2.3 Separating the Substances of a Mixture

Warm Up

A student scoops up a pail full of water and mud from the bottom of a pond. The mixture in the pail is a suspension of mud particles and algal cells and a solution of salts. Outline a method for separating these three components.

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Separating Mixed Substances

Most naturally occurring objects and materials are mixtures. Our atmosphere, our natural water systems, and the ores and petroleum products (such as crude oil and natural gas) that we extract from the ground are mixtures. Just as a compound can be decompounded (decomposed), a mixture can be unmixed. Since the ingredients of a mixture are not chemically combined, they retain their individual identities. The trick to separating the substances in a mixture is to pick a property that clearly differentiates the substances.

Consider a mixture of marbles and beads. Because the marbles and beads do not form any aggregates, they can easily be separated by pouring the mixture into a colander (a bowl full of holes). It would capture the marbles but allow the beads to pass through. Laboratory technicians perform a tremendous number of separations daily in medical, forensic, and analytical chemistry laboratories to allow the substances in the mixtures to be identified. Large industrial-scale separations are performed around the world in commercial refineries (for sugar, oil, metal, etc.) to obtain the target substances for their useful properties, their intrinsic values, or more commonly to use the substances to produce useful mixtures of our own design.

Mechanical Means of Separation

In Chemistry 12, you'll examine a chemical separation technique called selective precipitation. In this course we restrict our studies to **physical separations**: those not involving chemical reaction. Physical separation techniques include centrifugation, chromatography, recrystallization, decantation, density separation, distillation, electrophoresis, evaporation, extraction, flotation, filtration, freezing, magnetic separation, reverse osmosis, and sedimentation. Physical separations may be classified as mechanical or non-mechanical. Non-mechanical means of separation include techniques that use heat, electricity, magnetism, dissolving, or sticking to separate a mixture's components. **Mechanical means of separation** use gravity, contact forces, or motion to sort the components of a mixture. Terms such as picking, sifting, filtering, shaking, spinning, pouring, and skimming, describe the type of actions involved in mechanical separations. We'll just describe some of the more common techniques in this section.

Density Separation

To **sediment** (verb) means to fall or sink to the bottom of a liquid. **Sediment** (noun) is matter that has fallen or sunk to the bottom of a liquid. As Isaac Newton deduced, an object doesn't just fall of its own accord. A force is required to change an object's state of motion. A falling object is acting under the influence of gravity. The difference between falling through a vacuum (which is essentially empty space) and falling through a medium is the medium. A medium exerts an upward force called **buoyancy** on all objects immersed in it. As an object enters a fluid, it lifts the fluid it displaces. A buoyant force equal to the weight of this displaced fluid is redirected upward on the immersed object.

Every object surrounded by a fluid (air, water, etc.) has at least some of its weight supported by buoyancy.

If the object is less dense than the fluid, then the object will float because it will displace a weight of fluid greater than its own weight. Therefore, the force of buoyancy acting on it will be greater than the force of gravity acting on it. Density separation can be used to separate solids with different densities. By adding a liquid that is more dense than one of the solids in the mixture, only that solid float while the others sink. Conversely, by adding a liquid that is less dense than one of the solids in the mixture, only that solid sinks while the oth float. The solids must be insoluble in the liquid media used to selectivel float or sink them. This technique is used to separate plastics of differen densities.

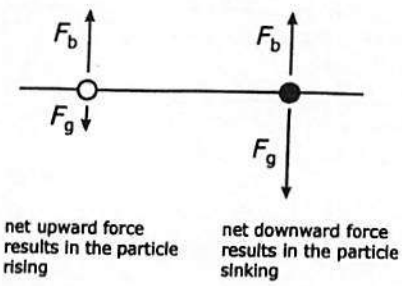

Figure 2.3.1 *Forces acting on particles suspended in a heterogeneous mixture*

Although density separation separates the solid particles from ea other, they are now mixed with the liquid(s) used to separate them. The particles that float can be skimmed off the top of the liquid and dried. Th particles that sediment can be separated from the liquid by decanting o the liquid or by filtering out the sediment. **Decanting** is carefully pourin off the liquid and leaving the sediment in the bottom of the original container. A small amount of liquid is usually left in the container and ca must be taken to prevent a small amount of sediment from flowing with the liquid out of the container.

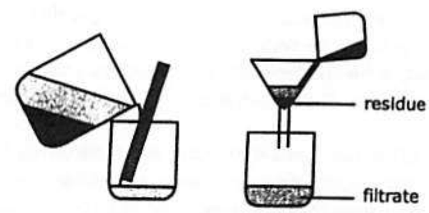

Figure 2.3.2 *Decanting (left) and filtering*

The sediment can also be separated from the liquid by filtration. In the simplest form of **filtration**, the liquid containing the sediment is poured into a folded piece of filter paper in a funnel. The material filtered out of the mixture is called the **residue**. The liquid that passes through the filter paper is called the **filtrate**. Dissolved substances and colloids are too small to be filtered out by regular filter paper but some colloids can be removed by ultra-filtration which uses filter paper with extremely small pores.

Centrifugation

Another mechanical means of separation is centrifugation or spinning. Centrifugation enhances density separation. Particles that would normally sink or rise still do so, just more rapidly.

When you are in a car that turns a sharp corner you may be "thrown" sideways. It might seem as though a force pushed you against the door. To explain this and similar phenomena, people have invented an imaginary or nonexistent force known as a centrifugal force, which is said to cause the outward motion. In fact, no force was necessary for you to keep travelling at a constant speed in a straight line. When the car turned, you didn't. Your body attempted to keep going in your original direction. All objects have a resistance to change in motion. This property is called **inertia**. The suspended particles in a mixture behave similarly in a centrifuge. As the tube changes its direction, the suspended particles initially maintain their linear motion. This process occurs continuously as the tube spins, directing the suspended particles to the bottom of the tube (Figure 2.3.3).

Figure 2.3.3 *The particle in the centrifuge tube continues to travel in a straight line while the tube turns. The spinning forces it to the bottom of the tube, as shown on the right.*

Quick Check

1. What force causes objects to float? ______________________
2. What is decanting?
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3. How does centrifugation work? ______________________
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Non-Mechanical Means of Separation

Chromatography

Chromatography is one of the most widely used techniques in scientific research today. The processes involved in the separation are generally mild ones. Chromatography has been successfully employed to separate some of the most fragile and elusive substances. Researchers have been able to devise a chromatographic method for separating all but a few mixtures.

Chromatography separates the substances in a solution by having a flowing liquid or gas carry them at different rates through a *stationary phase*. The flowing liquid or gas is called the *mobile phase*. Each substance travels through the stationary phase at its own characteristic rate, according to its relative affinities for the two phases. A substance that adheres strongly to the stationary phase but isn't very soluble in the mobile phase travels slowly through the chromatogram. Conversely, a substance that adheres weakly to the stationary phase but is very soluble in the mobile phase travels quickly through the chromatogram.

There are many forms of chromatography. These include gas chromatography, column chromatography, thin layer chromatography, and paper chromatography. In thin layer chromatography (TLC), the stationary phase is a thin layer of silica gel dried onto a glass plate. In paper chromatography, the stationary phase is a strip or sheet of paper. The mobile phase in both forms of chromatography could be water, an organic solvent such as alcohol, or a mixture of solvents. A drop of the solution to be separated is placed near the bottom of the sheet or plate and allowed to dry. Another drop of the solution is then placed on top of the first and also allowed to dry.

This process is repeated many times until there is a sufficient amount of each solute to produce a clear chromatogram. The bottom of the chromatogram is lowered into a pool of the solvent. **Capillary action** is the tendency of a liquid to rise in narrow tubes or to be drawn into small openings. Capillary action results from the adhesive forces between the solvent molecules and those of the wicking material in combination with the cohesive forces between the solvent molecules themselves. Capillary action causes the solvent to rise up the stationary medium, between the paper fibres or the grains of the gel, past the deposit of solutes, and up the remainder of the paper or glass plate.

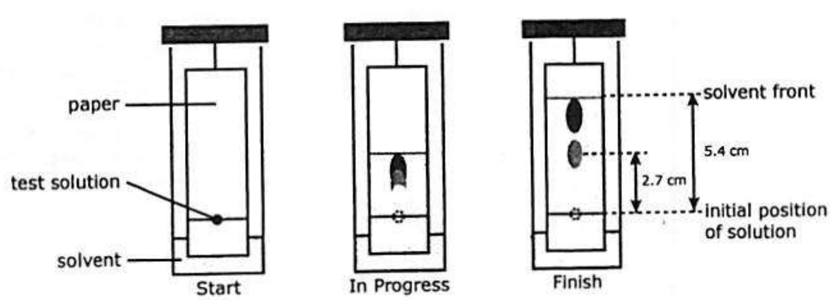

Figure 2.3.4 *Thin layer or paper chromatography*

A substance's R_f (retention factor) for any particular system is defined as its flow speed rel to that of the mobile phase. Here is an example calculation:

$$R_f = \frac{\text{distance the substance flows}}{\text{distance the solvent flows}} \text{ (in a given time period)}$$

$$= \frac{2.7 \text{ cm}}{5.4 \text{ cm}} = 0.50$$

A substance's R_f may help identify it or at least support its identification by more definitive means.

"Developing a chromatogram" is the spraying of chemicals on a chromatogram to form coloured complexes with the separated substances so they reveal their location. *Elution* is the pro of rinsing the separated substances off the chromatogram. Their recovery is usually necessary so they can be identified through further analysis. Chemists commonly run at least two chromatogr under identical conditions. One is developed to determine the location of the separated substanc The substances are then eluted from the same locations on the undeveloped chromatogram.

In column chromatography, the stationary phase is a glass tube packed with specially treat resin beads. The mobile phase is sometimes just the solution itself but another solvent may be ne to wash the solutes through. Column chromatography is an "open-ended" form of chromatograph in which the separated substances flow out the bottom end of the column at different times. Peri chemical tests or constant electronic monitoring indicates the presence of substances as they leav the column. For column chromatography, the substances' R_f values are calculated as:

$$R_f = \frac{\text{substance time}}{\text{solvent time}} \text{ (to travel through the column)}$$

Electrophoresis is similar to chromatography except that the stationary phase is a gel-coatec slide or gel-filled dish with oppositely charged electrodes at either end. Species are separated according to their charge or polarity, mass, and size. Other separation methods that involve solubi include solvent extraction and recrystallization. In solvent extraction, one or more compounds are soluble in a particular solvent while the others are not. In recrystallization, trace amounts of impuri stay in solution as the solution is cooled

Distillation

Distillation is any process that separates a mixture of substances by using their different vapour pressures or boiling points. Distillations require a heating device, a flask containing the original mixture, a condenser to cool and condense the vapours, and something to collect the condensed substances as they leave the condenser one after the other (Figure 2.3.5). Distilled water is produce by boiling tap water, cooling its vapours, and then collecting the condensate or **distillate**. The impurities that were dissolved in the water remain as **residue** in the original flask.

Such *simple distillations* are suitable for separating dissolved solids from a solvent but there is fundamental problem using this technique to separate two liquids. Liquids can evaporate long befo boiling occurs as evidenced by the puddles on our street that come and go without ever boiling. Because of this, the initial distillate is still a mixture although it is now richer in the liquid with the lower boiling point. If you took this distillate and repeated the distillation process, the next distillate would be richer still in this liquid. If you repeated this process many times, each time the distillate would become increasingly richer in the substance with the lower boiling point but this would be a tedious process. A mixture that cannot be completely separated by simple distillation is called an azeotropic mixture.

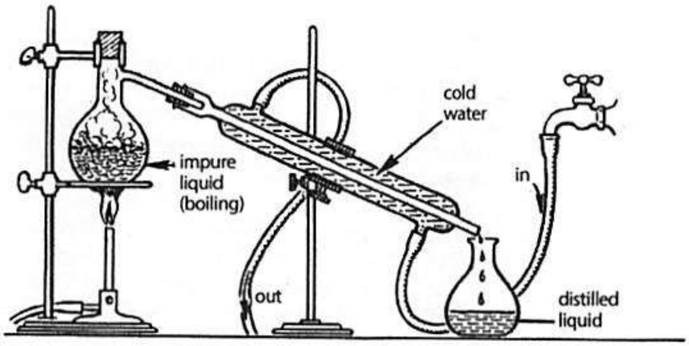

Figure 2.3.5 *Laboratory distillation apparatus*

Scientists have therefore devised a method called **fractional distillation** in which the simple distillation (vaporizing and condensing) is repeated many times within the one device. After evaporating, the vapour enters a *fractionating column*. This may be a tube packed with glass fibres, a tube containing overlapping glass lips or plates, or simply coiled tubing as popularized by backwoods stills. The idea is to provide surfaces on which the vapours can condense. As the hot vapours from below reheat the distillate, some compounds revapourize and travel farther up the column. At the same time, others with higher boiling points drip back in the opposite direction. This process is called *reflux*. The plates become progressively cooler as you move up the column. Each time the process is repeated, the distillate becomes richer in the liquid with the lower boiling point. The component liquids thus proceed at different rates up the fractionating column so as you move higher up, the mixture becomes increasing richer in the liquid with the lower boiling point. If the column is long enough, the liquid components may separate completely and enter the condenser one after the other. There are of course several variations on this same technique.

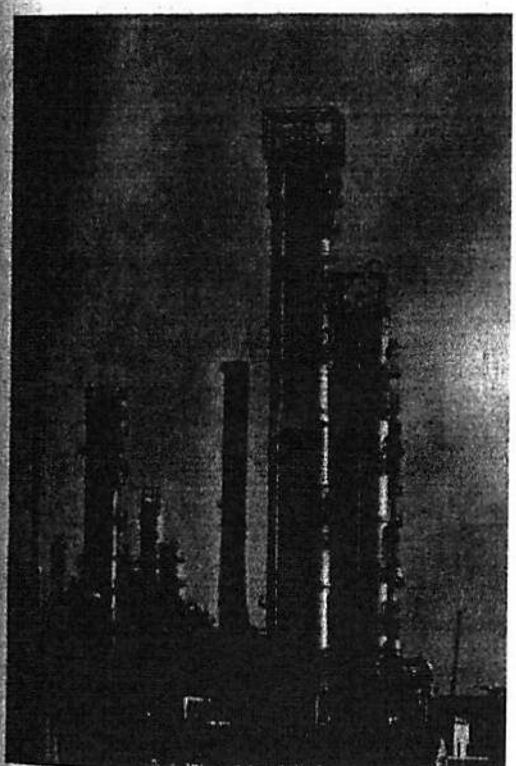

Figure 2.3.6 *Industrial distillation*

Distillation is an important laboratory and industrial process (Figure 2.3.6). Oil refineries employ distillation to separate the hundreds of different hydrocarbons in crude oil into smaller groups of hydrocarbons with similar boiling points. Chevron has an oil refinery in Burnaby and Husky has an oil refinery in Prince George. When distilling a single batch, as described and illustrated above, the temperatures within the column continuously change as the chemicals travel through the column much like solutes travelling up a piece of chromatography paper. By contrast, oil refineries continuously feed the vaporized crude oil mixture into large steel fractionating towers that electronically monitor and maintain a steady range of temperatures from 400°C at the bottom to 40°C at the top. Each compound rises until it reaches a section of the column that is cool enough for it to condense and be withdrawn from the column. For example, the gasoline fraction (meaning the fraction containing gasoline, itself a mixture) exits near the top of the tower at the 40°C to 110°C level.

Froth Flotation

BC is one of the world's major mining regions, and mining is a key contributor to the province's economy. Precious metals such as gold and silver are very stable or unreactive and are found in nature in their "native" or elemental form. This property is central to their value in jewellery. Other metal atoms such as copper are mostly found in nature in ionic compounds. Naturally occurring compounds are called **minerals**.

Rock containing a desired mineral is called **ore**. The first stage of mining is to extract the ore via blasting or drilling, depending on the kind of mine. The second stage is to mill or crush the ore into a fine powder. The third stage is to separate the target mineral(s) from the rest of the ore, called gangue. Copper compounds are separated by a technique called **froth flotation**. The powdered rock is mixed with water and then a small amount of pine oil is added that adheres to the mineral grains but not to the gangue. Oil and water don't mix so the grains are rendered **hydrophobic** or water repelling. Air is bubbled through the mixture and the hydrophobic grains of mineral escape the water by attaching to the air bubbles, which float them to the surface. The target mineral is then skimmed off, washed, dried, and shipped to a refinery where it is decomposed to recover the metal. Froth flotation is also used in wastewater treatment and paper recycling.

Quick Check

1. What is chromatography?

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2. What is distillation?

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3. Name three areas that use froth flotation.

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2.3 Review Questions

1. What is the difference between decomposing compounds and separating mixtures?

2. Give three reasons for separating the substances in a mixture.

3. Oil floats on top of water because it is less dense. However, oil pours more slowly than water because it is more viscous. Is the ability of a fluid to suspend particles more closely correlated to its density or its viscosity?

4. Inertia plays an integral role in most mechanical separations.
   (i) What is inertia?

   (ii) Describe the role inertia plays in centrifugation.

5. Rewrite the underlined part of the following statement to correct it.
   Heavier particles centrifuge more rapidly because <u>of the greater centrifugal force exerted on them.</u>

6. Devise a simple scheme for separating a mixture of sand, sugar, and iron filings. Each material must be recovered in its original solid form.

7. Briefly describe the role of a furnace filter.

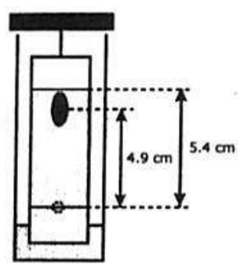
8. Briefly describe how chromatography separates the substances in a mixture.

9. What does the phrase "developing a chromatogram" refer to?

10. What is elution and what is its usual purpose?

11. Why should you mark the starting position of the deposited solution on the chromatography paper with pencil rather than pen?

12. What is the R_f of the compound shown in the diagram ?



13. What is the basic problem with simple distillation?

14. Identify two factors that affect how completely the components of a solution are separated by fractional distillation.

15. Air is approximately 78% nitrogen (boiling point: −196°C) and 21% oxygen (boiling point: −183°C). Briefly describe how you would separate nitrogen and oxygen from air.

16. Which process requires more energy: chromatography or distillation? Explain.

17. Both density separations and froth flotations involve some materials floating and others sinking, yet density separations are considered a mechanical means of separation while froth flotations are not. What is the main difference between these two techniques?