SURFING

NATIONAL BIOLOGY

Unit 2 Cells and Multicellular Organisms

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Contents

Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Cells as the Basis of Life

1 Assumed Knowledge

QUESTIONS

1. Identify seven properties of living organisms.
2. The cell is the basic unit of life. What structural features of cells are possessed by all living things?
3. Draw a fully labelled diagram of a plant cell as seen under a light microscope.
4. Draw a fully labelled diagram of an animal cell as seen under a light microscope.
5. Identify the following parts of a light microscope and use by a person.

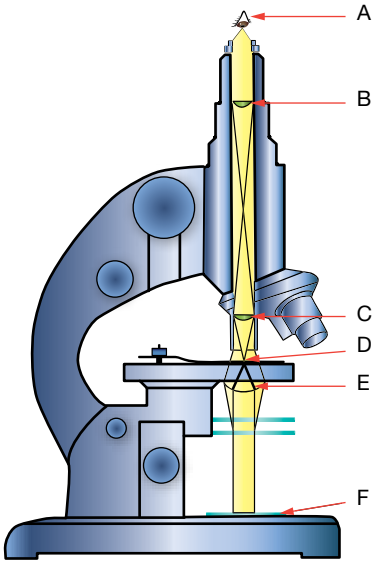


Figure 1.1 Light microscope.

6. Describe one safety precaution you should follow while using a light microscope.
7. What is the function of the nucleus of a cell?
8. What is the function of the cell membrane?
9. What is cytoplasm?
10. Define protoplasm.
11. Describe a chloroplast.
12. Define photosynthesis.
13. Which group of organisms can photosynthesise?
14. Identify the materials required by multicellular organisms for photosynthesis.
15. Why is photosynthesis an important process in ecosystems?
16. Name the four basic groups of organic compounds.
17. What are inorganic compounds?
18. What is the function of the digestive system?
19. Figure 1.2 shows the human digestive tract. Identify each part.
20. For each of the following parts of the digestive system, outline its structure and its main function.
    (a) Mouth. (b) Oesophagus.
    (c) Stomach. (d) Small intestine.
    (e) Large intestine. (f) Anus.

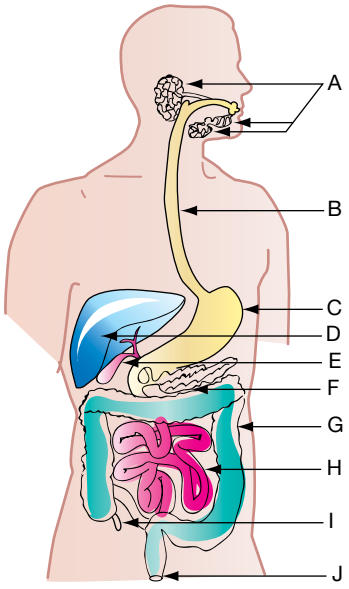


Figure 1.2 Human digestive tract.

21. Define respiration.
22. In humans, what structures make up the respiratory system?
23. Outline the function of the respiratory system.
24. Outline the function of the circulatory system.
25. In humans, what is the function of the heart in the circulatory system?
26. Identify the components of the human circulatory system.
27. In plants, what is the function of each of the following?
    (a) Xylem. (b) Phloem.
    (c) Leaves. (d) Roots.
28. Define transpiration.
29. Study the flow chart below.

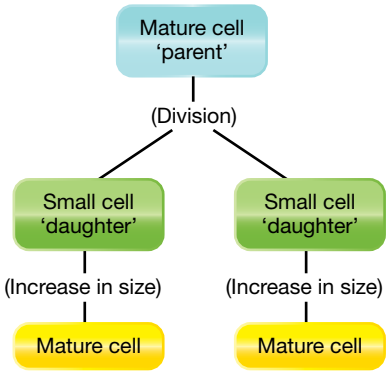


Figure 1.3 Division of a cell.

What type of division is indicated by this chart?

30. Define mitosis.
31. Explain why cell division is important.
32. How is genetic information transferred during cell reproduction?
33. Define a gene.
34. Define cytokinesis.

2 Characteristics of Living Things

There are nine characteristics of living things. These characteristics are used to define life.

1. Growth and development

Growth involves an increase in mass. This can occur due to an increase in the size of individual cells and/or an increase in the number of cells.

2. Reproduction

Reproduction is the ability to produce offspring. Reproduction can be asexual or sexual. **Asexual reproduction** involves one parent producing offspring that are genetically identical to the parent, e.g. by binary fission, budding or vegetative propagation. **Sexual reproduction** involves the union of two **gametes** in **fertilisation** to form a **zygote**.

3. Respiration

All living things can respire. Cellular respiration is a series of chemical reactions in which cells obtain energy from food. Each step in the series of reactions is controlled by enzymes with the energy being released at different stages in the process. Some of the energy is transferred to other molecules becoming available for other reactions.

4. Respond to stimuli

All living things respond to stimuli from both their external environment and their internal environment. The stimuli can be physical or chemical changes in the environment, e.g. a response to the intensity and direction of light or a change in the carbon dioxide levels in body fluids.

5. Movement and locomotion

Movement can be very obvious, e.g. a running animal or very slow and involve only part of the organism, e.g. a plant leaf moving to catch the maximum amount of sunlight. Locomotion is the ability to move from one place to another.

6. Nutrition or feeding

Nutrition is a process by which organisms obtain **matter** to produce their physical structure and **energy** to continue the functions of life. **Autotrophs** can make their own organic nutrients from inorganic materials, e.g. plants and cyanobacteria can use the energy from sunlight in **photosynthesis** and bacteria living in hot springs or oceanic hydrothermal vents use the energy in hydrogen sulfide (H_2S) in chemosynthesis. **Heterotrophs** consume other organisms to obtain organic nutrients. Their food needs to be broken down before it can be used.

7. Assimilation

Assimilation is the process of converting food into the living material of life.

8. Metabolism

Metabolism is the sum of all chemical reactions within the organism. In **anabolic reactions** small molecules are combined to form complex molecules, e.g. photosynthesis. In **catabolic reactions** chemical bonds are broken and complex molecules are broken down into smaller units, e.g. digestion. Sometimes energy is released.

9. Excretion

Excretion is the removal of unwanted waste products of metabolic reactions.

QUESTIONS

1. Construct a table to summarise the nine characteristics of living things.
2. Distinguish between asexual reproduction and sexual reproduction.
3. Define fertilisation.
4. Crystals can grow in size. Explain why crystals are not considered to be living though they show a characteristic of living things.
5. Distinguish between autotrophic and heterotrophic nutrition.
6. Distinguish between photosynthesis and chemosynthesis.
7. The diagram shows one of the features of living things.

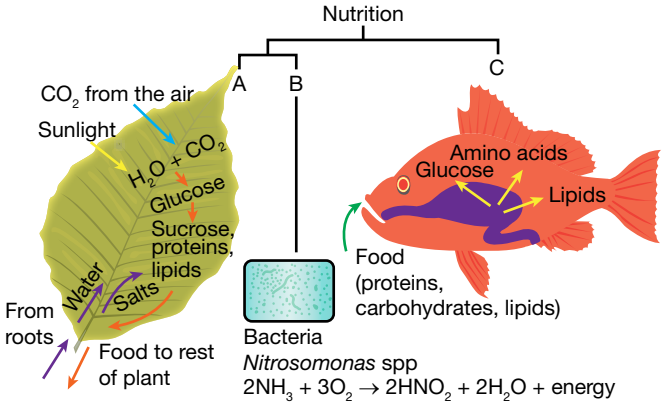


Figure 2.1 A feature of living things.

   (a) For the types of nutrition labelled A, B and C, which are autotrophic and which are heterotrophic?
   (b) What is the energy source for the bacteria *Nitrosomas* spp?
8. Distinguish between an anabolic reaction and a catabolic reaction.
9. Is respiration a catabolic or anabolic reaction? Explain your reasoning.

3 Developing the Cell Theory

The cell theory states the following.

- All living things are made of cells and of substances produced by cells.
- All cells come from pre-existing cells.
- The cell is the basic unit in which the processes of living take place.

The development of the cell theory is linked with the invention of technology that enabled scientists to see cells and to investigate the properties of cells.

Humans have made observations and recorded their findings about living things since the first mark was put on a cave wall, clay tablet or sheet of papyrus paper. These observations record the **macroscopic appearance** of living things – the features observed with the naked eye.

The development of glass lenses and the construction of the first microscope using a glass lens enabled scientists to observe the **microscopic appearance** of living things. The first cells were observed and the ideas about the structure of the building blocks of life were forever changed.

Hans and Zacharias Jansen

Hans and Zacharias Jansen are believed to have created the **first compound light microscope** around the 1590s. They placed several lenses in a tube and realised the object near the end of the tube could be magnified more than using a single lens in a magnifying glass.

Zacharias Jansen | Francesco Redi | Anton van Leeuwenhoek | Robert Brown

Figure 3.1 Jansen, Redi, van Leeuwenhoek and Brown.

Robert Hooke

In 1663 Robert Hooke observed cork under a microscope and introduced the term '**cell**'. He published his microscopical observations in 1665 in his book *Micrographia*. This book led to public interest in microscopy.

Francesco Redi

In 1668 Francesco Redi published the results of his experiment with insects which was one of the first steps in proving that living things do not arise from **spontaneous generation**. He showed that fly maggots did not spontaneously arise from dead meat as meat kept in jars covered with gauze did not get maggots.

Anton van Leeuwenhoek

Anton van Leeuwenhoek produced higher quality lenses that gave greater magnification and aided the development of the light microscope. He is considered to be the 'Father of Microbiology'. In 1674 he was the first to observe and describe **single-celled organisms** which he called *animalcules*. In 1676 when he sent his drawings of single-celled organisms to the Royal Society of London, his credibility was questioned. In 1680 his observations were vindicated after others observed the unicells. He discovered and made drawings of protozoa, bacteria, the vacuole of the cell, the banded pattern of muscle fibres and spermatozoa.

Robert Brown

Robert Brown described the **nucleus** in cells of the orchid and gave the structure its name. He travelled to Australia in 1801 on the HMS *Investigator* as the naturalist at the request of the commander of the vessel, Matthew Flinders. He collected many specimens and left Australia in 1805. In 1831 he read a paper about the cell nucleus to the Linnaean Society and published this work in 1833. Although the nucleus had been drawn by others, e.g. van Leeuwenhoek and Franz Bauer, Brown gave the structure its name. His observations of the random movement of pollen grains led to the naming of the phenomena now known as Brownian motion.

Matthias Schleiden

In 1838 Matthias Schleiden wrote *Contributions to Phytogenesis* and proposed that different parts of plants are made of cells. With Schwann he was the first to propose the **cell theory**. He also recognised the importance of the cell nucleus and its possible relationship with cell division.

Theodor Schwann

Theodor Schwann noted that parts of animals are made of cells and that non-cellular parts, e.g. nails, feathers and tooth enamel had a cellular origin. In 1839 he extended Schleiden's cell theory to animals and proposed that all living things are made of cells and cell products. The cell was the basic unit of life. This is now called the **Schleiden and Schwann cell theory**. Schwann also observed the cells associated with nerve fibres which are now called Schwann cells.

Rudolf Virchow

In 1855 Rudolf Virchow published a work that proposed that the origin of cells was the division of pre-existing cells and the cell theory was expanded to include the point that every cell originated from another living cell like it. This rejected the concept of spontaneous generation. Virchow is known as the 'father of modern pathology' and he developed a standard method of autopsy procedure.

Matthias Schleiden | Theodor Schwann | Rudolf Virchow

Figure 3.2 Matthias Schleiden, Theodor Schwann and Rudolf Virchow.

Louis Pasteur

In 1861 Louis Pasteur published his experiments demonstrating that fermentation was caused by micro-organisms which finally disproved the theory of spontaneous generation. The experiment also supported the germ theory.

Friedrich Miescher

In 1869 Friedrich Miescher isolated nucleic acids which he called *nuclein* from the nuclei of white blood cells. This was the first time DNA had been purified and led to investigations into its composition, properties and structure.

Camillo Golgi

In 1898 Camillo Golgi described the Golgi apparatus by staining cells with silver nitrate. At first some believed the structure was an optical illusion caused by the staining technique. The invention of the electron microscope in the 20th century proved the existence and shape of this organelle.

Louis Pasteur | Friedrich Miescher | Camillo Golgi

Figure 3.3 Louis Pasteur, Friedrich Miescher and Camillo Golgi.

Max Knoll and Ernst Ruska

In 1932 Max Knoll and Ernst Ruska invented the transmission electron microscope. The higher magnification and higher resolution meant greater details of the ultrastructure of cells could be observed and analysed and new structures were discovered, e.g. ribosomes.

QUESTIONS

1. State the cell theory.
2. Construct a table to summarise the historical development of the cell theory.
3. Explain how the invention of the light microscope is linked with the development of the cell theory.
4. Explain why Anton van Leeuwenhoek is known as the 'Father of Microbiology'.
5. Suggest why Leeuwenhoek's discovery of animalcules was at first disbelieved and explain why it was finally accepted.
6. Outline the discovery and naming of the nucleus.
7. What are the two points of the cell theory proposed by Schleiden and Schwann?
8. What is the theory of spontaneous generation?
9. Discuss how the theory of spontaneous generation was finally disproved.
10. How is the theory of spontaneous generation linked with the development of the cell theory?
11. (a) Why did people question the actual existence of the Golgi body in cells?
    (b) What evidence proved the existence of the Golgi body?
12. Explain how the invention of the electron microscope aided the development of knowledge about cell structure.
13. Who was the first person to isolate DNA?
    (A) Robert Hooke. (B) Robert Brown.
    (C) Rudolf Virchow. (D) Friedrich Miescher.
14. The timeline shows events in the development of the cell theory.
    From this timeline which event occurred before the nucleus was named?
    (A) Single-celled organisms were observed.
    (B) Golgi apparatus was described.
    (C) Nucleic acids were isolated.
    (D) Cell theory was expanded.

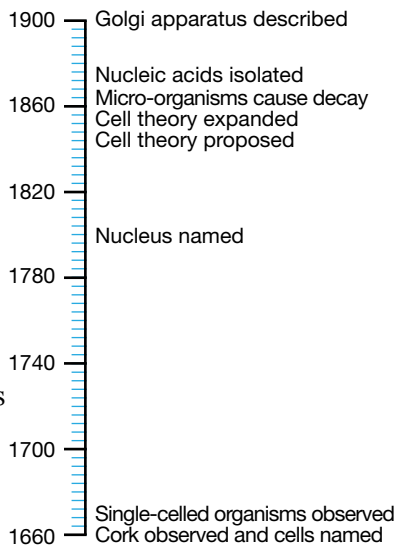


Figure 3.4 Cell theory timeline.

4 Cell Theory and Robert Hooke

Robert Hooke (1635-1703) was an experimental scientist who was interested in physics, astronomy, chemistry, biology, geology, architecture and naval technology, although his primary interest was microscopy, mechanics and instrumentation. There are no authenticated surviving portraits of Robert Hooke.

Robert Hooke invented a compound light microscope, i.e. a microscope with more than one lens and devised an illumination system for this microscope. Using this microscope he observed many organisms and drew accurate and detailed drawings of his findings. He also developed a micrometer; the universal, or Hooke's joint found in all cars; the spring control of the balance wheel in watches; the first reflecting telescope and was involved in creating different types of barometers.

Robert Boyle was Hooke's patron when Hooke began studying at Oxford. However, Hooke clashed with Isaac Newton and this may have affected his fame in history. It is believed that Newton destroyed the only portrait known to exist of Hooke.

Figure 4.1 Hooke's microscope.

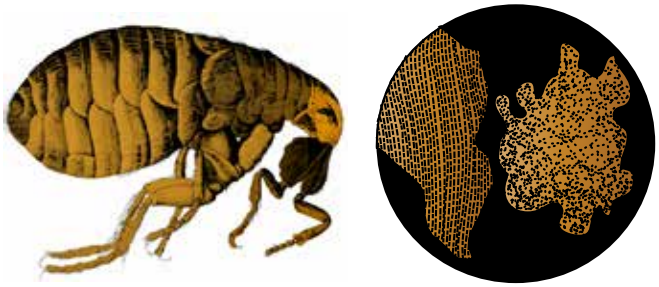
Robert Hooke's first publication was printed in 1661 and was a pamphlet on capillary action. In 1665, he published a book, *Micrographia*, which contained many drawings and records of his observations under the microscope, e.g. diagrams of insects, sponges, foraminifera, bird feathers and bryozoans. It also included a theory of light. The diagrams in *Micrographia* created a public interest in microscopy with some people believing it was a great advance in scientific knowledge and others calling it a trifling pursuit.

When Hooke observed a slice of cork under his microscope he discovered plant cells. He coined the term 'cells' to describe what he saw.

> 'Yet it was not unlike a Honeycomb in these particulars … these pores, or cells, … consisted of a great many little Boxes.'

He also put fossils under his microscope and observed the similarities of fossil shells with living mollusc shells. He noted that dead wood could be turned to stone due to minerals being deposited throughout the wood. Hooke suggested the fossils gave clues to the past history of life on Earth.

In 1678 Anton van Leeuwenhoek (1632-1723) reported the presence of 'little animals' in lake water. The Royal Society of London asked Robert Hooke to investigate these findings and when he confirmed the presence of small organisms, Leeuwenhoek's work was accepted.



(a) Drawing of a flea. (b) Drawing of a slice of cork.

Figure 4.2 Drawings by Robert Hooke from his book *Micrographia*.

QUESTIONS

1. Name two instruments invented by Robert Hooke.
2. What is meant by a 'compound' microscope?
3. Discuss the significance of the invention of the compound microscope.
4. How did the term 'cell' originate as used in biology?
5. Robert Hooke observed a honeycomb appearance under the microscope which he called 'cells'. What was he actually viewing?
6. The lenses used by Hooke were relatively low quality and caused some image distortion and separated colours giving a rainbow 'fringe' effect. Explain how opponents of Robert Hooke used these details to discredit his findings.
7. In *Micrographia* Hooke drew the microscopic structure of fossilised wood and compared its structure to a piece of rotten oak wood. Why did some people reject his conclusions about fossils showing extinction and past life forms?
8. In his book *Micrographia* Robert Hooke drew many diagrams.

Figure 4.3 Hooke's drawing of *Mucor* from Micrographia.

Discuss why the drawings in *Micrographia* were important in making the book a 'best seller'.

5 Cell Theory and Robert Brown

Robert Brown (1773-1858) was a Scottish botanist and protégé of Joseph Banks. He sailed on the HMS *Investigator* in 1801 under Captain Matthew Flinders. When he reached Australia, then called New Holland, he collected more than 500 plant species and made many drawings and notes of animals and plants, naming more than 140 new genera and over 1700 new species. He returned to England in 1805 and spent five years describing the 2200 species he had observed. He published his notes in 1811 in *Prodromus Florae Novae Hollandiae et insulae Van-Diemen* and further notes in 1814 in 'General Remarks, Geographical and Systemic, on the Botany of Terra Australis' as an appendix to Matthew Flinders' *Voyage to Terra Australis*.

Figure 5.1 Brown's microscope.

From 1805 he was Secretary to the Royal Linnean Society and from 1810 to 1820 he was the personal librarian to Joseph Banks. Brown was given the care of Sir Joseph Banks' home and collections when Banks died and when Brown organised the transfer of the specimens to the British Museum, he became the curator and Keeper of the British Museum for the rest of his life.

Using microscopes all through his adult life, in 1827 Brown was the first person to notice the constant movement of suspended particles and since then this movement has been called 'Brownian motion'.

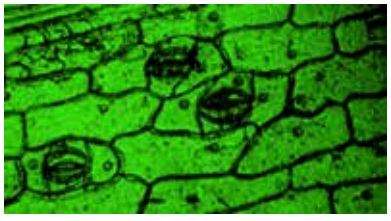


Figure 5.2 View obtained by Brown of cell nucleus in orchid epidermal cells.

In 1833, Brown observed the epidermis of orchids under his microscope and discovered an 'opaque spot' which he called the nucleus.

Early microscopists had drawn nuclei in animal cells Leeuwenhoek in 1700 figured nuclei in red blood cells of salmon in a letter to the Royal Society, but it was Hooke who coined the term 'nucleus'.

> 'In each cell of the epidermis of a great part of this family [Orchidaceae], … a singular areola, generally somewhat more opaque, … is observable … This areola, or nucleus of the cell as perhaps it might be termed, is not confined to the epidermis …'

Robert Brown continued to use his microscope and discovered nuclei in a range of plant tissues. At this stage the importance of the nucleus was still unknown.

QUESTIONS

1. Outline the epic expedition of discovery of Robert Brown.
2. Name two publications of Robert Brown.
3. How did the work of Robert Brown increase knowledge about Australian plants and animals?
4. What is 'Brownian motion'?
5. How did Brown discover the plant nucleus?
6. What term was coined by Brown?
7. Comment on the statement:
   'Robert Brown was the first to describe the structure and function of the nucleus'.
8. When Robert Brown described '… a singular areola, generally somewhat more opaque' spot in a cell, what organism was he studying?
   (A) Mouse epidermis. (B) Orchid epidermis.
   (C) Slice of cork. (D) Pond water.
9. The diagram shows a leaf epidermis with stomates under high power of a light microscope.

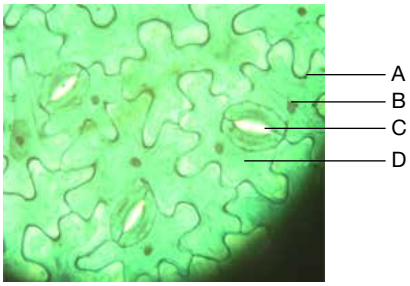


Figure 5.3 High power view of leaf epidermis.

   Which structure is the nucleus of a leaf epidermal cell?
   (A) A (B) B (C) C (D) D
10. Matthias Schleiden built on the work of Robert Brown. Schleiden believed that the nucleus is the most important part of a cell and has a vital role in cell reproduction. Why would Schleiden freely talk about his indebtedness to Robert Brown?
    (A) Brown was the first person to give a description of a cell.
    (B) Brown invented the staining techniques used by Schleiden.
    (C) Brown had named the nucleus and noted its presence in a range of different plants.
    (D) Brown showed that cells are formed from pre-existing cells.

6 Technology and the Development of the Cell Theory

The historical development of the cell theory has often depended on major advances in technology, taking over 300 years (1665-1838) to be fully established. Advances in technology still influence the development of knowledge about cells, organelles, biochemical reactions and how each structure contributes to life processes.

Development of the light microscope

The grinding of glass lenses with the invention of glass spectacles in the 14th century in Italy was one of the first steps leading to our ability to see cells. In the 1590s Hans and Zacharias Jansen are believed to have created the first compound light microscope. They placed several lenses in a tube and realised the object near the end of the tube could be magnified more than using a single lens in a magnifying glass.

But it was not until 1665 that **Robert Hooke** (1635-1703) with his compound microscope, first observed cells. In 1674 **Anton van Leeuwenhoek** (1632-1723) saw micro-organisms, '*animalcules*' using a new single lens microscope he had developed. Leeuwenhoek made better lenses with greater curvature which gave better magnification. His grinding and polishing techniques produced lenses able to magnify up to 270 diameters. **Jan Swammerdam** (1637-1680) was one of the first people to use a microscope in dissections and discovered animal cells describing the blood cells of a louse.

Joseph Jackson Lister (1786-1869) produced achromatic lenses and placed them at suitable distances to give better resolution without spherical aberrations that blurred the image. He published his findings in 1830 and by 1832 was one of the best microscope makers of his time.

Henri Dutrochet (1776-1847) studied plant cells using a microscope and named the process of osmosis and noted that the processes in all living things are similar. In 1824 he suggested that living things might be made of cells and therefore that cells may be the basic unit of all living things. In 1833 **Robert Brown** (1773-1858) was the first person to recognise the nucleus in plant cells and, although the structure had been observed in animal cells, he gave it a name.

In 1838 **Matthias Schleiden** (1804-1881) and **Theodor Schwann** (1810-1882) proposed that all living things are made of cells. They suggested that each cell functions not only independently of other cells but also in cooperation with them so that organisms can function as a whole. Schleiden studied different plant structures under a microscope and recognised the importance of the nucleus. Schwann viewed animal tissues under the microscope, especially nervous and muscle tissues.

Rudolf Virchow (1821-1902) encouraged his students to use microscopes, especially in pathological anatomy and in animal experiments. He found cells in bone and in connective tissue and in 1855 published a work that proposed that the origin of cells was the division of pre-existing cells. This is the last point of the cell theory.

In 1893 **August Kohler** developed a new way to illuminate the field of view in a light microscope. The Kohler illumination scheme provided even lighting which enabled high quality photomicrographs to be taken.

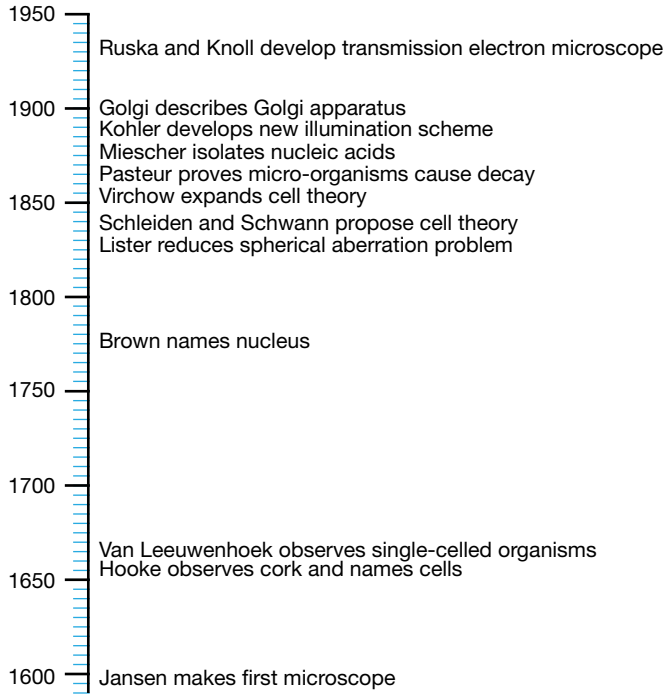


Figure 6.1 Timeline for the development of technology and the cell theory.

Development of staining techniques

The development of specific dyes was needed to help scientists discover the internal structures of a cell. Many dyes will stain specific chemicals, assisting in the identification of chemicals in cells, and the contrast in colour helps to outline different structures. For example, in 1849 the carminic acidic procedure was developed by Hartung and in 1863 the haematoxylin colouring was developed by Waldeyer. These methods led to the observation of cell and nuclear division. Carmine is a bright red pigment obtained from scale insects, e.g. cochineal scale and is used to stain glycogen or animal starch red and is used to colour nuclei and chromosomes. Haematoxylin stains cell nuclei blue.

Iodine is used in chemistry as a test for starch as the starch/iodine complex is a dark blue-black colour. Lugol's iodine solution is a cell stain used in biology to make the cell nuclei more visible.

New methods in making slides have also enabled cells to be seen more clearly. Fixing specimens, e.g. in formalin will harden tissues before embedding in wax and then cutting. New instruments, e.g. **microtomes** have enabled extremely thin slices of specimens to be cut more easily.

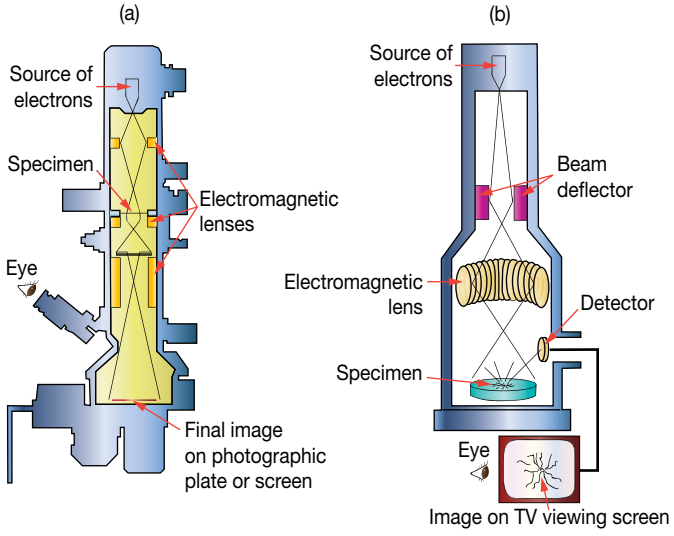


Figure 6.2 Comparing electron microscopes. (a) Transmission electron microscope. (b) Scanning electron microscope.

Development of the electron microscope

In 1932 **Ernst Ruska** (1906-1988) and **Max Knoll** (1897-1969) developed the first transmission electron microscope (TEM). The development of the electron microscope with its greater resolution and greater magnification compared to the light microscope has enabled scientists to see more details within the cell, e.g. the structure of the nuclear membrane, as well as discovering new parts, e.g. ribosomes. The transmission electron microscope uses a beam of electrons instead of a beam of light and uses electromagnets instead of glass lenses. It shows the internal appearance of cells.

Magnification refers to making things appear larger and **resolution** is the ability to distinguish between two points and makes detail appear more clearly.

QUESTIONS

1. Why is the development of the light microscope associated with the development of glass lenses?
2. When were cells first observed and why was this possible?
3. Outline the contribution of Anton van Leeuwenhoek to the development of the microscope.
4. What was the significance of Kohler's development of a new illumination method?
5. Which aspect of the cell theory was not correctly understood by Schleiden and Schwann?
6. What was the contribution of Virchow?
7. Construct a table to show the contributions of at least six people to the cell theory giving the year, the person and their contribution.
8. Describe the evidence used by Hooke to support the beginning of the cell theory.
9. Discuss how the electron microscope has assisted our understanding of cell structure.
10. Ernst Abbe (1840-1905) developed many optical instruments and from experiments worked out a formula to determine the resolution limit of a microscope. He showed resolution was inversely proportional to the wavelength of light. Use this information and the fact that electron beams have much shorter wavelengths than the wavelengths of visible light to compare the resolution of a light microscope with the resolution of an electron microscope.
11. Distinguish between magnification and resolution.
12. Draw a timeline to show the stages in the development of the cell theory including the work of Hooke, Leeuwenhoek, Dutrochet, Brown, Schleiden and Schwann and Virchow.
13. Assess the impact of the development of technology on the development of the cell theory.
14. The diagram shows a cross-section of a leaf as seen under low power light microscope.

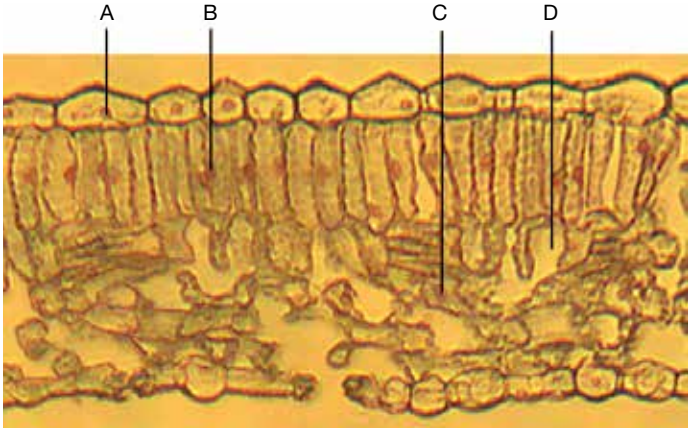


Figure 6.3 Cross-section of a leaf, low power light microscope.

Which arrow does *not* point to a nucleus of a cell?
(A) A (B) B (C) C (D) D

15. Which statement is *not* part of the cell theory?
    (A) All living things are made of cells.
    (B) All cells have a nucleus.
    (C) All cells come from pre-existing cells.
    (D) The cell is the basic unit of life in which the processes of living occur.
16. Name the scientist who proposed that all cells come from pre-existing cells.
    (A) Hooke.
    (B) Brown.
    (C) Leeuwenhoek.
    (D) Virchow.

7 The Modern Light Microscope

The compound light microscope operates on the main principle that an objective lens with a very short focal length can form a highly magnified real image of the object. Visible light passes through the specimen and then a series of lenses. The resolution of the microscope is limited by the shortest wavelength of light used to view the specimen.

Images from a light microscope can be captured with a camera to produce a **photomicrograph**. Digital images can be shown directly on a computer screen.

Table 7.1 Features of the modern light microscope.

Feature	Light microscope
Magnification	Effective up to 1000×.
Resolution	Up to 0.2 μm.
Stains	Allows the use of many different coloured stains to identify substances, structures and provide contrast for easier viewing.
Living specimen	The light microscope allows viewing of living specimen and processes occurring within a cell or within an organism.
Mounting	The specimen is mounted on a glass slide in air.
Focusing	By glass lenses.
Energy source for viewing	A beam of light is passed through the specimen.

How a light microscope works

The objective lens is brought close to the specimen to create an enlarged image of the object. The image is inverted. In most modern light microscopes the eyepiece is a compound lens near the back of an eyepiece tube. Light travels from the light source up the microscope to form an image at the eye.

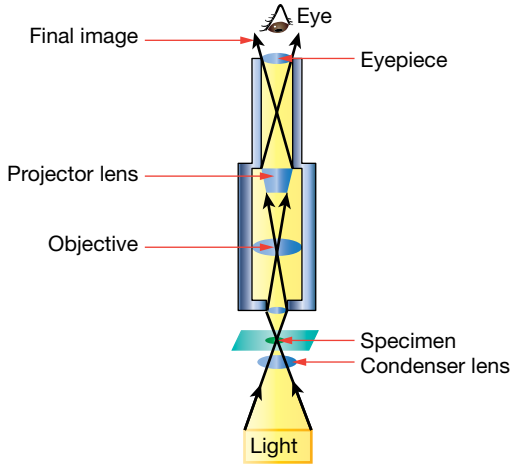


Figure 7.1 How light travels through a light microscope.

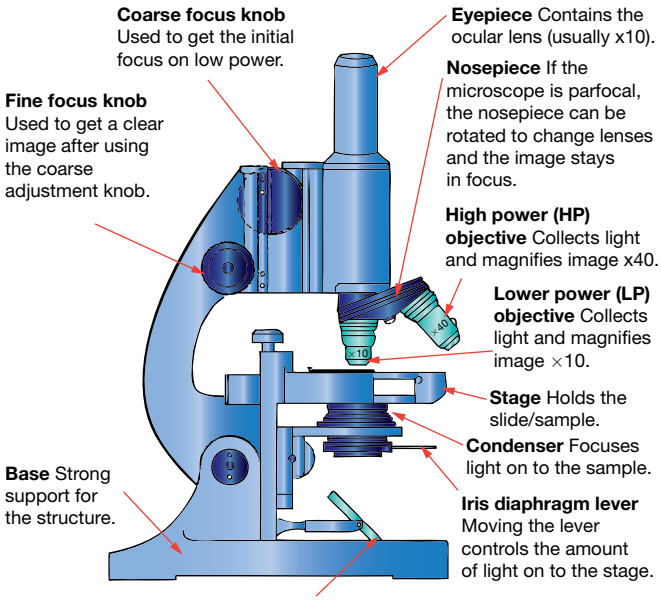


Figure 7.2 Features of the modern light microscope.

Advantages of a light microscope

The main advantages of light microscopes are that:

- Living cells can be observed.
- Coloured stains can be used.
- The specimens are easy to prepare.
- The microscopes are relatively inexpensive (compared to the cost of an electron microscope).
- Their size means they are relatively easy to store.

Disadvantages of a light microscope

The main disadvantages of the light microscope are:

- Its limited magnification (effective magnification begins to reduce after 1000×).
- Its limited resolution.

During the 20th century many different illumination techniques and other developments have increased the detection power of the light microscope for observing living cells.

Phase contrast microscopes

The phase contrast microscope uses interference rather than absorption of light to increase the contrast in unstained cells by amplifying variations in density within the cell. It improves our ability to study living, unpigmented cells in biological and medical research. Many dyes and stains stop chemical processes in cells which means the phase contrast microscope has improved our ability to see detail in living cells, e.g. the process of cell division. Frits Zernike was awarded with the Nobel Prize in Physics, 1953 for the development of phase contrast illumination.

Fluorescence microscopes

In the fluorescence microscope the specimen is illuminated through objective lenses with a narrow set of light wavelengths. The specimen either fluoresces in its natural form, e.g. chlorophyll or has been treated with fluorescing chemicals or antibodies. The fluorescent substances absorb UV light and emit visible light so that the fluorescence shows the location of specific molecules in the cell.

Other illumination techniques

Other illumination techniques include:

- **Bright field** – passes light through the specimen and contrast comes from the absorbance of light in the specimen. If the specimen is unstained or unpigmented there is little contrast.
- **Cross-polarised** – contrast occurs when polarised light is rotated through the sample.
- **Confocal** – is a type of fluorescence microscopy using optical sectioning by scanning lasers of fluorescently-stained specimens.

Stains and dyes used with the light microscope

There are many stains that are used to highlight structures being viewed under a light microscope.

- **Gram staining** – uses several stains, e.g. crystal violet, iodine, fuchsin or safranin to stain cell cells to differentiate bacteria into Gram positive (purple/blue colour occurs) and Gram negative (pink/red colour occurs). This is usually the first step in identifying bacteria.
- **DAPI** – is a fluorescent nuclear stain that shows a blue fluorescence when bound to DNA and viewed with ultraviolet light.
- **Eosin** – is used as a counterstain with haematoxylin in H&E staining and gives a pink/red colour to cytoplasmic material, red blood cells and cell membranes.

QUESTIONS

1. Outline the basic principle behind the operation of a light microscope.
2. When using a light microscope identify the function of:
   (a) The condenser.
   (b) The iris diaphragm.
3. What restricts the resolution of the light microscope?
4. Construct a table to compare the advantages and disadvantages of a light microscope.
5. What is a photomicrograph?
6. Outline the benefit of the phase contrast microscope.
7. Outline the benefit of fluorescence microscopy.
8. The table shows some objects and their sizes.

Object	Size (μm)
Frog egg	1100
Paramecium	100
Plant epithelial cell	60
Human ovum	10
Red blood cell	7 to 8
Mitochondrion	1.1
Nanobes	0.025

   Identify which objects could be seen with the naked eye and/or light microscope.
9. Use an example to show how the use of stains and the light microscope have increased our understanding of processes in cells.
10. Most modern light microscopes in schools have at least two different objectives. Name objectives you have used and state the purpose of each objective.
11. What is a parfocal microscope?
12. The diagram shows red blood cells as seen and as drawn by a biology student using a light microscope.

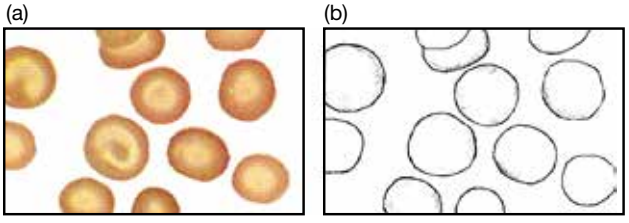


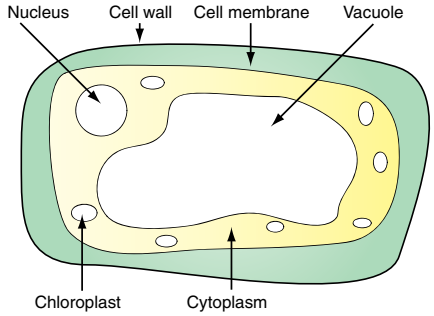
Figure 7.3 Red blood cells seen using a light microscope. (a) Seen under a light microscope. (b) As drawn by a student.

    Red blood cells are usually about 6 to 8 micrometres in diameter.
    Which objective would the student most likely have been using to view these cells as seen in the diagram? Explain your answer.
13. Explain why the Gram stain is used.
14. What is the correct order of the movement of light when an object is viewed under a light microscope?
    (A) Light → condenser → objective → eyepiece → eye
    (B) Light → objective → condenser → eyepiece → eye
    (C) Light → objective → eyepiece → condenser → eye
    (D) Eye → eyepiece → objective → condenser → light
15. What is the limit of resolution of a light microscope?
    (A) 0.2 centimetres
    (B) 0.2 millimetres
    (C) 0.2 micrometres
    (D) 0.2 nanometres

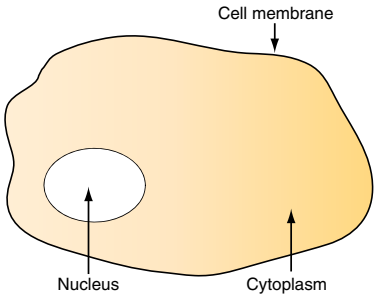
Answers

1 Assumed Knowledge

1. Living organisms can: 1. Respire. 2. Assimilate food and synthesise organic molecules. 3. Grow. 4. Reproduce. 5. Respond to stimuli from their environment. 6. Excrete. 7. Move about.
2. The cells of living things have a cell membrane, cytoplasm and DNA.
3. Plant cell.



4. Animal cell.



5. A = eye of person using the light microscope, B = ocular lens, C = objective lens, D = specimen, E = condenser lens, F = light source
6. When using a light microscope, you should always wear shoes with covered toes, as the microscope is heavy and if you drop it you could damage exposed skin on your feet.
7. The nucleus stores information needed to control all cell activities.
8. The cell membrane surrounds the cell contents from the external environment and controls the substances that can leave or enter the cell.
9. Cytoplasm is a general term for the contents of a cell outside the nucleus and within the cell membrane.
10. Protoplasm is the semifluid transparent substance that makes up the living matter of plant and animal cells including the nucleus and cytoplasm.
11. A chloroplast is a green organelle found in green tissues of plants that captures sunlight in photosynthesis to manufacture sugars from carbon dioxide and water.
12. Photosynthesis is a process where the energy of sunlight is used to convert carbon dioxide and water into sugars and oxygen.
13. Groups of organisms that can photosynthesise include plants, algae and photosynthetic bacteria.
14. Carbon dioxide and water are needed for photosynthesis using light energy and in the presence of chlorophyll.
15. Photosynthesis is important in ecosystems as it converts light energy into chemical energy to begin most food chains on Earth and also provides oxygen which is needed for respiration.
16. The four basic groups of organic compounds are proteins, carbohydrates, lipids and nucleic acids.
17. Inorganic compounds are molecules that do not contain carbon (excluding some carbonates and simple oxides of carbon).
18. The function of the digestive system is to break down ingested food into smaller particles so that nutrients can be absorbed into the body.
19. A = salivary glands, B = oesophagus, C = stomach, D = liver, E = gall bladder, F = pancreas, G = large intestine, H = small intestine, I = appendix, J = anus
20.

Part	Structure	Function
Mouth	Has teeth and openings from salivary glands	Teeth break food into small pieces and salivary enzymes begins chemical digestion
Oesophagus	Long tube	Moves food to stomach by peristalsis
Stomach	Muscles and glands in wall	Churns food and produces digestive enzyme to digest protein
Small intestine	Long thin tube with villi and glands	Digestion is completed and nutrients absorbed through walls
Large intestine	Long tube	Water, salts and vitamins absorbed
Anus	Muscular ring	Eliminates faeces

21. Respiration is the chemical reactions in which cells obtain energy from food.
22. In humans, the respiratory system consists of the lungs and passages which bring air into and out of the lungs, e.g. trachea, bronchi and alveoli.
23. The function of the respiratory system is the intake, expulsion and exchange of oxygen and carbon dioxide.
24. The circulatory system is the transport system of the body, e.g. it carries the glucose and oxygen to the cells and distributes heat around the body.
25. In humans the heart pumps the blood to keep it flowing away from the heart through the arteries.
26. The human circulatory system consists of the heart and blood vessels, e.g. arteries, veins and capillaries and blood.
27. (a) Xylem transports water up the plant from roots to leaves.
    (b) Phloem transports sugars up and down the plant.
    (c) Leaves are the site of photosynthesis where light energy is changed into chemical energy to be used by the plant.
    (d) Roots support the plant, anchor it in the soil and are the site of water absorption.
28. Transpiration is the evaporation of water from leaves of a plant.
29. Mitosis.
30. Mitosis is the process during cell division in which the cell nucleus divides into two.
31. Cell division is needed for growth, repair and reproduction.
32. During reproduction genetic information is transferred as DNA on chromosomes.
33. A gene is a section of DNA that relates to one characteristic.
34. Cytokinesis is the division of the cell's cytoplasm during cell division, following the division of the nucleus.

2 Characteristics of Living Things

1.

Characteristic	Description of characteristic
Growth and development	Involves an increase in mass due to an increase in the size of individual cells and/or and increase in the number of cells.
Reproduction	Is the ability to produce offspring and can be either sexual or asexual.
Respiration	Is a series of chemical reactions in which cells obtain energy from food.
Respond to stimuli	Stimuli from either the internal or external environvment cause a response in or by the organism.
Movement and locomotion	Part or the whole organism can move.
Nutrition or feeding	Organisms obtain matter and energy to build their physical structure and continue the functions of life.
Assimilation	Is the process of converting food into the living material of life.
Metabolism	Is the sum of all chemical reactions within the organism.
Excretion	Is the removal of unwanted waste products of metabolic reactions.

2. Sexual reproduction involves the union of two gametes in fertilisation to form a zygote. Asexual reproduction only involves one parent producing offspring that are identical to the parent.
3. Fertilisation is the union of two gametes.
4. Although crystals can grow in size they do not show any other characteristic of living things, e.g. respiration, response to a stimulus. To be classified as a living thing a combination of characteristics need to be present.
5. In autotrophic nutrition the organism can make its own organic nutrients from inorganic materials. In heterotrophic nutrition the organism needs to consume organic materials and existing foods.
6. In photosynthesis the autotroph uses energy from sunlight to create their own organic material while in chemosynthesis the autotroph uses a chemical source of energy to create their own organic material.
7. (a) A and B are autotrophic nutrition and C is heterotrophic nutrition.
   (b) *Nitrosomonas* spp uses ammonia as its source of energy. It oxidises ammonia to nitrous acid.
8. In anabolic reactions small molecules are combined to form more complex molecules. In catabolic reactions chemical bonds are broken and complex molecules are broken down into smaller units.
9. Respiration is a catabolic reaction as complex organic molecules, e.g. glucose are broken down into smaller units, e.g. carbon dioxide and energy is released.

3 Developing the Cell Theory

1. The cell theory states that: 1. All living things are made of cells and of substances produced by cells. 2. All cells come from pre-existing cells. 3. The cell is the basic unit in which the processes of living take place.
2.

Date	Person	Contribution
1590s	Hans and Zacharias Jansen	Created the first compound light microscope.
1663	Robert Hooke	Observed cork under a microscope and introduced the term 'cell'.
1668	Francesco Redi	Published the results of his experiments with insects showing living things do not arise from spontaneous generation.
1674	Anton van Leeuwenhoek	Improved the quality of lenses and aided the development of the light microscope. Discovered unicells, e.g. protozoa and bacteria. Discovered the vacuole and drew the banded pattern of muscle fibres and spermatozoa.
1833	Robert Brown	Published a paper naming and describing the cell nucleus in orchids.
1838	Matthias Schleiden	Proposed that different parts of plants are made of cells. This became part of the Schleiden and Schwann cell theory.
1839	Theodor Schwann	Extended Schleiden's cell theory to include animals. Schleiden and Schwann cell theory: 1. All living things are made of cells and cell products. 2. The cell is the basic unit of life.
1855	Rudolf Virchow	Extended the cell theory to include that every cell originated from a living pre-existing cell.
1861	Louis Pasteur	Fermentation experiments finally disprove the theory of spontaneous generation.
1869	Fredrich Miescher	Isolated DNA for the first time.
1898	Camillo Golgi	Described the Golgi apparatus by staining cells with silver nitrate.
1932	Max Knoll and Ernst Ruska	Invented the transmission electron microscope which gave greater resolution and magnification to study the ultrastructure of cells.

3. The invention of the light microscope is tightly linked with the development of the cell theory. When Robert Hooke used his compound microscope to view cork he discovered the cellular nature of plants and called the structures 'cells'. When van Leeuwenhoek used improved lenses to observe unicells he was not initially believed. It was the invention and development of light microscopes with higher magnification and resolution that enabled scientists to observe and study the cellular nature of living things.
4. Anton van Leeuwenhoek produced higher quality lenses and made many microscopes. The improved resolution and magnification of his microscopes meant he was able to observe smaller objects and he was the first to draw and describe single-celled organisms, e.g. protozoa and bacteria. This work led to him being called the 'Father of Microbiology'.
5. Leeuwenhoek's discovery of animalcules was at first disbelieved as the idea of single-celled organisms did not fit in with the early 17th century concept of 'life'. His work was finally accepted six years later when others observed unicells under the microscope.
6. Several scientists observed and drew diagrams of cells showing the presence of a nucleus, e.g. Anton van Leeuwenhoek and Franz Bauer. Robert Brown observed the nucleus in orchid cells and named the structure in 1831.
7. Schleiden and Schwann proposed that: 1. All living things are made of cells and of substances produced by cells. 2. The cell is the basic unit and building block of life.
8. The theory of spontaneous generation proposed that living things arose from non-living matter, e.g. maggots from dead flesh, rats from rubbish bins.
9. Fermentation experiments carried out by Louis Pasteur finally disproved the theory of spontaneous generation. He showed that micro-organisms were responsible for fermentation and bacteria caused the growths in boiled nutrient broths.
10. The cell theory states that all living cells come from pre-existing cells and clashes with the theory of spontaneous generation which proposes that living things can arise from non-living matter. As the cell theory developed, the theory of spontaneous generation had to be abandoned.
11. (a) Camillo Golgi discovered and used a new staining technique using silver nitrate to observe cells, e.g. in nervous tissue and to identify cell structures. Many believed that the body he found inside cells was an optical illusion caused by his staining technique.
    (b) The invention of the electron microscope which had greater magnification and resolution than the light microscope proved the existence and showed the ultrastructure of the Golgi body.
12. The invention of the electron microscope has greatly aided the development of knowledge about cell structure. The greater magnification and resolution gave more detailed information about known cell organelles, e.g. Golgi body and also discovered new structures, e.g. ribosomes that can only be seen under an electron microscope.
13. D
14. A

4 Cell Theory and Robert Hooke

1. Robert Hooke invented: 1. The compound microscope. 2. The first reflecting telescope.
2. A compound microscope has more than one lens arranged in such a way that the image is larger than the object being viewed.
3. The invention of a compound microscope meant that organisms could be seen with greater magnification and the structure of cells was now visible.
4. Robert Hooke used the term 'cell' to describe the structures he saw when he placed a slice of cork under his compound microscope.
5. Hooke saw the cell walls of cork tissue which formed a honeycomb appearance.
6. Opponents of Robert Hooke discredited Hooke's microscopic observations using the details about lens distortion and fringe effect to claim he was drawing artificial images created by the lenses. This led to some sections of the scientific community initially rejecting his findings.

7. In the 17th century there were several theories to explain the origin of fossils. Some believed, similar to Aristotle that fossils formed and grew within the Earth. When Hooke suggested that the fossils were clues to the past history of life on Earth, some people found it theologically unacceptable.
8. The drawings in *Micrographia* are highly detailed and accurately show the structure of many common organisms. People were fascinated by this new view of life making the book a subject of interest and discussion and thus a 'best seller'.

5 Cell Theory and Robert Brown

1. Brown sailed with Mathew Flinders on the *HMS Investigator* expedition 1801-1805. He travelled to Australia and Tasmania, collecting many plant specimens and describing over 2200 different plant and animal species.
2. He published his notes in 1811 in *Prodromus Florae Novae Hollandiae et insulae Van-Diemen* and further notes in 1814 in 'General Remarks, Geographical and Systemic, on the Botany of Terra Australis' as an appendix to Mathew Flinders' *Voyage to Terra Australis*.
3. Robert Brown travelled to Australia and collected and made drawings of many Australian species. He published his findings increasing the amount of data about Australian plants and animals available to the public. He also became responsible for the work and collection of Joseph Banks which preserved specimens collected by Banks on his Australian voyage with Captain James Cook.
4. Brownian motion is the constant movement of suspended particles.
5. Brown observed the epidermis of orchids under his microscope and discovered an 'opaque spot' which he called the nucleus.
6. Brown coined the term 'nucleus'.
7. The statement is inaccurate and untrue. It is inaccurate as Robert Brown was not the first to describe the nucleus – both Anton van Leeuwenhoek and Franz Bauer had drawn diagrams showing the presence of nuclei. It is untrue as the function of the nucleus had not yet been discovered.
8. B
9. B
10. C

6 Technology and the Development of the Cell Theory

1. The light microscope uses glass lenses to magnify objects. Thus the development of the light microscope is tightly linked with the ability to produce high quality glass lenses.
2. The first cells were observed in 1665, when Robert Hooke used his compound microscope to observe cork.
3. Anton van Leeuwenhoek made better lenses with greater curvature which gave better magnification. He also improved grinding and polishing techniques for making lenses.
4. August Kohler's illumination method gave an even distribution of light in the field of view. This meant that better and higher quality photomicrographs could be taken.
5. Schleiden and Schwann did not correctly understand how cells arose.
6. Virchow proposed that all cells come from pre-existing cells which provided the last point in the cell theory.
7.

Year	Person	Contribution
1665	Hooke	Observed cells in a slice of cork
1678	Leeuwenhoek	Observed micro-organisms
1824	Dutrochet	Living things are made of cells
1833	Brown	Observes nucleus in plant cells and names structure as nucleus
1838	Schleiden and Schwann	Tissues in all living things made of cells and cells function both independently and in cooperation
1858	Virchow	Cells come from pre-existing cells

8. Hooke observed cells in a slice of cork using his compound microscope, providing evidence that the tissue consists of cells.
9. The electron microscope has enabled scientists to see more details within the cell, e.g. the structure of the nuclear membrane, as well as discovering new parts, e.g. ribosomes.
10. Since the resolution of a microscope is inversely proportional to the wavelength of the radiation – the smaller the wavelength, the bigger the resolution. Since the wavelength of a beam of electrons is much smaller than the wavelength of visible light the electron microscope has a much higher resolution than a light microscope.
11. Magnification refers to making things bigger while resolution is the ability to distinguish between two points and see fine detail.
12.
- 1665 Robert Hooke described cells in cork
- 1678 Leeuwenhoek saw microbes
- 1824 Dutrochet – living things made of cells
- 1833 Brown named nucleus in plant cells
- 1838 Schleiden and Schwann – cell theory
- 1858 Virchow – cells from pre-existing cells

13. The cell theory states that: 1. All living things are made of cells. 2. All cells come from pre-existing cells. 3. The cell is the basic unit in which the processes of living take place. The development of these ideas was only possible as instruments and stains were developed so that scientists were able to see cells and their internal structure. For example, when Robert Hooke placed a slice of cork under his microscope, he was the first person to see these 'many little boxes', which he called cells. The discovery of staining techniques allowed the processes of cell and nuclear division to be seen. The development of the cell theory underpins our understanding of life on Earth, its structure, its physiology and why it behaves the way it does. Thus the development of technology has had a tremendous impact on the development of the cell theory as the theory could only expand as the technology allowed us to see what was present and how it behaved.
14. D
15. B
16. D

7 The Modern Light Microscope

1. The compound light microscope passes visible light through the specimen and then through a series of lenses. It operates on the main principle that an objective lens with a very short focal length can form a highly magnified real image of the object.
2. (a) The condenser focuses light on to the sample.
   (b) The iris diaphragm controls the amount of light on to the stage.
3. The resolution of the microscope is limited by the shortest wavelength of light used to view the specimen (wavelengths of visible light are 400 to 700 nm).
4.

Advantages of light microscope	Disadvantages of light microscope
Can view living specimens and observe processes in cells and within an organism. Allows the use of many different coloured stains to identify substances, structures and provide contrast for easier viewing. Specimens are easy to prepare, stain and observe in a short time frame. Relatively inexpensive and class sets can be purchased for use in schools. Light microscopes are not particularly large and are easy to store, e.g. in schools.	Limited magnification, e.g. effectively up to 1000×. Resolution limited to 0.2 micrometres.

5. A photomicrograph is a photograph made through a microscope.
6. The main benefit of the phase contrast microscope is that it increases the contrast in unstained cells. It improves our ability to study living, unpigmented cells in biological and medical research. Many dyes and stains stop chemical processes in cells which means the phase contrast microscope has improved our ability to see detail in living cells, e.g. the process of cell division.
7. The main benefit of fluorescence microscopy is that the fluorescence shows the location of specific molecules in the cell. Natural fluorescing substances, e.g. chlorophyll can be located or the specimen can be treated with fluorescing chemicals or antibodies to locate other particular section or substances in cells.

8.

Object	Size (μm)	Viewing
Frog egg	1100	Naked eye and light microscope
Paramecium	100	Light microscope
Plant epithelial cell	60	Light microscope
Human ovum	10	Light microscope
Red blood cell	7 to 8	Light microscope
Mitochondrium	1.1	Light microscope
Nanobes	0.025	Cannot be seen under a light microscope – need an electron microscope

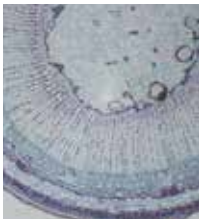
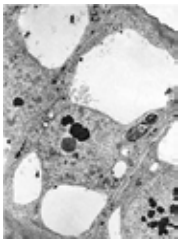
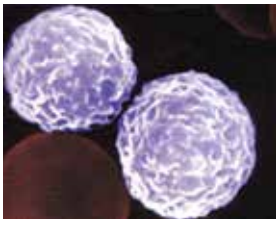
9. Stains and the light microscope have greatly increased our understanding of the processes in cells. For example, pH indicators which will show acidic or basic conditions can be used to show how the activity of micro-organisms change the pH balance of their environment such as bacterial action causing the souring of milk.
10. Objectives found on school light microscopes include 10× and 40×. The 10× objective is a low power lens used for first viewing the specimen to locate the area to be examined. The 40× objective is a high power lens and is used to make detailed observations of the specimen.
11. A parfocal microscope allows you to quickly focus using the lower power objective and then swivel the nosepiece to observe the specimen under a higher power objective without only minimal adjustment of the fine focus knob.
12. Red blood cells are very small – they have a diameter of 6 to 8 micrometres. This means the student would have been using a high power objective, e.g. 40× in the light microscope set-up to clearly observe these cells as seen in the diagram.
13. The Gram stain is usually used as the first step in identifying bacteria. It differentiates bacteria into two groups – Gram negative and Gram positive.
14. A
15. C

8 The Electron Microscope

1. The electron microscope has better resolution than the light microscope as it uses a beam of electrons to view the specimen. Since the beam of electrons has a much shorter wavelength than visible light resolution is greatly improved, e.g. approximately 0.002 nm, although in practical situations it can be limited to 2 nm. Resolution is inversely related to the wavelength of radiation used by the microscope for imaging.
2. The electron microscope sends a stream of electrons through a vacuum. The electron beam is focused by electromagnets, magnified by an objective lens and projected onto a fluorescent screen or photographic film.
3.

Advantages of electron microscope	Disadvantages of electron microscope
Increased magnification, e.g. up to 300 000×. Increased resolution, e.g. approximately 0.0005 μm SEM shows a three-dimensional image of the specimen.	Cannot view living specimens and observe processes happening in cells. Cannot use coloured stains. Relatively expensive and are not available in schools.

4. The main benefit of the TEM is that it shows the internal ultrastructure of cells at higher magnification and resolution than the light microscope. You can see objects to the order of several nanometres (10^{-9} m) which means new organelles have been discovered using the TEM, e.g. ribosomes and there is an increased capacity for medical, biological and materials research.
5. The main benefit of the SEM is that it gives a three-dimensional detailed view of the surface of the specimen. The image has great depth of field and gives a view of the actual appearance of the specimen.
6.

Image A	Image B
 Scanning electron microscope	 Light microscope
Image C	**Image D**
 Light microscope	 Transmission electron microscope
Image E	**Image F**
 Scanning electron microscope	 Light microscope

7. D

9 The Stereo Microscope

1. The stereo microscope is easily identified as it has two ocular eyepieces that each view the object from different angles. There are two separate optical paths for viewing.
2. You are likely to use a stereo microscope when dissecting small organisms or when you need to observe the external features of a specimen.
3. The parts of the stereo microscope are:
   A = ocular lens
   B = objective lens
   C = stage clip
   D = stage
   E = focus knob
   F = arm
4. If a compound microscope has two eyepieces which give the same image then the image will not be three-dimensional and give a 'stereo' image. To provide a three-dimensional image there must be two images each from slightly different viewing angles.
5. In a stereo microscope the lens is a distance away from the object and this gives poor resolution.
6. A typical school stereo microscope has a magnification ranging from 10× to 40× while a typical school monocular microscope has a magnification from 40× to 400×.
7. Salt crystals are light coloured and usually translucent. The dark colour beneath the crystal is needed to provide contrast so that the crystal can be properly viewed.
8. When using a stereo microscope some parts of an organism may not be in focus as the specimen is three-dimensional with several levels. The microscope is focusing on one level making other levels appear out of focus.
9. A