LIKE DISSOLVES LIKE

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Brief description of demonstration

Three clear liquids form three distinct layers in a cylinder. Iodine crystals sprinkled on the top layer sink and form pink solutions with the top and bottom layers but do not dissolve in the middle. When the liquids are mixed, two layers form: a pink layer on the bottom, and a colorless layer on top. When white potassium iodide crystals are added and the liquids are mixed again, the colorless layer turns yellow.

Concepts illustrated:

- Phases and phase boundaries (surfaces)
- Density
- Polar/non-polar (hydrophilic/hydrophobic) interactions
- Solubility, miscibility
- Chemical reaction
- Extraction
- [Solution and emulsion]

Materials

- Clear glass reaction cylinder or gas-washing bottle, at least 200 mm tall, with ground glass stopper (A cylindrical container is preferable to a separatory funnel for this experiment. The stopper must be non-reactive, and, to prevent a potentially dangerous pressure build-up, the stopper must be easily released. For a very small class, a large test tube with a suitable stopper is adequate.)
- Equal volumes of chloroform, water, and hexane (The volume of each liquid should be a little more than one-fourth the volume of the cylinder.)
- Iodine crystals and small spatula
- Potassium iodide crystals and medium spatula

Preparation

Work in a hood. Pour the chloroform into the reaction cylinder. Add the water and allow the liquids to separate completely. (If necessary, speed the process by holding the cylinder vertical and gently swirling the solution with a circular motion.) Tip the cylinder and pour the hexane slowly down the side to prevent mixing. Close the cylinder and set it aside, away from sources of heat, until time for the demonstration.

Presentation

To make the layers and the surfaces between them easier for a large audience to see, hold the cylinder against a white background and illuminate it with a strong light such as an overhead projector lamp.

Choose the vocabulary and emphasize the points that fit your lesson. I use this demonstration in many different contexts and alter the presentation accordingly.

- The procedure below uses the terms "non-polar", "polar", and "ionic" to describe the degree of charge separation within molecules or other chemically connected groups of atoms. If you are using this demonstration as part of a unit on biological or ecological systems, you may wish to substitute the terms "hydrophobic" for "non-polar" and "hydrophilic" for "polar" and "ionic".
- If you are using the demonstration to reinforce the concepts of density or phase, include the gas phase in the discussion.

1. **Show the cylinder and ask students to describe its contents:** the phases present in the cylinder and their number, relative density, state of matter, color, etc.
    - What evidence indicates that more than one liquid phase is present? [Surfaces are visible as lines between layers.]
    - [optional] Discuss phases, phase boundaries, or density in appropriate depth.
2. **Tell students that the middle layer of liquid is water**, **a polar liquid**, **and** that **the surrounding liquids are non-polar.**
    - [optional] Specifically identify the non-polar liquids as chloroform and hexane.
3. **Identify iodine as a non-polar substance**
    - [optional] Discuss the polarity of the I_2 molecule or ask students to predict its polarity.
4. **Ask students to predict what will happen when a non-polar substance is added to the cylinder.**
5. .**Sprinkle a few iodine crystals on top of the hexane and replace the stopper.**
    - Keep the cylinder vertical so the layers don't mix.
    - The iodine sinks immediately to the hexane/water interface. [Note: Usually, some of the iodine crystals sit at the hexane/water interface for a short time before sinking further. You may use this observation to discuss surfaces and surface tension.]
6. **Swirl the liquids gently to break the surface tension between the layers and to allow the iodine to mix with each liquid as it sinks**. **Show the results** [Iodine dissolves in the hexane and the chloroform to give violet-pink top and bottom layers surrounding a colorless water layer. (Molecular iodine does not dissolve to any appreciable extent in water.)]

7. **Ask students to predict the number of layers that will form if the liquids are allowed to mix**.
8. **Tip the cylinder to allow the liquids to mix.** (Vent the cylinder when necessary to prevent pressure build-up.)
9. [optional] If your discussion includes types of mixtures, point out that the liquids were clear before they were mixed. While they are being mixed, the liquid looks cloudy. A cloudy appearance means the mixture is heterogeneous (contains more than one phase).
10. **Allow the phases to separate.** [The two pink non-polar phases will combine to form a single, double-volume pink layer on the bottom. The colorless water phase will form a single-volume layer on top.]
    - The non-polar layer may be slightly cloudy and take some time to clear.
11. [optional] Describe the order in which you added the liquids to the cylinder to get three liquid layers [1) chloroform, 2) water, 3) hexane]. Ask students to predict the number of liquid layers that would form in the cylinder if you added the liquids in a different order:
    - 1) Chloroform, 2) hexane, 3) water [two]
    - 1) Hexane, 2) chloroform, 3) water [two]
    - 1) Hexane, 2) water, 3) chloroform [two]
    - 1) Water, 2) chloroform, 3) hexane [three]
12. **Identify potassium iodide as an ionic solid.**
13. **Ask students to predict what will happen if an ionic solid, is added to the cylinder**. (Will it mix? With which layer?)
14. Add some white solid potassium iodide to the cylinder and replace the stopper. [Caution: Add no more than a small amount of potassium iodide at this time. If too much potassium iodide is added, the density of the polar phase will become very similar to the density of the non-polar phase, the phases may not separate quickly after they are mixed. See optional demonstration of an emulsion, below.]
    - Keep the cylinder vertical to keep the liquids from mixing.
    - **Swirl the liquid in the cylinder gently to allow the potassium iodide to dissolve in the water before it sinks.**
    - Potassium iodide forms a colorless solution with water. [Note that the aqueous layer at the interface may start to turn yellow.]
    - Note that undissolved potassium iodide crystals become red-brown as they sink through the iodine-containing layer. The color change indicates a chemical reaction. (See below.)
15. **Tip the cylinder several times,** venting when necessary, to increase the surface area between the phases and to allow undissolved potassium iodide to contact water.

16. **Allow the phases to separate, and ask students to describe them.** .
    - The aqueous layer (top) will be brownish-yellow. **The change in color is evidence of a chemical reaction.** At the interfaces between polar and non-polar phases, violet non-polar iodine molecules react with colorless iodide ions to form water-soluble red-brown triiodide ions.
    - The non-polar layer (bottom) will be pink. [Note: The non-polar layer may still contain yellow-brown bubbles]
17. **[Optional demonstration of an emulsion**] Add more potassium iodide to increase the density of the aqueous phase. Tip the cylinder to mix the layers as above. As the density of the aqueous phase approaches the density of the non-polar phase, gravity does not help in the battle with entropy, and the phases take longer to separate. Repeat addition and mixing until the phases form an emulsion.

Discussion

This main focus of this demonstration is the effect of polarity (charge separation within molecules) on interactions between molecules. The general rule is "Like likes like." Polar water maximizes its interactions with itself and other polar substances. It forms single phase mixtures (solutions) with other polar and ionic substances. It forms clearly defined surfaces (an indication of lack of interaction) with non-polar chloroform and hexane. Iodine dissolves easily in chloroform and hexane but does not dissolve in water. When polar and non-polar are mixed, water finds other water and forms spherical bubbles. Since water is less dense than this non-polar mixture, the bubbles rise to the top. Potassium iodide, an ionic compound, dissolves easily in water but does not dissolve in chloroform and hexane.

The demonstration also includes a chemical reaction that changes solubility. Although non-polar molecular iodine cannot dissolve in water, it reacts with iodide ion to form something that can: the triiodide ion. When iodide and iodine meet at water/chloroform-hexane surfaces, the triiodide ion formed dissolves in the water, not the non-polar solvent mixture. Solubility changes that follow chemical change are important in ecology. A chemical change may make a substance that is harmless because it is insoluble, into something soluble and toxic. .

Polarity refers to the degree of charge separation present in a molecule. Polar substances contain a permanent dipole: an average concentration of negative charge on one side and a corresponding average positive charge on the other. Water is a polar molecule. An ionic substance, which consists of charged particles held together by purely electrostatic forces, may be considered an extreme case of "polarity". Non-polar substances do not contain a significant permanent dipole. A molecule that consists of two identical atoms is definitely non-polar. Some non-polar molecules do contain polar bonds, but the vector sum for charge distribution over the whole molecule is essentially zero, Dipoles in non-polar substances are transient.

Why does "Like like like?" The attractive dipole-dipole forces between polar substances are stronger than the dipole-induced dipole attractions possible between polar and non-polar substances. Since water is a polar substance, polar and ionic substances are hydrophilic ("water-loving"). Non-polar substances are left to interact primarily with themselves and with other non-polar substances. Since they cannot interact as strongly with water as strongly as water interacts with itself, non-polar substances are hydrophobic ("water-fearing"). When mixed, polar and non-polar materials tend to form separate phases with minimal surface area between them. (Surfaces are often curved or spherical because a sphere encloses the largest volume with the smallest surface area.) Surface tension is another manifestation of the forces that keep phases apart.

The demonstration also provides opportunity to talk about pure substances, types of mixtures, and phases and their properties, and phase boundaries. How do we see phases in the first part of this experiment? With some exceptions, different phases have different optical densities. The practical result is that we see a surface, the boundary between two phases, because light is reflected differently from each phase. A solution (homogeneous mixture) has no phase boundaries. It looks uniform throughout. Liquid solutions are frequently transparent. Heterogeneous mixtures have many phase boundaries and are seldom transparent.

Emulsions are heterogeneous mixtures of liquids. You may produce one or more (by accident or design) in the course of this demonstration, especially when you are adding potassium iodide to the aqueous phase. The potassium iodide and the iodine that reacts with it increase the density of the phase. The solutions form a heterogeneous mixture. As the densities of the two solutions become more and more similar, the emulsion takes longer and longer to separate. Surfactants, molecules with both polar and non-polar character, also keep emulsions stable. The non-polar part of the surfactant interacts with the non-polar phase, and the polar part interacts with water. Surfactants can form micelles around the non-polar phase, with their hydrophilic part showing.

<u>Disposal</u>

Reduce all iodine species to iodide by shaking the mixture with sodium thiosulfate until the mixture is colorless. Separate the aqueous phase from the organic solvents. Flush the aqueous phase down the drain with plenty of water. Dispose of the solvents as hazardous waste, according to your state and local regulations.

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