CHEM FAX!
P.O. Box 219 • Batavia, IL 60510
(800) 452-1261 • Fax (866) 452-1436
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Separating a Synthetic Pain Relief Mixture

AP* Chemistry Big Idea 3, Investigation 9

An Advanced Inquiry Lab

Introduction

Most over-the-counter drugs consist of mixtures, or physical blends, of active drug ingredient(s) and binders. The main characteristic of a mixture is that it has a variable composition—the components of the mixture may be present or mixed in varying proportions. The substances in a mixture retain their distinctive chemical identities, as well as some of their unique physical properties. The purpose of this investigation is to study the physical properties of ingredients in a synthetic pain relief mixture and determine its percent composition.

Concepts

- Mixture vs. pure substance
- Over-the-counter drugs
- Physical and chemical changes
- Separation of a mixture
- Homogenous vs. heterogeneous
- Mass percent composition

Background

A mixture is a combination of two or more pure substances that retain their separate chemical identities and properties. Since the amount of each substance making up a mixture can be changed, the physical properties of a mixture will depend on its composition. Pharmaceutical companies manufacture different over-the-counter drug formulations with varying amounts of active drug ingredients, binders, and other inert materials. Binders are added to drug mixtures to form the pill, hold it together, and control release of the drug in the body at varying rates. Pain relievers usually contain starch or silica gel as the binder. Two common active drug ingredients in pain relievers are aspirin and acetaminophen. When not combined into pill form, aspirin and acetominophen, like all pure substances, have characteristic physical properties. Examples of physical properties that can be used to separate pure substances from a mixture and identify them include solubility, conductivity, magnetism, density, boiling point, and melting point.

By taking advantage of the unique physical properties of individual components within a mixture, it is possible to separate a mixture into its components. For example, if one component in a mixture of two solids dissolves in water, while the second component does not, the substances can be separated by adding water to the mixture and then filtering the residue. Subjecting the mixture to a physical change in this way would change the ratio of components in the mixture. This leads to one of the definitions of a mixture—a substance whose composition can be altered by a physical change. Physical changes that can be used to separate the components of a mixture include filtration, evaporation, crystallization, distillation, and extraction.

Extraction is a convenient method for isolating and separating organic substances. Solid–liquid extraction is a familiar technique used to prepare beverages such as coffee or tea—organic compounds, including caffeine and various flavor ingredients, are extracted using hot water. In liquid–liquid extraction, a substance that is at least partially soluble in two immiscible liquids can be transferred from one liquid to the other. This is usually done in a separatory funnel by shaking a solution containing two or more solutes with a second, immiscible solvent that will dissolve only one of the solutes. The liquids separate into two layers in the separatory funnel, with the more dense liquid in the bottom layer and the less dense liquid in the top layer.

The structures of acetylsalicylic acid (aspirin) and acetaminophen are shown below in Figure 1. Acetylsalicylic acid is an organic carboxylic acid (—CO_2H group) that also contains an ester functional group (CH_3CO_2—)as a side chain on the benzene ring. Acetaminophen has two primary functional groups, a hydroxyl group on the benzene ring, as well as an amide side chain (CH_3CON—).

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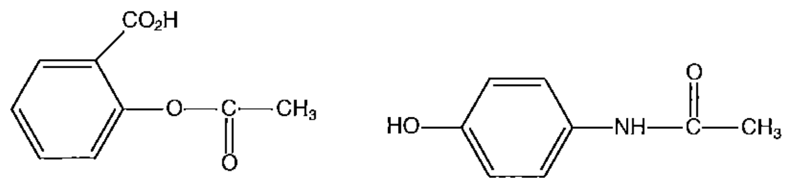

Acetylsalicylic Acid   Acetaminophen

Figure 1.

Carboxylic acids that do not dissolve in water can be extracted from an organic solvent with an aqueous solution containing an inorganic base, such as dilute sodium hydroxide. The base converts the carboxylic acid to its conjugate base, a sodium salt that is soluble in water. An example of this process is shown in Equation 1 as the neutralization reaction of benzoic acid with sodium hydroxide.

$$C_6H_5CO_2H(s) + NaOH(aq) \rightarrow C_6H_5CO_2Na(aq) + H_2O(l) \qquad \textit{Equation 1}$$

Benzoic acid

Mass percent composition is a convenient way to express the actual composition of a mixture in terms of the amount of each component. The mass percentage of each component in a mixture is calculated as follows:

$$\text{mass \% of component} = (\text{mass of component/total mass of mixture}) \times 100\%$$

In order to determine the percent composition of a mixture, it is necessary to separate the components quantitatively—ideally, without loss of material—and then measure the mass of each recovered component. The sum of the mass percentage of all components in a mixture equals 100%.

A flow chart is often used to illustrate the steps involved in separating a mixture. In a flow chart, the substances in the mixture are listed inside boxes that are connected by arrows. The actual physical steps that must be carried out to separate the components are listed next to the arrows. Imagine a sample of seawater that has been collected at the beach. There is a liquid layer, consisting of dissolved salt in water, and solid sand particles suspended in the liquid. Figure 2 shows a simple method for separating and determining the amount of each component in a sample of seawater.

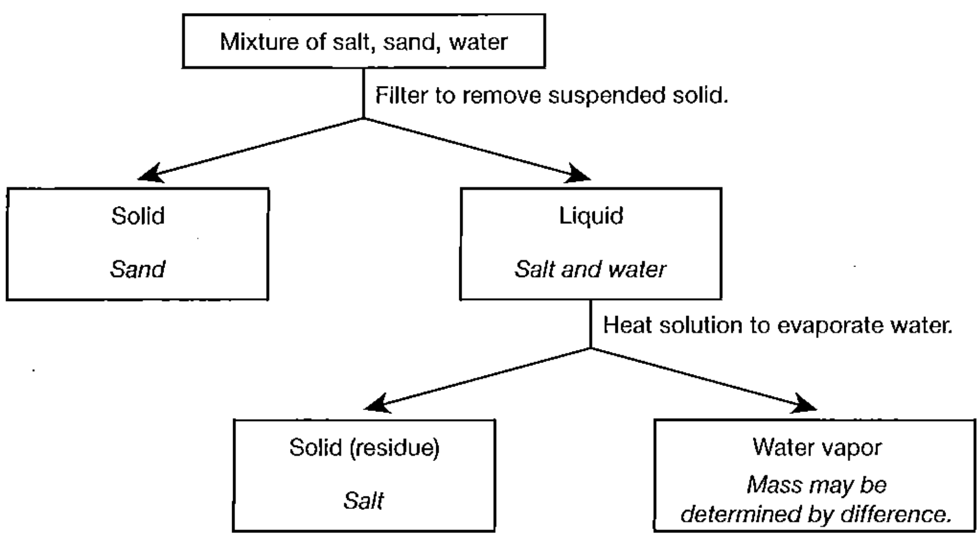

Figure 2.

Experiment Overview

The purpose of this advanced inquiry investigation is to separate a mixture that represents a pain reliever. The mixture may contain binder, acetaminophen, and acetylsalicylic acid in varying amounts. The lab begins with an introductory activity to test the solubility of each possible component in an organic solvent, ethyl acetate, and in a basic aqueous solution of sodium bicarbonate. The results provide a model for the guided-inquiry design of a flow chart that will map the procedure used to separate components in a mixture and determine percent composition. Optional extension activities include varying the amounts of individual components in the synthetic mixtures and analyzing consumer samples. Students may also measure the melting points of the isolated components, acetylsalicylic acid and acetaminophen, to confirm their identity.

Pre-Lab Questions

1. The Department of Transportation uses a mixture of sand and salt to de-ice roadways in the winter. The mixture contains 8.35 tons of salt and 6.28 tons of sand. What is the mass percent of each component in the mixture?
2. A bakery needs a mixture of flour and sugar to make cookies. The mixture should contain 62.5% flour and 37.5% sugar. You are in charge of ordering the components to make 275 pounds of the mixture. How many pounds of flour and sugar should be ordered?
3. In the *Introductory Activity*, the solubility of the possible components in the synthetic pain relief mixture will be tested using 10% sodium bicarbonate solution. Is this solution acidic or basic? What is the likely pH of the sodium bicarbonate solution?
4. Predict which component in the synthetic pain relief mixture is likely to dissolve in sodium bicarbonate solution. Explain.

Materials

Acetaminophen, C_8H_9NO, 10 mg
Acetylsalicylic acid, $C_9H_8O_3$, 10 mg
Ethyl acetate, $CH_3CO_2CH_2CH_3$, 65 mL
Hydrochloric acid, HCl, 6 M, 40 mL
Silica gel, 10 mg
Sodium bicarbonate solution, $NaHCO_3$, 10%, 50 mL
Synthetic pain relief mixture, 450 mg
Balance, 0.001-g precision
Beakers, 150-mL, 2
Boiling stones, 2
Capillary tubes, 2 (optional)
Erlenmeyer flask, 125-mL
Filter paper
Funnel
Graduated cylinder, 50-mL
Hot plate
Ice bath
Magnetic stirrer and stir bar, or stirring rod
Melting point apparatus (optional)
pH test strips, 3
Separatory funnel, 250-mL
Spatula
Support stand and ring clamp
Test tubes, 5
Watch glasses, 2
Weighing dishes

Safety Precautions

The 6 M hydrochloric acid is toxic by inhalation and ingestion. It is severely corrosive to all body tissues, especially skin and eyes. Ethyl acetate is a colorless, fragrant and flammable liquid. Handle ethyl acetate in a properly ventilated area such as a fume hood and keep away from flames, sparks, and other sources of ignition. Ethyl acetate is also slightly toxic by inhalation, ingestion, and skin absorption. Acetaminophen is harmful by ingestion and irritating to skin and eyes, and mucous membranes. It is a possible sensitizer. Aspirin (acetylsalicylic acid) is toxic by ingestion. It is an allergen and irritant and may cause internal bleeding. The acetaminophen and aspirin are not sold for human consumption. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the lab. Please follow all normal laboratory safety guidelines.

Introductory Activity

1. Obtain small, pea-size amounts (1–2 mg each) of acetylsalicylic acid, acetaminophen, and silica gel in separate labeled test tubes.
2. Add 1 mL of ethyl acetate to each test tube and record observations.
3. Add 1 mL of deionized or distilled water to the three test tubes containing ethyl acetate and dissolved or undissolved solids. Record all observations.

4. Obtain additional 1–2 mg samples of acetylsalicylic acid and acetaminophen in separate clean and labeled test tubes. Add 1 mL of 10% sodium bicarbonate to each test tube and record observations.

5. Slowly and carefully add about 1–2 mL of 6 M hydrochloric acid drop-wise to the test tube mixtures from step 4. Record observations. Place test tubes in an ice bath for 5 minutes and record any additional observations.

Guided-Inquiry Design and Procedure

Form a working group with other students and discuss the following questions.

1. Which potential component in the synthetic pain relief mixture can be separated from the others based on the results of the solubility test with ethyl acetate? Explain.
2. Which potential component in the synthetic pain relief mixture could be separated from the mixture using liquid-liquid extraction with sodium bicarbonate solution? Explain.
3. Explain how this component could be recovered from the resulting aqueous extract.
4. Write balanced chemical equations for the extraction of the component with a base (Question 2) and the subsequent recovery of the component (Question 3).
5. Review the design of a separatory funnel and the following procedure for using a separatory funnel with volatile organic solvents. Explain the reasoning for each step and precaution (precautions are shown in italics).
   - Place the separatory funnel in a ring clamp that is attached to a support stand. *Make sure the stopcock is closed* and pour the organic solvent (or solution) into the funnel.
   - Add water or another aqueous solution to the solvent in the funnel and place the stopper in the top of the funnel.
   - Remove the funnel from the ring clamp and carefully invert it, making sure to *hold the stopper with one hand. Immediately after inverting the separatory funnel, open the stopcock.*
   - Close the stopcock and gently shake the funnel once to mix the aqueous and organic layers. Keep the separatory funnel inverted, and make sure to hold on to the stopper!
   - Open and close the stopcock. *Repeat the shaking/venting process a few times.*
6. Which liquid will be the bottom layer in the separatory funnel? Explain.
7. Which component will remain in the ethyl acetate solution after the extraction step? How can this component be recovered to determine its amount?
8. What precautions are needed when carrying out the recovery step in Question 7? Explain.
9. Draw a flow chart and outline a process for separating and recovering the components in a synthetic pain relief mixture.
10. Write a detailed, step-by-step procedure for separating the components and determining the percent composition of the mixture. Include the safety precautions, and specify the glassware and equipment you will need, the amounts of any solvents and additional chemicals, and any observations or measurements you will need to make. *Note:* Use about 450 mg of the synthetic pain relief mixture.
11. Review additional variables that may affect the reproducibility or accuracy of the experiment and how these variables will be controlled.
12. Carry out the experiment and record results in an appropriate data table.

Analyze the Results

Calculate the mass percent composition of all the components in the synthetic pain relief mixture.