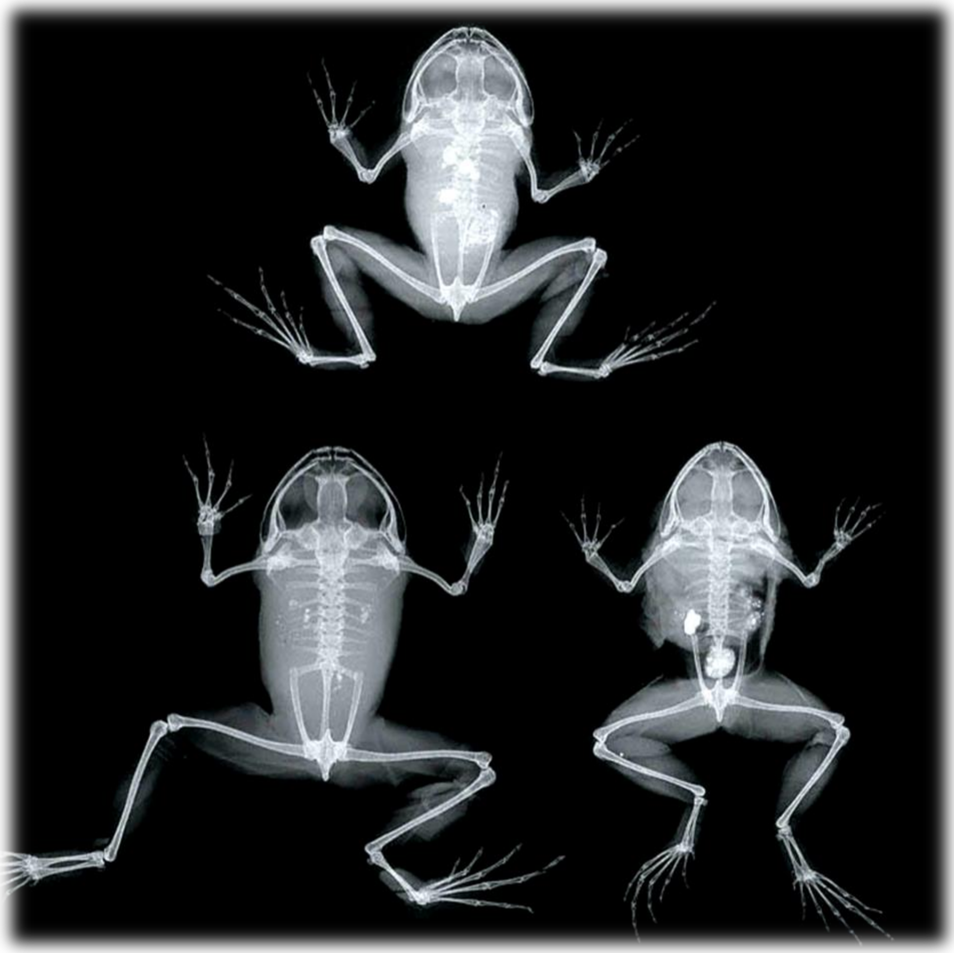
FOURTH FORM BIOLOGY



THE AUTUMN TERM PART I

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Introduction

The purpose of this handbook is to provide you with a summary of the work that you have completed during the fourth form biology course. It is to complement your homeworks, practicals, handouts and your own notes taken during lessons. In some cases there is extra information provided in this booklet that we would not have time to cover in the lessons. It is to replace a fourth form text book and can be used to make a concise set of revision notes for tests or exams.

The Autumn term starts with the structure of cells and then introduces the variety of life and how organisms are classified into groups. We look at the characteristics of each of the 5 kingdoms in turn, starting with Prokaryotes (bacteria) and moving on to the Eukaryotes (Protoctista, plants, fungi and animals). The biology of viruses was also covered and the reasons why biologists do not consider them living organisms.

Characteristics of Life

Living organisms may be distinguished from non-living objects by the possession of the following characteristics. Note that although **viruses** show some of the characteristics (most notably **reproduction**), the fact that they do not carry out any biochemical reactions (such as **respiration**) independently of their host cell and that they are not made of cells leads most biologists to not regard them as true living organisms.

Biologists have focused on the following eight characteristics because, in one way or another, they are applicable to all organisms, whether bacteria or humans. Thus, the definitions of these characteristics focus on their general aspects rather than any specific example. Sensitivity, for example, is defined as the ability to respond to changes in their environment, not just the idea of the ability to 'feel things' which would only apply to a subset of organisms with a well-developed nervous system. Likewise, homeostasis is not simply the maintenance of a constant body temperature.

Movement

Many animals have to ability to move in the sense of locomotion (moving the whole organism from place to place), although of course plants and some animals such as corals are fixed in one place.

Nonetheless, we do consider movement one of the characteristics of life since all cells are able to move components around inside the cytoplasm, even if this is not immediately visible to the naked eye.

Some plants have the ability to move some tissues or organs, such as the opening and closing of stomata, and Venus fly traps can rapidly close their traps. Both of these are reversible, and so considered movement. The way in which plants 'bend' towards the light, however, is in fact a growth response and irreversible, and so not considered movement.

Respiration

Respiration is the **release** [<u>not</u> *creation* or *production*] of energy (usually in the form of the molecule called ATP) through the oxidation of an energy source (such as glucose).

Note that this kind of 'cellular' respiration is not respiration in the sense of breathing (taking in air into the lungs), although the oxygen we breathe is used in cellular respiration. In bacteria, respiration takes place in the cytoplasm. In Eukaryotes respiration takes place in specialised organelles called **mitochondria**.

Aerobic respiration requires oxygen; anaerobic respiration can occur in the absence of oxygen and is carried out by some bacteria, some fungi and to a very limited extent by human muscles. This year you will come across anaerobic respiration by some bacteria and fungi in the production of yoghurt and beer.

Plants carry out respiration just like animals (and therefore use up oxygen) *as well as* carrying out photosynthesis (which produces oxygen).

The details of respiration will be covered in the Autumn term of the Fifth form.

Sensitivity

Sensitivity is the ability to **respond** to **changes** in their surroundings. In large multicellular animals this is either through nervous systems or by using hormones (chemical messengers carried in the bloodstream). In plants, responses usually take the form of changes in the pattern of growth, and are regulated by chemicals.

In unicellular (single-celled) organisms, sensitivity is usually confined to moving in response to stimuli such as light or to chemicals.

Growth

Organisms may grow through two processes:

- by enlarging cells by increasing the volume of cytoplasm
- by cell division, which will increase the number of cells in the organism.

Multicellular organisms carry out both kinds of growth.

When single-celled organisms divide, however, the two daughter cells are considered separate organisms.

Reproduction

Reproduction is a feature of all organisms. Most organisms reproduce sexually, which leads to offspring that are variable. Some organisms may reproduce asexually, in which case the offspring are genetically identical to each other and to the parent organism.

Reproduction in plants and animals is covered in the Summer term of the Fourth form.

Excretion

Excretion is the removal of waste *products* from an organism. The key part of this definition is that the substances excreted were *produced* by the organism. Examples include getting rid of **carbon dioxide** (a waste product from aerobic respiration), and **urea** (from the breakdown of excess proteins). Excretory products need to be removed from the cell or from the organism as they are often toxic at high concentrations.

Note that excretion is different from **egestion**. Egestion is the removal from the body of *undigested* food in the form of faeces. The cellulose cell walls of plant cells is a large component of faeces; humans are unable to digest cellulose and so this passes through the digestive system unchanged.

Nutrition

Nutrition is the obtaining of chemicals either for:

(i) use in respiration to release energy

(ii) for use in the building new molecules with which to construct new cells.

A cell or an organism may be described as carrying out **heterotrophic** or **autotrophic** nutrition. Heterotrophic organisms use pre-existing food molecules which they may digest and use. Animals are examples of heterotrophs. Autotrophic organisms synthesise food molecules from simpler molecules. All photosynthetic organisms are autotrophic – they use carbon dioxide and water to synthesise simple sugars such as glucose.

The most common nutrients you will encounter are glucose (a simple sugar) that is the main substance used in respiration, and amino acids, which are used to synthesise proteins.

Homeostasis

Homeostasis is the *maintenance of constant internal conditions despite changes in the external environment*.

For complex multicellular organisms such as humans, this includes many factors such as keeping the concentration of the blood (i.e. water balance), temperature, blood pH and the concentrations of mineral ions within strict limits.

For unicellular organisms such as bacteria, they clearly have less of an ability to control factors such as temperature, but they still regulate the chemical composition of the cytoplasm such as pH, water levels and mineral ion concentrations.

Additional Features of All Organisms

Those given above ("MRS GREN" plus homeostasis) are the conventional characteristics of life given in many biology text books. However, there is one other feature which also applies to all organisms.

Genetic Material (Nucleic Acids)

All living organisms contain DNA in their cells. In Prokaryotes (bacteria), the DNA molecule is a single loop located in the cytoplasm. In Eukaryotes, the DNA is packaged using proteins into multiple linear strands called **chromosomes**.

DNA is the molecule which provides the instructions for how a cell is built and functions. In simple terms, the DNA molecule is a molecular code which determines which proteins are synthesised by the cell. The precise type of DNA that a cell contains determines which organism the cell belongs to; in other words, the DNA in the nucleus of a frog cell is different from the DNA in the nucleus of a human cell.

DNA is an example of a **nucleic acid**. The other type of nucleic acid found in organisms is RNA.

Viruses, although not living organisms, also contain a nucleic acid – some have DNA and others RNA. When a virus infects a cell, it injects its DNA or RNA into the cell, and the infected cell then uses them to make more copies of the virus proteins.

Cells

Cell Theory

Until the Seventeenth Century, many people believed that life spontaneously arose. For example, if rotting meat was left out then maggots would spontaneously appear. However, a series of experiments, such as those by Louis Pasteur (1822 – 1895), demonstrated that living organisms can only come from pre-existing organisms and are not generated spontaneously from chemical components.

Cell theory states that:

1. All organisms are made up of cells.
2. The cell is the smallest unit of life.
3. Cells can only be derived from pre-existing cells.

The cell is the simplest entity that can exist as an independent unit of life. Note that viruses are not made of cells.

Two Major Types of Cells

All cells consist of:

1. A **cell surface membrane** (also known as the **plasma membrane**)
2. **Cytoplasm**
3. Genetic material in the form of **DNA**
4. **Ribosomes**.

However, a range of other components are found in many cells. There are two fundamental types of cell found in organisms: **prokaryotic** and **eukaryotic**. Prokaryotic cells are only found in bacteria, and contain fewer components. In particular, prokaryotes lack a membrane-bound **nucleus**, in which the DNA is packaged into chromosomes. Prokaryotic cells are generally much smaller than eukaryotic cells.

Eukaryotic cells make up all organisms other than bacteria – i.e. plants, animals, fungi and the Protoctista. They contain an extensive set of membrane-bound compartments, notably the **nucleus**, **mitochondria** and, in photosynthetic cells, **chloroplasts**. Structures in a cell that carry out a particular function, such as chloroplasts, mitochondria and ribosomes, are known as **organelles**.

Cell Structure

Cell Surface Membrane (Plasma Membrane)

This is a thin (about 5 nm thick) layer that forms a boundary between the cytoplasm and the outside. It is mostly made up of lipids and proteins. The basic structure of the cell surface membrane is the same in both prokaryotes and eukaryotes. Cell membranes are **selectively permeable**. This means that the cell is able to control what substances can enter or leave the cell.

Cytoplasm

The cytoplasm is a gelatinous material made predominantly of water with many substances dissolved in it. Other structures described below, such as the nucleus, ribosomes and mitochondria are found in the cytoplasm. Many chemical reactions of the cell take place in the cytoplasm.

Nucleus

Eukaryotic cells contain a membrane-bound nucleus. A few cells, such as red blood cells or mature xylem cells in plants (which lack any cytoplasm and are dead) lack a nucleus. The nucleus controls the activities of the cell. This is done through the DNA which determines which proteins a cell can make. In eukaryotes the DNA is packaged into several linear **chromosomes**. Human cells contain 46 chromosomes, although other species have different numbers (e.g. cucumber cells have 14, bats have 44, turkeys have 82 chromosomes). The DNA in chromosomes is arranged into sections called **genes**; one gene codes for one specific protein. Although chromosomes vary in length, they can contain several hundred to a few thousand genes each.

Ribosomes

All cells, prokaryotes and eukaryotes, contain ribosomes. These are too small to be seen with a light microscope, but are present in the cytoplasm. Proteins are made on ribosomes.

Mitochondrion

All living eukaryotic cells contain mitochondria (plural: **mitochondria**). Cells which have a high demand for energy, such as muscle cells, have large numbers of mitochondria. Some of the reactions of respiration take place in mitochondria.

Note that since bacteria do not possess mitochondria, all of the reactions of respiration (and photosynthesis for those bacteria that are autotrophic) must take place in the cytoplasm in those cells.

Cell Wall

The cell wall is a layer of non-living material that is found outside the cell membrane of some cells. In plants, it is made of **cellulose** (a carbohydrate made from glucose), in fungal cells it is made of **chitin**, and in bacteria it is made of **peptidoglycan** (a mixture of carbohydrate and amino acids).

The cell wall is a tough layer that helps the cell keep its shape, and is why plant cells have a fixed shape; animal cells, which lack a cell wall, can be more variable in shape. The contents of a plant cell (vacuole and cytoplasm) push outwards against the cell wall which gives the plant support.

Cell walls have large holes in them, so it is not a barrier to water or dissolved substances. It is **freely permeable**.

Chloroplast

Cells of the green part of plants have chloroplasts. Like mitochondria, chloroplasts are enclosed by a membrane that separates their contents from the rest of the cytoplasm. Chloroplasts absorb light energy to make food in the form of sugars such as glucose in the process of photosynthesis. Chloroplasts are green because they contain a green pigment called **chlorophyll** (note that chloroplast and chlorophyll are not the same thing). Plant cells that are not green, such as in roots, lack chloroplasts.

Vacuole

Plant and fungal cells contain a large, permanent vacuole. This is a membrane-bound compartment that is used for storage of molecules such as dissolved sugars, mineral ions, pigments (e.g. in petals). The watery contents of the vacuole is known as **cell sap**. Although similar structures can be found in animal cells (we refer to those as vesicles), they are small and temporary.

Microscopy

Microscopes

Modern microscopes are the result of continuous improvements since the first microscopes were produced in the 17th Century. A good light microscope can magnify up to x1,800 and see an object 0.0002 mm (0.2 μm) across. This is approaching the limit of what is possible using light to view an image. If you want more than that you need an **electron microscope**, perfected in the 1950's, which can magnify up to a million times.

The following is a list of the main parts of a light microscope:

Objective Lens

Works in combination with the eyepiece lens to magnify the image; there may be several to choose from on a rotating turret. The school microscopes have a 4x, 10x and 40x lens.

Eyepiece Lens

This is the one you look down; the school microscopes have an eyepiece lens that magnifies the image ten times.

Stage

Where the specimen (slide) goes. There are usually clips of some description to hold it in place.

Diaphragm

There are various different types, but all vary the amount of light passing through the specimen. The diaphragm is just below the stage.

Light Source

Sometime a bulb, sometimes just a mirror.

Focus Knob

One for fine and one for coarse focus; you should always focus with both hands to avoid straining the mechanism.

Follow this list of steps to use a microscope properly. Never be tempted to miss steps out or skip straight to high power, you probably won't be able to find what you're looking for.

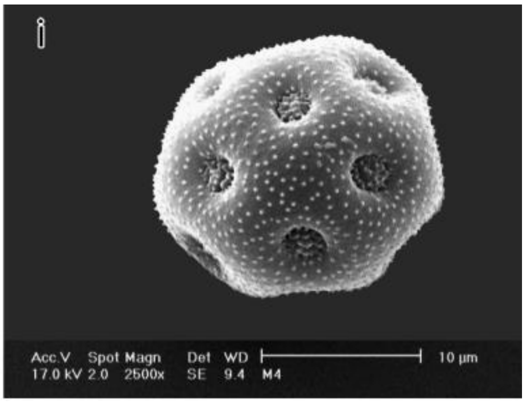
1. Set the microscope on low power (the short lens, x4 magnification).
2. Using two hands wind the stage down as far as it will go.
3. Carefully place the slide on the stage.
4. Using two hands and looking from the side, wind the stage up as far as it will go.
5. Look down the microscope. Try to keep both eyes open, you get less eyestrain.
6. Focus down carefully until you see a sharp image.
7. Gently move the slide until an object you want to study is right in the centre.

Very often that's as much as you need to do, but for very small objects you may need to increase the magnification to medium (x10 objective lens) or high power (x40 objective lens).

8. Always focus with low power before using medium/high magnification lenses. Set the microscope to medium power.
9. Focus down gently using only the fine focus.
10. Set the microscope to high power.
11. Focus down gently, using fine focus. Never use coarse focus when using high or medium power lenses as you risk breaking the slide and damaging the lens.

Scale and Magnification

Magnification is how many times larger a microscope makes an object look. The number of times an object has been magnified is often shown on or next to a picture so you can work out its actual size. Sometimes there may be a **scale bar** given instead – the actual length of the bar in the image (e.g. measured in millimeters) represents the stated length (usually in micrometers) of the real object. Below is a photograph of a pollen grain taken using an electron microscope. The scale bar is shown in the bottom right. The length of the white line represents 10 μm.



The image in a compound microscope (like a school one) is magnified twice, once by the objective lens and once by the eyepiece lens. The total magnification is the product of the two magnifications, e.g. 400 times if using the high power lens (10x for the eye piece lens multiplied by 40x for the objective lens.)

To convert between ***image size***, ***actual size of object***, and ***magnification***, use the following equations:

Image size = magnification x object size

Magnification = image size / object size

Object size = image size / magnification

However, don't mix your units when calculating the magnification!

Units in Microscopy

An average bacterium is 0.001 mm long. However, it is more convenient to use a smaller unit of distance and so avoid using so many decimal places.

The common units you will encounter in biology are metre (m), millimetre (mm) and micrometre (μm). These units differ by a factor of a thousand, thus:

1 m = 1000 mm (or 1 mm = 0.001m)

1 mm = 1000 μm (or 1 μm = 0.001 mm)

When measuring the size of cells, the most useful unit is the μm – Eukaryotic cells typically range from 10 to 100 μm (although there are exceptions).

If you are measuring the size of an *image* it is most helpful to measure it in millimetres, rather than centimetres. This makes it easier (and less prone to you making mistakes) to convert it to μm by multiplying the value by 1000.

Worked example.

An image of a cell has a diameter of 86 mm when magnified 1900 times. What is the actual size of the cell?

First, convert the size of the image into micrometres:

86 mm = 86 000 μm.

Object size = image size / magnification, therefore object size =

86 000 / 1900 = 45 μm (2 S.F.)

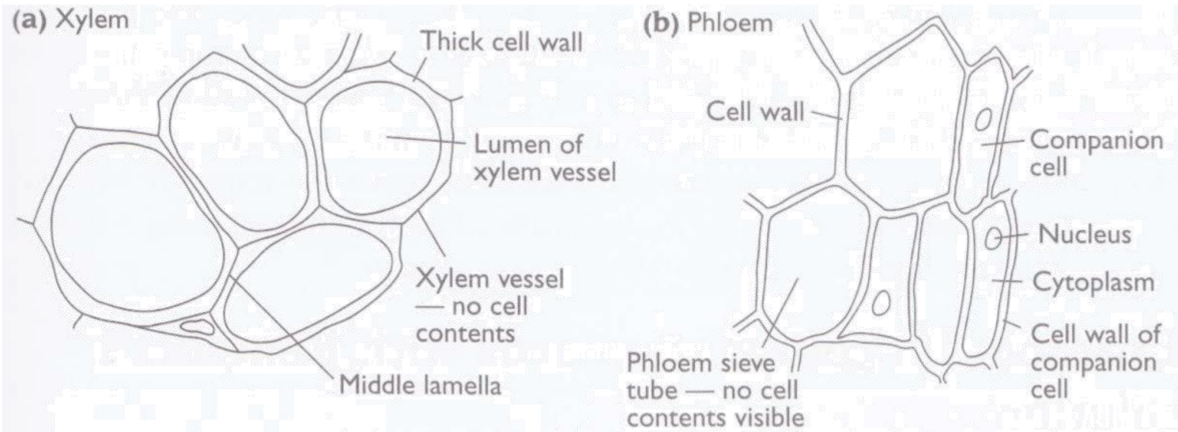
Biological Drawings

You may be asked to record your observations in biology in the form of a drawing. These are not meant to be complex pieces of art but they should accurately record the key observable features that you can see.

There are some guidelines that should be followed when making a biological drawing:

- Use a sharp pencil (do not draw in pen). Lines should be <1 mm wide.
- Use a single, unbroken line.
- Do not use any shading or colouring.
- Add labels – use a pencil and ruler to draw straight lines from the drawing to the label. Make sure the label line touches the object you are labelling so it is clear what you are referring to.
- The cell wall of a plant cell is, by convention, drawn as a double line.
- Ensure that any structures you draw (e.g. the nucleus) are in proportion to the whole cell.

Here are two drawings of plant cells; (a) is of 4 cells from xylem and (b) of 6 cells from phloem.



Bacteria

Bacteria are small, single celled organisms, typically 1-2 μm in diameter. Their cell structure is far simpler than most organisms with which you are familiar. Critically, bacterial cells lack a nucleus or any other membrane-bound organelles such as mitochondria or chloroplasts.

The term **Prokaryote** is applied to bacteria, which means "before the nucleus", a reference to the fact that bacteria successfully occupied the Earth for nearly 2 billion years before more complex cells arose (the Eukaryotes which possess a membrane-bound nucleus).

Features of a Bacterial Cell

DNA

A long molecule divided into regions called genes which determine the characteristics of bacteria and control the activities of the cell. In bacteria the DNA molecule forms a circular loop.

Plasmids

A small, extra loop of DNA. Plasmids may contain extra genes, and they are used extensively in genetic engineering to transfer new genes into bacteria. Bacterial cells may have one or several plasmids.

Cytoplasm

A complex chemical mixture but mainly water. This is where important chemical reactions take place in the cell.

Cell Surface Membrane

Also referred to as the **plasma membrane**. This is made of lipids and controls what substances enter or leave the cell. Cell membranes are referred to as **selectively permeable**, which means that some molecules are able to cross the membrane, but others are prevented from crossing the membrane.

Cell Wall

Made of a material called **peptidoglycan** (not cellulose as found in plant cells). Peptidoglycan is a mixture of amino acids and sugars. The cell wall prevents a bacterial cell from bursting, and also provides support for the cell.

Capsule

Not always present, this is a layer of protective slime surrounding the cell wall.

Flagellum

(*Plural:* ***flagella***). Not always present, this allows bacteria to move. In bacteria it acts as a kind of motor, rotating the long flagellum and propelling the cell through water.

Growing Bacteria in the Lab

Bacteria are able to survive in a wide range of places and so it is relatively easy to grow bacteria in the laboratory when you provide them with optimum conditions. However, this also means that it is very easy to contaminate your experiment with bacteria from the air, the workbench, from non-sterile implements or from you. Thus, when working with bacteria in the lab we use a set of procedures (**aseptic technique**) to minimise the possibility of contamination.

There are two main purposes of using aseptic technique:

(i) To prevent unwanted bacteria contaminating experiments.
(ii) To protect you by reducing the possibility of infection by potentially pathogenic bacteria.

Some of the most important safety tips include

- Washing hands before and after the experiment. Washing before means bacteria from your hands don't contaminate the experiment, washing afterwards means you don't accidentally transfer the bacteria you have been working with onto anything else or inadvertently ingest them, rub them in your eyes etc. which could cause infection.
- Working near a Bunsen flame. This creates an updraft which will carry airborne bacteria up and away from your experiment.
- Wearing safety glasses. Protects you from accidental splashes of bacteria.
- Sterilise instruments before and after the experiment. Same reasons as washing your hands. This kills any bacteria or other microorganisms.
- Sterilise your working area before and after the experiment.
- Label everything clearly so that everyone knows what it is.
- Incubate bacteria at a temperature warm enough to encourage growth, but not at body temperature as this may encourage pathogenic (disease causing) bacteria. $30^{o}C$ is good.
- Keep containers such as Petri dishes closed as much as possible.

Bacterial Growth

The growth of bacteria requires:

(i) A suitable temperature

(ii) Water
(iii) Nutrients such as glucose (or another sugar) and amino acids
(iv) Mineral ions
(v) Oxygen (if they respire aerobically – some bacteria are only able to survive in the *absence* of oxygen).

In the laboratory we can grow them in Petri dishes on a jelly-like substance called **agar** which contains water, nutrients and mineral ions, or in a liquid solution called **nutrient broth**.

The agar or nutrient broth will have been sterilized before you **inoculate** them with a sample of bacteria.

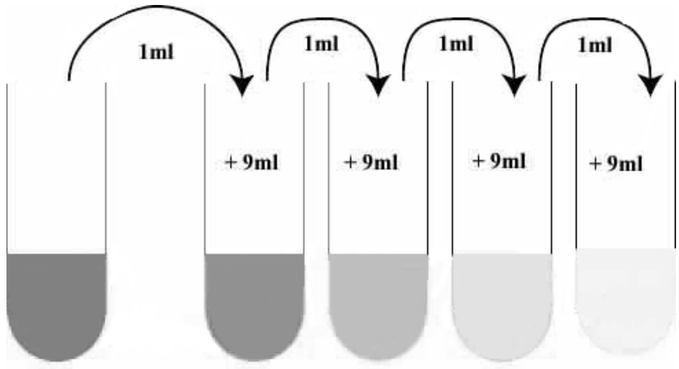
Bacteria reproduce by splitting into two, a process called **binary fission**. Bacteria will form discrete colonies when grown on agar or cause cloudiness in a liquid.

Serial Dilutions

A single bacterium is far too small to be seen by the naked eye, and even under the school microscopes they will look like a small dot at best. Therefore, you can't just put a sample of the bacteria under the microscope and count the number of bacteria present.

However, if we want to produce an estimate of the density of bacteria in a particular sample (you used a sample of Thames water in your experiment) then we can culture them under controlled conditions, i.e. growing them on a Petri dish containing nutrient agar and keeping them at a constant temperature. Each bacterium present in the sample will divide repeatedly by binary fission to produce a single **colony** of bacteria. Bacterial colonies contain so many bacteria that they are now visible to the naked eye, and can therefore be counted – each colony will correspond to one individual bacterium in the original sample.

However, in order to be able to count individual colonies the concentration of bacteria in the sample must be low enough so that you do not end up with the Agar plate completely covered in bacteria colonies that have merged into each other (a 'lawn' of bacteria). Very often you will need to dilute the original sample before growing them on the Agar plate. A **serial dilution** is a method that is frequently employed to produce a set of solutions of decreasing concentrations, as shown in the diagram below.



A sample from each successive test tube is taken and diluted by 10% each time (1 ml of sample is added to 9 ml of sterile water, making it a 10% dilution). In the above example, the test tubes contain (from left to right): 100%, 10%, 1%, 0.1%, 0.01%.

If a sample from each of the five test tubes above were grown on an Agar plate, one of them would probably produce a sufficient number of colonies that can be easily counted; the very dilute samples may not produce many colonies at all, and the very concentrated samples would produce too many colonies that grew into each other and could not be counted.

In order to calculate the concentration of bacteria in the original sample, we would need to multiply up the number of colonies counted to take into account the dilution. So, if 45 colonies were counted from a sample of 1 ml of 0.1% solution, you need to multiple 45 by 1000.

The Ecology of Bacteria

Some bacteria carry out photosynthesis (and so are **autotrophic**), but most are **heterotrophic**. While some bacteria are **pathogenic** (disease causing), the vast majority are either harmless or beneficial.

Examples of useful bacteria include *Lactobacillus*, a rod shaped bacterium used in the production of yoghurt from milk; *Pneumococcus* (also known as *Streptococcus*), a spherical bacterium that acts as the pathogen causing pneumonia; *Vibrio cholerae* which causes cholera.

Other examples of bacteria that are useful to man are:

(i) **Skin bacteria.** Many of the harmless bacteria living on your skin take up space and prevent pathogenic bacteria from colonising your skin.

(ii) **Gut bacteria.** Some prevent undesirable bacteria growing in your gut, others assist the digestive process by producing enzymes.

(iii) **Decomposing bacteria.** These break down dead organic waste (dead organisms, faeces etc.) as a source of food. These are important recyclers in ecosystems and are vital for sewage treatment (see below).

(iv) **Edible bacteria.** There are many examples of bacteria that are used in foods or food production including sauerkraut, chorizo sausage, soy sauce and vinegar. Be careful not to confuse bacteria with yeast, used to make bread and alcohol, which is a fungus.

Lactobacillus

Lactobacillus is used to turn milk into yoghurt. It respires the sugar **lactose** found in milk, and produced **lactic acid** as a waste product. The bacteria respire **anaerobically** (in the absence of oxygen); this kind of respiration in microorganisms is known as **fermentation**.

The lactic acid causes the proteins in milk to thicken (they **denature**) and makes it sour because the pH is lowered. Lactobacillus is able to tolerate a much lower pH than other bacteria (although their growth rate falls as the pH gets lower), and so the growth of other microorganisms is prevented; thus the milk in the yoghurt is preserved and can stay fresh for longer.

The stages below summarise the process of making yoghurt:

1. Milk is pasteurised at 85 – 95 °C for 15 – 30 minutes. This kills any bacteria that are present in the milk.
2. Milk is homogenised. This process distributes the fat globules in the milk evenly.
3. Milk is cooled to 40 – 45 °C and inoculated with a starter culture of lactic acid bacteria.
4. Mixture is incubated at this temperature for several hours while the bacteria digest the milk proteins and ferment lactose to lactic acid. The pH falls to about 4.4 (optimum conditions for *Lactobacillus*).
5. Thickened yoghurt is stirred and cooled to 5 °C.
6. Flavourings, colourants and fruit may be added before packaging.

Pathogenic Bacteria

Most bacteria are either harmless or useful, however a small minority are **pathogenic** (disease causing) and cause a wide variety of diseases. Here are just two examples:

Streptococcus

Pneumonia is caused by the bacterium *Streptococcus pneumoniae*, sometimes called *Pneumococcus*. Pneumonia occurs when this bacterium infects the lungs, leading to a build-up of fluid, difficulty breathing, chest pain and a cough. Pneumonia is particularly common in young children, the elderly and in other people with weakened immune systems, such as AIDS patients.

Pneumonia is spread by **droplet infection** when an infected person coughs out droplets of water or mucus which contain the bacteria. These may be inhaled by someone else, or land on a surface which someone else then touches. The bacteria are then likely to enter their body when the person eats, rubs their eyes, etc.

Streptococcus infections can be treated with **antibiotics** like **penicillin**, although there is an increasing problem with strains of bacteria that are drug-resistant.

Cholera

Cholera is a disease caused by the bacterium *Vibrio cholera*e. It causes very severe diarrhoea leading to dehydration and death. In places with poor sanitation, especially when human waste enters the water supply, the bacterium is present in drinking water. Cholera used to be an important disease in Europe until improvements in social infrastructure, such as the construction of good sewerage systems in London by the Victorian engineer Sir Joseph Bazalgette (1819 – 1891), reduced the contamination of water supplies; it is still widespread in developing countries.

The most effective treatment for cholera is oral rehydration therapy where patients are regularly given a solution of water and salts. If dehydration can be avoided their immune system will clear up the infection in a few days. Antibiotics may also be given which will either kill or reduce the growth of the *Vibrio* bacteria.

The link between cholera and water supplies was first shown by Dr John Snow (1813 – 1858), known as 'The father of epidemiology'. **Epidemiology** is the scientific study of the origin and spread of infectious diseases. Snow famously investigated an epidemic in Soho, London and by drawing a map of the area showing the addresses of victims was able to demonstrate that a water pump on Broad Street in Soho was the source of the infection.

Koch's Postulates and Germ Theory

The development of cell theory in the Nineteenth Century by Louis Pasteur helped pave the way to the development of the germ theory of disease by Robert Koch (1843 – 1910). Koch studied the disease anthrax, caused by the bacterium *Bacillus anthracis*. Koch's work led to the development of a set of criteria for establishing that a disease is caused by a specific microorganism:

1. The organism must always be present in animals suffering from the disease and should not be present in healthy organisms.
2. The organism must be cultivated in a *pure culture* (i.e. a culture containing only that specific microorganism) away from the body.
3. Such a pure culture, when inoculated in susceptible animals, must initiate the characteristic of the disease symptoms.
4. The organism must be re-isolated from these experimental animals and cultured again in the laboratory, after which it should still be the same as the original organism.

Koch's postulates enabled scientists to directly link a specific microorganism with a disease which then led to the development of successful treatments for the prevention and cure of many infectious diseases.

Key Terms and Definitions

Aerobic respiration: Reaction that releases energy from food. Uses oxygen and produces carbon dioxide and water.

Agar: Jelly-like substance used as a culture medium for growing microorganisms

Anaerobic respiration: Reaction that releases energy from food, without using oxygen. Produces lactate in mammals, carbon dioxide and ethanol in yeast

Antibiotics: Chemicals produced by some bacteria and fungi which kill or inhibit the growth of bacteria.

Aseptic technique: Method of culturing bacteria or other microorganisms in the laboratory to avoid contamination of the sample by other microorganisms.

Autotrophs: Cells or organisms that are able to synthesize organic molecules such as glucose from carbon dioxide. All green plants are autotrophic.

Bacteria (singular = **bacterium**): Small single-celled organisms with no nucleus.

Binary fission: The process by which bacteria divide in two when they reproduce.

Capsule (of bacteria): Slime layer covering some bacterial cells. Protects the bacterium and stops it drying out.

Cell: Basic structural unit of living organisms.

Cell membrane: Thin surface layer around the cytoplasm of a cell. Forms a partially permeable barrier between the cell contents and the outside of the cell.

Cell wall: Non-living layer outside the cell membrane of certain types of cell. Made of cellulose (plants and algae), chitin (fungi) or peptidoglycan (bacteria).

Chitin: Substance that makes up the cell wall of fungi and the outside skeleton of insects.

Chloroplast: Organelle found in some plant cells. The site of the reactions of photosynthesis.

Colony: A group of bacteria that has formed by repeated binary fission of one original bacterium.

Cytoplasm: Jelly-like material that makes up most of a cell; the site of chemical reactions of a cell.

Deoxyribonucleic acid (**DNA**): Chemical of which genes are made.

Chromosome: Thread-like structure found in the nucleus of a cell, made of DNA and protein. Contains the genetic information (genes).

Eukaryotic: Cells that have a nucleus (the cells of all living organisms except bacteria).

Fermentation: Anaerobic respiration carried out by microorganisms such as bacteria or fungi.

Gene: Part of a chromosome. A length of DNA that controls a characteristic of an organism by coding for the production of a specific protein.

Heterotrophs: Cells or organisms that acquire pre-formed organic molecules such as glucose. All animals are heterotrophic.

Inoculate: To introduce an agar plate or other medium with a specific bacterium or fungus.

Lactic acid bacteria: Type of bacteria that produces lactic acid. Used in fermenting milk to make yoghurt and cheese.

Mitochondrion (plural = **mitochondria**): Organelle that carries out aerobic respiration, releasing energy for the cell.

Multicellular: Composed of many cells.

Nucleus: Cell organelle that contains chromosomes. Controls the activities of the cell.

Organ: Structure in the body of an animal or plant that is a collection of different tissues working together to perform a function.

Organ system: Collection of different organs working together, e.g. the heart and blood vessels of the circulatory system.

Organelle: Part of the cell with a particular function, e.g. the nucleus, mitochondrion.

Partially permeable membrane: Membrane (e.g. the cell surface membrane) that allows some molecules to cross it but not others.

Pathogen: Organism that causes disease.

Penicillin: Antibiotic obtained from the mould *Penicillium*.

Prokaryotic: Cells of bacteria, which are small and lack a nucleus or membrane-bound organelles.

Ribosome: Tiny structure in the cytoplasm of cells, the site of protein synthesis.

Tissue: Collection of similar cells working together to perform a function.

Unicellular: Composed of a single cell

Vacuole: Membrane-bound space in a plant cell, filled with a solution of sugars and salts called cell sap.

Viruses: Very small microorganisms that are not composed of cells. Virus particles consist of genetic material (DNA or RNA) surrounded by a protein coat.