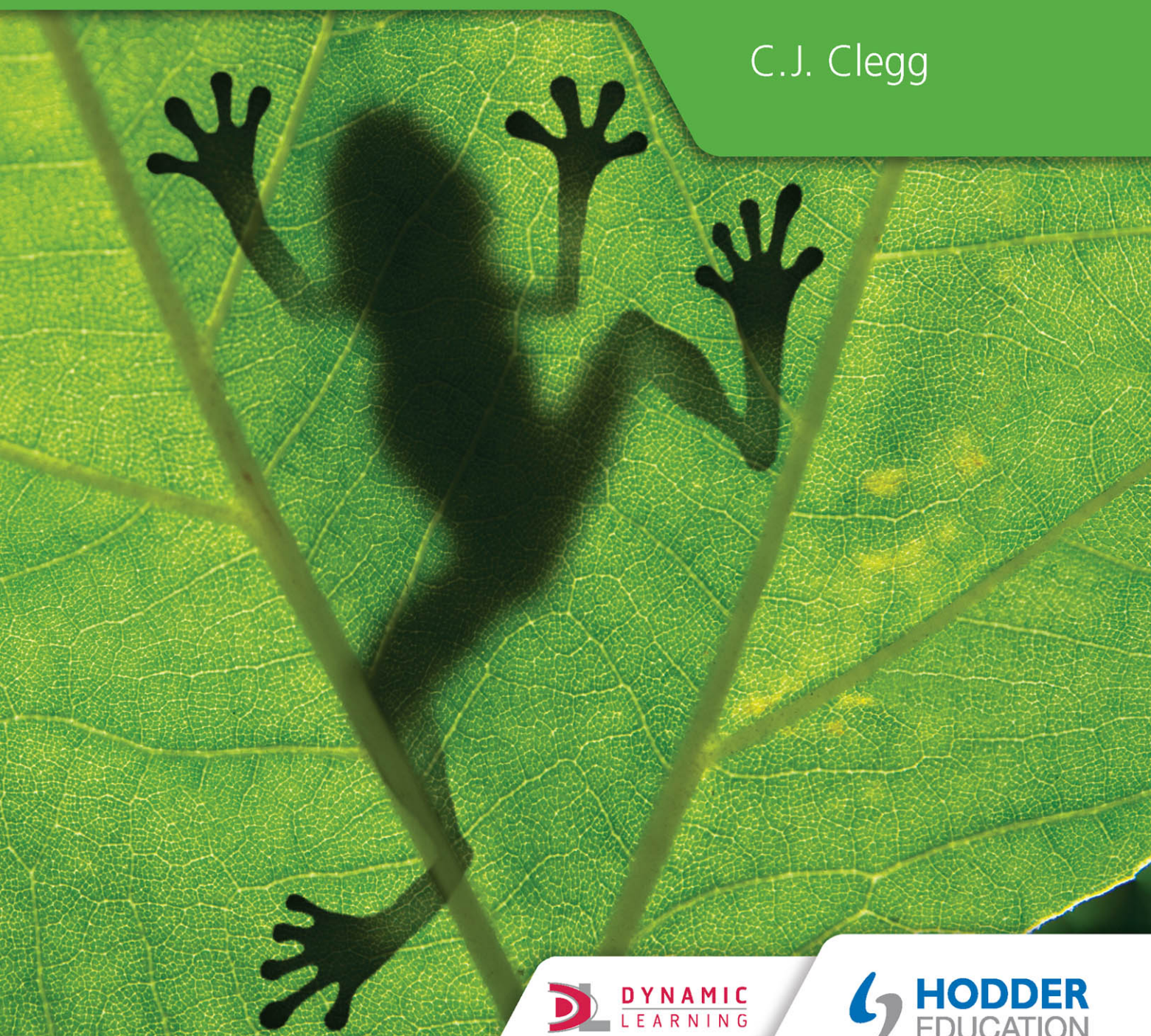
FOR THE
IB DIPLOMA

SECOND EDITION

# Biology

C.J. Clegg



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# Contents

# Introduction

Welcome to the second edition of *Biology for the IB Diploma*, updated and designed to meet the criteria of the 2014 International Baccalaureate (IB) Diploma Programme Biology Guide. The structure and content of this second edition follow the structure and content of the IB Biology Subject Guide.

## Using this book

Special features of the chapters of Biology for the IB Diploma include:

- Each chapter begins with **Essential ideas** that summarize the concepts on which the chapter is based.
- **Applications** in the Guide are integrated within the main content and are used to illustrate the various **Understandings** listed in the Guide.

- **Skills** are highlighted with this icon. Students are expected to be able to show these skills in the examination, so we have explicitly pointed these out when they are mentioned in the Guide.

Nature of Science

- The **Nature of Science (NoS)** is a theme that runs throughout the course, and can be examined in Biology papers. It explores the scientific process itself, and how science is represented and understood by the general public. It also examines the way in which science is the basis for technological developments and how these new technologies, in turn, drive developments in science.

- **International mindedness** explores how the exchange of information and ideas across national boundaries has been essential to the progress of science, and illustrates the international aspects of Biology.
- **Self-assessment questions (SAQs)** are phrased so as to assist comprehension and recall, but also to help familiarize students with the assessment implications of the command terms. Answers to all SAQs are given, either in this book or on the accompanying website.
- Links to the interdisciplinary **Theory of Knowledge (TOK)** element of the IB Diploma course are made at appropriate places in most chapters.

- Links to relevant material available on the website that accompanies this book (www.hoddereducation.com/IBextras) are highlighted with this icon.
- At the end of each chapter, there is a selection of **examination questions**. Some are questions taken from past exam papers, others are exam-style questions written for this book. Answers are available on the accompanying website.

The Options (Chapters 12–15) are available on the website accompanying this book, as are useful appendices and additional student support for Chapters 1–11, including further opportunities to practise data response questions: www.hoddereducation.com/IBextras

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Dr Andrew Davis, Head of Environmental Science, St Edward's School, Oxford, UK:

- Option C (Chapter 14) Ecology and conservation.
- The data in 'Practical ecology: Testing for associations between species' (pages 187–91).

Mrs Lucy Baddeley, Biology Department, St Edward's School, Oxford, UK:

- Use of the Gene Bank database to determine differences in base sequence of a gene in two species (pages 137–38).

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Dr Chris Clegg
Salisbury
Wiltshire
UK
June 2014

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# 1 Cell biology

## ESSENTIAL IDEAS

- The evolution of multicellular organisms allowed cell specialization and cell replacement.
- Eukaryotes have a much more complex cell structure than prokaryotes.
- The structure of biological membranes makes them fluid and dynamic.
- Membranes control the composition of cells by active and passive transport.
- There is an unbroken chain of life, from the first cells on Earth to all cells in organisms alive today.
- Cell division is essential but must be controlled.

## 1.1 Introduction to cells *– the evolution of multicellular organisms allowed cell specialization and cell replacement*

The cell is the basic unit of living matter – the smallest part of an organism which we can say is alive. It is cells that carry out the essential processes of life. We think of them as self-contained units of structure and function.

Cells are extremely small – most are only visible as distinct structures when we use a **microscope** (although a few types of cell are just large enough to be seen by the naked eye).

Observations of cells were first reported over 300 years ago, following the early development of microscopes (Figure 1.2, page 3). Today we use a compound light microscope to investigate cell structure – perhaps you are already familiar with the light microscope as a piece of laboratory equipment. You may have used one to view living cells, such as the single-celled animal, *Amoeba*, shown in Figure 1.1.

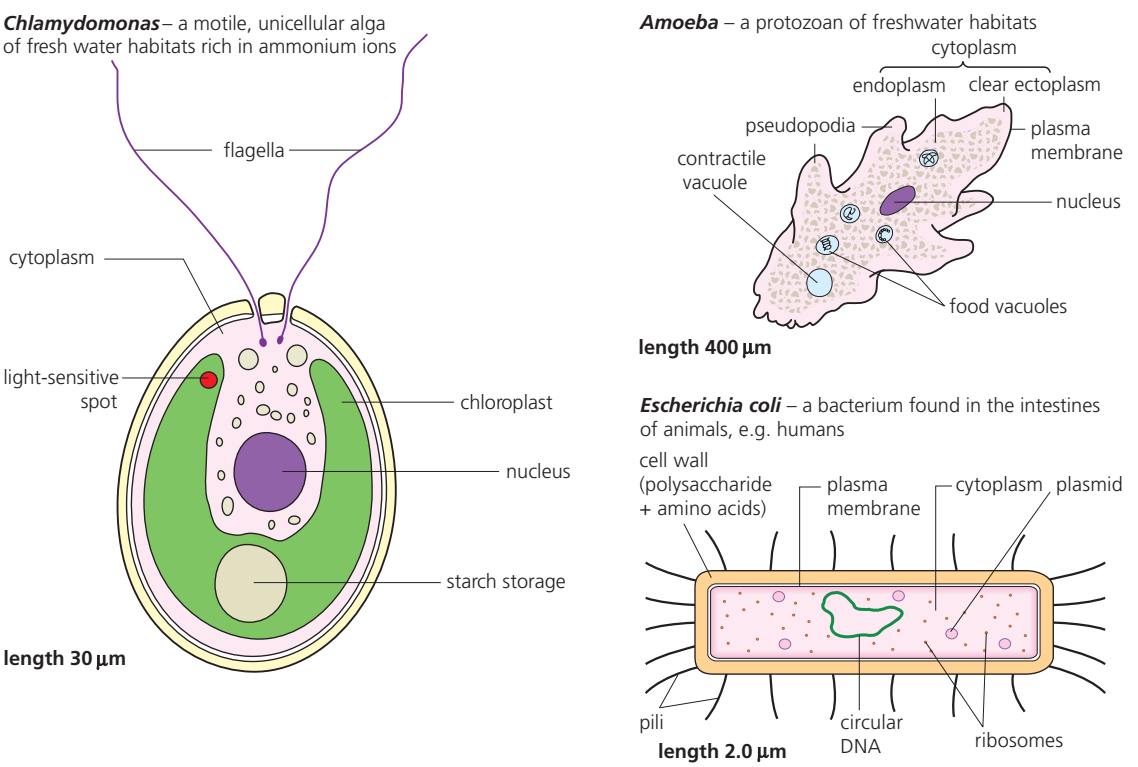



**Figure 1.1** Introducing unicellular organization

## Unicellular and multicellular organisms

Some organisms are made of a single cell and are known as **unicellular**. Examples of unicellular organisms are introduced in Figure 1.1. In fact, there are vast numbers of different unicellular organisms in the living world, many with very long evolutionary histories.

Other organisms are made of many cells and are known as **multicellular** organisms. Examples of multicellular organisms are the mammals and flowering plants. Much of the biology in this book is about multicellular organisms, including humans, and the processes that go on in these organisms. But remember, single-celled organisms carry out all the essential functions of life too, within the confines of a single cell.

1 **State** the essential processes characteristic of living things.

## The features of cells

A cell consists of a **nucleus** surrounded by cytoplasm, contained within the cell membrane. The nucleus is the structure that controls and directs the activities of the cell. The **cytoplasm** is the site of the chemical reactions of life, which we call 'metabolism'. The cell membrane, known as the **plasma membrane**, is the barrier controlling entry to and exit from the cytoplasm.

Newly formed cells grow and enlarge. A growing cell can normally divide into two cells. Cell division is very often restricted to unspecialized cells, before they become modified for a particular task.

Cells may develop and specialize in their structure and in the functions that they carry out. A common outcome of this is that many fully specialized cells are no longer able to divide, for example. But as a consequence of specialization, **cells show great variety in shape and structure**. This variety in structure reflects the evolutionary adaptations of cells to different environments, and to different specialized functions – for example, within multicellular organisms.

## Cell theory – a summary statement

The **cell theory** – the statement that cells are the unit of structure and function in living things – contains three very basic ideas:

- Cells are the building blocks of structure in living things.
- Cells are the smallest unit of life.
- Cells are derived from other cells (pre-existing cells) by division.

Today, we can confidently add two concepts to the theory:

- Cells contain a blueprint (information) for their growth, development and behaviour.
- Cells are the site of all the chemical reactions of life (metabolism).

## Cell size

Since cells are so small, we need appropriate units to measure them. The **metre** (symbol **m**) is the standard unit of length used in science (it is an internationally agreed unit, or **SI unit**).

| | |
|---|---|
| 1 metre (m) | = 1000 millimetres (mm) |
| 1 mm | = 1000 micrometres (μm) (or microns) |
| 1 μm | = 1000 nanometres (nm) |

**Table 1.1** Units of length used in microscopy

*Look at Table 1.1, showing the subdivisions of the metre that are used to measure cells and their contents.* These units are listed in descending order of size. You will see that each subdivision is one thousandth of the unit above it. The smallest units are probably quite new to you; they may take some getting used to.

So, the dimensions of cells are expressed in the unit called a **micrometre** or micron (**μm**). Notice, this unit is one thousandth ($10^{-3}$) of a millimetre. This gives us a clear idea about how small cells are when compared to the millimetre, which you can see on a standard ruler.

Bacteria are really small, typically 0.5–10 μm in size, whereas the cells of plants and animals are often in the range 50–150 μm or larger. In fact, the lengths of the unicells shown in Figure 1.1 are approximately:

- *Chlamydomonas* 30 μm
- *Escherichia coli* 2 μm
- *Amoeba* 400 μm (but its shape and, therefore, length vary greatly).

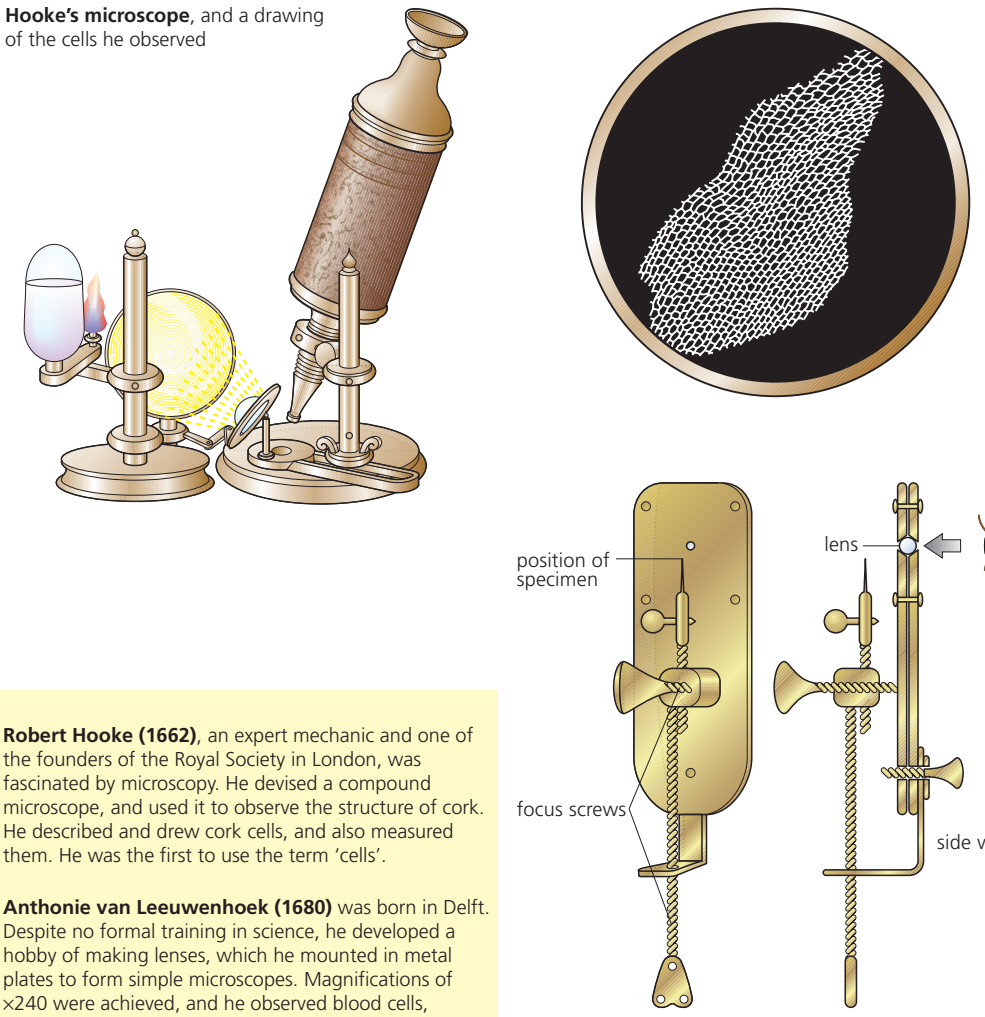
2 **Calculate:**
**a** how many cells of 100 μm diameter will fit side by side along a millimetre line
**b** the magnification of the image of *Escherichia coli* in Figure 1.1.

## The origins of cell theory

Many biologists contributed to the development of the cell theory. This concept evolved gradually in Western Europe during the nineteenth century, as a result of the steadily accelerating pace of developments in **microscopy** and **biochemistry**. You can see a summary of the earliest steps in Figure 1.2.

**Figure 1.2** Early steps in the development of the cell theory

**Hooke's microscope**, and a drawing of the cells he observed




**van Leeuwenhoek's microscope**

**Robert Hooke (1662)**, an expert mechanic and one of the founders of the Royal Society in London, was fascinated by microscopy. He devised a compound microscope, and used it to observe the structure of cork. He described and drew cork cells, and also measured them. He was the first to use the term 'cells'.

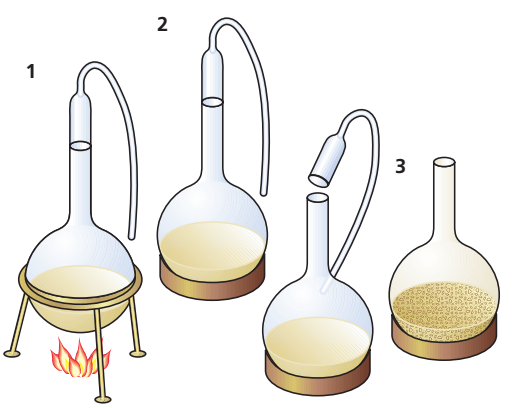
**Anthonie van Leeuwenhoek (1680)** was born in Delft. Despite no formal training in science, he developed a hobby of making lenses, which he mounted in metal plates to form simple microscopes. Magnifications of ×240 were achieved, and he observed blood cells, sperms, protozoa with cilia, and even bacteria (among many other types of cells). His results were reported to the Royal Society, and he was elected a fellow.

**Robert Brown (1831)**, a Scottish botanist, observed and named the cell nucleus. He also observed the random movements of tiny particles (pollen grains, in his case) when suspended in water (Brownian movement).

**Matthias Schleiden (1838) and Theodor Schwann (1839)**, German biologists, established cells as the natural unit of form and function in living things: 'Cells are organisms, and entire animals and plants are aggregates of these organisms arranged to definite laws.'

**Rudolf Virchow (1856)**, a German pathologist, established the idea that cells arise only by division of existing cells.

**Louis Pasteur (1862)**, a brilliant French microbiologist, established that life does not spontaneously generate. The bacteria that 'appear' in broth are microbes freely circulating in the air, which contaminate exposed matter.



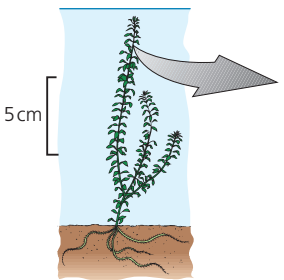

**Pasteur's experiment**, in which broth was sterilized (**1**), and then either exposed to air (**3**) or protected from air-borne spores in a swan-necked flask (**2**). Only the broth in **3** became contaminated with bacteria.

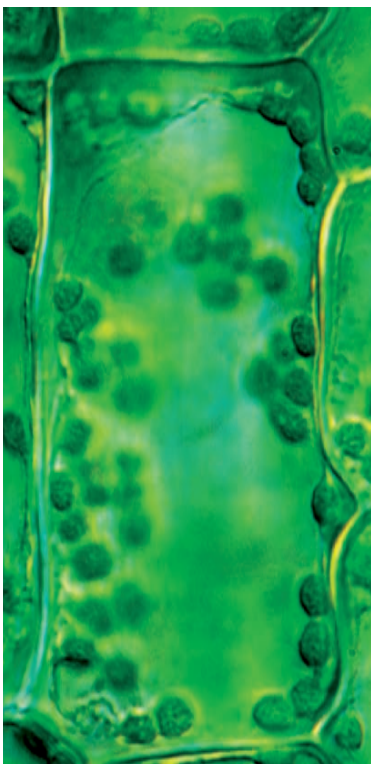
## Introducing animal and plant cells

No 'typical' cell exists – there is a very great deal of variety among cells. However, we shall see that most cells have features in common. Viewed using a compound microscope, the *initial* appearance of a cell is of a simple sac of fluid material, bound by a membrane, and containing a nucleus. *Look at the cells in Figure 1.3.*

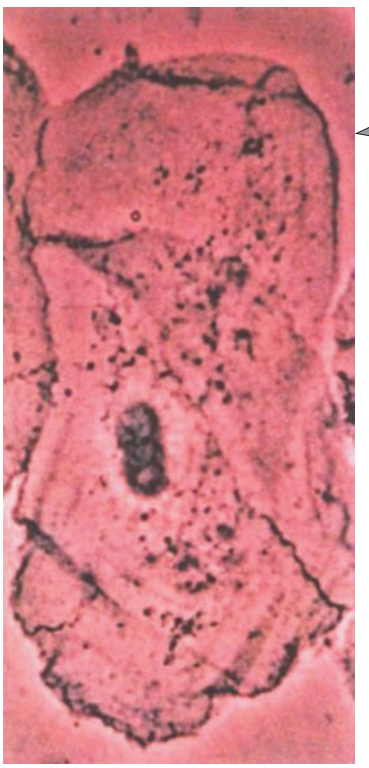
**Figure 1.3**
Animal and plant cells from multicellular organisms

**Canadian pondweed** (*Elodea*) grows submerged in fresh water



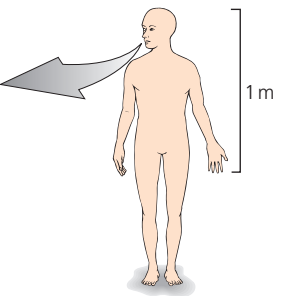



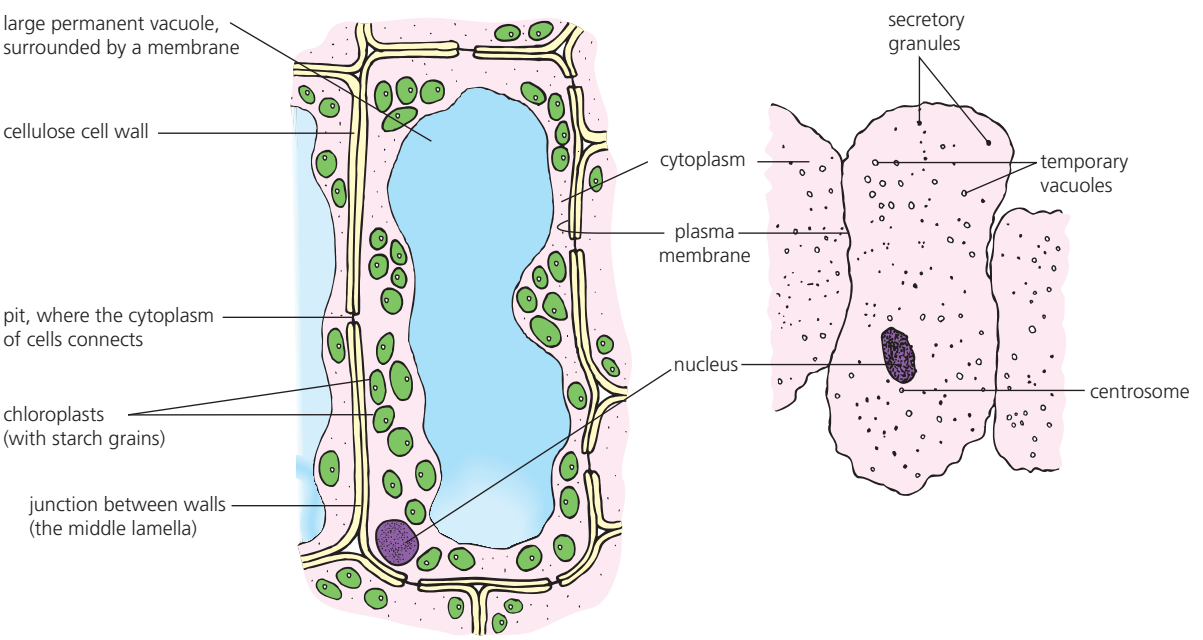
**photomicrograph of a leaf cell of *Elodea*** (×400)



**photomicrograph of a human cheek cell** (×800)

human



Animal and plant cells have at least three structures in common. These are their **cytoplasm** with its **nucleus**, surrounded by a **plasma membrane**. In addition, there are many tiny structures in the cytoplasm, called **organelles**, most of them common to both animal and plant cells. An organelle is a discrete structure within a cell, having a specific function. Organelles are all too small to be seen at this magnification. We will learn about the structure of organelles using the electron microscope (page 17).

There are some important basic differences between plant and animal cells (Table 1.2). For example, there is a tough, slightly elastic **cell wall**, made largely of cellulose, present around plant cells (page 4). Cell walls are absent from animal cells.

A **vacuole** is a fluid-filled space within the cytoplasm, surrounded by a single membrane. Plant cells frequently have a large, permanent vacuole present. By contrast, animal cells may have small vacuoles, but these are mostly temporary.

Green plant cells also contain organelles called **chloroplasts** in their cytoplasm. These are not found in animal cells. The chloroplasts are the sites where green plant cells manufacture food molecules by a process known as photosynthesis.

The **centrosome**, an organelle that lies close to the nucleus in animal cells (Figure 1.22), is not present in plants. This tiny organelle is involved in nuclear division in animal cells.

Finally, the **storage carbohydrate** (energy store) differs, too. Animal cells may store glycogen (page 79); plant cells normally store starch.

The profoundly different ways that unicellular organisms may differ are illustrated in Figure 1.5.

**Table 1.2** Differences between plant and animal cells

| Plant cells | Feature | Animal cells |
|---|---|---|
| cellulose cell wall present | **cell wall** | no cellulose cell walls |
| many cells contain chloroplasts; site of photosynthesis | **chloroplasts** | no chloroplasts; animal cells cannot photosynthesize |
| large, fluid-filled vacuole typically present | **permanent vacuole** | no large permanent vacuoles |
| no centrosome | **centrosome** | a centrosome present outside the nucleus |
| starch | **carbohydrate storage product** | glycogen |

## TOK Link

### Living and non-living

You are familiar with the characteristics of living things (question 1). How could these be used to **explain** to non-biologists why a copper sulfate crystal growing in a solution of copper sulfate (or stalactites and stalagmites growing in a cave) are not living, yet corals are?

**Flooded limestone cave where stalactites have formed in the roof and stalagmites on the floor beneath**

**Corals are formed by sedentary animals called polyps that secrete a calcareous shell around themselves**

**Figure 1.4**

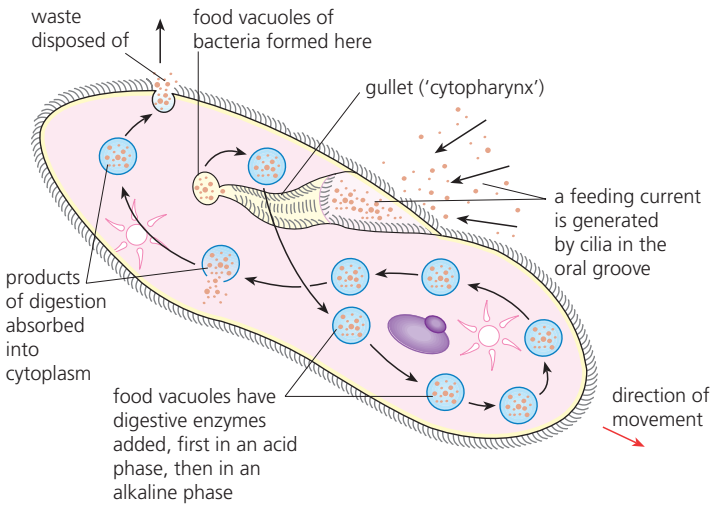
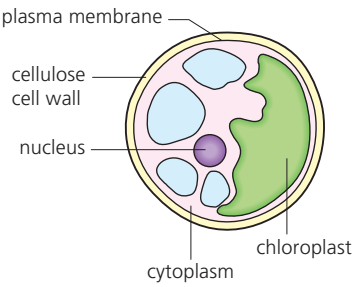
| ***Paramecium* – a large protozoan (about 600 µm), common in freshwater ponds.** | | ***Chlorella* – a small alga (about 20 µm), abundant in freshwater ponds where its presence colours the water green.** |
|---|---|---|
|  | |  |
| A 'particle feeder', it takes in small floating unicellular organisms into food vacuoles in the cytoplasm where the contents are digested and the products absorbed. | **nutrition** | Manufactures sugars by photosynthesis in the light, using carbon dioxide and water (in a way that is almost identical to photosynthesis in flowering plants). |
| Respires aerobically, transferring energy to maintain cell functions. | **respiration** | Respires aerobically, transferring energy to maintain cell functions. |
| Obtains the biochemicals it requires for metabolism by digestion of food particles. Energy transferred by respiration makes this possible. | **metabolism** | Manufactures all biochemicals it requires for metabolism using sugars (from photosynthesis) and ions (such as nitrates) from the surrounding water. Energy transferred by respiration makes this possible. |
| Loss of waste products (mainly $CO_2$ and $NH_3$) over the entire cell surface. | **excretion** | Loss of waste products (mainly $CO_2$) over the entire cell surface. |
| Commonly, reproduction occurs by nuclear division followed by a transverse constriction of the cytoplasm. | **reproduction** | Periodically the cell contents divide into four autospores that each forms a cell wall around themselves. Eventually these are released by breakdown of the mother-cell wall. |
| Swims rapidly through the water, rotating as it goes.<br>Food vacuoles within can be seen being carried around the cytoplasm. | **movement/locomotion** | A stationary cell.<br>Cytoplasm within stream around within the plasma membrane. |
| Typically detects favourable food particles in the water and moves towards them. | **sensitivity** | Typically responds to the absence of light by nuclear followed by cell division. |
| Small cells grow to full size prior to cell division (dividing into two cells). | **growth/development** | Small cells grow to full size prior to cell division into autospores. |

**Figure 1.5** Investigating the functions of life in unicellular organisms

## Examining cells, and recording structure and size

We use microscopes to magnify the cells of biological specimens in order to view them. Figure 1.6 shows two types of light microscope.

In the simple microscope (**hand lens**), a single biconvex lens is supported in a frame so that the instrument can be held very close to the eye. Today, a hand lens is mostly used to observe external structure, although some of the earliest detailed observations of living cells were made with single-lens instruments.

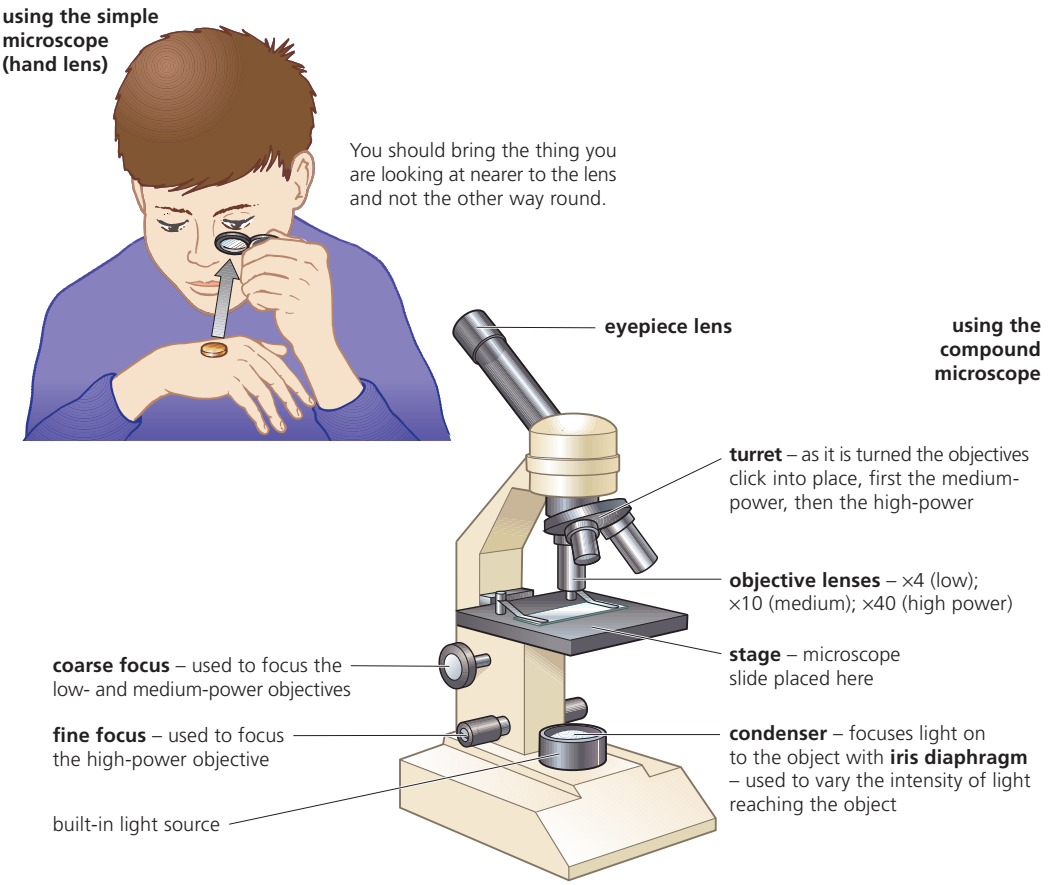
In the **compound microscope**, light rays are focused by the **condenser** on to a specimen on a microscope slide on the stage of the microscope. Light transmitted through the specimen is then focused by two sets of lenses (hence the name 'compound microscope'). The **objective lens** forms an image (in the microscope tube) which is then further magnified by the **eyepiece lens**, producing a greatly enlarged image.

Biological material to be examined by compound microscopy must be sufficiently transparent for light rays to pass through. When bulky tissues and parts of organs are to be examined, thin sections are cut. Thin sections are largely colourless.

**Table 1.3**
The skills of light microscopy

| You need to master and be able to demonstrate these aspects of good practice |
|---|
| Knowledge of the parts of your microscope, and care of the instrument – its light source, lenses and focusing mechanisms. |
| Use in low-power magnification first, using prepared slides and temporary mounts. |
| Switching to high-power magnification, maintaining focus and examining different parts of the image. |
| Types of microscope slides and the preparation of temporary mounts, both stained and unstained. |
| **Getting started**: With a slide, a drop of water and a cover slip, you can trap tiny air bubbles under the cover slip. Now try examining one of these air bubbles under low-power magnification and then its meniscus under high power. |

**Figure 1.6**
Light microscopy




## Recording observations

Images of cells and tissues may be further magnified, displayed, projected and saved for printing by the technique of **digital microscopy** (Figure 1.7). A digital microscope is used or, alternatively, an appropriate video camera is connected by microscope coupler or eyepiece adaptor that replaces the standard microscope eyepiece. Images are displayed via video recorder, TV monitor or computer, and may be printed out by the latter.

Alternatively, a record of what you see via the compound microscope may be recorded by drawings of various types (Figure 1.9). For a clear, simple drawing:

- use a sharp HB pencil and a clean eraser
- use unlined paper and a separate sheet for each specimen you record
- draw clear, sharp outlines, avoiding shading or colouring (density of structures may be represented by degrees of stippling)
- label each drawing with appropriate information, such as the species, conditions (living or stained; if stained, note which stain was used) and type of section (transverse section, TS, or longitudinal section, LS)
- label your drawing fully, with labels well clear of the structures shown, remembering that label lines should not cross
- annotate (add notes about function, role and development) if appropriate
- include a statement of the magnification under which the specimen has been observed.

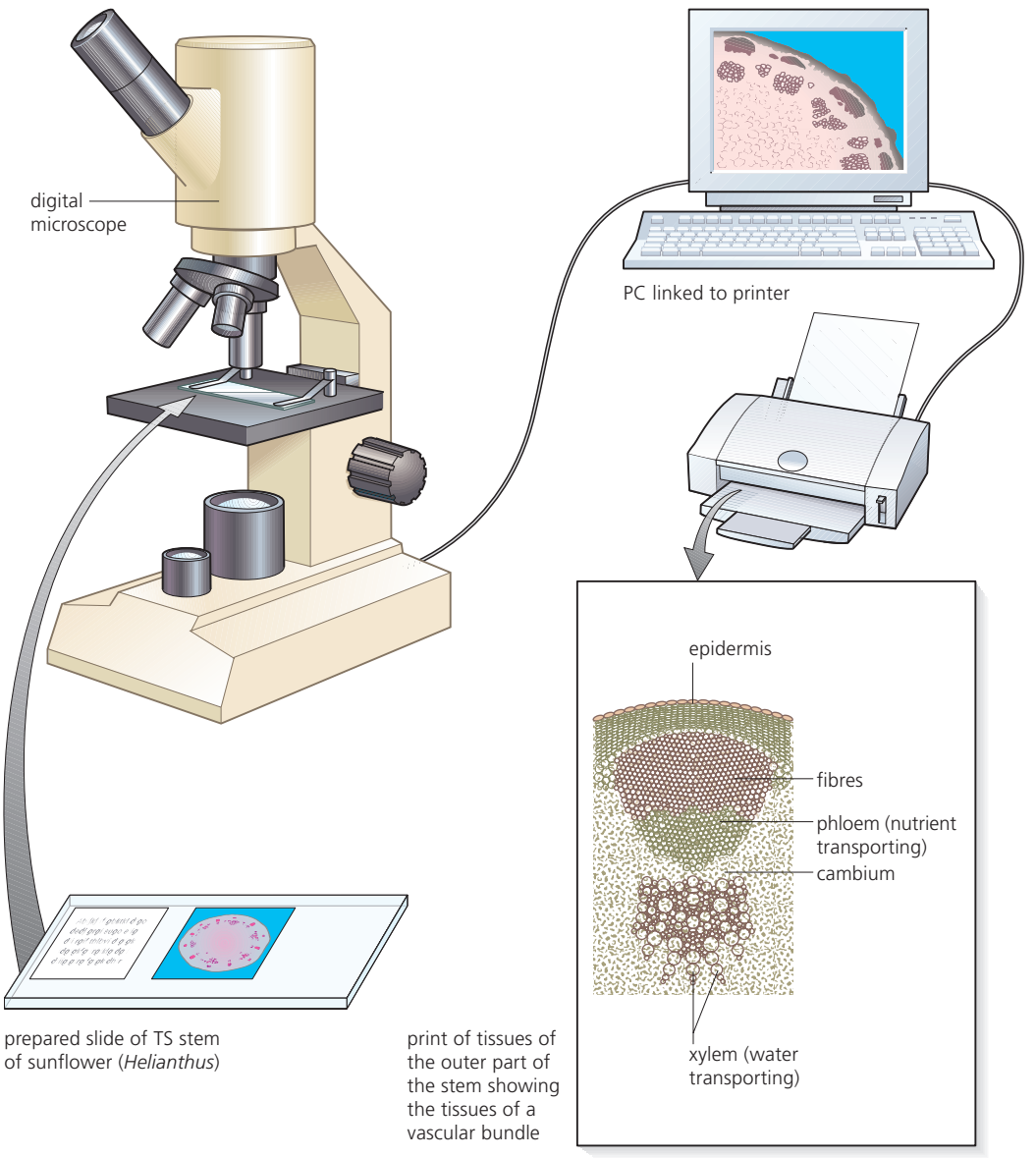



**Figure 1.7** Digital microscopy in action

## Measuring microscopic objects

The size of a cell can be measured under the microscope. A transparent scale, called a **graticule**, is mounted in the eyepiece at the focal plane (there is a ledge for it to rest on). In this position, when the object under observation is in focus, so too is the scale. The size (for example, length or diameter) of the object may then be recorded in arbitrary units. Next, the graticule scale is calibrated using a **stage micrometer** – in effect, a tiny, transparent ruler, which is placed on the microscope stage in place of the slide and then observed. With the eyepiece and stage micrometer scales superimposed, the true dimensions of the object can be estimated in micrometres. Figure 1.8 shows how this is done.

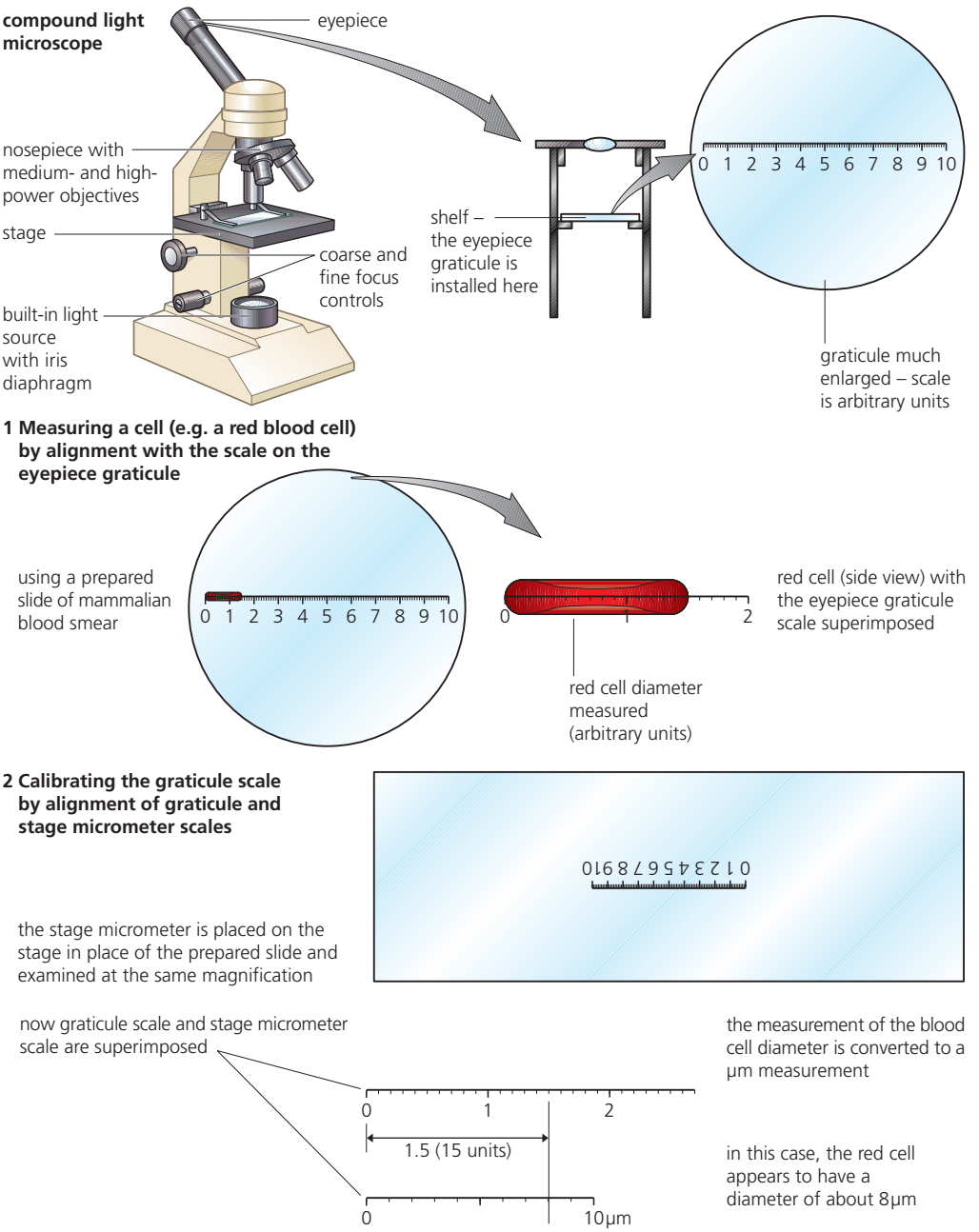



**Figure 1.8** Measuring the size of cells

Once the size of a cell has been measured, a scale bar line may be added to a micrograph or drawing to record the actual size of the structure, as illustrated in Figure 1.10.