Experimental Studies of Organic Ice Nuclei

N. Fukuta

Radiophysics Laboratory, CSIRO, Sydney, Australia

(Manuscript received 24 May 1965, in revised form 27 July 1965)

ABSTRACT

The ability of 329 selected organic compounds to nucleate ice has been tested by three methods. Their activity was found to depend strongly on the method of preparation. More than 20 compounds were found to nucleate ice at temperatures above $-5\,\text{C}$ when freshly ground. Some meta and para derivatives of benzene showed excellent activity. Particles prepared by condensation were less active, the only newly-discovered material effective above $-5\,\text{C}$ being 1,5-dihydroxynaphthalene. Its use as a cloud seeding agent is suggested.

Crystals of effective materials generally have molecules which display rotational symmetry. The role of molecular symmetry is discussed in connection with the formation of crystal planes with dense hydrogen bonding groups. The behavior of organic nuclei with nonsymmetrical molecules is also considered.

1. Introduction

Recent studies have brought to light a number of organic compounds which can act as ice nuclei at comparatively high temperatures.

The first of these was phloroglucinol, reported by Bashkirova and Krasikov (1957). The ice-forming properties of some aromatic compounds were examined by Komabayashi and Ikebe (1961). Compounds studied by Head (1961, 1962) included steroids and fluorene derivatives. They found that thermal cracks were active sites for ice nucleation. This was demonstrated by epitaxy by Fukuta and Mason (1963). Alpha-phenazine was once suggested as a suitable material for cloud seeding (Head, 1962a). A warning, however, has been recently given about a possible toxic hazard in its use (Garten and Head, 1965). Power and Power (1962) reported that some amino acids are active ice nuclei. The effectiveness of phloroglucinol was confirmed by Langer et al. (1963), who tested thirty-two organic compounds in all. This led to field trials of phloroglucinol by Braham (1963).

Such studies of organic ice nuclei are important not only for the discovery of potential cloud seeding materials but also because of the light that can be shed on the fundamental mechanism of heterogeneous ice nucleation. Organic compounds provide a vast field for the study of the relation of nucleation efficiency to other properties. In the present work more than 300 organic compounds were examined. The discovery of metaldehyde which has the highest temperature for ice nucleation so far known, has already been reported (Fukuta, 1963).

2. Experimental

The physical and chemical natures of common organic compounds were surveyed and a preliminary selection made on the basis of properties known to be essential for efficient ice nuclei; (a) the molecules should possess polar or hydrogen-bonding groups, (b) the compounds should have low solubility in water, and (c) they should be crystalline solids of reasonably high melting point. For obvious reasons we add the further criteria, of (d) low toxicity, and (e) low price.

Three methods were used to test the ice nucleation threshold of selected organic compounds where the threshold is defined as the temperature at which $10^4$ ice crystals per gram of material form in two minutes.

a. Soap film method (Schaefer, 1948; Mason and Maybank, 1958). A soap film on a ring of fine wire, 5 cm in diameter was placed a few centimeters above the bottom of a cold chamber, with a fine-wire thermocouple just below the film. A subcooled water cloud was formed in the chamber and sample crystals shaken into it from the end of a clean glass rod. Ice crystals falling on the soap film could be detected by their further growth.

This method is very easy to use but not very precise. It was therefore used to make a preliminary classification of materials into those which were inactive at $-10\,\text{C}$, those active between $-10$ and $-5\,\text{C}$, and those active above $-5\,\text{C}$. By further experiments these limits could be narrowed to $1\,\text{C}$.

b. Subcooled polyvinyl alcohol solution poured on ground crystals. Test materials were freshly ground in a mortar. Commercial compounds usually contain impurities and by producing fresh cleavage surfaces and cracks and thus increasing the surface to volume ratio, the number concentration of impurities sticking to the old surfaces could be reduced.

About 1 mg of ground crystals, average particle size a few tens of microns, were dispersed onto a flat metal dish 5 cm diameter, the surface of which was covered with a thin layer of paraffin wax to prevent
spurious ice formation. The dish was placed on the bottom of a cold chamber at known temperature. Moisture was supplied for two minutes from a sausage skin containing warm water kept at the top of the cold chamber. A solution of 2 or 5 per cent polyvinyl alcohol, already cooled to the chamber temperature, was then poured over the particles in the dish. Ice crystals which grew could be easily observed.

This method provides well-defined test conditions due to the good thermal contact of the metal dish with the copper bottom of the cold chamber.

After a preliminary run at $-10^\circ$C, further tests were made until the nucleation threshold could be narrowed down to $\pm 0.5^\circ$C.

c. Smoke prepared by condensation method. One milligram of sample was placed on a hot metal plate and the released vapor was rapidly sucked together with air into a syringe. This produced fine “smoke” particles which were injected into a cold chamber in which a cloud was formed using the sausage skin humidifier. A tray of subcooled polyvinyl alcohol solution at the bottom of the chamber was used to detect ice nucleation. Those materials found to be effective ice nuclei at temperatures above $-10^\circ$C by method b. were tested by this further technique.

3. Results and discussions

Experimental results are shown in Table 1. The materials effective between $-5$ and $-10^\circ$C and those ineffective at $-10^\circ$C by method b. are listed in Appendices 1 and 2, respectively.

In the table the results of method a. show that the surface of commercial compounds are relatively inactive in ice nucleation probably because of contamination.

It is noteworthy that 25 compounds, including metaldehyde, have been found effective at temperatures above $-5^\circ$C by method b. Ice nucleation above $-5^\circ$C is no longer uncommon as far as freshly ground crystals are concerned. Six compounds, acetocetanilide, $p$-bromocetophenone, coumarin, $m$-nitroaniline, phthalic anhydride, and 2,4,6-trichloroaniline, show ice-nucleation thresholds almost as high as metaldehyde. The crystal structures of the 25 compounds are little known; details of five of them are shown in Table 2.

---

**Table 1. Properties of effective organic ice nuclei.*

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Melting point ($^\circ$C)</th>
<th>Boiling point ($^\circ$C)</th>
<th>Solubility (grams per 100 ml of water)</th>
<th>Onset temperatures ($^\circ$C) for ice nucleation (10 ice crystals per gram within two minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetoacetanilide</td>
<td>CH$_3$COCH$_2$CONHC$_2$H$_4$</td>
<td>85</td>
<td>-</td>
<td>sl.s.</td>
<td>$-2$</td>
</tr>
<tr>
<td>2-Aminoanthraquinone</td>
<td>NH$_2$C$_6$H$_4$(CO)$_2$C$_6$H$_4$</td>
<td>302</td>
<td>subl.</td>
<td>i</td>
<td>$-7$</td>
</tr>
<tr>
<td>m-Aminophenol</td>
<td>NH$_3$C$_6$H$_4$OH</td>
<td>122-3</td>
<td>-</td>
<td>2.6</td>
<td>$-7$</td>
</tr>
<tr>
<td>p-Anisidine</td>
<td>C$_6$H$_5$C$_6$H$_4$</td>
<td>59</td>
<td>240</td>
<td>v.s.l.s.</td>
<td>$-7$</td>
</tr>
<tr>
<td>p-Bromocetophenone</td>
<td>BrC$_6$H$_4$C$_6$H$_4$</td>
<td>50</td>
<td>255.5</td>
<td>v.s.l.s.</td>
<td>$-7$</td>
</tr>
<tr>
<td>p-terti-Butylyphenol</td>
<td>HO$_2$C$_6$H$_6$(CH)$_3$</td>
<td>98</td>
<td>237</td>
<td>i.c.</td>
<td>$-7$</td>
</tr>
<tr>
<td>Chloranilic acid</td>
<td>C$_6$H$_5$(OH)CO$_2$H</td>
<td>283-4</td>
<td>-</td>
<td>v.s.l.s.</td>
<td>$-7$</td>
</tr>
<tr>
<td>2-Chloro-4-nitroaniline</td>
<td>C$_6$H$_4$(NO$_2$)C$_6$H$_4$</td>
<td>107-8</td>
<td>-</td>
<td>sl.s.</td>
<td>$-7$</td>
</tr>
<tr>
<td>4-Chloro-2-nitroaniline</td>
<td>C$_6$H$_4$(NO$_2$)C$_6$H$_4$</td>
<td>116-7</td>
<td>-</td>
<td>sl.s.</td>
<td>$-7$</td>
</tr>
<tr>
<td>Coumarin</td>
<td>C$_6$H$_4$OCOCH$_2$CH</td>
<td>67-8</td>
<td>302</td>
<td>0.01 at 25C</td>
<td>$-7$</td>
</tr>
</tbody>
</table>

---

* Abbreviations: anh.—anhydrous; c.—cold; d.—decomposes; h.—hot; i.—insoluble; ineff.—ineffective; s.—soluble; sl.—slightly; subl.—sublimes; v.—very. See text for description of experimental methods.

Table 2. Crystal structure of some effective nuclei and their possible matching to ice.

<table>
<thead>
<tr>
<th>Name</th>
<th>Symmetry</th>
<th>Ice nuclei parameter (Å)</th>
<th>Matching plane</th>
<th>Ice matching Molecule</th>
<th>Direction</th>
<th>Misfit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetocetanilide</td>
<td>Orthorhombic</td>
<td>a = 19.50, b = 9.46, c = 7.96</td>
<td>(0001) 1/4</td>
<td>[1010] 1.6</td>
<td>[1102] 4.6</td>
<td>8.0</td>
</tr>
<tr>
<td>m-Aminophenol</td>
<td>Orthorhombic</td>
<td>a = 6.14, b = 11.10, c = 8.38</td>
<td>(0001) 1/4</td>
<td>[1010] 7.0</td>
<td>[1102] 5.2</td>
<td>3.0</td>
</tr>
<tr>
<td>m-Nitroaniline</td>
<td>Orthorhombic</td>
<td>a = 19.23, b = 6.43, c = 5.06</td>
<td>(0001) 1/12</td>
<td>[1102] 1.1</td>
<td>[1102] 0.4</td>
<td>4.5</td>
</tr>
<tr>
<td>2-Nitrodiphenylamine</td>
<td>Orthorhombic</td>
<td>a = 6.86, b = 14.68, c = 10.21</td>
<td>(0001) 1/6</td>
<td>[1102] 1.2</td>
<td>[1102] 4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Phthalic anhydride</td>
<td>Orthorhombic</td>
<td>a = 7.74, b = 6.48, c = 5.86</td>
<td>(0001) 1/6</td>
<td>[1102] 1.2</td>
<td>[1102] 4.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Examination of the available structural data for compounds in Appendices 1 and 2 give no direct clue to the reasons for their low activity.

In examining for structural resemblance to ice, an orthorhombic unit of ice, a, v3a and c, is useful since crystals having hexagonal symmetry usually used to describe the ice structure are rather rare among the organics.

The behavior of smoke particles prepared by the condensation method as ice nuclei was totally different from that of the freshly-ground particles. The former method hardly appears to be a valid test of the nucleation ability of an organic compound. Indeed among the new series of compounds only 1,5-dihydroxynaphthalene showed activity at −5°C.

1,5-dihydroxynaphthalene has a melting point of 265°C and is insoluble in water. Heating on a metal plate easily gives submicron particles and a large proportion of those obtained are effective only slightly below −5°C. The smoke particles show no delay in nucleation and in this respect differ from the common organic nucleators. It is comparatively cheap and merits further investigation as a possible cloud seeding agent. The crystal structure is not known but from a comparison of its melting point with that of 1,5-dichloronaphthalene, it is expected to have intermolecular hydrogen bonding although its structure might be considerably different from the latter compound. The compound with −NH2 substituted for one of the OH groups, namely, 5-amino-1-naphthol, is ineffective as an ice nucleus.

The profound effect of preparation method on the apparent ice forming ability of organic particles provides a clue to their mode of action.

The nucleation efficiency of a particle must depend upon its surface nature. The low activity of condensed particles may be due to one of the following surface conditions:

1) supercooled liquid or glass
2) structure different from the bulk material
3) different bulk crystal structures or polymorphic forms
4) adsorption or accumulation of impurities on the surface.

The first of these possibilities is discussed further below.

When organic vapors are cooled, they generally condense in the liquid phase unless they have a subliming nature. Further cooling will result in crystallization, nucleation being dependent upon the molecules possessing an activation energy sufficient to overcome the potential barrier of the viscous resisting forces at the nucleus boundary. For homologous compounds, viscosity increases with molecule size. To obtain ice nuclei of small particle size that are stable against evaporation, compounds of low vapor pressure or high melting point are necessary. Such substances when cooled to room temperature from the melt, undergo large supercooling and the viscosity rises considerably. For effective ice nuclei the molecules should possess hydrogen bonding groups and this implies a high viscosity in the melt because of interactions between the groups. These factors favor glass formation and in fact we have observed glass formation in steroids (see also Head, 1962) and fluorenone, which sometimes crystallized under the microscope. In using the condensation method as the best way of producing a large number of nuclei, one faces the drawback that the chance of crystallization of submicron smoke particles will be even slimmer as the result of the volume effect.

Organic crystals are often found in a number of polymorphic forms, depending on the method of preparation, but the available crystallographic data on the various forms are inadequate for any useful discussion of their effect on nucleation.

4. The ice-nucleation properties of materials whose molecules possess rotational symmetry

Unlike non-symmetrical molecules which tend to point their active hydrogen bonding groups inwards to
get minimum surface free energy in the crystal, the molecules of rotational symmetry cannot avoid exposing their active groups at the surface. The hydrogen bond is energetically costly and, to minimize the surface free energy, the smallest number of exposed hydrogen bonding groups tends to result. This results in a larger “contact angle” between the ice embryo and the crystal face of organic nuclei, which is undesirable for ice nucleation (Fletcher, 1960). This could perhaps be the reason why in some materials such as steroids, active nucleating sites are situated along thermal cracks rather than on the outer surface. In the process of cooling after crystallization the surface molecules would probably keep their polar groups interlocked while cracking by thermal shrinkage. Cracking might open some of the hydrogen bonds or expose possible places for hydrogen bonds to be formed. Garten and Head (1964) suggest proper density of hydrogen bonding groups as one of the requirements for efficient ice nuclei.

In addition to molecular symmetry, suitable molecular dimensions seem essential for effective ice nucleation. Some molecules of central symmetry, for example, benzidine, 1,5-dihydroxynaphthazine, 4,4'-dihydroxydiphenyl and p-phenylendiamine, were ineffective regardless of the way the particles were prepared.

The requirements that we have suggested above are largely fulfilled by the four smokes that are effective above —5°C, namely metaldehyde, phenazine, chloroglutino and 1,5-dihydroxynaphthalene. These all have symmetrical molecules, and three of them sublime. Their tendency to sublime indicates that the condensing vapor will have a similarly strong tendency towards crystallization rather than drop formation.

Recently a theory of electric link dipole moments was proposed to account for the activity of organic crystals whose molecules have central symmetry (Langer, et al., 1963). They suggest what is important for activity of ice nuclei is not crystalline similarity to ice but the non-polar nature of the molecule resulting from the balancing of constituent link moments. Our results show too many exceptions to make this theory tenable. For instance the metaldehyde crystal, which nucleates ice at temperatures as high as —1°C, has a long needle-like shape because of the dipolar attraction of its molecules. Along its needle axis it shows pyroelectric effects characteristic of polar crystals (Pauling and Carpenter, 1936). The molecular symmetry of the crystal is four and the molecule is an electric dipole which does not agree with their theory.

Our experimental results indicate: (i) there is no simple relationship between ice-forming ability and the molecular symmetry of the crystal when tested as a freshly-ground powder; (ii) rotational symmetry of the molecule appears to have an influence only with smokes prepared by condensation; but (iii) suitable molecular dimensions, i.e., shape and size, are also necessary.

5. Meta and para derivatives of benzene and their ice nucleation ability

Although there were some exceptions, meta derivatives of benzene, were found to be highly effective when powdered. The results from nitroanilines were typical. m-nitroaniline was effective at —1°C and has a crystal face matching one of the prism planes of ice with reasonably small misfits (see Table 2), while o- and p-derivatives showed poor activity and have no suitable crystal plane matching ice. Para derivatives sometimes showed high activity but ortho derivatives were rarely effective.

The role of meta and para positions in the benzene ring is not fully understood. However, it should be related to the arrangement of the active groups on the crystal plane, both in position and direction.

6. Concluding remarks

Molecular shape is important for the activity of potential ice nuclei and in the formation of surfaces where the density of hydrogen bonding groups is high. Molecules having rotational symmetry form such surfaces irrespective of the method of preparation. Suitable planes for ice nucleation should have such hydrogen bonding groups matching to ice in position as well as direction. Flexibility of hydrogen bonding groups and of the crystal lattice may further help to reduce the strain energy for embryo formation.

There is a tendency for the density of free hydrogen bonding groups to be reduced at surfaces in order to minimize the surface free energy and some nucleation phenomena may be explained by this effect.

Acknowledgments. The author thanks Professor S. J. Angyal of the University of New South Wales for kindly providing many organic compounds, Professor W. G. Daub, University of California for a sample of trans-cis-Decal-2-ol and the Commonwealth Scientific and Industrial Research Organization for a fellowship which enabled this work to be carried out.

APPENDIX 1

Organic compounds found to be effective at various temperatures between —5 and —10°C by method 6

<table>
<thead>
<tr>
<th>Onset temperature of ice nucleation (°C)</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>—6</td>
<td>L-Aspartic acid, Benzoin oxime, Chloramine-T, 1,4-Dihydroxynaphthazine, 2,4-Dinitrophenylamine, sym-Diphenylurea, Glucocamine, Hematoxylin, dl-Isoleucine, p-Nitroaniline, p-Nitrobenzaldehyde.</td>
</tr>
</tbody>
</table>
Acridone, Benzil, m-Hydroxybenzoic acid, \\
−7 p-Hydroxybenzoic acid, 8-Hydroxyquinoline, m-Iodosobenzonic acid, p-Nitrophenylacetic acid, Succinamid, Vanilin.

Allantoin, DL-Asparagin, α-Benzylidoxime, Chlorosuccinic acid, 2,6-Diiodo-4-nitroaniline, 8-Hydroxyquinoline oxide, m-Iodosobenzonic acid, Meconic acid, Oxamide, Tetrachlorophthalic anhydride, Theophylline, 2,6-Xylenol.

α-Benzil dioxime, Benzoin, Choraline, Di-tert-butylhydroquinone, p-Nitrobenzhydrazide, Resorcinol, Tetramorphthalic anhydride, dl-Valine.

Aceto-p-toluidide, Adipamide, Adipic acid, 1-Aminomethylquinone, Anisoin, Aurine-tricarboxylic acid, Benzamide, 4-Chlorophthalic acid, 4-Chlororesorcinol, 2,4-Dinitrophenol, sym-Diphenylcarbazide, Ethyl gallate, Hippuric acid, 2-Methyl-1,4-naphthaquinone, 1-Naphthoxyacetic acid, n-Octadecanoyl, Oxalic acid, 1-Phenylsemicarbazide, Tetramorphophthal frame, Xanthohydro.

APPENDIX 2

Organic compounds found to be ineffective at −10C by method b

Acetanilide, Aceto-α-toluidide, Aceto-m-toluidide, p-Acetyliminophenol, Acetyl-α-salicylic acid, Acetyl salicylic acid, Acidine, Alizarin, Alizarin red S, Alloxantin, p-Aminoacetanilide, p-Aminoacetophenone, p-Aminozlenzene, o-Aminobenzonic acid, m-Aminobenzoic acid, p-Aminobenzoic acid, 2-Aminobenzothiazole, 4-Amino-2,6-dibromophenol, 4-Amino-2,6-dichlorophenol, p-Aminophurpuric acid, 5-Amino-1-naphthol, 1-Amino-7-naphthol, 1-Amino-1-naphthol-4-sulfonic acid, 1-Amino-8-naphthol-4-sulfonic acid, 4-Amino-3-nitrotoleune, o-Aminophenol, p-Aminophenylacetic acid, 5-Aminosalicylic acid, Amygdalin, p-tert-Amylsolphenol, Anthrone, Azelaic acid;

Behenic acid, Benzanilide, Benzanthrone, Benzhydrol, Benzidine, Benzilic acid, Benzoac, Benzoic acid, Benzoic anhydride, o-Benzoylbenzoic acid, p-Benzylphenol, Biuret, Borneol, p-Bromoaniline, o-Bromobenzoic acid, m-Bromobenzoic acid, p-Bromobenzoic acid, p-Bromophenol, Brucine, p-tert-Butylcatechol;

Caffeine, dl-Camphor, Camphoric acid, Camphor oxide, Carbazol, Celulose acetate, p-Chloranil, m-Chlorobenzoic acid, p-Chlorobenzoic acid, 1-Chloro-2-naphthol, 4-Chloro-3,5-Xylenol, Cholic acid, Cinchonine, Cinchoninone-HCl, Cinamalic acid, o-Coumaric acid, Creatine, Crotonic acid, Crystal violet, r-Cystine;

p,p-Dimethoxydiphenylmethane, o-Dianisidine, 3,5-Dibromo-o-cresol, 2,4-Dibromo-1-naphthol, 2,6-Dibromo-4-nitrophenol, 1,6-Dibromo-2-naphthol, 2,4-Dibromophenol, 1,2-Dibromo-2-phenylpropionic acid, Dibromosuccinic acid, 3,4-Dichlorobenzoic acid, 2,4-Dichloro-1-naphthol, Dicyandiamide, 1,5-Dihydroxyanthraquinone, 1,8-Dihydroxyanthraquinone, 2,4-Dihydroxybenzoic acid, 3,5-Dihydroxybenzoic acid, 4,4'-Dihydroxydiphenyl, 1,6-Dihydroxynaphthalene, 1,7-Dihydroxynaphthalene, 2,3-Dihydroxynaphthalene, Dimedone, β,β'-Dimethylacrylic acid, p-Dimethylaminobenzaldehyde, sym-Dimethylidihydrophenures, Dimethylglyoxime, Di-β-naphthol, 2,4-Dinitroaniline, 3,5-Dinitrobenzoic acid, 3,5-Dinitrosalicylic acid, 2,4-Dinitroresorcinol, Diphenic acid, Diphenylacetic acid, Diphenylamine, Diphenylene oxide, Diphenyl sulphone, sym-Diphenylthiourea, Diphenylthiourea, Dithiooxamide, Dithiobisacilic acid, Di-p-tolylamine, Di-p-tolylketone;

Ethyl-p-aminobenzoate;

Fluorescein, Fumaric acid, Furoic acid;

Gallein, Gallic acid, Gluco-δ-lactone, l-Glutamic acid-Na salt;

Hesperidin, Hydrazobenzene, p-Hydroxyacetophenone, p-Hydroxybenzaldehyde, p-Hydroxybenzonitrile, 2-Hydroxy-3,5-diodobenzoic acid, 4-Hydroxy-3,5-diodobenzoic acid, 2-Hydroxydiphenyl, 4-Hydroxydiphenyl, 3-Hydroxy-2-naphthoic acid, p-Hydroxypropionophene, 2-Hydroxyquinoline;

Indigotin, Inulin, p-Iodosobenzonic acid, Isatin, Itaconic acid;

Kojic acid;

Lactic acid, Lauric acid, dl-Leucine, dl-nor-Leucine;

Menthol, 2-Mercaptobenzothiazole, Metanilic acid, 4-Methoxybenzoic acid, dl-Methionine, 2-Methylanthraquinone, Methyl gallate, Methyl red, Mucic acid, Myristic acid;

1-Naphthoic acid, 1-Naphthol, 1-Naphthylamine, 2-Naphthylamine, Nicotinic acid, o-Nitroacetanilide, p-Nitroacetanilide, o-Nitroaniline, 4-Nitro-o-anisidine, 5-Nitro-o-anisidine, o-Nitrobenzaldehyde, m-Nitrobenzhydride, o-Nitrobenzoic acid, m-Nitrobenzoic acid, p-Nitrobenzene, N-Benzylaclohol, m-Nitrocinamic acid, p-Nitrocinamic acid, 4-Nitro diphenylamine, o-Nitrophenol, m-Nitrophenol, p-Nitrophenol, 4-(p-Nitrophenylazo)-orcinol, 3-Nitrophenic acid, 3-Nitrophthalic anhydride, 4-Nitrophthalimide, 6-Nitroquinolne, 3-Nitrosalicylic acid, 5-Nitroso-o cresol, 6-Nitroso-m cresol, p-Nitroso dimethylaniline, m-Nitrosodiphenylamine, 1-Nitros-2-naphthol, 2-Nitroso-1-naphthol, 4-Nitroresorcinol;

Orcin;
Palmitic acid, Paraformaldehyde, Pentachlorophenol, Phenacetin, Phenacyl bromide, Phenanthraquinone, Phenazine, Phenol red, Phenothiazine, Phenylacetamide, Phenylacetanilide, Phenylacetic acid, n-Phenylanthranilic acid, p-Phenylenediamine, p-Phenylenediamine, n-Phenyl-2-naphthylamine, 2-Phenylpropionic acid, Phenylthiohydantoic acid, Phenylthiourea, Phthalimide, Phthalimide, Picramic acid, Picrolonic acid, Pyrogallol;

Quinalizarin, Quinhydrorn;

Resacetophenone, Rosaniline, Rosolic acid;

Saccharin, Salicylamide, Salicylanilide, Saligenin, Salol, Succinic anhydride, Suddan III;

Tetrachlor-p-aminquinone, Tetrachlorophthalic acid, Theobromine, Thiosalicylic acid, Thiosemicarbazide, Thymol, α-Tolidine, β-Toluidine, 1,2,3-Triacetoxybenzene, 2,4,6-Tribromophenol, DL-Tryptophan, L-tyrosine;

Uric acid;

Xanthone.

REFERENCES


