Physical properties

Physical properties are properties that can be determined without changing the chemical composition of a substance. Examples of physical properties are:

- melting point
- boiling point
- strength
- density
- malleability (ability to be beaten into sheets)
- ductility (ability to be drawn into wires)
- electrical conductivity
- thermal conductivity
- solubility
- state
- hardness.

While pure substances may have similar physical properties and so can be classified into broad groupings such as metals and non-metals, there are always differences that allow individual substances to be identified.

Consider the pure substances water and hydrogen peroxide. Their properties are listed in Table C2.1.

Table C2.1 Properties of water and hydrogen peroxide

Property	Water (H_2O)	Hydrogen peroxide (H_2O_2)
Colour	Colourless	Colourless
State (at 25°C)	Liquid	Liquid
Density (g mL^{-1})	1	1.4
Melting point (°C)	0	−0.4
Boiling point (°C)	100	150

While hydrogen peroxide could be easily mistaken for water because they are both colourless liquids, there are other properties that distinguish them. It would be disastrous to drink hydrogen peroxide as it harmful and corrosive.

Chemical properties

Chemical properties relate to the ability of a substance to react to form new substances. In determining chemical properties, the chemical composition of the original substance is changed. This is one way to distinguish physical and chemical properties. Common chemical properties include:

- decomposition by heat
- effect of light
- reactions with water, acids, bases, oxygen and other substances. For example, iron reacts with oxygen in air and water to form rust (Figure C2.7).

123RF/Wouter Tolenaars.

Figure C2.7 ▲ Iron reacts with oxygen and water to form rust – a new compound.

Although it is important to know whether a substance will react, for chemists it is just as important to find out if a substance does not react. For example, the fact that carbon dioxide is not flammable (does not react with oxygen) is why it is used in fire extinguishers.

The chemical properties of substances can be used to identify them and distinguish between different substances. Chemists use the properties of substances to identify unknown substances (for example, in forensic chemistry) or to identify if they come from the same source (see weblink 'Lava sampling').

Physical and chemical changes

Matter can undergo physical and chemical changes. **Physical changes** are changes in the physical properties, such as density, state and colour. In a physical change, there is no change in the chemical composition of the substance. Tearing paper, dissolving salt and freezing water are all examples of physical changes.

A change in which at least one new substance is formed is a **chemical change**. The chemical composition of the original substance has changed and the new substance formed has different chemical and physical properties. The types of chemical change a substance undergoes relate to its chemical properties.

Burning, digestion and fermenting are all examples of chemical changes. When copper is placed in colourless nitric acid, the liquid turns blue and a brown gas is given off. This indicates a chemical change has occurred.

Chemical changes are also referred to as chemical reactions. Common ways of determining whether a chemical change has occurred are if:

- a solid (called a precipitate) is formed; for example, when lead nitrate and sodium iodide solutions are mixed, a bright yellow solid is produced
- a gas is produced; for example, when magnesium metal is dropped into hydrochloric acid, a gas is produced
- there is a colour change; for example, when iron is exposed to air and water, it turns a reddish brown
- there is a significant change in temperature (energy is released or absorbed); for example, when sodium is dropped into water, heat is given off
- an insoluble solid disappears; for example, copper in nitric acid, as shown in Figure C2.8.

LAVA SAMPLING

Watch this video to see how the chemical properties of collected lava samples are used to determine whether two different volcanoes in Hawaii, USA, are connected.

To learn more about materials, refer to Context 2, 'Materials for a purpose', page 31.

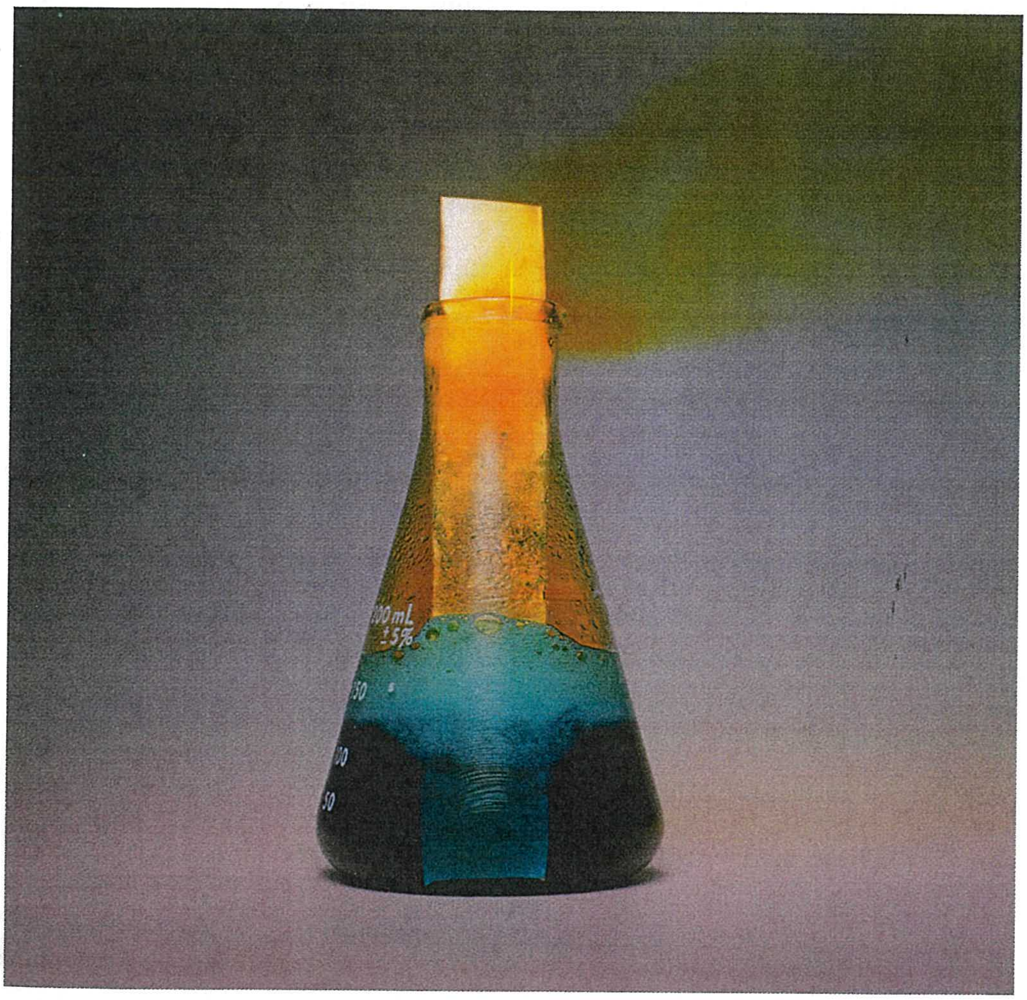


Figure C2.8
The reaction of copper with nitric acid produces a blue solution and a brown gas.

2.3 Separating mixtures

Most of the substances found naturally on Earth are mixtures. One of the most important substances, water, is a compound of hydrogen and oxygen. However, all natural sources of water are mixtures containing many dissolved salts, the most common of which is sodium chloride.


iStockphoto/rusm.

◀ **Figure C2.10**
Sea water is a mixture of water, sodium chloride and other compounds.

WOW

Salts from the Dead Sea

The Dead Sea contains such large amounts of dissolved salts that almost nothing can live in its waters. The Dead Sea's salts are valuable to both industry and agriculture. Countries adjacent to the Dead Sea extract the salts sodium chloride, potassium chloride, magnesium chloride and magnesium bromide from the water. The extraction process relies on one physical property – solubility. The salts are separated by differences in solubility at different temperatures.

Mixtures are combinations of two or more pure substances that have not been combined chemically, so they can be separated into their components by physical or mechanical means.

Chemists have developed many different separation techniques based on the properties of the materials they want to separate. Table C2.2 summarises mixture types, possible separation methods and properties the methods depend upon. The table does not list all possible separation techniques and you will learn about others during your Chemistry course.

The properties of the components in a mixture determine the technique used to separate them.

DISTINGUISH BETWEEN A MIXTURE AND A COMPOUND

Visit this website and try the animations, video and simulations of many of the separation techniques discussed.

Table C2.2 Separation method, typical mixture and properties

Separation method	Typical mixture separated by this method	Property used in separation
Electrostatic attraction	Mixture of electrostatic and non-electrostatic materials	Difference in electrical charge
Filtration	Mixture of insoluble solid and liquid	Difference in state and size of particles
Fractional distillation	Mixture of liquids	Significant but small difference in boiling points
Magnetic separation	Mixture of magnetic and non-magnetic material	Difference in attraction to a magnetic field
Separating funnel	Mixture of immiscible (undissolved) liquids	Difference in densities
Sieving	Mixture of solids or solids and liquids	Difference in particle size
Simple distillation	Mixture of liquids or liquids and solids	Big difference in boiling points
Vaporisation (evaporation or boiling)	Solution containing dissolved solids	Liquid has a much lower boiling point than dissolved solid

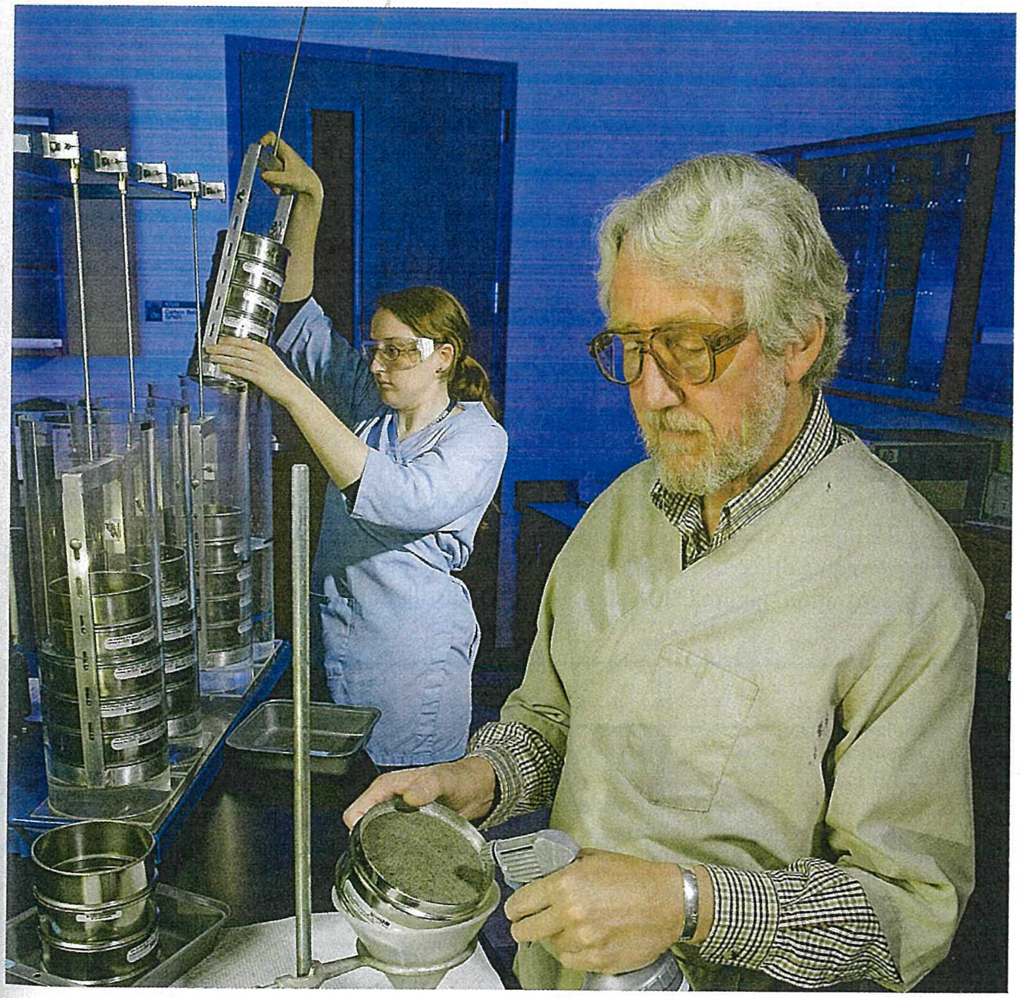
Many mixtures cannot be separated by only one technique and several techniques need to be applied in a particular sequence to obtain the desired products. For example, to separate a mixture of salt water, iron filings and sand, the techniques and order in which they were performed would determine the final products. You could use a magnet to remove the iron filings, and then filter the remaining combination of salt water and sand to separate out the sand, and then evaporate the water to obtain the salt. In this process, the water is not collected. If the water was also a required product, then simple distillation could be used instead of evaporation.

Separation by difference in particle size

There are two techniques that separate mixtures according to the size of the particles.

Sieving is one way of separating mixtures of solids, or solids and liquids with different-sized particles. The mixture is poured through a sieve (wire gauze in a frame) and particles that are smaller than the sieve pass through while the larger particles are trapped by the sieve.

Sieving is commonly used in cooking. For example, a mixture of rice and water is poured through a sieve to capture the rice and remove the water. Sieving is also used in the pharmaceutical, ceramics and mining industries. Sometimes, several sieves are stacked together with each one having smaller holes than the one above. In banks, mixtures of coins are



Science Source

Figure C2.11
Sieving is a common way of separating mixtures.

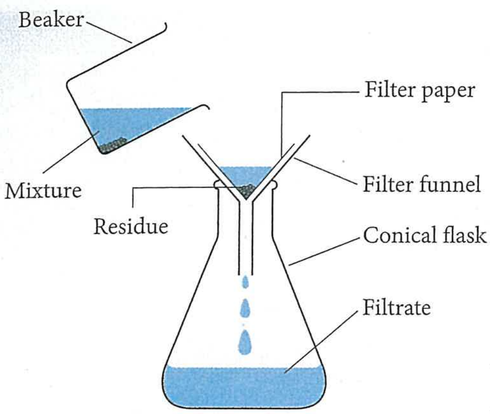


Figure C2.12 ▲ Filtration in the laboratory

separated by pouring them into a stack of sieves of different sizes. The stack is shaken and the smaller coins fall through until there is a tray of 5 cents on the bottom, a tray of $2 coins above that and so on.

Filtration is a separation technique that also depends on particle size. It is more commonly used for mixtures of solids and liquids, particularly when the solid particles are quite small. A typical filtration set up used in the laboratory is shown in Figure C2.12.

The liquid or solution is poured into the filter paper. The liquid passes through the filter paper and the solid, or **residue**, is trapped by the filter paper. The liquid or solution that passes through is called the **filtrate**.

Filtration is also used to separate larger particles suspended in air or to remove pollutants from exhaust gases produced by cars or power stations to prevent them being released into the atmosphere.

Separation by difference in boiling point

Three main separation techniques depend on differences in boiling point. **Vaporisation** is most commonly used to retrieve a solid that has been dissolved in a liquid (i.e., when there is a solution). The liquid component of the solution (solvent) is converted to vapour by either boiling the solution or allowing it to evaporate, leaving behind the dissolved solid (solute). Boiling is a much quicker process than evaporation. This technique is based on the large differences in boiling point of the solute and solvent.

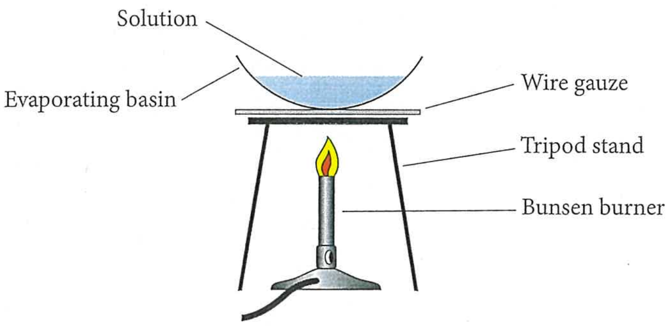


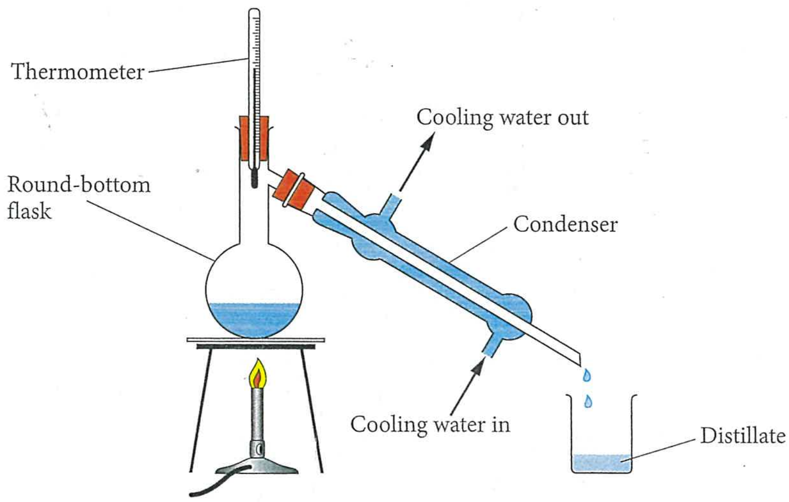
Figure C2.13 ▲ Vaporising a solution.

Figure C2.13 shows a laboratory set-up for vaporising a solution through boiling. Chemists frequently use boiling to remove all the solvent from the solution to obtain a dry solute. They call this evaporating to dryness.

Vaporising the liquid is effective when the dissolved solid is the desired product; for example, if you want to recover salt from sea water. However, this technique does not recover the liquid. If you want to recover the liquid, or the liquid and solid, then simple distillation should be used.

Distillation, or simple distillation, is a technique for separating two or more liquids or separating the liquid from the solids in a solution but also retrieving the liquid component. This technique relies on a difference of at least 50°C in boiling point between components to obtain an effective separation. Figure C2.14 shows a simple distillation apparatus.

Figure C2.14 ▶ Simple distillation apparatus



The mixture to be separated is placed in a round-bottom flask and heated to boiling. The vapour rises up the neck of the flask and then flows into the water-cooled condenser. The vapour condenses back to a liquid called the **distillate** and is collected in a beaker.

The liquid with the higher boiling point and any solids are left in the round-bottom flask. If the boiling points are not sufficiently different, then the distillate will still be a mixture.

Fractional distillation is the technique used to separate liquids that have boiling points that are close together. The mixture is heated and the components or fractions with different boiling points rise up the fractionating column to different heights. The component with the lowest boiling point is collected at the top of the column, while the component with the highest boiling point is at the bottom of the column. Figure C2.15 shows a fractional distillation column used to separate crude oil into its components.

Fractional distillation is widely used in industry for:

- separating crude oil into its components at oil refineries
- natural gas processing
- cryogenic air separation to obtain oxygen, nitrogen and argon from liquid air.

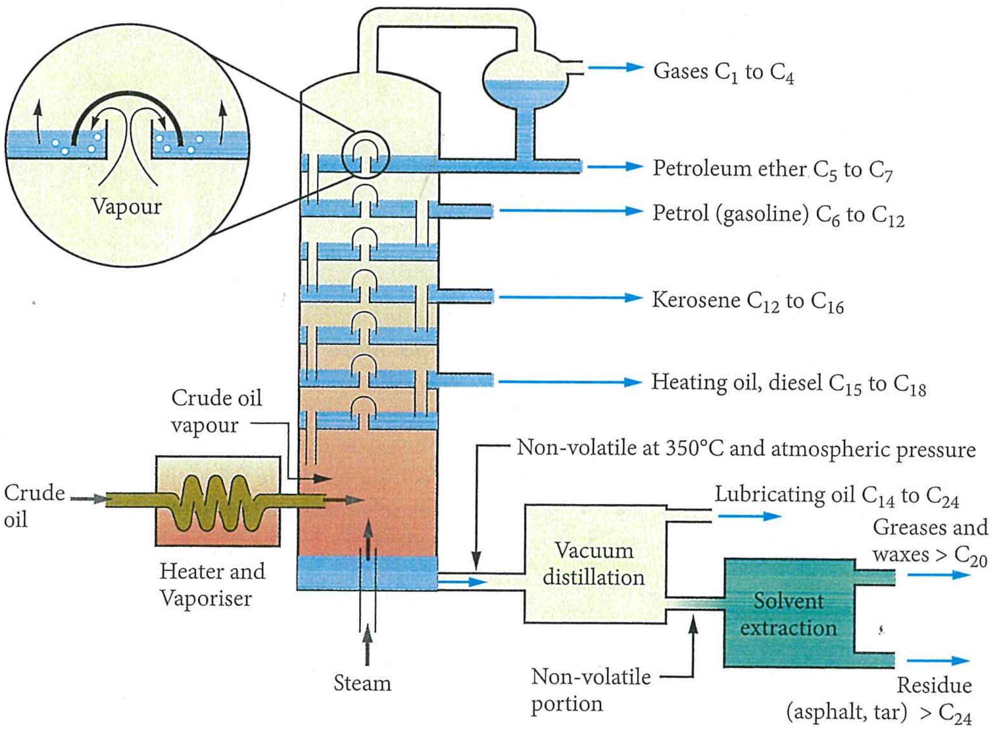


Figure C2.15
Fractional distillation of crude oil

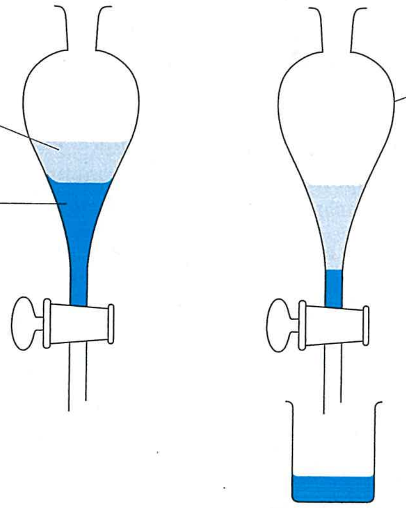
Discovery of the noble gases

In 1894, Sir William Ramsay and Lord Rayleigh, using two different methods, separated all known gases from air and found a monatomic, chemically inert gaseous element remaining that they called argon. In 1898, Ramsay isolated the elements neon, krypton and xenon from air brought to a liquid state at high pressure and low temperature. The discovery of the noble gases changed the periodic table and led to new ideas about chemical bonding and atomic structure. Ramsay was awarded a Nobel Prize for his discovery.

Separation by density and solubility

A **separating funnel** as shown in Figure C2.16 can be used to separate two **immiscible** liquids, such as oil and water. Immiscible liquids separate into two layers, one (the less dense) on top of the other (the more dense), if left to stand. These liquids are not soluble in each other.

Figure C2.16 ▶ Two immiscible liquids in a separating funnel



To learn more about making use of materials, refer to Context 2, 'Materials for a purpose', page 31.

When the stopcock at the base of the funnel is opened, the denser component runs into a beaker, leaving the less dense component in the funnel.

Solids of different densities are often separated by using running water and agitation. For example, when panning for gold, the gravel mixture is put into a pan, which is swirled in a running stream. The lighter particles are carried away by the running water and the heavier gold sinks to the bottom of the pan.

A mixture of solids with similar-sized particles can be easily separated if the solids have different solubilities in a solvent. Simply add sufficient solvent to ensure the entire soluble component is dissolved, filter the mixture to separate the soluble and insoluble components and then evaporate the solvent to retrieve the soluble component.

Separation by magnetism and electrostatic attraction

Magnetic separation and electrostatic separation are techniques widely used in the mining industry.

Magnetic separation uses the degree to which a substance is attracted to a magnetic field. Strongly magnetic materials such as iron, cobalt and nickel (and their ores) can be removed from low or non-magnetic materials by a low-intensity magnetic separator.

In Experiment 2.1, you used a magnet to determine which materials were magnetic, and you could have separated the iron and sulfur mixture by using magnetic separation. A simple example of magnetic separation can be seen in a junkyard where an electromagnet is used to separate out iron-based objects.

An **electrostatic separation** method separates particles on the basis of differences in electrical charge. As a mixture is brought into an electric field, differently charged particles will be attracted or repelled and follow different paths so they can be caught separately.

This separation technique is used in industrial plants that process mineral sands containing zircon, rutile and monazite.

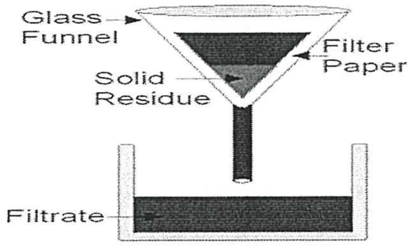
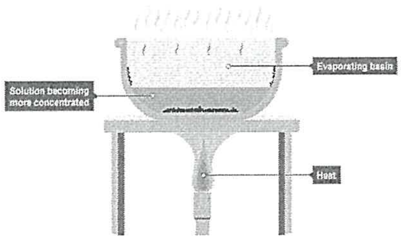
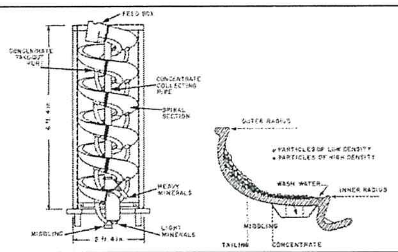
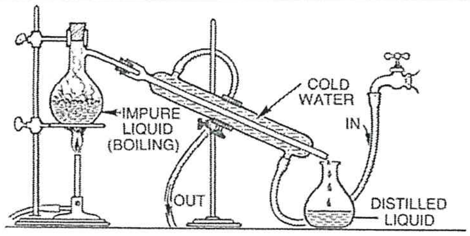
SEPARATION OF MIXTURES BY DIFFERENT TECHNIQUES

Visit this website for theory, animations, videos and simulations of many separation techniques.

9780170246644

Separation Technique	Physical Property that allows for separation of the mixture of substances.	Soluble/ insoluble mixture?
Filtration		
Evaporation		
Re-crystallisation		
Simple distillation		
Fractional Disitillation		
Decantation		
Skimming		
Centrifugation		

Separation Techniques (using Physical Properties)

TECHNIQUE	DIAGRAM	HOW IT WORKS
SIEVING		
FILTRATION		
EVAPORATION		
GRAVITY SEPARATION		
DISTILLATION		
FRACTIONAL DISTILLATION