Classification of Matter, Mixtures and Separation Methods

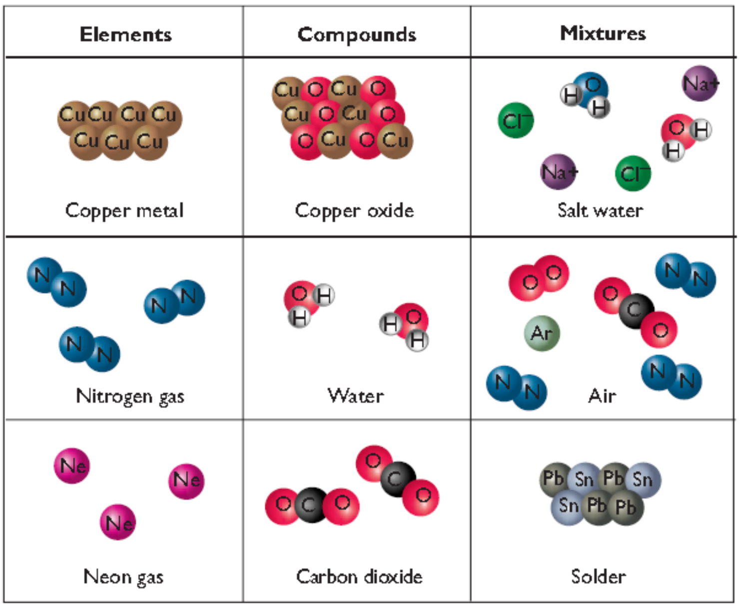
• identify the difference between elements, compounds and mixtures in terms of particle theory

Atoms are the basic building blocks of matter.
Elements are composed of the same type of atoms or molecules (made up of the same type of atoms).
Compounds are composed of fixed numbers of atoms of different elements.
Mixtures have various particle types and compositions.

• present information by using symbols and formulae

Elements	Compounds	Mixtures
oxygen, O	water, H_2O	air
silver, Ag	silver oxide, Ag_2O	brass
magnesium, Mg	magnesium sulfide, MgS	steel
silicon, Si	silicon dioxide, SiO_2	sand

• present information using a variety of pictorial representations



• *Pure substances* have a fixed composition and fixed properties. They cannot be decomposed by simple physical separation techniques.

• *Impure substances* are mixtures. They have variable composition and variable properties. They can be separated into their components by various physical separation techniques.

Mixtures are impure substances.

Pure substances can be further classified into elements and compounds.

• *Elements* are the simplest pure substances consisting of only one type of atom. They cannot be broken down (or decomposed).

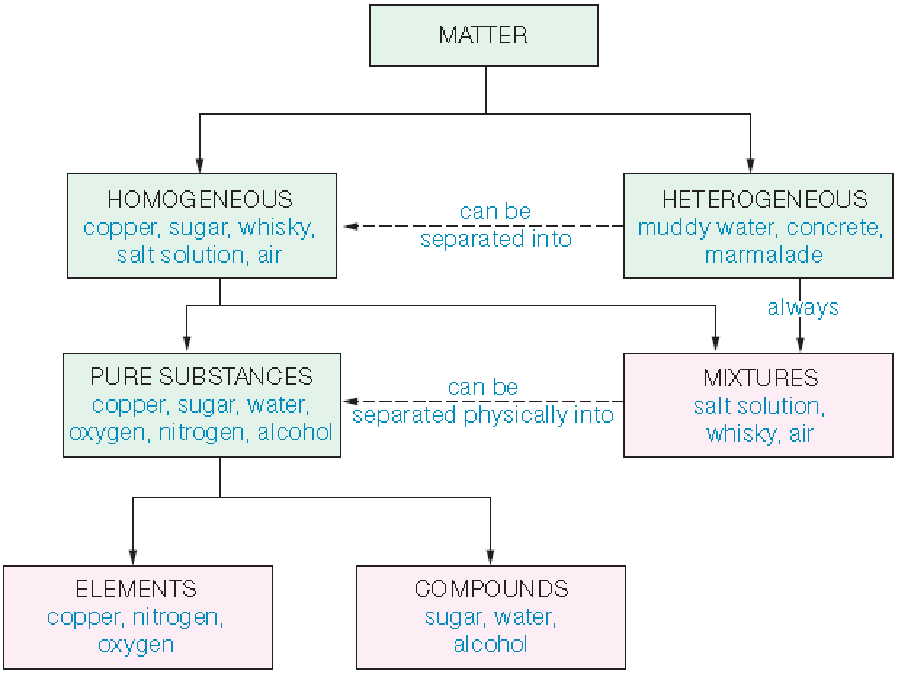
• *Compounds* are also pure substances. They are composed of two or more elements that are chemically bonded together. They are composed of a fixed number of atoms of each component element. They can be decomposed into their component elements or into simpler compounds.

Differences between a mixture and a pure substance

A mixture	A pure substance
can be separated into two or more pure substances by physical or mechanical means such as filtering, boiling or using a magnet or tweezers	cannot be separated into two or more substances by physical or mechanical means
may be homogeneous (tap water, air) or heterogeneous (fruit cake, concrete)	is homogeneous (crystals of sugar, piece of copper)
displays the properties (characteristics) of the pure substances making it up (different parts of the mixture show different properties)	has properties (characteristics) such as appearance, colour, density, melting and boiling points, which are constant throughout the whole sample
has properties that can change as the relative amounts of the substances present are changed	has properties that do not change regardless of how it is prepared or how many times it is subjected to purification procedures
has a variable composition; that is, the relative amounts of each pure substance present can be varied	has a fixed composition, no matter how it is made or where it comes from
Examples: sea water, air, coffee, milk, petrol, whisky, brass, and 'silver' coins	Examples: table salt, sugar, copper, aluminium, diamond, gold, polyethylene and alcohol

Contrasting properties of bauxite, aluminium oxide and aluminium

Bauxite (mixture)	Aluminium oxide (compound)	Aluminium (element)
red pebbly solid	crystalline white solid	silvery lustrous solid
no definite melting point	melting point is 2045°C	melting point is 660°C
composition varies from mine to mine	constant composition by mass (52.9% aluminium)	
can be *separated* into aluminium oxide, iron(III) oxide and dirt	can be *decomposed* (by electrolysis) into aluminium and oxygen	cannot be decomposed into simpler substances
density varies with composition	density is 4.0 g/mL	density is 2.7 g/mL
fairly easily ground into a fine powder	the small crystals are hard and brittle	fairly soft, but malleable and ductile

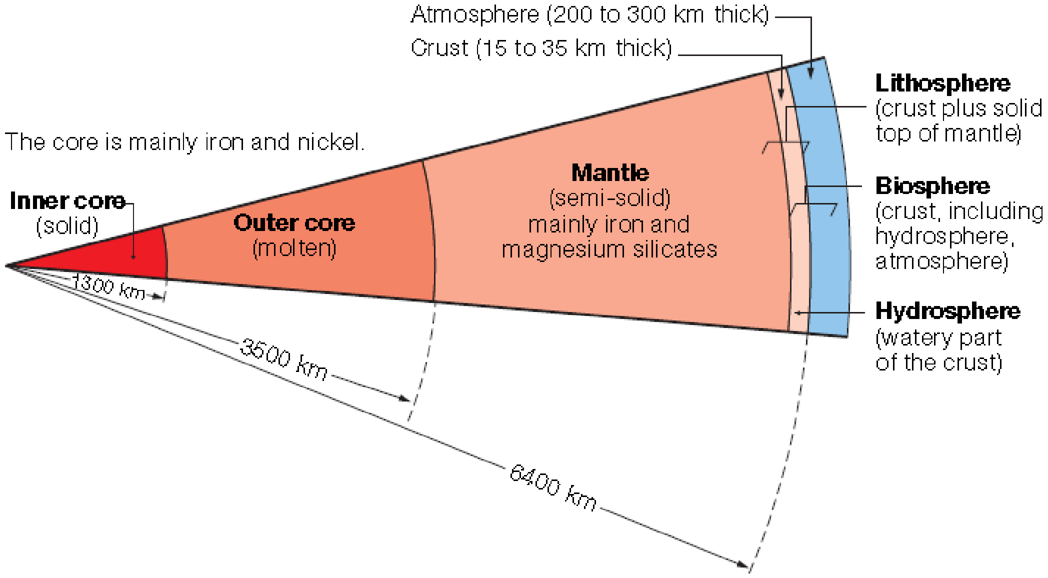


homogeneous mixture: a mixture in which all the particles are uniformly distributed

heterogeneous mixture: a mixture in which the particles are not uniformly distributed

MIXTURES AND THE SPHERES OF THE EARTH

• present information clearly and succinctly using a variety of pictorial representations to show relationships



The various 'spheres' of Earth

lithosphere	crust plus the top portion of the mantle
hydrosphere	the water of the Earth's crust: salt water of the oceans, fresh water of rivers and lakes, and ground water (water stored under the Earth's surface)
atmosphere	layer of gas about 200 to 300 km thick that surrounds the planet (75% of the mass of the atmosphere is in the lower 15 km and 99.997% in the lower 90 km)
biosphere	the portion of Earth inhabited and used by living matter: the **biosphere** consists of the atmosphere, hydrosphere and lithosphere

The atmosphere

Gas	Composition (%v/v)*
nitrogen	78.09
oxygen	20.94
argon	0.93
carbon dioxide	0.037
neon	0.0018
helium	0.0005
methane	0.00015

• identify that the biosphere, lithosphere, hydrosphere and atmosphere contain examples of mixtures of elements and compounds

The hydrosphere

Water is the most abundant compound in the hydrosphere.

Sea water is a mixture of water and sodium chloride (about 3.5%) along with smaller amounts of other *compounds* such as magnesium and calcium chlorides and various bromides, iodides and sulfates.

Ground water (water stored under the Earth's surface) is a mixture similar to river water, except that it generally contains larger amounts of dissolved solids such as chlorides and sulfates.

Apart from dissolved oxygen and nitrogen, the mixtures of the hydrosphere contain only *compounds*.

The lithosphere

The **lithosphere** contains an extremely diverse range of mixtures. There are:

- *rocks* which are mixtures of various silicates (compounds of silicon, oxygen and various metals)
- *sand* which is mainly silicon dioxide with variable amounts of ground-up shells or finely divided dirt
- *soils* which are mixtures of various aluminosilicates (clays, compounds containing aluminium, silicon, oxygen and metals), sand, and decomposing animal and vegetable matter
- *mineral ores* which are mainly oxides, sulfides, carbonates, sulfates and chlorides of metals mixed with various silicates or aluminosilicates, and
- *coal, oil* and *natural gas* which are mixtures of compounds of carbon formed from decayed plant and animal matter.

Living matter

- Animals, plants, algae and bacteria consist of carbon containing compounds along with water and small amounts of minerals.
- Insoluble carbohydrates and proteins like cellulose, skin and hair (make up the structure).
- Soluble carbohydrates and proteins (help in the functioning of the organism).
- Fats.
- Vitamins.
- Free elements like nitrogen and dissolved oxygen.

• identify and describe procedures that can be used to separate naturally occurring mixtures

PHYSICAL SEPARATION TECHNIQUES

Useful materials in the spheres of the Earth usually need to be separated from unwanted material. For example:

- salt is obtained from sea water by evaporating the water
- metallic minerals are removed from unwanted rocky material by crushing, sieving and froth flotation
- oxygen is extracted from the air by fractional distillation of liquid air.

Separating solids

Solid particles of different particle size or weight can be separated using techniques such as sieving, sedimentation, magnetic separation or froth flotation.

Sieving

Mixtures in which the particles of the different substances have different sizes can be separated by **sieving**.

Examples:

- Separate lumps from a powdery substance such as flour.
- At quarries, fine sand is separate from coarser material to make concrete.

Froth flotation

- The ground minerals are mixed with water, detergents and other oily chemicals.
- Air is blown through the mixture to create a froth to which the mineral grains adhere.
- The floating froth layer is scraped from the surface and removed for further treatment.
- This material is the concentrate (higher percentage of the metallic ore).

- The gangue settles to the bottom of the vessel.

Magnetic separation

- Separates iron mineral grains from grains of crushed rock.
- The mixture can pass along a conveyor belt beneath a turning magnetic roller. The magnets hold the magnetic grains while the crushed rock remains fall off the end of the belt.

Separating solids and liquids

Filtration and centrifugation are two common methods of separating solids from liquids.

Filtration

Insoluble solids can be separated from *soluble* solids by filtration.

The liquid or solution (filtrate) passes through the paper while the suspended solid (residue) remains on the top of the filter paper.
Example:
Sand can be separated from sea water.

Sedimentation

It is the process in which insoluble solids (coarse or very dense) settle to the bottom.

Decanting or decantation

It is the process of carefully pouring off the liquid and leaving the solid undisturbed at the bottom of the container.
Example: Pouring off tea leaves.

Centrifugation

- Centrifuges can be used to accelerate the process of sedimentation of a suspension. The suspension is spun at high speed so sediments collect at the base of the centrifuge tubes in layers according to their particle size and weight.
- Examples:
    - Cream separated from milk.
    - Blood cells separated from plasma.
    - Particulates, such as soot and dust from polluted air.

Separating dissolved solids and liquids

Evaporation and crystallisation are used to separate dissolved solids from liquids.

Evaporation

- The process of evaporation separates a mixtures by vaporising the low boiling point component to leave the high boiling component as the residue.
- Examples:

Salt crystals from sea water in large salt pans.

Distillation

Distillation is the process in which a solution or mixture of liquids is boiled with the vapour formed being condensed back to a liquid in a different part of the apparatus and so separated from the mixture.

- It is a technique in which a solution of a solid and liquid or liquids may be separated on the basis of their different boiling points.
- The mixture is placed in the flask and heated to boiling. The lower boiling point component changes to vapour, rises up the neck of the flask and diffuses down the side arm and into the water-cooled condensed, where the vapour is cooled and condensed back to a liquid, which is collected in the beaker.
- The lower boiling point component vaporises first (distillate), leaving behind the higher boiling component.

- Examples:
  - Salt from sea water.
  - Oils and pigments from turpentine.

Separating liquids

Immiscible liquids can be separated using a separating funnel. **Miscible** liquids can be separated by distillation.

If a mixture of a volatile liquid with non-volatile impurities (solid or liquid) is distilled, the distillate is pure liquid. If a mixture of two liquids of comparable volatility (similar boiling points) is distilled, the distillate is generally richer in the more volatile liquid.

volatile: describes substances that readily vaporise and exert a high vapour pressure.

more **volatile** (lower boiling point)

Miscible liquids:

miscible: describes liquids that mix to form one phase. For example, water and ethanol mix to form alcoholic solutions in all proportions.

A mixture of two or ted by distillation if the boiling points of the liquids are suffici
Example: Separation lycol (198 ^{o}C).

If the liquids do not have greatly differing boiling points, then the distillate is not a pure substance. In such cases, fractional distillation is used. This arrangement allows for repeated condensations and vaporisations up the column, effectively giving many separate distillations. This results in obtaining a pure sample of the distillate (more volatile substance).
Example: Separation of ethanol (78 ^{o}C) and water (100 ^{o}C)

Separation of benzene (80 ^{o}C) and cyclohexene ^{o}C)

Fractional distillation is widely used in industry. Examples of this are:

- separation of crude oil into various commercial products
- separation of ethanol (for use as a fuel additive) from fermented solutions of sugar molasses or grain mashes
- production of liquid nitrogen and argon gas from liquefied air.

Immiscible liquids:

Immiscible liquids can be separated using a separating funnel.

Separating funnel

If left standing for some time, immiscible liquids separate into two distinct layers, one on top of the other.

The separating funnel is a pear-shaped piece of apparatus, tapering to a narrow tube just above the stopcock. This shape allows one to run out the bottom liquid without getting contaminated with any of the top one.

Example:

A mixture of kerosene and water.

A mixture of petrol and water.

SEPARATION BASED ON SOLUBILITY

A **suspension** is a dispersion of particles through a liquid with the particles being sufficiently large that they settle out on standing.

A suspension is heterogeneous in that the dispersed particles can be seen either by eye or by using a microscope. Examples are sand in water, milk and paint.

A **solution** is a homogeneous mixture in which the dispersed particles (molecules or ions) are so small that they never settle out and cannot be seen by a microscope.

Examples are salt or sugar in water, iodine in alcohol, and brandy.

- Mixtures of solids can be easily separated if one solid is soluble in a particular solvent while the others are not.
- Sufficient solvent is added to the mixture to dissolve the soluble component.
- The insoluble components are filtered off.
- The soluble salt is recovered by evaporating the filtrate (solution of that solid) to dryness.
- Examples:
  - Salt and sand mixture; add sufficient water to dissolve the salt, filter off the sand and evaporate the salt solution to obtain the salt.
  - Iodine and charcoal mixture; add sufficient hexane to dissolve the iodine, filter off the carbon (insoluble in hexane).

• assess separation techniques for their suitability in separating examples of earth materials, identifying the differences in properties that enable these separations

SEPARATING GASES

Gas mixtures are generally separated by using either differences in boiling points or differences in solubilities in liquids such as water.

Separation of atmospheric air:

- Fractional distillation is used because the boiling points of nitrogen, oxygen and argon are so close together.
- First the air is liquefied (by cooling it to below -196^{o}C).
- The mixture is fractionally distilled. (Nitrogen, having the lowest boiling point, comes off first, followed by argon and finally oxygen.)

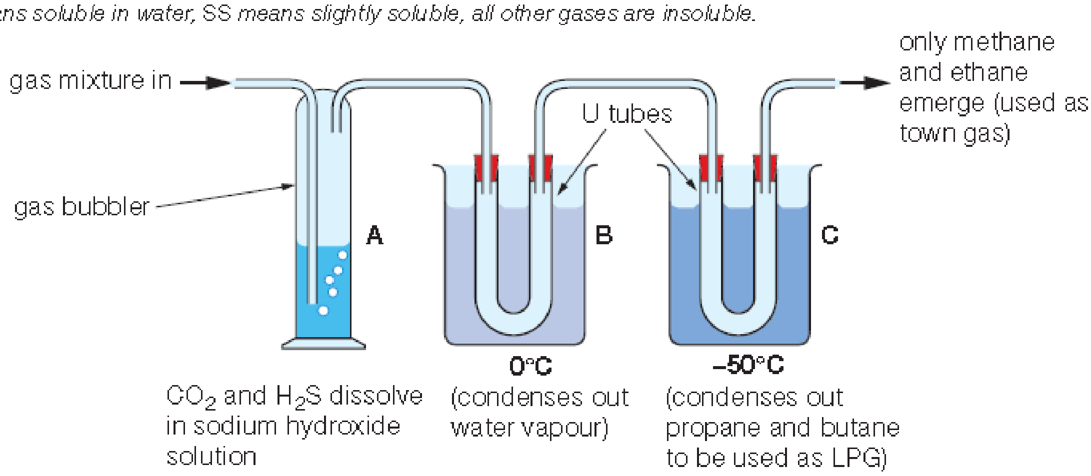
Separation of natural gas:

- Natural gas contains carbon dioxide, hydrogen sulphide and water vapour in addition to useful substances, methane, ethane, propane and butane.
- It can be separated into unwanted gases (carbon dioxide, hydrogen sulphide and water), propane and butane (for liquefied petroleum gas, LPG) and town gas (methane and ethane).
- The mixture is passed through a bubbler and a pair of U-tubes.
- The bubbler A contains sodium hydroxide solution (which dissolves carbon dioxide and hydrogen sulphide more readily than pure water does).
- Tube B at a temperature of about 0 ^{o}C condenses out water vapour.
- Tube C at about -50 ^{o}C condenses out the propane and butane.
- Methane and ethane pass through as gases to be used as town gas.

Boiling points of some common gases (at standard atmospheric pressure)

Gas	Boiling point (°C)	Gas	Boiling point (°C)
ammonia	–33 S[a]	hydrogen sulfide	–60 SS
argon	–186	methane	–161.5
butane	–0.5	nitric oxide	–152
carbon dioxide	–78 SS[a]	nitrogen	–196
carbon monoxide	–192	nitrogen dioxide	21 S
chlorine	–35 SS	oxygen	–183
ethane	–88.6	propane	–42
hydrogen	–253	sulfur dioxide	–10 S

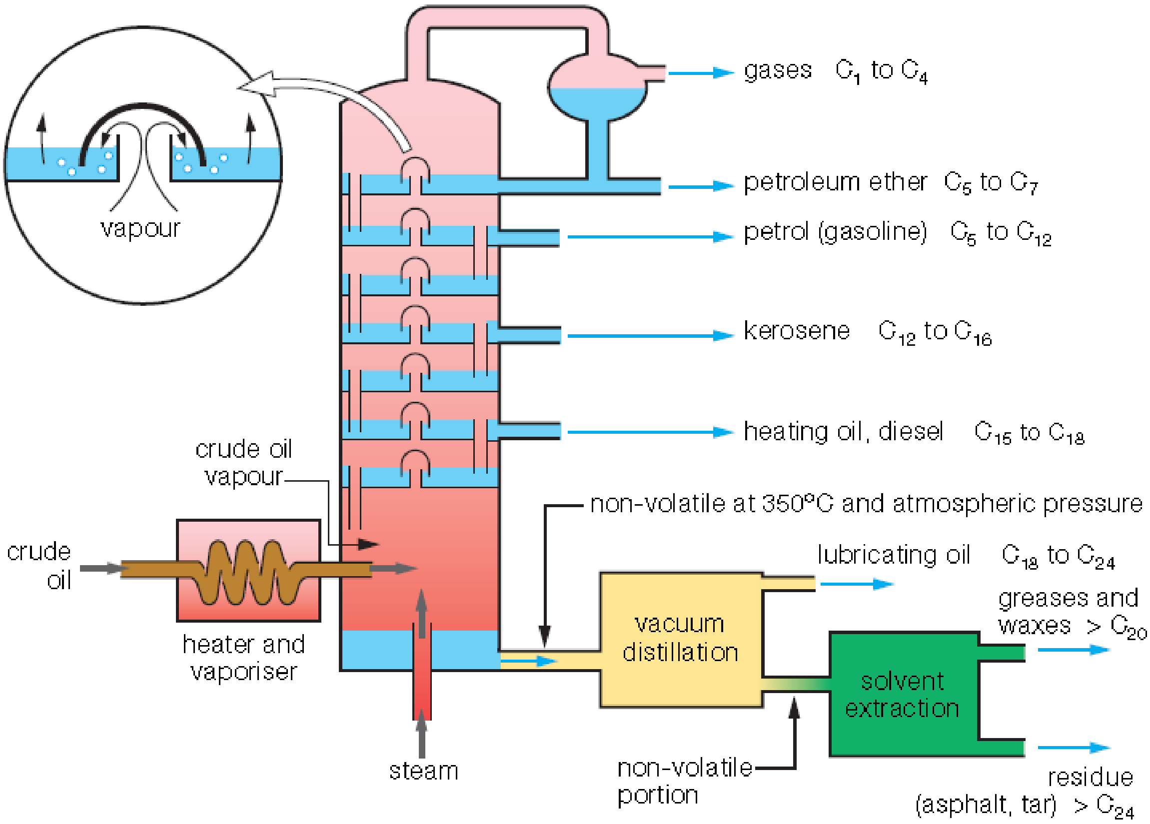
[a] *S means soluble in water, SS means slightly soluble, all other gases are insoluble.*



FRACTIONAL DISTILLATION OF CRUDE OIL

Crude oil is a complex mixture of hydrocarbons :

- The components of crude oil are separated according to their boiling points.
- Since boiling point increases as molecular weight increases, the separation os roughly in order of increasing molecular weights.
- The crude oil is vaporised by heating, then fed into the bottom of the fractionating column which contains a series of trays.
- The temperature falls as the vapour rises up through the column.
- The least volatile components (higher boiling points and hence highest molecular weights) condense near the bottom of the column while the most volatile ones do not condense until they reach the top of the column.
- Liquids are drawn off the column at various heights and these are the various fractions which are collected.
- Lubricating oils are obtained from the least volatile fraction by distilling under vacuum.
- Greases are separated from the remaining non-volatile material by solvent extraction and the final residue is asphalt or tar, which is used for road-making.



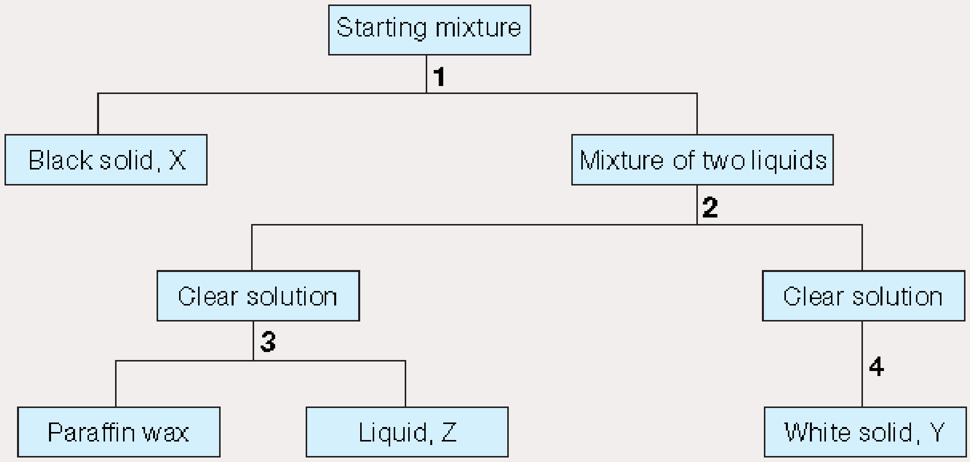
SUMMARY OF METHODS OF SEPARATION

Separation methods and the properties they depend upon

Separation method	Property used in the separation
sieving	particle size
vaporisation (evaporation or boiling)	liquid has a much lower boiling point than the solid
distillation	big difference in boiling points
fractional distillation	significant but small difference in boiling points
filtration	one substance a solid, the other a liquid or solution
adding a solvent, then filtration	one substance is soluble in the chosen solvent, while the others are insoluble
using a separating funnel	components are immiscible liquids

Exercises

A pair of students were given a mixture of powdered charcoal, kerosene, paraffin wax, sodium sulfate and water. They were asked to obtain pure samples of the charcoal, kerosene, wax and sodium sulfate from this mixture. A flow chart of the procedure they followed is shown below.



a Name the separation procedures, 1, 2, 3 and 4, that they used. Draw a diagram showing how each of these procedures would be performed in the laboratory.
b Identify the solids X and Y and the liquid Z.
c How would you vary their procedure in order to recover a pure sample of water as well?

A school's supply of crystalline magnesium sulfate became contaminated with some barium sulfate. Draw a flow chart for the method you would use to separate these two substances, ending up with dry pure crystals of each substance. Magnesium sulfate is soluble in water; barium sulfate is not.

Research Task

• identify data sources, gather, process and analyse information from secondary sources to identify the industrial separation processes used on a mixture obtained from the biosphere, lithosphere, hydrosphere or atmosphere, and use the available evidence to:
– identify the properties of the mixture used in its separation
– identify the products of separation and their uses
– discuss issues associated with wastes from the processes used.