sample (say, 4 ml.) in an evaporating dish on a water bath in order to determine the amount of volatile components, if any. If the solvent distils at the temperature of the boiling water bath, it is advisable to distil off this solvent on a water bath and to replace it by ether.

Place 15–20 ml. of the liquid mixture in a 50 ml. distilling flask arranged for distillation (Fig. *II*, *13*, 2), and heat the flask on a boiling water bath until no more liquid passes over : redistil the distillate and if it is a single substance, identify it in the usual manner. Dissolve the residue (*R*) in ether and employ the same proportions as given for a solid mixture.

Step 1. Extraction and separation of the acidic components. Shake 5–10 g. of the solid mixture (or of the residue *R* obtained after the removal of the solvent on a water bath) with 50 ml. of pure ether.* If there is a residue (this probably belongs to Solubility Group II or it may be a polysaccharide), separate it by filtration, preferably through a sintered glass funnel, and wash it with a little ether. Shake the resulting ethereal solution in a small separatory funnel with 15 ml. portions of 5 per cent. aqueous sodium hydroxide solution until *all* the acidic components have been removed. Three portions of alkali are usually sufficient. Set aside the residual ethereal solution (E_1) for *Step 2.* Combine the sodium hydroxide extracts and wash the resulting mixture with 15–20 ml. of ether : place the ether in the *ETHER RESIDUES* bottle. Render the alkaline extract acid to litmus with dilute sulphuric acid and then add excess of solid sodium bicarbonate.

Separate any *phenolic or enolic compounds* which may be present by extracting the sodium bicarbonate solution with two 20 ml. portions of ether ; remove the ether from the extract and examine any residue for phenols (or enols).

Strongly acidify the residual sodium bicarbonate solution to Congo red with dilute sulphuric acid. If a solid acid forms, filter. Extract the filtrate or the acidified solution with two 20 ml. portions of ether : keep the aqueous solution (*A*). Distil off the ether, and add the residual acid (if a solid) to the solid separated by filtration. Identify the acid.

Now distil the filtrate (*A*) and collect the distillate as long as it is acid to litmus. Should any solid separate out in the distilling flask during the distillation, add more water to dissolve it. Set aside the residue (*B*) in the flask. Identify the volatile acid in the distillate. A simple method is to just neutralise it with sodium hydroxide solution, evaporate to dryness and convert the residual sodium salt into the S-benzyl-*iso*-thiuronium salt (Section **III,85**,*5*).

The residue (*B*) in the distilling flask may still contain a water-soluble, non-volatile acid. Cool the acid solution. neutralise it with dilute sodium hydroxide solution to Congo red, and evaporate to dryness on a water bath under reduced pressure (water pump). Heat a little of the residual salt (*C*) upon the tip of a nickel spatula in a Bunsen flame and observe whether any charring takes place. If charring occurs, thus

---

* Peroxide-free ether should be employed : for detection and removal of peroxides in diethyl ether, see Section **II,47**,*1*.

indicating the presence of organic matter, extract the solid residue with 25 ml. portions of hot absolute ethyl alcohol. Evaporate the alcoholic extract and identify the material which remains. The residue (*C*) contains the sodium salt of a water-soluble, non-volatile acid, which may be characterised as the S-benzyl-*iso*-thiuronium salt.

Step 2. Extraction of the basic components. Extract the ethereal solution (E_1) with 15 ml. portions of 5 per cent. hydrochloric acid until *all* the basic components have been removed : two or three portions of acid are usually sufficient. Preserve the residual ethereal solution (E_2) for the separation of the neutral components. Wash the combined acid extracts with 15–20 ml. of ether : discard the ether extract as in *Step 1.* Make the acid extract alkaline with 10–20 per cent. sodium hydroxide solution : if any basic component separates, extract it with ether, evaporate the ether, and characterise the residue. If a water-soluble base is also present, it may be recognised by its characteristic ammoniacal odour : it may be isolated from the solution remaining after the separation of the insoluble base by ether extraction by distilling the aqueous solution as long as the distillate is alkaline to litmus. Identify the base with the aid of phenyl *iso*-thiocyanate (compare Section **III,123**) or by other means.

Step 3. The neutral components. The ethereal solution (E_2) remaining after the acid extraction of *Step 2* should contain only the neutral compounds of Solubility Groups V, **VI** and VII (see Table **XI,5**). Dry it with a little anhydrous magnesium sulphate, and distil off the ether. If a residue is obtained, neutral compounds are present in the mixture. Test a portion of this with respect to its solubility in concentrated sulphuric acid ; if it dissolves in the acid, pour the solution slowly and cautiously into ice water and note whether any compound is recovered. Examine the main residue for homogeneity and if it is a mixture devise procedures, based for example upon differences in volatility, solubility in inert solvents, reaction with hydrolytic and other reagents, to separate the components.

The above procedure for water-insoluble mixtures is shown, in outline, in tabular form in Table **XI,9,1.** If the mixture is a liquid, the volatile solvent is assumed to have been removed.

TABLE XI,9,1. GENERAL SCHEME FOR SEPARATION OF A WATER-INSOLUBLE MIXTURE

Treat the mixture with pure ether and filter, if necessary.					
Residue. Examine for polysaccharides etc., according to nature of original mixture.	**Filtrate or ether solution.** Extract with 5% NaOH solution and separate the ethereal layer.				
	Sodium hydroxide extract. This will contain the acids and phenols (or enols) present. Acidify (litmus) with dilute sulphuric acid, add excess of solid $NaHCO_3$. Extract with ether.		**Ether solution (E_1).** Extract with 5% HCl. Separate ether layer.		
			Hydrochloric acid extract. This will contain any basic components present. Render alkaline with 10–20% NaOH and extract with ether.		**Ether solution (E_2).** This will contain any neutral compounds present. Dry with anhydrous magnesium sulphate, and distil off the ether. A residue indicates the presence of a **neutral component.** Determine the solubility of a portion in conc. H_2SO_4. Apply any other suitable tests.
	Ether solution. Contains **phenolic** (or enolic) **compounds.**	**Sodium bicarbonate solution.** Acidify with dilute H_2SO_4. (i) Filter or extract **acid** with ether. (ii) Distil aqueous solution (A) from (i) as long as distillate is acid to recover **water-soluble volatile acids.** (iii) Neutralise aqueous solution (B) from (ii), evaporate to dryness, and extract with absolute ethyl alcohol to recover **water-soluble, non-volatile compounds.** The residue may contain the sodium salt of a water soluble, non-volatile acid.	**Ether solution.** Contains **water-insoluble amines.**	**Aqueous solution.** Will possess ammoniacal odour of water-soluble amines present. Distil as long as distillate is alkaline to recover **volatile water-soluble amines.**	

3. SEPARATION OF WATER-SOLUBLE MIXTURES

A water-soluble mixture may be in the form of a mixture of water-soluble solids or in the form of a liquid. The liquid mixtures are frequently aqueous solutions. The preliminary examination of a liquid mixture (see *1*) will indicate whether a volatile solvent (*i.e.*, removable on a boiling water bath) is present. If a volatile solvent is present, distil 20 g. of the mixture from a water bath until no more liquid passes over: set aside the volatile solvent for identification. Dissolve the residue (*R*) in water as detailed below for a mixture of solids.

Step 1. Distillation from acid solution and the separation of the volatile acidic and neutral compounds. Dissolve 6–10 g. of a solid mixture in 50–75 ml. of water: for a liquid mixture, use 6–10 g. of the residue (*R*) (non-volatile from a boiling water bath) and dilute with 50–75 ml. of water: for an aqueous solution use sufficient of it to contain 6–10 g. of the dissolved components and dilute, if necessary, to 50–75 ml. Acidify the solution with sufficient 20 per cent. sulphuric acid to decompose the salts of all the acidic components and to ensure the presence of a slight excess of acid: many organic acids give an acid reaction with Congo red, hence it is necessary to add the sulphuric acid somewhat beyond the point at which the mixture is acid to this indicator. If an insoluble acidic component separates, filter it off and identify it. Distil the acid solution so long as the distillate appears turbid, or is acid to litmus, or until 100–150 ml. are collected: in the last case, add more water to the contents of the distilling flask if the volume has been reduced below one-fourth of the original volume. Keep the residue (R_1) in the distilling flask for *Step 2.*

The distillate may contain volatile neutral compounds as well as volatile acids and phenols. Add a slight excess of 10–20 per cent. sodium hydroxide solution to this distillate and distil until the liquid passes over clear or has the density of pure water. The presence of a volatile, water-soluble neutral compound is detected by a periodic determination of the density (see Section XI,2); if the density is definitely less than unity, the presence of a neutral compound may be assumed. Keep this solution (S_1) for *Step 4.*

Cool the alkaline solution resulting from the distillation of the volatile neutral compounds, make it acid to litmus with dilute sulphuric acid, and add an excess of *solid* sodium bicarbonate. Extract this bicarbonate solution with two 20 ml. portions of ether; remove the ether from the combined ether extracts and identify the residual phenol (or enol). Then acidify the bicarbonate solution cautiously with dilute sulphuric acid; if an acidic compound separates, remove it by two extractions with 20 ml. portions of ether; if the acidified solution remains clear, distil and collect any water-soluble, volatile acid in the distillate. Characterise the acid as under *2.*

Step 2. Distillation from alkaline solution. Treat the solution (R_1) remaining in the distilling flask after the volatile acidic and neutral compounds have been removed with 10–20 per cent. sodium hydroxide solution until distinctly alkaline. If a solid separates, filter it off and identify it. Distil the alkaline solution until no more volatile bases pass over (turbid distillate or no further basic reaction to litmus: water-soluble bases also possess characteristic odours): add more water to the contents of the flask if the solution becomes too concentrated during this distillation. (Set aside the solution in the distilling flask (S_2) for *Step 3.*) If the volatile basic compounds are insoluble in water, remove them by extraction with two 20 ml. portions of ether, and identify the bases (compare Sections **III,123** and **IV,100**) after evaporation of the ether. The water-soluble amines may be identified with phenyl *iso*-thiocyanate: it is best to concentrate the bases by redistilling and collecting the first half of the distillate separately.

Step 3. The non-steam-volatile compounds. The alkaline solution (S_2) remaining in the distilling flask from *Step 2* may contain water-soluble, non-volatile acidic, basic or neutral compounds. Add dilute sulphuric acid until the solution is just acid to Congo red, evaporate to dryness, and extract the residual solid with boiling absolute ethyl alcohol: extraction is complete when the undissolved salt exhibits no sign of charring when heated on a metal spatula in the Bunsen flame. Evaporate the alcoholic solution to dryness and identify the residue.

Step 4. The steam-volatile neutral compounds. The solution (S_1) containing water-soluble neutral compounds obtained in *Step 1* is usually very dilute. It is advisable to concentrate it by distillation until about one-third to one-half of the original volume is collected as distillate; the process may be repeated if necessary and the progress of the concentration may be followed by determination of the densities of the distillates. It is frequently possible to salt out the neutral components from the concentrated distillate by saturating it with solid potassium carbonate. If a layer of neutral compound makes its appearance, remove it. Treat this upper layer (which usually contains much water) with solid anhydrous potassium carbonate: if another aqueous layer forms, separate the upper organic layer and add more anhydrous potassium carbonate to it. Identify the neutral compound.

Notes.

Some neutral compounds (*e.g.*, methyl alcohol) cannot be salted out with potassium carbonate: distillation of the saturated aqueous potassium carbonate solution frequently yields the organic compound in a comparatively pure state, or at least in sufficiently concentrated a form to enable certain derivatives to be prepared.

The above procedure for the separation of a water-soluble mixture is summarised in Table **XI,9,2.**

TABLE XI,9,2. GENERAL SCHEME FOR SEPARATION OF A WATER-SOLUBLE MIXTURE

<table>
<tr><td colspan="7">Acidify the aqueous solution (50–75 ml.): prepared from (<i>a</i>) 6–10 g. of the solid mixture, (<i>b</i>) from 6–10 g. of the liquid residue (<i>R</i>) after distillation from a boiling water bath, or (<i>c</i>) from sufficient of original aqueous solution to contain 6–10 g. of solute) with 20% H_2SO_4 and distil.</td></tr>
<tr><td colspan="4">Distillate. This will contain the steam-volatile acidic and neutral components present. Render alkaline with 10–20% NaOH and distil.</td><td colspan="3">Aqueous acid solution (R_1). Render alkaline with 10–20% NaOH and distil.</td></tr>
<tr><td rowspan="3">Distillate (S_1). This will contain the volatile neutral components present. Concentrate by distillation and saturate with solid K_2CO_3 : the neutral component may separate.</td><td colspan="3">Aqueous alkaline solution. This will contain any acids or phenols present. Cool, acidify (litmus) with dilute H_2SO_4, and add excess of solid $NaHCO_3$. Extract with ether.</td><td colspan="2">Distillate. Extract with ether.</td><td rowspan="3">Aqueous alkaline solution (S_2). Neutralise with dilute H_2SO_4 (Congo red). Evaporate to dryness and extract with absolute ethyl alcohol. The alcoholic extract contains the water-soluble, non-volatile components.</td></tr>
<tr><td rowspan="2">Ether solution. Contains phenolic compounds</td><td colspan="2">Sodium bicarbonate solution. Acidify with dilute H_2SO_4. Extract with ether.</td><td rowspan="2">Ether solution. Contains volatile water-insoluble amines.*</td><td rowspan="2">Aqueous solution. Concentrate by distillation contains volatile water-soluble amines.*</td></tr>
<tr><td>Ether solution. Contains volatile water-insoluble acids.</td><td>Aqueous solution. Distil. The distillate may contain volatile water-soluble acids.</td></tr>
</table>

* The separation of a mixture of amines by means of benzenesulphonyl chloride or *p*-toluenesulphonyl chloride (Hinsberg's procedure) is described in Section IV,100,(viii).