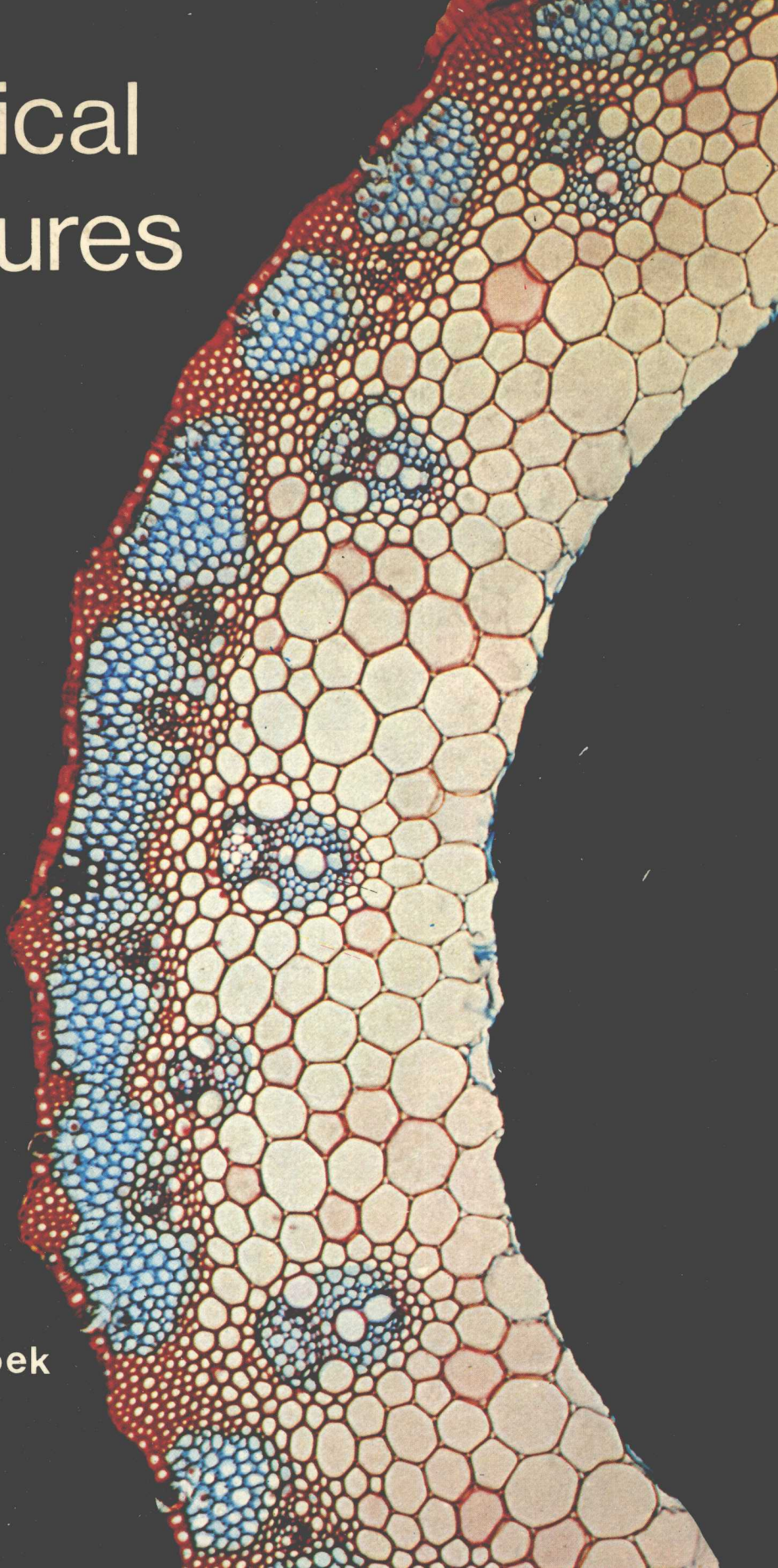
Biological Structures



W Krommenhoek
J Sebus
G J van Esch

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G. J. van Esch

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Preface

Learning about how living organisms are constructed is an essential feature of any serious study of the biological sciences. Ideally, such learning will be based on actual observations of appropriate structures, but in practice the necessary combination of suitable specimens, specialized equipment and advanced techniques is rarely available.

This practical and informative *atlas* is an effective answer to the problem. The photographs, showing details of a wide variety of cells, tissues and organs, were obtained using the most modern techniques. Each is accompanied by a succinct description pinpointing essential and distinctive features. No attempt has been made to give detailed theory, since the atlas can be used in conjunction with any standard theoretical textbook.

Only through the collaboration of several authors, each able to make use of unique collections in his own field, has it been possible to present such a large and coherent collection of photographs, not tied to any one syllabus, and designed as an aid to all who are studying biology at an advanced level.

W. Krommenhoek
J. Sebus
G. J. van Esch

Contents

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W. Linnemans and P. Ververgaert, Department of Electronmicroscopy, Centre for Submicroscopic Research of the State University of Utrecht;
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1 The ultrastructure of the cell: *techniques of electron microscopy*

In this section the ultrastructure of a variety of cells is presented. Organelles and their mutual relationships are shown, with reference to the techniques of preparation and observation that provide the electronmicrographs.

The human eye has a resolving power of about 0.1 mm. That is, it can make a distinction between two points 0.1 mm apart. The resolving power of the light (optical) microscope is about 0.5 μm, whereas that of the transmission electron microscope is about 0.3 nm (1 nm = 1/1000 μm and 10^{-9} m), sufficient to show very fine detail of subcellular structures. The electron microscope is in consequence an essential tool of present-day biological inquiry. Full accounts of its physics and of specimen preparation may be found elsewhere; the following is intended to aid understanding of the pictures in Section 1.

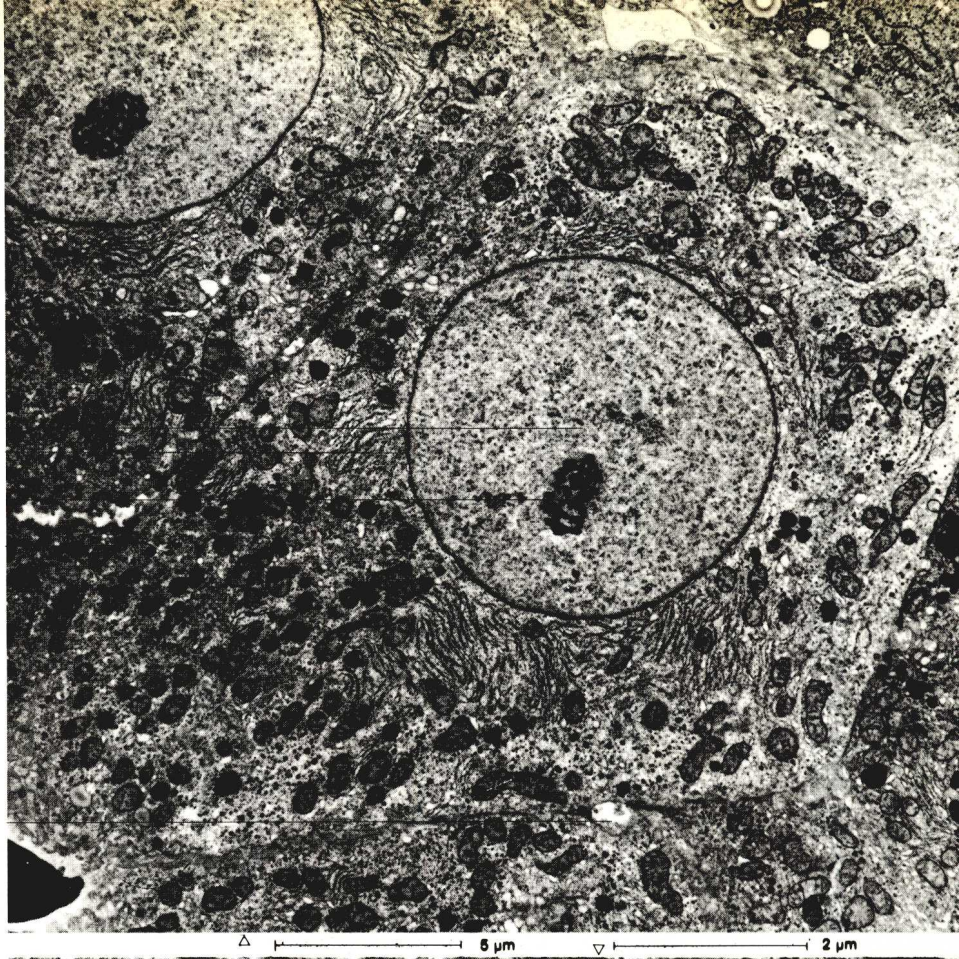
In the transmission electron microscope an electron beam is directed at the specimen in a high vacuum. Some electrons are scattered; this occurs to a degree directly related to (1) the nuclear masses of the atoms in the specimen, and (2) the thickness of the specimen. Electrons colliding with atomic nuclei are deflected, and the depleted emerging beam therefore reflects the variations of the specimen substance, in an image formed on a fluorescent screen. Since most atoms of biomolecules (including H C N O S) are of low atomic mass and weak deflectors of electrons, the image of an untreated specimen lacks contrast and clarity of detail. Therefore techniques are used to introduce selectively, heavy-metal (highly electron-scattering) atoms in a 'staining' process. A compound often used is osmium tetroxide (OsO_4) that reacts with lipid double bonds and which is also able to 'fix' the specimen, stabilizing its structure against the effects of high vacuum and electron bombardment. Further stains may be added (e.g. containing U or Pb) to enhance contrast.

An ultrathin section is made from a specimen which has first been fixed, stained, then dehydrated and embedded before the section of thickness less than 50 nm is cut. Ultrathin sections are the best source of visual information on cell ultrastructure that the electron microscope provides. Whole mounts (e.g. viruses and bacteria) may be negative-stained, that is, they are embedded in a stain medium; their image then shows them light against a dark background.

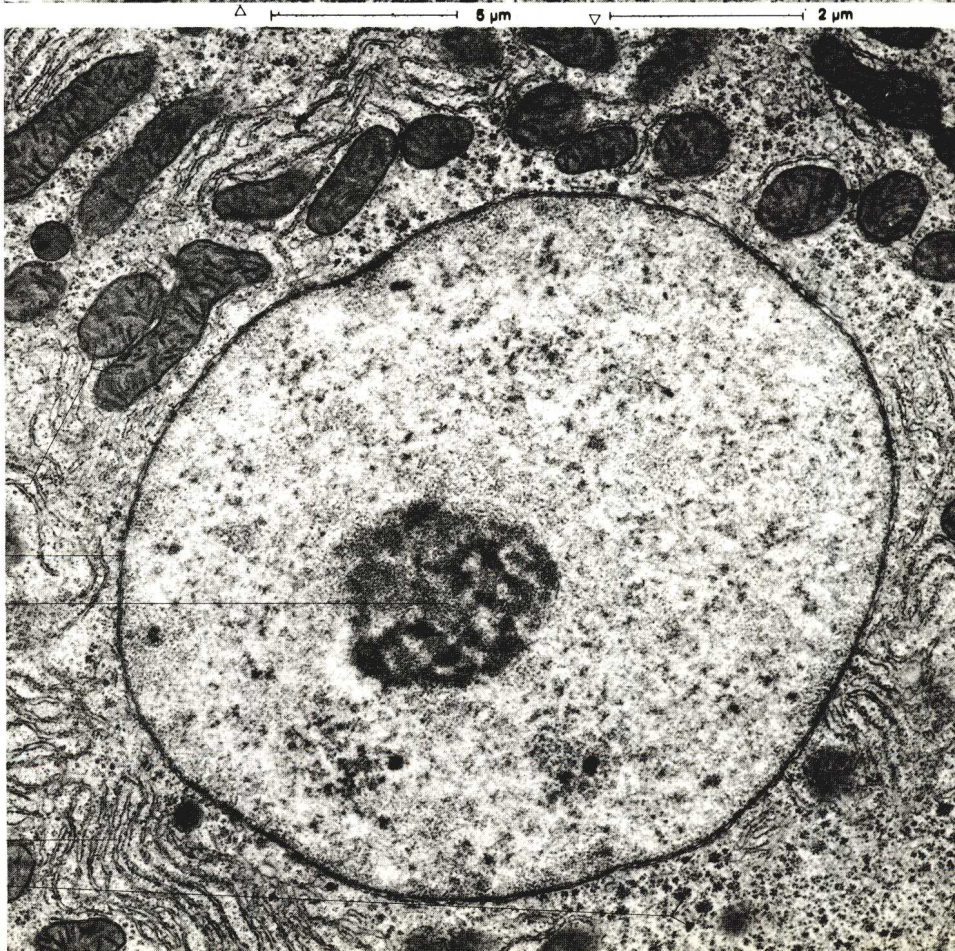
Quasi-three-dimensional images of specimen surfaces are produced using the scanning electron microscope (resolving power 20 nm). The specimen is instantly supercooled to −196 °C, then heavy-metal coated (e.g. with Au–Pd alloy) at an angle which registers the minute detail of the surface. This is scanned by an electron beam and the reflected electrons, together with secondary electrons emitted from the specimen surface, produce a signal that is transformed into an image on a screen like that of a television. Alternatively, a specimen may be frozen, fractured and, if required, etched (i.e. water, as ice, sublimes under vacuum to leave non-aqueous surface detail in relief) before being metal coated. A durable replica may be made if a metal coating (e.g. of platinum) between 1 and 2 nm thick, is reinforced by a carbon layer. The specimen is washed from it, leaving a mirror-image replica for examination. By these means, not only sections through organelles but their three-dimensional surfaces, and significantly the internal fracture faces of membranes, have been studied.

Animal structures

Liver cell (hepatocyte) structure (ultrathin section).
The cell is polyhedral and has many organelles: a large nucleus, nucleolus, numerous mitochondria and extensive endoplasmic reticulum. At top right, the plasma membrane borders on the space of Disse which receives blood passing through the discontinuous endothelium of the sinusoid beyond (part of red blood cell visible). Here, exchange of liver cell products and substances in blood takes place.



Nucleus of a liver cell (ultrathin section).
Clearly shown is the double membrane (containing pores) which bounds the almost circular nucleus. The nucleolus is an RNA-rich structure found in association with the mass of chromatin that contains DNA and which arranges itself into chromosomes when the nucleus divides. The nucleus is often polyploid.
In the cytoplasm are mitochondria, the endoplasmic reticulum (a labyrinthine system of double membranes) and glycogen particles.



Animal structures

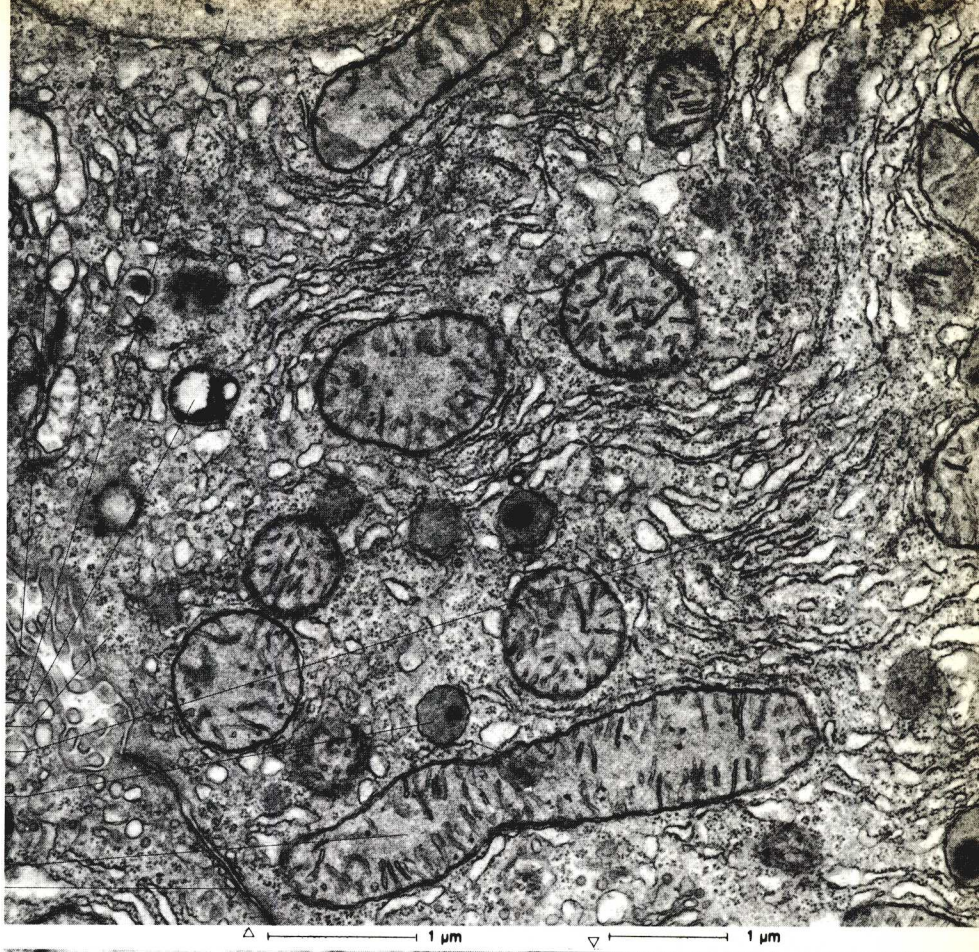
The cytoplasm of a liver cell showing prominent organelles in detail (ultrathin section).

In the mitochondria, the powerhouses of the cell, aerobic respiration takes place. Three-carbon molecules (from partial oxidation in the cytoplasm of carbohydrates, proteins and fats) pass into the mitochondria where they are further oxidized, the energy released converting ADP to ATP. ATP is the energy source for cell metabolism.

The endoplasmic reticulum is involved in protein synthesis. It is a system of double membranes forming fluid-filled sacs and tubes and covered in many areas with granular ribosomes.

The Golgi apparatus (specialized endoplasmic reticulum) has a secretory role (p. 14). The granules (lysosomes and peroxisomes) contain enzymes.

Glycogen (animal starch) functions as a food reserve. The plasma membrane bounds the cell and divides it from adjacent cells.



Transverse (ultrathin) section of a group of smooth muscle fibres.

Two have been cut through their nuclei. Each fibre is surrounded by a thin membrane. The space between the fibres is taken up with connective tissue. The contractile elements, very fine myofilaments that form the bulk of the cytoplasm, cannot be seen separately at this magnification.

There are many pinocytotic vesicles along the plasma membrane formed from invaginations of the plasma membrane.

Animal structures

Innervation of striated muscle: structure.

This micrograph continues at the top with the foot of the micrograph on p. 11 (ultrathin sections × 10 000). It shows part of the plasma membrane (sarcolemma) of mammalian striated muscle cell that makes synapse with the final branches (axon terminals) of a motor nerve fibre. The structures at the synapse constitute the motor end plate. Each axon terminal, containing synaptic vesicles, makes a synapse at an in-curved region of the sarcolemma (postsynaptic membrane), which itself is further deeply infolded (T-system).

A muscle fibre is a multinucleate giant cell originating from the fusion of many embryonic muscle cells (myoblasts). Along its length are myofibrils, each of many fine filaments. A myofibril has a repeating sequence of transverse light and dark bands: a sarcomere is that part between the darkest, Z, lines. Running across the centre of the sarcomere is the thin M line with each side a narrow pale H band. The A band, incorporating M line and H bands, extends further each side as a wide denser zone. Beyond the A band are the lighter I bands.

These bands arise from the arrangement of the filaments running lengthwise: the I band is of actin filaments extending out from the Z line (and joined to it); these overlap in the denser A band zone with the thicker myosin filaments extending from the M line; the H band has myosin filaments only. (See also p. 11.)

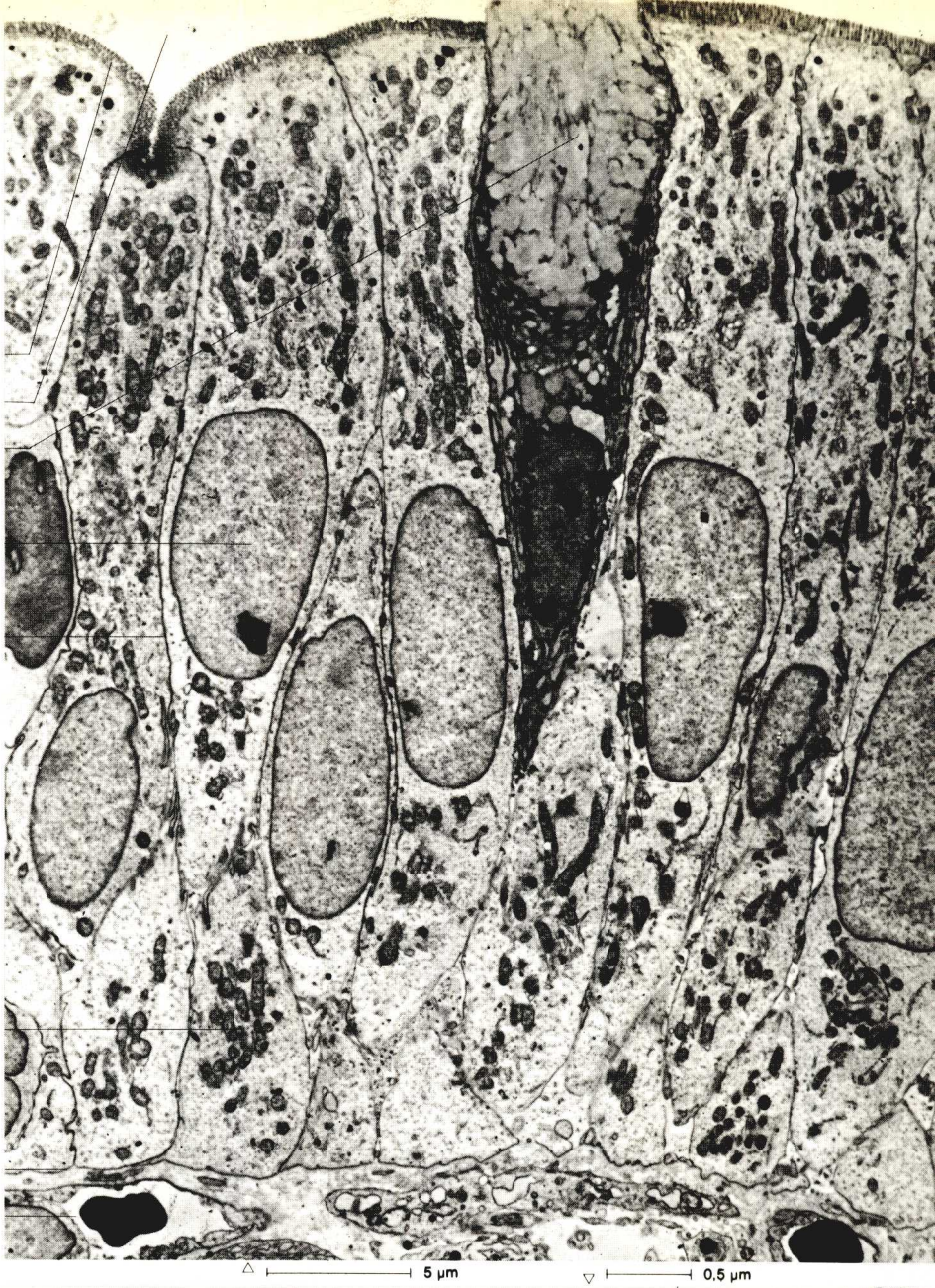
Between the fibrils in the sarcoplasm is the sarcoplasmic reticulum; it is associated with the transverse tubules of the T-systems. These structures coordinate contraction of the myofibrils. Present also are many mitochondria.

Animal structures

Muscle contraction: mechanism.
By active ion transport, the muscle fibre maintains a resting potential across the sarcolemma (it is polarized). It is considered that an impulse (action potential) passing down a motor nerve induces a chemical transmitter (e.g. acetylcholine) to pass from the synaptic vesicles, across the synaptic cleft and through the postsynaptic membrane of the muscle fibre. If sufficient transmitter enters, it causes 'ion gates' to form in the membrane and allow inflow of Na^+ ions, depolarizing the whole sarcolemma including its invaginations, the T-system membranes. This causes the release of Ca^{2+} ions from the sarcoplasmic reticulum, resulting in activation of enzymes, including ATPase. These induce contraction in the myofibrils, when the overlapping (interdigitating) actin and myosin filaments are seen to slide further between each other (the I and H bands disappear). A nerve fibre contacts many muscle fibres, constituting a motor unit. Contraction of a whole muscle depends on the number of motor units activated and the motor nerve impulse frequency.

Animal structures

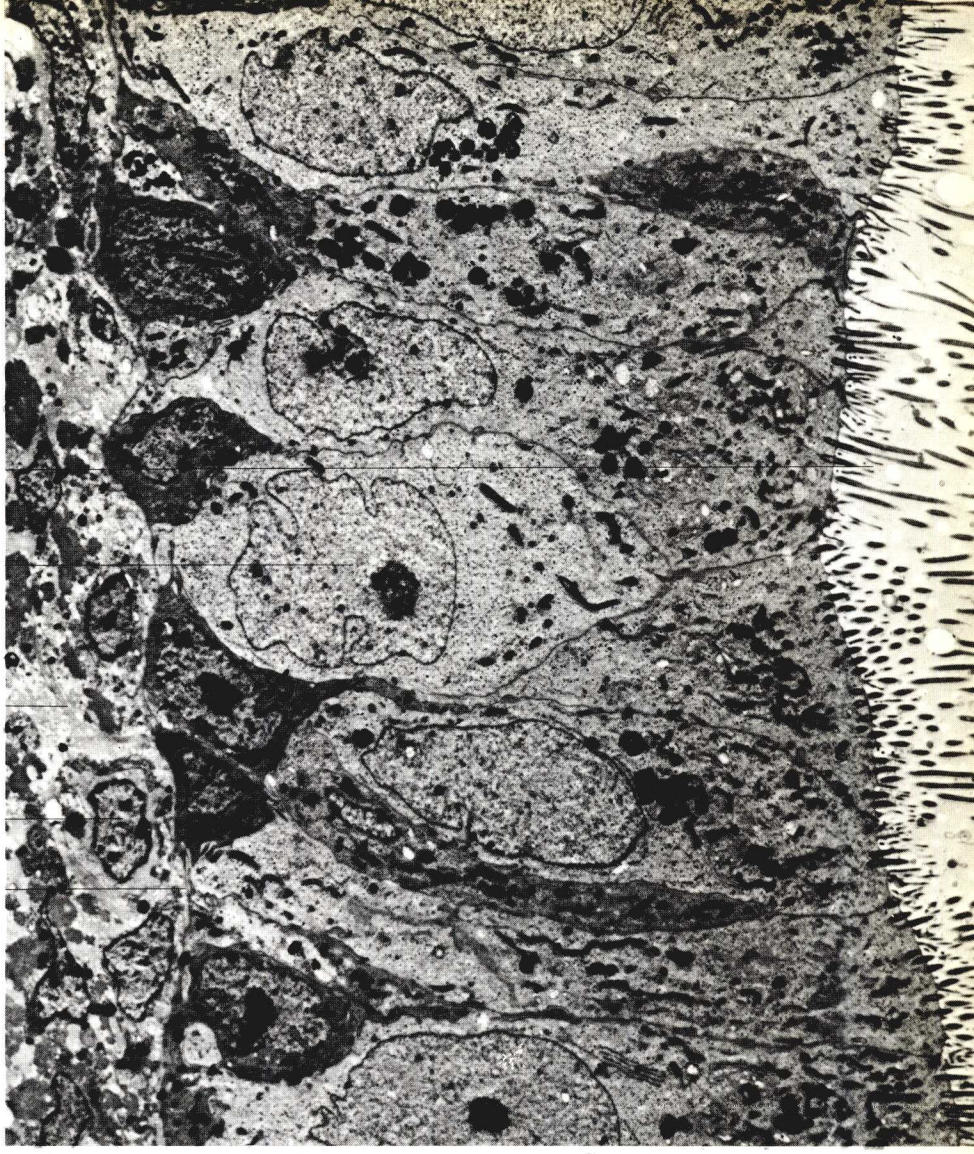
Epithelium of the wall of mammalian small intestine (ultrathin section).
The brush border of microvilli is just visible. The tall epithelial cells with the oval nuclei are interposed by cells secreting mucus into the lumen, to aid (by lubrication) the passage of food and protect the gut cells from enzyme digestion. Notice the large number of mitochondria in the epithelial cells.



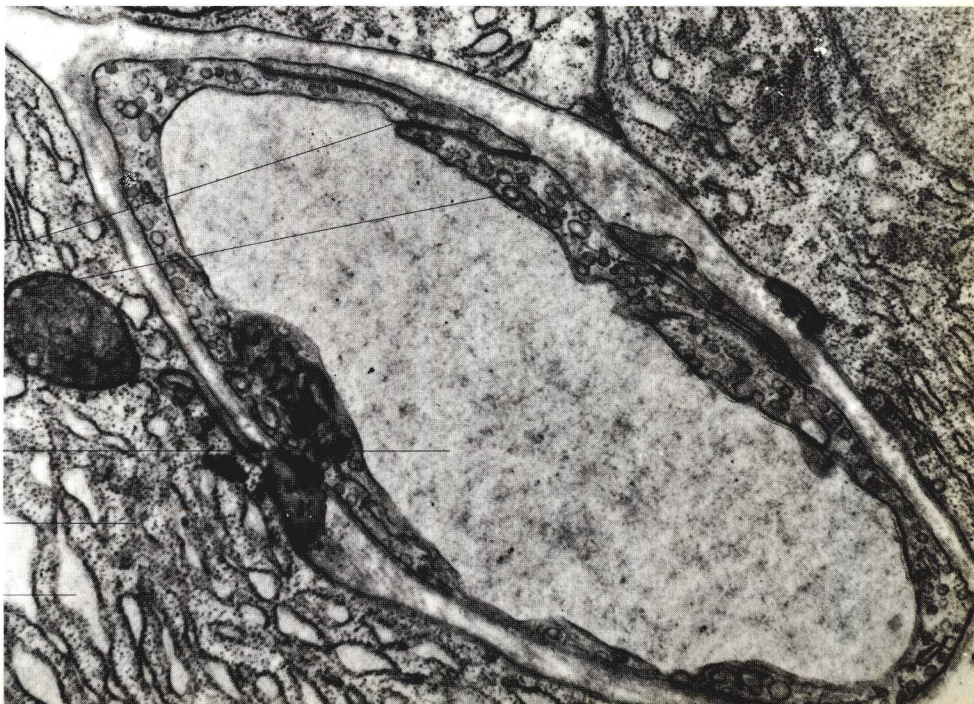
Wall of an alveolus (ultrathin section).
There are capillaries each side of the wall. The boundary between air and blood is double. In contact with air is the outer alveolar wall, which overlies the capillary wall, the endothelium. Each is one cell thick. The layer of connective tissue between is just visible. These layers form a very narrow partition between air and blood.

Animal structures

Ciliated epithelium of the trachea (ultrathin section × 3600).
Two cell types can be distinguished: the tall columnar epithelial cells with cilia, and the basal cells which are much smaller and darker. All these cells are attached at their bases to the basal lamina. Under this lamina lie connective tissue cells, including fibroblasts which produce collagen (white, inelastic) fibres.



Capillary in the pancreas (ultrathin section × 15 000).
The endothelial cells overlap. They contain many pinocytotic vesicles formed when parts of the inner membrane invaginate and believed to convey macromolecular material from the blood in the lumen to tissue outside the capillary (see everting vesicles, lower right).

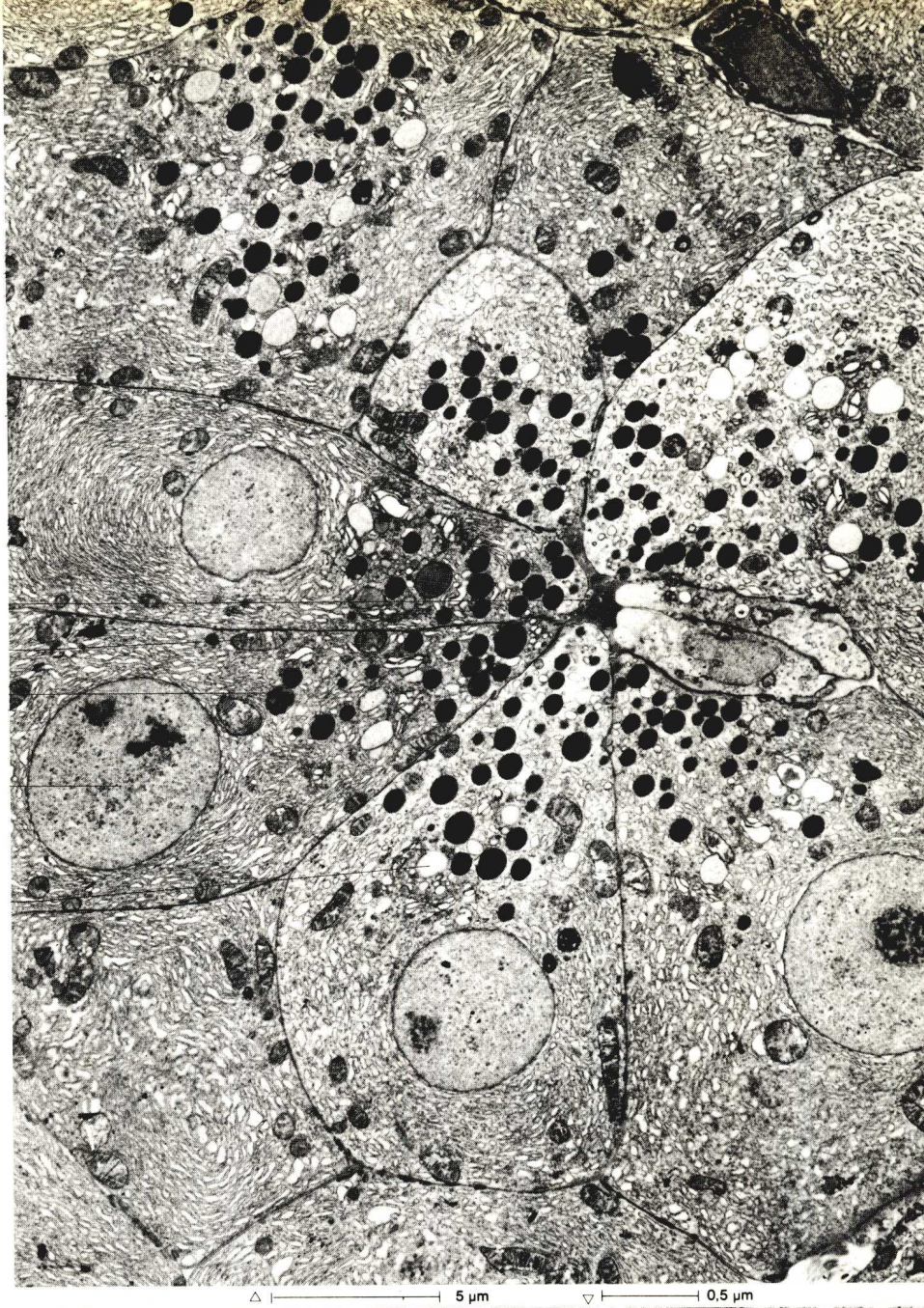


Animal structures

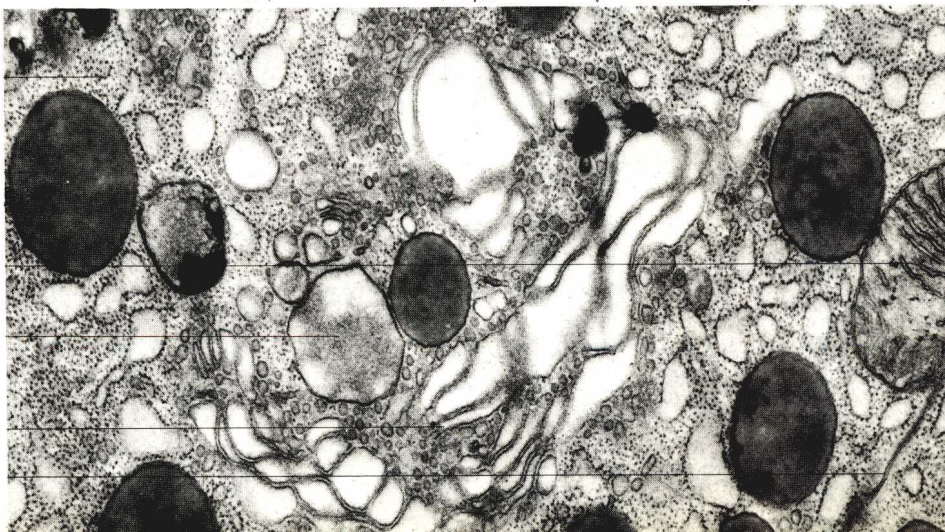
Gland cluster (acinus) from the exocrine region of the pancreas (ultrathin section).

This section passes through six cells of the acinus and the nucleus of four of these. The cells surround a central secretory duct into which they discharge an alkaline mixture of the digestive enzymes lipase, amylase, trypsinogen and chymotrypsinogen. Visible in the cells are mitochondria and various membranous systems.

Concentrated towards the inner boundaries of each cell are large numbers of zymogen granules thought to be areas of enzyme storage prior to secretion. Notice the many small vacuoles, characteristic of glandular cell activity.



Below, a vertical section of a Golgi apparatus is seen. The apparatus can be visualized as a stack of irregular saucer-shaped structures (cisternae) with interconnections. Each is of a double membrane enclosing a lumen. Peripherally, membrane-bound vesicles (lysosomes) are pinched off. Proteins, synthesized at the ribosomes, pass through endoplasmic reticulum and accumulate in the Golgi apparatus. The lysosomes convey the resulting enzymes to sites of digestion within or outside the cell.



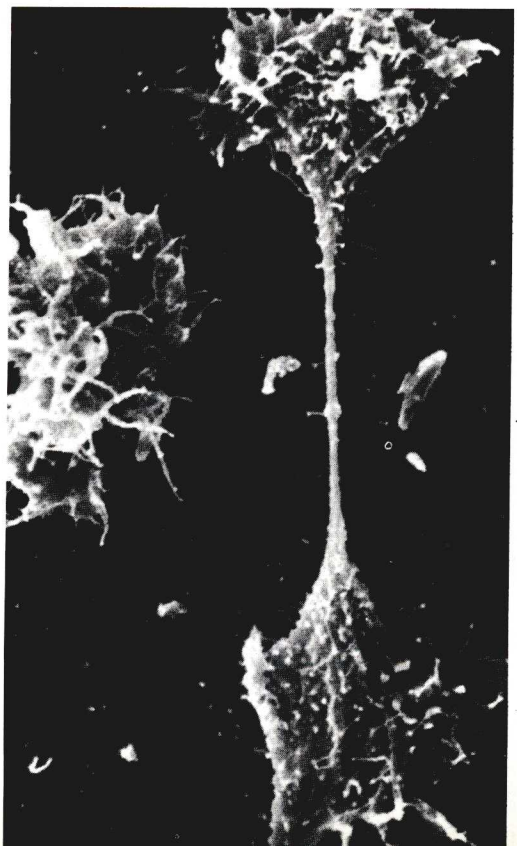
Animal structures

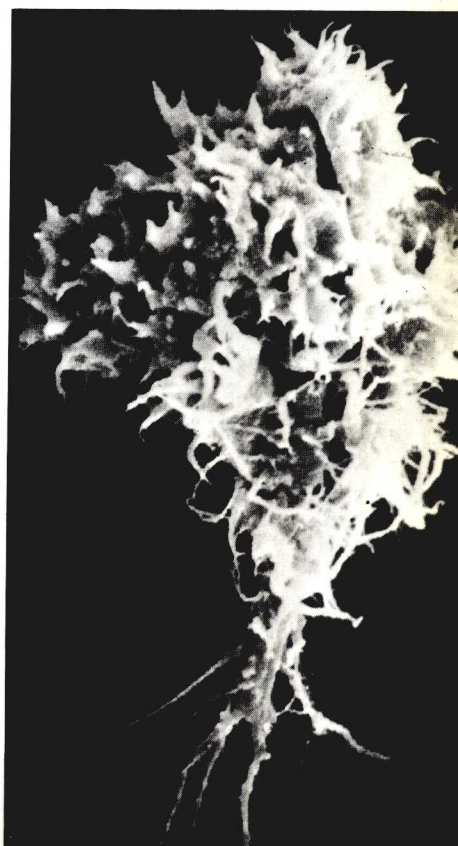
Scanning electron micrographs.

Detail of part of the head of the fruit fly (drosophila).
The honeycomb structure of part of the compound eye is visible to the left of the picture (× 1550).

Left: *an amoeba in process of division.* After the nucleus has divided, the two halves of the cell move in opposite directions until the thread of cytoplasm joining them breaks (× 2500).

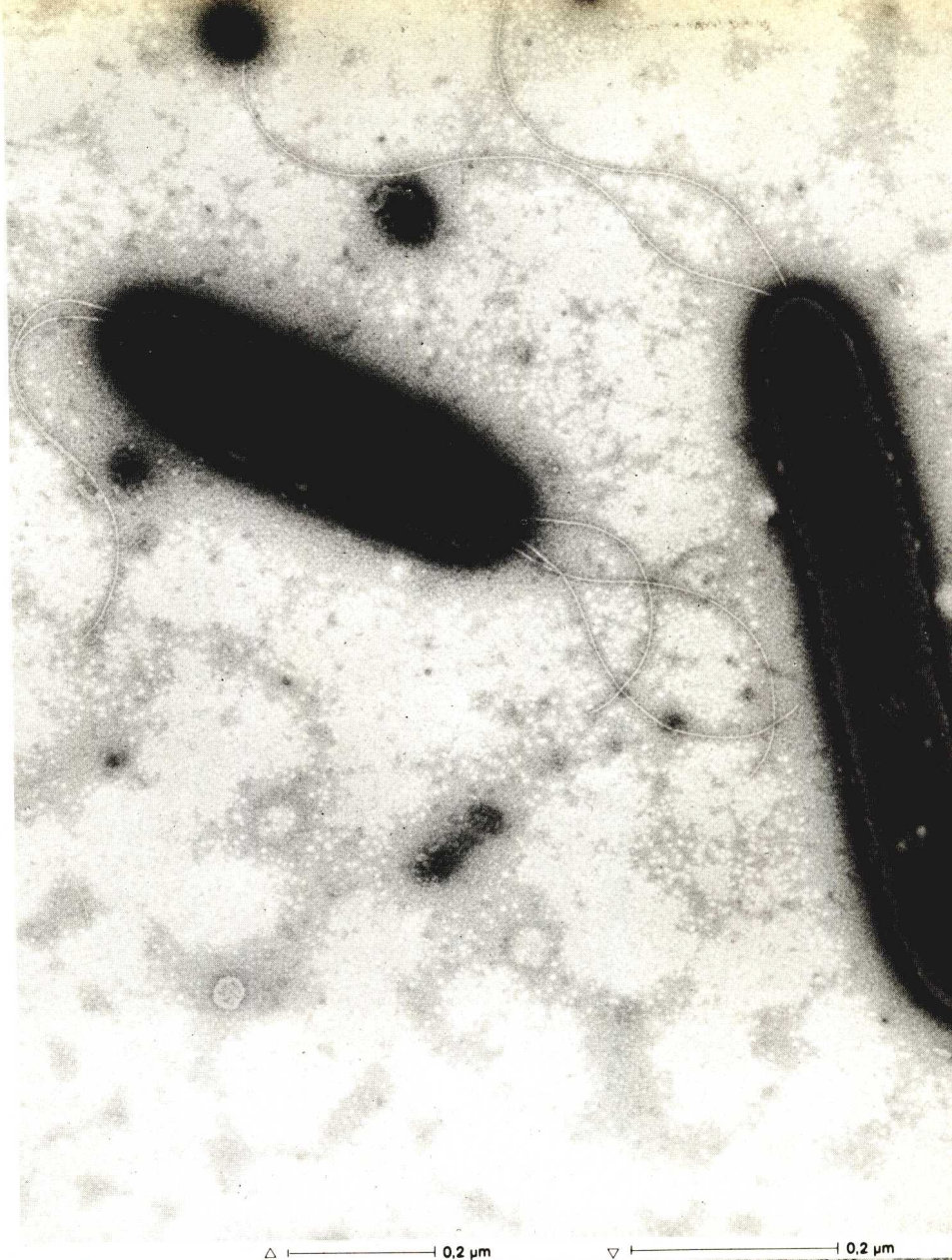
Right: *an amoeba using filamentous pseudopodia for locomotion (× 3000).*





Bacteria

Surface view of two rod-shaped bacteria (bacilli) (whole mount).
Clearly visible are the highly convoluted walls of these single-celled organisms and the flagella at both ends.



Whooping-cough bacillus (ultrathin section).
Note the double membrane enclosing the bacterium, and the nuclear zone, a system of filamens of nuclear material that lacks a nuclear membrane. Bacteria show very little internal differentiation.