The background of the cover is a photograph of a laboratory setting. It features several pieces of glassware, including Erlenmeyer flasks and beakers, some containing liquids of various colors like orange, yellow, and blue. The lighting is soft, creating a bokeh effect with out-of-focus light spots. The overall color palette is warm, dominated by oranges, yellows, and blues.

PURIFICATION OF LABORATORY CHEMICALS

FOURTH EDITION

W. L. F. Armarego • D.D. Perrin

Argentum EX1031

Page 1

PURIFICATION
OF
LABORATORY
CHEMICALS

Fourth Edition

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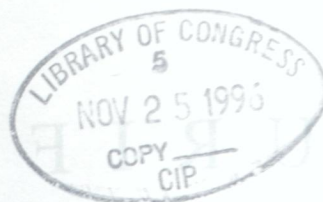
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the material to be purified, in a desiccator. The desiccator is sealed and left to stand at room temperature for several days. The volatile components distribute themselves between the two beakers whereas the non-volatile contaminants remain in the original beaker. This technique has afforded metal-free pure solutions of ammonia, hydrochloric acid and hydrogen fluoride.

SUBLIMATION

Sublimation differs from ordinary distillation because the vapour condenses to a solid instead of a liquid. Usually, the pressure in the heated system is diminished by pumping, and the vapour is condensed (after travelling a relatively short distance) on to a cold finger or some other cooled surface. This technique, which is applicable to many organic solids, can also be used with inorganic solids such as aluminium chloride, ammonium chloride, arsenious oxide and iodine. In some cases, passage of a stream of inert gas over the heated substance secures adequate vapourisation.

RECRYSTALLISATION

Techniques

The most commonly used procedure for the purification of a solid material by recrystallisation from a solution involves the following steps:

- (a) The impure material is dissolved in a suitable solvent, by shaking or vigorous stirring, at or near the boiling point, to form a near-saturated solution.
- (b) The hot solution is filtered to remove any insoluble particles. To prevent crystallisation during this filtration, a heated (jacketed) filter funnel can be used or the solution can be somewhat diluted with more of the solvent.
- (c) The solution is then allowed to cool so that the dissolved substance crystallises out.
- (d) The crystals are separated from the mother liquor, either by centrifuging or by filtering, under suction, through a sintered glass, a Hirsch or a Büchner, funnel. Usually, centrifuging is much preferred because of the much greater ease and efficiency of separating crystals and mother liquor, and also because of the saving of time and effort, particularly when very small crystals are formed or when there is entrainment of solvent.
- (e) The crystals are washed free from mother liquor with a little fresh cold solvent, then dried.

If the solution contains extraneous coloured material likely to contaminate the crystals, this can often be removed by adding some activated charcoal (decolourising carbon) to the hot, but not boiling, solution which is then shaken frequently for several minutes before being filtered. (The large active surface of the carbon makes it a good adsorbent for this purpose.) In general, the cooling and crystallisation step should be rapid so as to give small crystals which occlude less of the mother liquor. This is usually satisfactory with inorganic material, so that commonly the filtrate is cooled in an ice-water bath while being vigorously stirred. In many cases, however, organic molecules crystallise much more slowly, so that the filtrate must be set aside to cool to room temperature or left in the refrigerator. It is often desirable to subject material that is very impure to preliminary purification, such as steam distillation, Soxhlet extraction, or sublimation, before recrystallising it. A greater degree of purity is also to be expected if the crystallisation process is repeated several times, especially if different solvents are used. The advantage of several crystallisations from different solvents lies in the fact that the material sought, and its impurities, are unlikely to have similar solubilities as solvents and temperatures are varied.

For the final separation of solid material, sintered-glass discs are preferable to filter paper. Sintered glass is unaffected by strongly acid solutions or by oxidising agents. Also, with filter paper, cellulose fibres are likely to become included in the sample. The sintered-glass discs or funnels can be readily cleaned by washing in freshly prepared *chromic acid cleaning mixture*. This mixture is made by adding 100ml of concentrated sulphuric acid slowly with stirring to a solution of 5g of sodium dichromate in 5ml of water. (The mixture warms to about 70°).

For materials with melting points below 70° it is sometimes convenient to use dilute solutions in acetone, methanol, pentane, ethyl ether or $\text{CHCl}_3\text{-CCl}_4$. The solutions are cooled to -78° in Dry-ice, to give a filterable slurry which is filtered off through a precooled Büchner funnel. Experimental details, as applied to the purification of nitromethane, are given by Parrett and Sun [*J Chem Educ* 54 448 1977].

Where substances vary little in solubility with temperature, isothermal crystallisation may sometimes be employed. This usually takes the form of a partial evaporation of a saturated solution at room temperature by leaving it under reduced pressure in a desiccator.

However, in rare cases, crystallisation is not a satisfactory method of purification, especially if the impurity forms crystals that are isomorphous with the material being purified. In fact, the impurity content may even be greater in

such recrystallised material. For this reason, it still remains necessary to test for impurities and to remove or adequately lower their concentrations by suitable chemical manipulation prior to recrystallisation.

Filtration

Filtration removes particulate impurities rapidly from liquids and is also used to collect insoluble or crystalline solids which separate or crystallise from solution. The usual technique is to pass the solution, cold or hot, through a fluted filter paper in a conical glass funnel (see Vogel's *Textbook of Practical Organic Chemistry*, p 46).

If a solution is hot and needs to be filtered rapidly a Büchner funnel and flask are used and filtration is performed under a slight vacuum (water pump), the filter medium being a circular cellulose filter paper wet with solvent. If filtration is slow, even under high vacuum, a pile of about twenty filter papers, wet as before, are placed in the Büchner funnel and, as the flow of solution slows down, the upper layers of the filter paper are progressively removed. Alternatively, a filter aid, e.g. Celite, Florisil or Hyflo-supercel, is placed on top of a filter paper in the funnel. When the flow of the solution (under suction) slows down the upper surface of the filter aid is scratched gently. Filter papers with various pore sizes are available covering a range of filtration rates. Hardened filter papers are slow filtering but they can withstand acidic and alkaline solutions without appreciable hydrolysis of the cellulose (see Table 3). When using strong acids it is preferable to use glass micro fibre filters which are commercially available (see Table 3).

Freeing a solution from extremely small particles (e.g. for ORD or CD measurements) requires filters with very small pore size. Commercially available (Millipore, Gelman, Nucleopore) filters other than cellulose or glass include nylon, Teflon, and polyvinyl chloride, and the pore diameter may be as small as 0.01 micron (see Table 4). Special containers are used to hold the filters, through which the solution is pressed by applying pressure, e.g. from a syringe. Some of these filters can be used to clear strong sulphuric acid solutions.

As an alternative to the Büchner funnel for collecting crystalline solids, a funnel with a sintered glass-plate under suction may be used. Sintered-glass funnels with various porosities are commercially available and can easily be cleaned with warm chromic or nitric acid (see above).

When the solid particles are too fine to be collected on a filter funnel because filtration is extremely slow, separation by **centrifugation** should be used. Bench type centrifuges are most convenient for this purpose. The solid is placed in the centrifuge tube, the tubes containing the solutions on opposite sides of the rotor should be balanced accurately (at least within 0.05 to 0.1g), and the solutions are spun at maximum speed for as long as it takes to settle the solid (usually *ca* 3-5 minutes). The solid is washed with cold solvent by centrifugation, and finally twice with a pure volatile solvent in which the solid is insoluble, also by centrifugation. After decanting the supernatant the residue is dried in a vacuum, at elevated temperatures if necessary. In order to avoid "spitting" and contamination with dust while the solid in the centrifuge tube is dried, the mouth of the tube is covered with silver paper and held fast with a tight rubber band near the lip. The flat surface of the silver paper is then perforated in several places with a pin.

Choice of Solvents

The best solvents for recrystallisation have the following properties:

- The material is much more soluble at higher temperatures than it is at room temperature or below.
- Well-formed (but not large) crystals are produced.
- Impurities are either very soluble or only sparingly soluble.
- The solvent must be readily removed from the purified material.
- There must be no reaction between the solvent and the substance being purified.
- The solvent must not be inconveniently volatile or too highly flammable. (These are reasons why ethyl ether and carbon disulphide are not commonly used in this way.)

The following generalisations provide a rough guide to the selection of a suitable solvent:

- Substances usually dissolve best in solvents to which they are most closely related in chemical and physical characteristics. Thus, hydroxylic compounds are likely to be most soluble in water, methanol, ethanol, acetic acid or acetone. Similarly, petroleum ether might be used with water-insoluble substances. However, if the resemblance is too close, solubilities may become excessive.
- Higher members of homologous series approximate more and more closely to their parent hydrocarbon.
- Polar substances are more soluble in polar, than in non-polar, solvents.

Although Chapters 3, 4 and 5 provide details of the solvents used for recrystallising a large portion of commercially available laboratory chemicals, they cannot hope to be exhaustive, nor need they necessarily be the best choice. In other cases where it is desirable to use this process, it is necessary to establish whether a given solvent is suitable. This is usually done by taking only a small amount of material in a small test-tube and adding enough solvent to cover it. If it dissolves readily in the cold or on gentle warming, the solvent is unsuitable. Conversely, if it remains insoluble when the solvent is heated to boiling (adding more solvent if necessary), the solvent is again unsuitable. If the material dissolves in the hot solvent but does not crystallise readily within several minutes of cooling in an ice-salt mixture, another solvent should be tried. Solvents commonly used for recrystallisation, and their boiling points, are given in Table 5.

Mixed Solvents

Where a substance is too soluble in one solvent and too insoluble in another, for either to be used for recrystallisation, it is often possible (provided they are miscible) to use them as a mixed solvent. (In general, however, it is preferable to use a single solvent if this is practicable.) Table 6 contains many of the common pairs of miscible solvents.

The technique of recrystallisation from a mixed solvent is as follows:

The material is dissolved in the solvent in which it is the more soluble, then the other solvent (heated to near boiling) is added cautiously to the hot solution until a slight turbidity persists or crystallisation begins. This is cleared by adding several drops of the first solvent, and the solution is allowed to cool and crystallise in the usual way.

A variation of this procedure is simply to precipitate the material in a microcrystalline form from solution in one solvent at room temperature, by adding a little more of the second solvent, filtering this off, adding a little more of the second solvent and repeating the process. This ensures, at least in the first or last precipitation, a material which contains as little as possible of the impurities which may also be precipitated in this way. With salts the first solvent is commonly water, and the second solvent is alcohol or acetone.

Recrystallisation from the Melt

A crystalline solid melts when its temperature is raised sufficiently for the thermal agitation of its molecules or ions to overcome the restraints imposed by the crystal lattice. Usually, impurities weaken crystal structures, and hence lower the melting points of solids (or the freezing points of liquids). If an impure material is melted and cooled slowly (with the addition, if necessary, of a trace of solid material near the freezing point to avoid supercooling), the first crystals that form will usually contain less of the impurity, so that fractional solidification by partial freezing can be used as a purification process for solids with melting points lying in a convenient temperature range (or for more readily frozen liquids). In some cases, impurities form higher melting eutectics with substances to be purified, so that the first material to solidify is less pure than the melt. For this reason, it is often desirable to discard the first crystals and also the final portions of the melt. Substances having similar boiling points often differ much more in melting points, so that fractional solidification can offer real advantages, especially where ultrapurity is sought.

The technique of recrystallisation from the melt as a means of purification dates back from its use by Schwab and Wichers (*J Res Nat Bur Stand* 25 747 1940) to purify benzoic acid. It works best if material is already nearly pure, and hence tends to be a final purification step. A simple apparatus for purifying organic compounds by progressive freezing is described by Matthias and Coggeshall (*AC* 31 1124 1959). In principle, the molten substance is cooled slowly by progressive lowering of the tube containing it into a suitable bath. For temperatures between 0° and 100°, waterbaths are convenient. Where lower temperatures are required, the cooling baths given in Table 7 can be used. Cooling is stopped when part of the melt has solidified, and the liquid phase is drained off. Column crystallisation has been used to purify stearyl alcohol, cetyl alcohol, myristic acid; fluorene, phenanthrene, biphenyl, terphenyls, dibenzyl; phenol, 2-naphthol; benzophenone and 2,4-dinitrotoluene; and many other organic (and inorganic) compounds. [See, for example, *Developments in Separation Science* N.N.Lee (ed), CRC Press, Cleveland, Ohio, 1972]. Thus, an increase in purity from 99.80 to 99.98 mole% was obtained when acetamide was slowly crystallised in benzene [Schwab and Wichers *J Res Nat Bur Stand* 32 253 1944].

Fractional solidification and its applications to obtaining ultrapure chemical substances, has been treated in detail in *Fractional Solidification* by M.Zief and W.R.Wilcox eds, Edward Arnold Inc, London 1967, and *Purification of Inorganic and Organic Materials* by M.Zief, Marcel Dekker Inc, New York 1969. These monographs should be consulted for discussion of the basic principles of solid-liquid processes such as zone melting, progressive freezing and column crystallisation, laboratory apparatus and industrial scale equipment, and examples of applications. These include the removal of cyclohexane from benzene, and the purification of aromatic amines, dienes and naphthalene,

and inorganic species such as the alkali iodides, potassium chloride, indium antimonide and gallium trichloride. The authors also discuss analytical methods for assessing the purity of the final material.

Zone Refining

Zone refining (or zone melting) is a particular development for fractional solidification and is applicable to all crystalline substances that show differences in soluble impurity concentration in liquid and solid states at solidification. The apparatus used in this technique consists essentially of a device by which a narrow molten zone moves slowly down a long tube filled with the material to be purified. The machine can be set to recycle repeatedly. At its advancing side, the zone has a melting interface with the impure material whereas on the upper surface of the zone there is a constantly growing face of higher-melting, resolidified material. This leads to a progressive increase in impurity in the liquid phase which, at the end of the run, is discarded. Also, because of the progressive increase in impurity in the liquid phase, the resolidified material becomes correspondingly less further purified. For this reason, it is usually necessary to make several zone-melting runs before a sample is satisfactorily purified. This is also why the method works most successfully if the material is already fairly pure. In all these operations the zone must travel slowly enough to enable impurities to diffuse or be convected away from the area where resolidification is occurring.

The technique finds commercial application in the production of metals of extremely high purity (impurities down to 10^{-9} ppm), in purifying refractory oxides, and in purifying organic compounds, using commercially available equipment. Criteria for indicating that definite purification is achieved include elevation of melting point, removal of colour, fluorescence or smell, and a lowering of electrical conductivity. Difficulties likely to be met with in organic compounds, especially those of low melting points and low rates of crystallisation, are supercooling and, because of surface tension and contraction, the tendency of the molten zone to seep back into the recrystallised areas. The method is likely to be useful in cases where fractional distillation is not practicable, either because of unfavourable vapour pressures or ease of decomposition, or where super-pure materials are required. It has been used for the latter purpose with anthracene, benzoic acid, chrysene, morphine and pyrene. (See references on p. 47).

DRYING

Removal of Solvents

Where substances are sufficiently stable, removal of solvent from recrystallised materials presents no problems. The crystals, after filtering at the pump (and perhaps air-drying by suction), are heated in an oven above the boiling point of the solvent (but below their melting point), followed by cooling in a desiccator. Where this treatment is inadvisable, it is still often possible to heat to a lower temperature under reduced pressure, for example in an Abderhalden pistol. This device consists of a small chamber which is heated externally by the vapour of a boiling solvent. Inside this chamber, which can be evacuated by a water pump or some other vacuum pump, is placed a small boat containing the sample to be dried and also a receptacle with a suitable drying agent. Convenient liquids for use as boiling liquids in an Abderhalden pistol, and their temperatures, are given in Table 9. In cases where heating above room temperature cannot be used, drying must be carried out in a vacuum desiccator containing suitable absorbants. For example, hydrocarbons, such as benzene, cyclohexane and petroleum ether, can be removed by using shredded paraffin wax, and acetic acid and other acids can be absorbed by pellets of sodium, or potassium, hydroxide. However, in general, solvent removal is less of a problem than ensuring that the water content of solids and liquids is reduced below an acceptable level.

Removal of Water

Methods for removing water from solids depends on the thermal stability of the solids or the time available. The safest way is to dry in a vacuum desiccator over concentrated sulphuric acid, phosphorus pentoxide, silica gel, calcium chloride, or some other desiccant. Where substances are stable in air and melt above 100° drying in an air oven may be adequate. In other cases, use of an Abderhalden pistol may be satisfactory.

Often, in drying inorganic salts, the final material that is required is a hydrate. In such cases, the purified substance is left in a desiccator to equilibrate above an aqueous solution having a suitable water-vapour pressure. A convenient range of solutions used in this way is given in Table 10.

The choice of desiccants for drying liquids is more restricted because of the need to avoid all substances likely to react with the liquids themselves. In some cases, direct distillation of an organic liquid is a suitable method for drying both solids and liquids, especially if low-boiling azeotropes are formed. Examples include acetone, aniline, benzene, chloroform, carbon tetrachloride, ethylene dichloride, heptane, hexane, methanol, nitrobenzene, petroleum ether, toluene and xylene. Addition of benzene can be used for drying ethanol by distillation. In carrying out distillations intended to yield anhydrous products, the apparatus should be fitted with guard-tubes containing calcium chloride or silica gel to prevent entry of moist air into the system. (Many anhydrous organic liquids are appreciably hygroscopic).

**TABLE 5. COMMON SOLVENTS USED IN RECRYSTALLISATION
(and their boiling points)**

Acetic acid (118°)	*Cyclohexane (81°)	Methyl cyanide (82°)
*Acetone (56°)	Diethyl cellosolve (121°)	Methylene chloride (41°)
Acetylacetone (139°)	*Diethyl ether (34.5°)	*Methyl ethyl ketone (80°)
*Benzene (80°)	Dimethyl formamide (76°/39mm)	Methyl isobutyl ketone (116°)
Benzyl alcohol (93°/10mm)	*Dioxane (101°)	Nitrobenzene (210°)
<i>n</i> -Butanol (118°)	*Ethanol (78°)	Nitromethane (101°)
Butyl acetate (126.5°)	*Ethyl acetate (78°)	*Petroleum ether (various)
<i>n</i> -Butyl ether (142°)	Ethyl benzoate (98°/19mm)	Pyridine (115.5°)
γ -Butyrolactone (206°)	Ethylene glycol (68°/4mm)	Pyridine trihydrate (93°)
Carbon tetrachloride (77°)	Formamide (110°/10mm)	*Tetrahydrofuran (64-66°)
Cellosolve (135°)	Glycerol (126°/11mm)	Toluene (110°)
Chlorobenzene (132°)	Isoamyl alcohol (131°)	Trimethylene glycol (59°/11mm)
Chloroform (61°)	*Methanol (64.5°)	Water (100°)

*Highly flammable, should be heated or evaporated on steam or electrically heated water baths only (preferably in a nitrogen atmosphere).

TABLE 6. PAIRS OF MISCIBLE SOLVENTS

Acetic acid: with chloroform, ethanol, ethyl acetate, methyl cyanide, petroleum ether, or water.
Acetone: with benzene, butyl acetate, butyl alcohol, carbon tetrachloride, chloroform, cyclohexane, ethanol, ethyl acetate, methyl acetate, methyl cyanide, petroleum ether or water.
Ammonia: with ethanol, methanol, pyridine.
Aniline: with acetone, benzene, carbon tetrachloride, ethyl ether, <i>n</i> -heptane, methanol, methyl cyanide or nitrobenzene.
Benzene: with acetone, butyl alcohol, carbon tetrachloride, chloroform, cyclohexane, ethanol, methyl cyanide, petroleum ether or pyridine.
Butyl alcohol: with acetone or ethyl acetate.
Carbon disulphide: with petroleum ether.
Carbon tetrachloride: with cyclohexane.
Chloroform: with acetic acid, acetone, benzene, ethanol, ethyl acetate, hexane, methanol or pyridine.
Cyclohexane: with acetone, benzene, carbon tetrachloride, ethanol or ethyl ether.
Dimethyl formamide: with benzene, ethanol or ether.
Dimethyl sulphoxide: with acetone, benzene, chloroform, ethanol, ethyl ether or water.
Dioxane: with benzene, carbon tetrachloride, chloroform, ethanol, ethyl ether, pet. ether, pyridine or water.
Ethanol: with acetic acid, acetone, benzene, chloroform, cyclohexane, dioxane, ethyl ether, pentane, toluene, water or xylene.
Ethyl acetate: with acetic acid, acetone, butyl alcohol, chloroform, or methanol.
Ethyl ether: with acetone, cyclohexane, ethanol, methanol, methylal, methyl cyanide, pentane or pet.ether.
Glycerol: with ethanol, methanol or water.
Hexane: with benzene, chloroform or ethanol.
Methanol: with chloroform, ethyl ether, glycerol or water.
Methylal: with ethyl ether.
Methyl ethyl ketone: with acetic acid, benzene, ethanol or methanol.
Nitrobenzene: with aniline, methanol or methyl cyanide.
Pentane: with ethanol or ethyl ether.
Petroleum ether: with acetic acid, acetone, benzene, carbon disulphide or ethyl ether.
Phenol: with carbon tetrachloride, ethanol, ethyl ether or xylene.
Pyridine: with acetone, ammonia, benzene, chloroform, dioxane, petroleum ether, toluene or water.
Toluene: with ethanol, ethyl ether or pyridine.
Water: with acetic acid, acetone, ethanol, methanol, or pyridine.
Xylene: with ethanol or phenol.

material. The phenol is recovered by acidification of the aqueous phase with 20% sulphuric acid, and either extracted with ether or steam distilled. In the second case the phenol is extracted from the steam distillate after saturating it with sodium chloride. A solvent is necessary when large quantities of liquid phenols are purified. The phenol is fractionated by distillation under reduced pressure, preferably in an atmosphere of nitrogen to minimize oxidation. Solid phenols can be crystallised from toluene, petroleum ether or a mixture of these solvents, and can be sublimed under vacuum. Purification can also be effected by fractional crystallisation or zone refining. For further purification of phenols *via* their acetyl or benzoyl derivatives, see p. 53.

Polypeptides and proteins . See Chapter 5.

Quinones. These are neutral compounds which are usually coloured. They can be separated from acidic or basic impurities by extraction of their solutions in organic solvents with aqueous basic or acidic solutions, respectively. Their colour is a useful property in their purification by chromatography through an alumina column with, e.g. toluene as eluent. They are volatile enough for vacuum sublimation, although with high-melting quinones a very high vacuum is necessary. *p*-Quinones are stable compounds and can be recrystallised from water, ethanol, aqueous ethanol, toluene, petroleum ether or glacial acetic acid. *o*-Quinones, on the other hand, are readily oxidised. They should be handled in an inert atmosphere, preferably in the absence of light.

Salts (organic). (a) **With metal ions:** Water-soluble salts are best purified by preparing a concentrated aqueous solution to which, after decolorising with charcoal and filtering, ethanol or acetone is added so that the salts crystallise. They are collected, washed with aqueous ethanol or aqueous acetone, and dried. In some cases, water-soluble salts can be recrystallised satisfactorily from alcohols. Water-insoluble salts are purified by Soxhlet extraction, first with organic solvents and then with water, to remove soluble contaminants. The purified salt is recovered from the thimble.

(b) **With organic ions:** Organic salts (e.g. trimethylammonium benzoate) are usually purified by recrystallisation from polar solvents (e.g. water, ethanol or dimethyl formamide). If the salt is too soluble in a polar solvent, its concentrated solution should be treated dropwise with a miscible nonpolar solvent (see p. 14) until crystallisation begins.

(c) **Sodium alkane disulphonates:** Purified from sulphites by boiling with aq HBr. Purified from sulphates by adding BaBr₂. Sodium alkane disulphonates are finally pptd by addition of MeOH. [Pethybridge and Taba *JCSFT* 1 78 1331 1982].

Sulphur compounds. (a) **Disulphides** can be purified by extracting acidic and basic impurities with aqueous base or acid, respectively. However, they are somewhat sensitive to strong alkali which slowly cleaves the disulphide bond. The lower-melting members can be fractionally distilled under vacuum. The high members can be recrystallised from alcohol, toluene or glacial acetic acid.

(b) **Sulphones** are neutral and extremely stable compounds that can be distilled without decomposition. They are freed from acidic and basic impurities in the same way as disulphides. The low molecular weight members are quite soluble in water but the higher members can be recrystallised from water, ethanol, aqueous ethanol or glacial acetic acid.

(c) **Sulphoxides** are odourless, rather unstable compounds, and should be distilled under vacuum in an inert atmosphere. They are water-soluble but can be extracted from aqueous solution with a solvent such as ethyl ether.

(d) **Thioethers** are neutral stable compounds that can be freed from acidic and basic impurities as described for disulphides. They can be recrystallised from organic solvents and distilled without decomposition.

(e) **Thiols** are stronger acids than the corresponding hydroxy compounds but can be purified in a similar manner. However, care must be exercised in handling thiols to avoid their oxidation to disulphides. For this reason, purification is best carried out in an inert atmosphere in the absence of oxidising agents. Similarly, thiols should be stored out of contact with air. They can be distilled without change, and the higher-melting thiols (which are usually more stable) can be crystallised, e.g. from water or dilute alcohol. They oxidise readily in alkaline solution but can be separated from the disulphide which is insoluble in this medium. They should be stored in the dark below 0°. *All operations with thiols should be carried out in an efficient fume cupboard because of their unpleasant odour and their TOXICITY.*

(f) **Thiolsulphonates (disulphoxides)** are neutral and are somewhat light-sensitive compounds. Their most common impurities are sulphonyl chlorides (neutral) or the sulphinic acid or disulphide from which they are usually derived. The first can be removed by partial freezing or crystallisation, the second by shaking with dilute

alkali, and the third by recrystallisation because of the higher solubility of the disulphide in solvents. Thiolsulphonates decompose slowly in dilute, or rapidly in strong, alkali to form disulphides and sulphonic acids. Thiolsulphonates also decompose on distillation but they can be steam distilled. The solid members can be recrystallised from water, alcohols or glacial acetic acid.

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S- α -Pinene [7785-26-4] M 136.2, b 155-156°/760mm, d 0.858, n 1.4634, $[\alpha]_D^{20}$ -47.2°. Isomerised by heat, acids and certain solvents. Should be distd under reduced pressure under nitrogen and stored in the dark. Purified *via* the nitrosochloride [Waterman et al. *Rec Trav Chim Pays-Bas* 48 1191 1929]. For purification of optically active forms see Lynn [*JACS* 91 361 1919].

Small quantities (0.5ml) have been purified by GLC using helium as carrier gas and a column at 90° packed with 20 wt% of polypropylene sebacate on a Chromosorb support. Larger quantities were fractionally distd under reduced pressure in a column packed with stainless steel gauze spirals. Material could be dried with CaH₂ or sodium, and stored in a refrigerator: CaSO₄ and silica gel were not satisfactory because they induced spontaneous isomerisation. [Bates, Best and Williams *JCS* 1521 1962].

dl-Pipecolic acid [4043-87-2] M 129.1, m 264°. Crystd from water.

Piperazine [110-85-0] M 86.1, m 110-112°, 44° (hexahydrate 142-63-2) b 125-130°/760mm. Crystd from EtOH or anhydrous benzene, and dried at 0.01mm. It can be sublimed under vacuum and purified by zone melting.

Piperazine-N,N'-bis(2-ethanesulphonic acid) (PIPES) [5625-37-6] M 302.4. Crystd from boiling water (maximum solubility is about 1g/L) or as described for ADA, pK_a²⁰ 7.85.

Piperazine dihydrochloride (H₂O) [6094-40-2] M 177.1, m 82.5-83.5°. Crystd from aqueous EtOH. Dried at 110°.

Piperazine-2,5-dione [106-57-0] M 114.1, m 309-310°. Crystd from water.

Piperazine phosphate (H₂O) [18534-18-4] M 197.6. Crystd twice from water, air-dried and stored for several days over Drierite. The salt dehydrates slowly if heated at 70°.

Piperic acid [136-72-1] M 218.2, m 217°. Crystd from EtOH. Protect from light.

Piperidine [110-89-4] M 85.2, f.p. -9°, b 35.4°/40mm, 106°/760mm, d 0.862, n 1.4535, n²⁵ 1.4500. Dried with BaO, KOH, CaH₂, or sodium, and fractionally distd (optionally from sodium, CaH₂, or P₂O₅). Purified from pyridine by zone melting.

dl-Piperidine-2-carboxylic acid see **pipecolic acid**.

Piperidinium hydrochloride [6091-44-7] M 121.6, m 244-245°. Crystd from EtOH/ethyl ether in the presence of a small amount of HCl.

Piperidinium nitrate [6091-45-8] M 145.2, m 110°. Crystd from acetone/ethyl acetate.

Piperine [94-62-2] M 285.4, m 129-129.5°. Crystd from EtOH or benzene/ligroin.

Piperonal [120-57-0] M 150.1, m 37°, b 140°/15mm, 263°/760mm. Crystd from aqueous 70% EtOH or EtOH/water.

Piperonylic acid [94-53-1] M 166.1, m 229°. Crystd from EtOH or water.

Pivalic acid (trimethylacetic acid) [75-98-9] M 102.1, m 35.4°, b 71-73°/0.1mm. Fractionally distd under reduced pressure, then fractionally crystd from its melt. Recrystd from benzene.

Pivaloyl chloride (trimethylacetyl chloride) [3282-30-2] M 120.6, b 57.6°/150mm, 70-.5-71/250mm, 104°/754mm, 104-105°/atm, 105-108°/atm, d₄²⁰ 1.003, n_D²⁰ 1.4142. First check the IR to see if OH bands are present. If absent, or present in small amounts, then redistil under moderate vac. If present in large amounts then treat with oxalyl chloride or thionyl chloride and reflux for 2-3h, evap and distil

residue. **Strongly LACHRYMATORY - work in a fumecupboard.** Store in sealed ampoules under N_2 . [Traynham and Battiste *JOC* 22 1551 1957; Grignard reactns: Whitmore et al. *JACS* 63 647 1941].

Pixyl chloride see **9-chloro-9-phenylxanthene**.

Plumbagin [481-42-5] **M 188.1, m 78-79°**. Crystd from aqueous EtOH.

Polyacrylonitrile [25014-41-9]. Ppted from dimethylformamide by addition of MeOH.

Polybrene see **1,5-Dimethyl-1,5-diazaundecamethylene polymethobromide**.

Poly(diallyldimethylammonium) chloride. Ppted from water in acetone, and dried in vacuum for 24h. [Hardy and Shriner *JACS* 107 3822 1985].

Polyethylene [9002-88-4]. Crystd from thiophen-free benzene and dried over P_2O_5 under vacuum.

Polygalacturonic acid see **pectic acid**.

Polymethyl acrylate [9002-21-8]. Ppted from a 2% soln in acetone by addition of water.

Polystyrene [9003-53-6]. Ppted repeatedly from $CHCl_3$ or toluene soln by addition of MeOH. Dried *in vacuo* [Miyasaka et al. *JPC* 92 249 1988].

Polystyrenesulphonic acid (sodium salt) [25704-18-1]. Purified by repeated pptn of the sodium salt from aqueous soln by MeOH, with subsequent conversion to the free acid by passage through an Amberlite IR-120 ion-exchange resin. [Kotin and Nagasawa *JACS* 83 1026 1961].

Also purified by passage through cation and anion exchange resins in series (Rexyn 101 cation exchange resin and Rexyn 203 anion exchange resin), then titrated with NaOH to pH 7. The sodium form of polystyrenesulphonic acid ppted by addition of 2-propanol. Dried in a vac oven at 80° for 24h, finally increasing to 120° prior to use. [Kowblansky and Ander *JPC* 80 287 1976].

Polyvinyl acetate [9003-20-7]. Ppted from acetone by addition of *n*-hexane.

Poly(*N*-vinylcarbazole) [25067-59-8]. Ppted seven times from tetrahydrofuran with MeOH, with a final freeze-drying from benzene. Dried under vacuum.

Polyvinyl chloride [9002-81-2]. Ppted from cyclohexanone by addition of MeOH.

Poly(4-vinylpyridine) [25232-41-1] **M (105.1)_n**. Purified by repeated pptn from solns in EtOH and dioxane, and then EtOH and ethyl acetate. Finally, freeze-dried from *tert*-butanol.

Poly(*N*-vinylpyrrolidone) [9003-39-8] **M (111.1)_n, crosslinked [25249-54-1] m >300°**. Purified by dialysis, and freeze-dried. Also by pptn from $CHCl_3$ soln by pouring into ether. Dried in a vacuum over P_2O_5 . For the crosslinked polymer purification is by boiling for 10min in 10% HCl and then washing with glass-distilled water until free from Cl ions. Final Cl ions were removed more readily by neutralising with KOH and continued washing.

Pontacyl Carmine 2G [3734-67-6] **M 510.4**,

Pontacyl Light Yellow GX [6359-98-4] **M 552.3**. Salted out three times with sodium acetate, then repeatedly extracted with EtOH. See *Chlorazol Sky Blue FF*. [McGrew and Schneider *JACS* 72 2547 1950].

Prednisone [53-03-2] **M 358.5, m 238°(dec)**, $[\alpha]_D^{20} +168°$ (c 1, dioxane), λ_{max} 238nm (log ϵ 4.18) in MeOH. Crystd from acetone/hexane.

Pregnane [24909-91-9] **M 300.5, m 83.5°**, $[\alpha]_D^{20} +21°$ ($CHCl_3$). Crystd from MeOH.