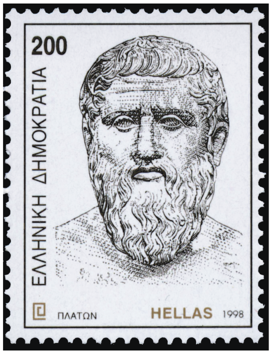

Figure 1.1.1
Plato. *Source: Silvio / Adobe Stock.*

Figure 1.1.2
Euclid.

Figure 1.1.3
Plinius the Elder.

Figure 1.1.4
Claudius Ptolemy.

1 Introduction

1.1 Desire to magnify objects

The understanding of nature and natural sciences is first limited by our sensory- perception. The predominance of our eyes explains the desire for optical devices that magnify – either out of pure curiosity or for astronomical, scientific, and medical reasons.

In the late Middle Ages, optical lenses were already widespread. Their use as spectacle lenses in the 13th century is very well documented. A few highlights are intended to show how early optics had a significance in the development of natural sciences.

Plato (Greek. 424–347 BC) described the reflection on hollow and cylindrical mirrors (Figure 1.1.1).

Euclid (Figure 1.1.2) is the author of the oldest work with mathematical treatment of optics (300 BC).

Gaius Plinius the Elder (Roman 23–79 AD; Figure 1.1.3) described in his scientific work *Naturalis historia*, among other things, the magnifying effect of a water-filled glass sphere. These were still used in the 20th century as "shoemaker's balls" to concentrate the light of an oil lamp on the workplace.

Claudius Ptolemy (Greek astronomer and mathematician; 100–178 AD; Figure 1.1.4) already carried out systematic studies on the refraction of light.

Ibn Al-Haitham (Egypt. 965–1039; Figure 1.1.5) wrote the book "*Treasure of Optics*." He wrote about the principles of vision, refraction, and reflection. Groundbreaking is his consideration to support the eye with ground optical lenses!

Johannes Kepler (1571–1630; Figure 1.1.6) stood at the beginning of modern optics with the first correct explanation of the effect of glasses, the light path through lenses, etc.

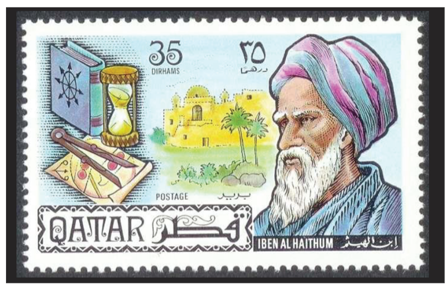

Figure 1.1.5
Ibn Al-Haitham.

Willebrord Snell van Rojen from Leiden (lat. *Snellius*; 1581–1626; Figure 1.1.7) published the law of refraction in a five-volume work on optics. The first high magnifying lenses were formed in the 17th century.

A Practical Guide to Scanning Electron Microscopy in the Biosciences, First Edition. Gerhard Wanner.

Figure 1.1.10
Sir Isaac Newton.

Figure 1.1.11
Christiaan Huygens.

Figure 1.1.12
Thomas Young.

Figure 1.1.6
Johannes Kepler

Figure 1.1.7
Willebrord Snellius.

Figure 1.1.8
A. van Leeuwenhoek.

Figure 1.1.9
Robert Hooke.

Antoni van Leeuwenhoek (1632–1723; Figure 1.1.8) ground and melted extremely magnifying lenses. His "microscope" is – in contrast to the light microscope of the Englishman **Robert Hooke** (1635–1702; Figure 1.1.9) – formally a magnifying glass and not a microscope.

Interesting are the fundamentally different views on the nature of light. **Isaac Newton** (1643–1727; Figure 1.1.10) represented the "particle theory" of light in 1669. He was the first to formulate a measure for the refractive power of materials:

$$n^2 = 1 : d$$

n = refractive index and d = density of the body.

He discovered the "Newton rings," named after him.

Christiaan Huygens (1629–1695; Figure 1.1.11) represented the "wave theory of light" a few years after Newton's particle theory in 1672 and stated that the Newton rings are the best proof of the wave nature of light.

The proof of the wave nature of light was then achieved in 1807 by **Thomas Lawrence Young** (1773–1829; Figure 1.1.12) with his ingenious diffraction experiments. Light is, like sound, a wave phenomenon. Diffraction, interference, and polarization of light can be explained by wave theory. He describes the interference phenomena: "*When two Undulations, from different Origins, coincide either perfectly or very nearly in Direction, their joint effect is a Combination of the Motions belonging to each.*"

Two outstanding scientists later researched the interference phenomena of light:

Figure 1.1.13
Joseph von Fraunhofer discovered the Fraunhofer lines named after him.

Joseph von Fraunhofer (1787–1826; Figure 1.1.13) became famous for the "Fraunhofer diffraction" of light on optical gratings, the measurement of the refractive index of optical glasses with extreme accuracy, and the production of considerably better lenses.

Figure 1.1.14
Jean Augustin Fresnel.

In 1815, the Frenchman **Jean Augustin Fresnel** (1788–1827; Figure 1.1.14) made pioneering investigations on diffraction, interference, polarization, birefringence, and aberration of light: "*Mémoire sur la diffraction de la lumière*." He formulated for the first time exactly the wave theory of light.

Figure 1.1.15
Ernst Abbe, his sine formula and Carl Zeiss. *Source: Carl Zeiss Archiv / Wikimedia Commons / Public Domain.*

$$d = \frac{\lambda}{2n \sin \alpha}$$

Ernst Abbe (1840–1905; Figure 1.1.15), together with Carl Zeiß (later Zeiss) and Otto Schott, created the foundations of modern optics. His sine formula is a highlight of optics to this day: the resolution of a lens system depends on the wavelength of the light and the aperture angle of the objective. From this realization sprang the phrase:

. . . But I believe that those tools which may one day perhaps support our senses more effectively than today's microscopy in the exploration of the last elements of the body world will have little in common with it other than its name.

Ernst Abbe (1876)

1.2 Size is relative

At first glance, it may seem strange to compare the different proportions in the animal and plant kingdom. However, in the practice of electron microscopy, knowledge of these dimensions is very important.

There are complex, highly developed individuals that can be adequately fixed as a whole and provide very good ultrastructural results in investigations. However, there are also huge unicellular organisms that, until today, cannot be fixed with any method to obtain useful ultrastructural results.

In the case of biological samples, the question almost always arises whether an individual can be examined as a whole or whether it must be dissected before examination. Any change of an individual can lead to artificial structural changes. Biological molecules are in the range of a few nanometers (Figures 1.2.1–1.2.4).

Several extremes from the animal and plant kingdom will be compared Table 1.2.1 and Figures 1.2.5–1.2.16).

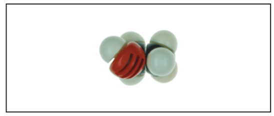

Figure 1.2.1
Ethanol.
Diameter 0.3 nm.

Figure 1.2.2
D-Glucose (ring form).
Diameter 1 nm.

Figure 1.2.3
Tetrapeptide.
Diameter 2–4 nm.

Figure 1.2.4
Triglyceride.
Length 3–5 nm.

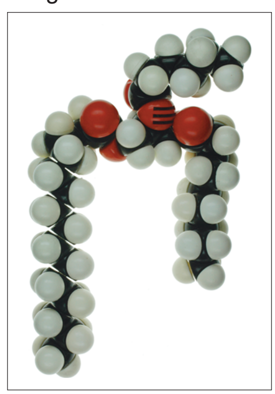

Table 1.2.1
Comparison of extremely large and small, single and multicellular individuals and cells, molecules, and atoms.

	Size
Multicellular giants	
Sequoia (*Sequoiadendron giganteum*)	100 m/2400 t
Blue whale (*Balaenoptera musculus*)	33 m/200 t
Multicellular dwarfs	
Dwarf lens (*Wolffia arrhiza*)	1 mm
Itch mite (*Notoedres cati*)	0.2 mm
Giant cells	
Ramie fiber	20 cm
Egg cell (ostrich)	16 cm/1.5 kg
Giant axon (squids)	Ø 1 mm/1 m
Unicellular dwarfs	
Dwarf green alga (*Ostreococcus tauri*)	0.8 µm
Flagellate (*Bodo putrinus*)	5 µm
Prokaryotes/molecules/atoms	
Bacteria	200 nm–100 µm (!)
Viruses	20 nm (!)–300 nm
DNA (diameter)	2 nm
Sugar molecule	1 nm
Hydrogen atom	0.1 nm

Figure 1.2.5
Trees can grow to a height of 100 m and weigh 2400 t.

Figure 1.2.6
Whales and elephants belong to the largest animals.

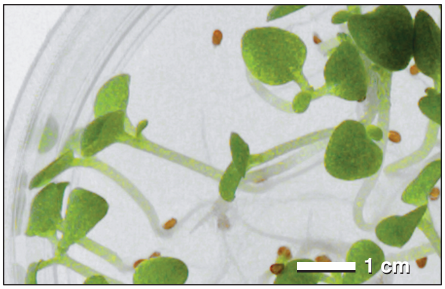

Figure 1.2.7
Even from large plants, seedlings are often only a few millimeters or centimeters in size, but still whole individuals.

Figure 1.2.8
Among the smallest multicellular animals are the mites with a length of 200–300 µm.

Figure 1.2.9
A particularly large single cell is the mermaid's wine glass (*Acetabularia mediterranea*) with up to 10 cm length.

Figure 1.2.10
The largest egg (one cell!) comes from the (extinct) elephant bird with 34 cm length and approximately 9 l content (≙ 200 chicken eggs).

Figure 1.2.11
A diatom is a single eukaryotic plant cell.

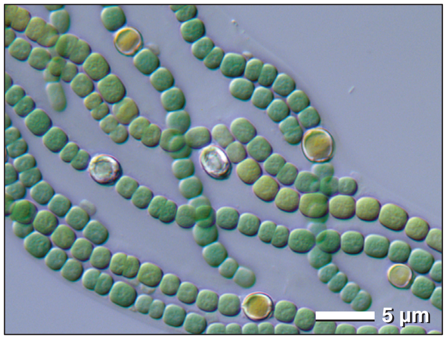

Figure 1.2.12
Cyanobacteria are prokaryotes with thylakoid membranes (photosynthesis).

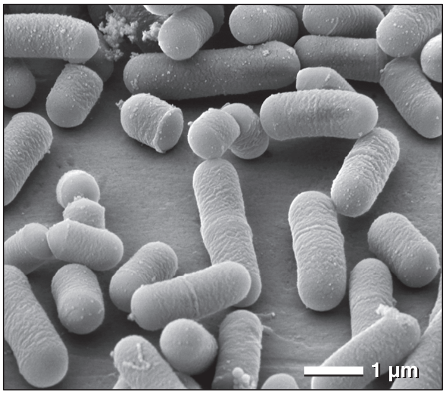

Figure 1.2.13
Lactic acid bacteria (*Lactobacillus plantarum*).

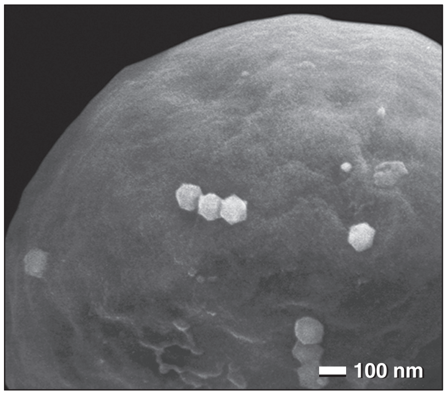

Figure 1.2.14
Viruses are widespread. They also occur as “phages” in unicellular prokaryotes and eukaryotes (*Chlorella* phage).

Figure 1.2.15
HIV virus particles on a cell surface.

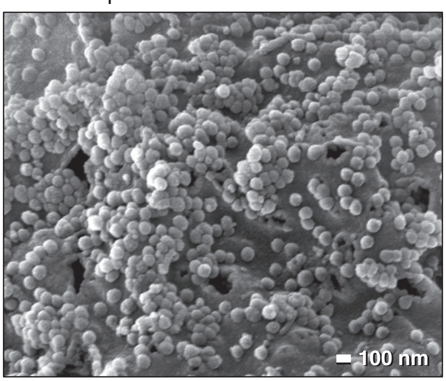

Figure 1.2.16
80-S ribosomes with 25 nm diameter.