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Experiment #13: Classification of Chemical Substances

Most chemicals can be classified based on the type of bonding that holds the atoms together as: ionic, molecular, network-covalent, or metallic substances. Molecular compounds can be further classified as being polar or non-polar.

All of these labels are somewhat arbitrary, and some substances have properties that would place them in a borderline category somewhere intermediate between one group and another. It is useful, however, to consider some of the general characteristics of typical ionic, molecular, network, and metallic substances since many very common substances can be readily assigned to one category or another.

IONIC SUBSTANCES

Ionic substances are all solids at room temperature. They are typically crystalline but may exist as fine powders or clearly defined crystals. While most ionic substances are stable up to their melting points, some decompose upon heating. It is common for an ionic crystal to release loosely bound waters of hydration at temperatures below 200 ^{o}C. Anhydrous (or dehydrated) ionic compounds generally have high melting points, usually above 300 ^{o}C but below 1000 ^{o}C. They are not readily volatilized and boil at only very high temperatures. Typical examples include NaCl (water soluble) or $CaCO_3$ (which is not very water soluble).

When molten, ionic compounds conduct an electric current. In the solid state, they do not conduct electricity. The conductivity of the molten liquid is attributed to the freedom of motion of the ions, which arises when the crystal lattice is no longer present.

Ionic substances are frequently but *not always* soluble in water. The solutions produced conduct the electric current rather well. The conductivity of a solution of a slightly soluble ionic substance is often several times higher that of the solvent water. Ionic compounds are usually not as soluble in other liquids as they are in water. For a liquid to be a good solvent for ionic compounds, it must be highly polar and contain molecules with well-defined positive and negative regions which can interact with the ions.

MOLECULAR SUBSTANCES

All gases and essentially all liquids at room temperature are molecular in nature. If the molecular weight of a substance is over about a hundred, it may be a solid at that temperature. The melting points of molecular substances are usually below 300 ^{o}C; these substances are relatively volatile, but a good many will decompose before they boil. Most molecular substances do not conduct electric current either when solid or when molten.

Organic compounds, which contain mostly carbon and hydrogen, are usually molecular in nature. If an organic compound decomposes upon heating, the residue is frequently a black, sooty material. A large numbers of inorganic substances are also molecular; those which are solids at room temperature include some of the binary compounds of elements in Groups IVA, VA, VIA, and VIIA.

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Molecular substances are frequently soluble in at least a few organic solvents, with the solubility enhanced if the substance and the solvent are similar in molecular structure. Compounds that dissolve in solvents like xylene, toluene, or hexane are called *non-polar molecular* compounds. Compounds that dissolve in ethanol or methanol (or sometimes water) are called *polar molecular* compounds. Examples of polar organic compounds include aspirin, sugar, or vitamin C. Non-polar organic examples would include the edible triglyceride fats or the oil-soluble vitamins (*e.g.* Vitamin A)

Molecular compounds such as acids and bases are markedly polar, which tends to increase their solubility in water and other polar solvents. Such substances may ionize appreciably in water or even melt so that they become conductors of electricity. Often, the conductivity is considerably lower than that of an ionic material. Most polar molecular compounds in this category are organic, but a few, including some of the salts of the transition metals, are inorganic.

NETWORK-COVALENT SUBSTANCES

When every atom in a sample has covalent bonds whose crystal structures are more restricted by the geometrical constraints of the directional bonds, the compound is designated as a network-covalent substance. These are all solids at room temperature, possess extremely high (>1000 ^{o}C) melting points, and low volatility. They are typically very resistant to thermal decomposition, generally do not conduct electric current, and are often good insulators. Network-covalent solids are not soluble in water or any organic solvents. They are frequently chemically inert and may be used as abrasives or refractories. Examples include diamond (C), quartz (SiO_2), aluminum oxide (Al_2O_3), and tungsten carbide (W_2C).

METALLIC SUBSTANCES

The properties of metals stem mainly from the freedom of movement by their bonding electrons. Metals are good electrical conductors in the solid form with characteristic luster and malleability. Most metals are solid at room temperature and have melting points that range from below 0 ^{o}C to over 2000 ^{o}C. They are not soluble in water or organic solvents. Some metals are prepared as black powders which may not appear to be electrical conductors; if such powders are heated, the particles will coalesce to give good electrical conductivity. Examples of metals include iron, gold, or aluminum.

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Procedure

In this experiment, you will investigate the properties of several substances with the purpose of determining whether they are ionic, molecular, network-covalent, or metallic. In some cases, the classification will be very straightforward. In others, you may find that the substance behaves in a way that would not clearly place it in a given category but in some intermediate group.

Determine the rough melting point range. Substances with low melting points, less than 100^{o}C, for example, will melt readily when warmed gently in a Pyrex test tube. A test tube heated to about 300 ^{o}C will impart a yellow-orange color to the Bunsen flame. This color becomes more pronounced between 300^{o} and 550 ^{o}C, at which temperature the Pyrex tube will begin to soften. When heating samples you should loosely cover the test tube with a metal cap. Do not breathe any vapors that are given off. Look for liquid condensing on the cooler portions of the tube and for indications that sublimation is occurring. For the higher temperature studies possible in the lab, heat the sample in a crucible with a strong Bunsen flame; a noticeable red color will appear in the crucible at about 600 ^{o}C. Do not heat samples to 600 ^{o}C unless their solubility and conductivity properties have been studied at lower temperatures with indecisive results.

Electrical conductivities of your solutions will be measured with a conductivity meter for that purpose. Distinguish between completely nonconducting, slightly conducting, and highly conducting liquids.

The substances to be studied in the first part of the experiment are on the laboratory tables along with two organic solvents, one polar and one nonpolar. Carry out enough tests on each substance to establish its classification as best you can. Report your observations on each substance, how you would classify it, and your reason for the classification.

When you have completed your tests, report to your instructor, who will check your results and issue you two unknowns for characterization. Some judgment needs to be used when determining if a compound is soluble. For example, calcium carbonate (chalk) is not soluble in water and will eventually settle to the bottom. However, if you shake some chalk in water, the water will look milky white, leading to the false conclusion that it was soluble.

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1. Melting Point

   A. Place a small sample into a clean, dry test tube and loosely cover the tube with a metal cap.

   B. Heat the test tube and record observations (see previous page).

   C. If the melted sample cannot be easily removed, discard the tube. If the sample can be easily removed, discard the sample and reuse the test tube.

2. Solubility

   A. Place a very small sample into a clean, dry test tube.

   B. Add the appropriate solvent to approximately half-fill the tube.

   C. Stopper the tube and gently shake the contents. Observe and record as soluble, insoluble, or questionable.

   D. Save the aqueous solution for the conductivity test.

   E. Discard the test tube contents of the polar and nonpolar solvents into the appropriate waste container in the fume hood.

3. Conductivity - Aqueous Solution

   A. Add more solid (in small amounts) to saturate the solution. Shake contents to assure saturation.

   B. Pour the liquid into a clean, dry evaporating dish and test for electrical conductivity using the tester.

   C. Discard any remaining solid in the waste container. Clean and reuse or discard the test tubes.

4. Conductivity - Solid Sample

   Use the tester directly on the solid sample in an evaporating dish. Remember to place both copper leads on the same small crystal or press down on the sample to ensure that the leads are making adequate contact.

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Data and Results

Substance	Melting range (check one)	Soluble in xylene?	Soluble in ethanol?	Soluble in water?	Conducts electricity as a solid?	Conducts as an aqueous solution?	Classification: Metallic Ionic Molecular (P) Molecular (NP) Network-Cov.
Known A	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Known B	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Known C	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Known D	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Known E	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Known F	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Unknown A	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						
Unknown B	□ <100 °C □ 100–300 °C □ 300–600 °C □ 600 °C						