Microbiology

Unit 1 · Lesson 1 · Finding microbes, two cell plans

The notes for Lesson 1 of Unit 1: chapters 1.1 to 1.2 of the unit book, with their figures, worked examples, exam traps and quizzes, in one file. The full unit book, with every chapter, the exam question bank and the glossary, is linked at the end.

Lesson 1 of 4 | 2 chapters | Chapters 1.1 to 1.2

About these notes

These are the notes for **Lesson 1 · Finding microbes, two cell plans** of the University free n easy video lessons on Microbiology Unit 1, Foundations: Microbial World and Microscopy. They are chapters 1.1 to 1.2 of the unit book, unchanged, so a page here is the same page in the full book.

1.1 History, scope and branches of microbiology

Microbiology is the study of living things too small to be seen clearly with the naked eye: bacteria, archaea, fungi, algae and protozoa, together with the non-cellular agents (viruses, viroids and prions). Its history is the story of three questions being answered: do microbes exist, where do they come from, and what do they do? Microscopes answered the first, Pasteur's flasks the second, and the germ theory of disease and fermentation the third.

Seeing microbes for the first time

Robert Hooke's book *Micrographia* (1665) showed what a compound microscope could reveal; he used the word "cell" for the small boxes he saw in cork. The first person to see bacteria and protozoa was Antonie van Leeuwenhoek, a cloth merchant in Delft (the Netherlands), who ground single lenses that magnified a few hundred times. In 1676 he described moving "animalcules" in pepper water in a letter to the Royal Society of London, and he later drew bacteria scraped from his own teeth. He is called the father of microbiology.

The end of spontaneous generation

Spontaneous generation (abiogenesis) was the belief that life arises from non-living matter: maggots from meat, microbes from broth. Biogenesis is the opposite idea: living cells come only from living cells. The argument took two centuries to settle.

1. **Francesco Redi (1668)** kept meat in open jars and in jars covered with gauze. Maggots appeared only where flies could lay eggs. But microbes were too small for this test.
2. **John Needham (1740s)** boiled mutton broth briefly, sealed it and still saw microbes grow, which seemed to support spontaneous generation.
3. **Lazzaro Spallanzani (1760s)** boiled broth longer in flasks sealed by melting the glass; they stayed clear. Critics replied that sealing kept out a "vital force" carried by air.
4. **Louis Pasteur (1861)** answered them with swan-neck flasks that let air in but trapped dust in the bend of the neck (see the worked example).
5. **John Tyndall (1870s)** found that hay infusions needed repeated heating, and Ferdinand Cohn showed why: some bacteria form heat-resistant endospores. Sterilization methods are in Unit 5, *Physical control: heat, filtration and radiation*.

Germ theory and the golden age (1857–1914)

Pasteur's studies of wine and beer showed that fermentation is done by living microbes: yeasts make alcohol, and contaminating bacteria turn wine sour. Gentle heating to kill the spoilers is still called pasteurization. If microbes cause fermentation, specific microbes might cause specific diseases: this is the germ theory. Ignaz Semmelweis (1847) cut deaths from childbed fever in a Vienna hospital by making doctors wash their hands in chlorinated lime, and Joseph Lister (1867) began antiseptic surgery with carbolic acid (phenol). Pasteur went on to vaccines against anthrax (1881) and rabies (1885), building on Edward Jenner's use of cowpox against smallpox (1796).

Robert Koch supplied the proof. In 1876 he showed that *Bacillus anthracis* causes anthrax. He grew pure cultures on solid media: first gelatin, then agar (suggested by Fanny Hesse) in the dish designed by Julius Petri (1887). He found the tuberculosis bacillus (1882) and isolated the cholera vibrio in Calcutta (1884). His reasoning is known as Koch's postulates:

1. The same microbe is present in every case of the disease and absent from healthy hosts.
2. It is isolated from the sick host and grown in pure culture.
3. The pure culture causes the same disease when inoculated into a healthy, susceptible host.
4. The same microbe is isolated again from that experimentally infected host.

The postulates fail for healthy carriers (people who shed *Salmonella* Typhi without illness), for microbes that will not grow in the lab (*Mycobacterium leprae*, *Treponema pallidum*), for diseases with no animal model, and for diseases caused by several microbes together.

India is part of this story. Ronald Ross, working in Secunderabad in 1897, showed that mosquitoes carry the malaria parasite (Nobel Prize, 1902). Waldemar Haffkine made vaccines

against cholera (1892) and plague (1897); his Bombay laboratory became today's Haffkine Institute. In Kolkata, Sambhu Nath De showed in 1959 that *Vibrio cholerae* causes diarrhoea through a toxin.

After 1890 the field branched out. Dmitri Ivanovsky (1892) and Martinus Beijerinck (1898) found that tobacco mosaic disease passes through bacteria-proof filters, which began virology; Beijerinck and Sergei Winogradsky founded microbial ecology. Paul Ehrlich's Salvarsan (1910) began chemotherapy and Alexander Fleming's penicillin (1928) the antibiotic era. Later came Carl Woese's discovery of the archaea (1977) and the PCR (1983), now run with a heat-stable DNA polymerase from the hot-spring bacterium *Thermus aquaticus*.

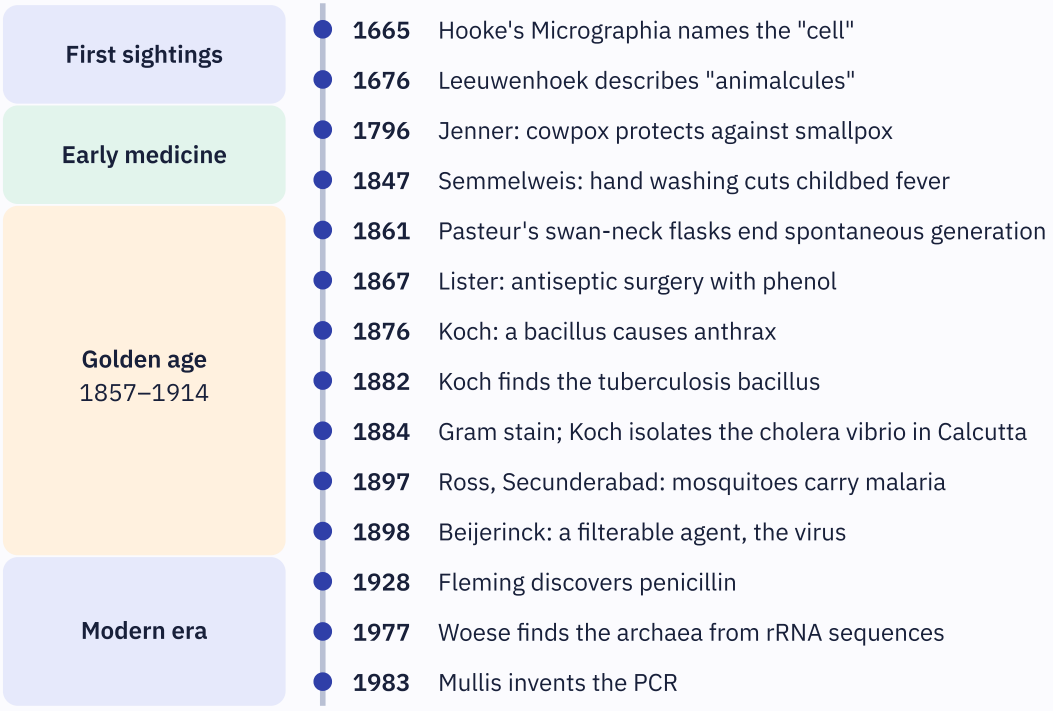


Figure 1.1.1 Fourteen landmarks of microbiology, grouped into four eras (rows are evenly spaced, not to scale). Notice how crowded the golden age is: in about forty years microbes were linked to fermentation, surgery, anthrax, tuberculosis, cholera and malaria.

Scope and branches

Some branches are named after the organisms studied: bacteriology, virology, mycology (fungi), phycology (algae), protozoology and parasitology. Others are named after what the knowledge is used for:

BRANCH	WHAT IT COVERS	EXAMPLE
Medical	Disease-causing microbes, diagnosis, vaccines	TB sputum smear

BRANCH	WHAT IT COVERS	EXAMPLE
Food and dairy	Fermented foods, spoilage, food safety	Curd, idli batter
Industrial	Products made by microbes at large scale	Penicillin, citric acid, ethanol
Agricultural and soil	Soil fertility, plant disease, biofertilizers	*Rhizobium* in pulse root nodules
Environmental and aquatic	Water quality, sewage, clean-up of pollution	Sewage treatment plant
Genetics and biotechnology	Microbial genes and their use as tools	Human insulin made in *E. coli*

So the objectives of microbiology are to understand microbes, to control the harmful ones (disease and spoilage), to use the helpful ones (fermentation, antibiotics, enzymes, vaccines, biofertilizers), and to use simple microbes such as *E. coli* and yeast as models for all of biology.

WORKED EXAMPLE

Question (8 marks). Describe Pasteur's swan-neck flask experiment. Predict what happens to the boiled broth when (a) the neck is left intact, (b) the neck is broken off, (c) the flask is tilted so that broth runs into the bend and back. What did the experiment prove?

1. **Set-up.** Nutrient broth is put in a flask, the neck is heated and drawn into an S-shaped curve, and the broth is boiled to kill the microbes already in it. The neck stays open to the air, which answers the "vital force in air" objection.
2. **(a) Intact neck.** Air moves in and out, but dust particles carrying microbes settle on the moist walls of the bend. The broth stays clear for months.
3. **(b) Neck broken.** Dust falls straight into the broth, which turns cloudy (turbid) with growth within a day or two.
4. **(c) Flask tilted.** The broth washes over the trapped dust and carries microbes back down; it turns turbid.
5. **Conclusion.** Microbes in the broth come from microbes in the air, not from the broth itself. Air reached the broth in (a), so boiling had not destroyed any "vital force". This supports biogenesis.

Examiners look for a labelled flask sketch, the role of the bend, the broken-neck control and a one-line conclusion.

EXAM TRAPS

- Leeuwenhoek did not invent the microscope; he made better single lenses and was the first to see bacteria. Hooke saw cells in cork, not bacteria.
- Needham's result seemed to **support** spontaneous generation; Spallanzani's opposed it. Students often swap the two.
- Pasteur showed that microbes cause fermentation; Koch's postulates proved that a specific microbe causes a specific disease.
- Write all four postulates in order. The favourite follow-up is "state the limitations": give carriers and *M. leprae* as examples.

CHECK YOURSELF

– REMEMBER **Who first described bacteria, when, and with what kind of microscope?** 2 marks

Antonie van Leeuwenhoek, in 1676, with a hand-made single-lens microscope magnifying a few hundred times.

– REMEMBER **State Koch's postulates.** 4 marks

Microbe present in every case and absent in healthy hosts; isolated and grown in pure culture; the pure culture causes the same disease in a healthy susceptible host; the same microbe is re-isolated from that host.

– UNDERSTAND **Why did Spallanzani's sealed flasks fail to convince his critics, and how did Pasteur's design answer them?** 4 marks

Sealing kept out air, so critics said a vital force in air was missing. Pasteur's swan neck let air in freely but trapped dust and microbes in the bend, and the broth still stayed sterile.

– APPLY **A hay infusion boiled once for 15 minutes turned cloudy; one boiled for a few minutes on three days in a row stayed clear. Explain.** 4 marks

Hay carries bacterial endospores that survive one boiling. Between heatings the spores germinate into vegetative cells, which the next boiling kills. This intermittent heating is tyndallization.

– ANALYZE *Mycobacterium leprae* has never been grown on lab media. Which postulates cannot be met, and how is it still accepted as the cause of leprosy? 4 marks

Postulates 2 and 3 need a pure culture, so they fail. The cause is accepted because acid-fast bacilli are found in the lesions of every case, the bacterium multiplies in mouse footpads and armadillos, and its DNA is found in patients' tissue.

BEYOND THE SYLLABUS

Since the 1990s microbiology has become a genome science: the first complete bacterial genome, of *Haemophilus influenzae*, was published in 1995. CRISPR–Cas9, a bacterial defence against viruses, became a gene-editing tool and won the 2020 Nobel Prize in Chemistry. Search "One Health antimicrobial resistance" to read further; none of this is needed for the exam.

1.2 Prokaryotic and eukaryotic cells compared

Every cellular microbe is built on one of two plans. A prokaryotic cell (Greek *pro*, before; *karyon*, kernel or nucleus) has no nucleus: its DNA lies in the cytoplasm. Bacteria and archaea are prokaryotes. A eukaryotic cell (*eu*, true) keeps its DNA inside a membrane-bound nucleus and has other membrane-bound organelles; fungi, algae and protozoa are eukaryotes, like plants and animals. The two plans also differ in size, ribosomes, walls, membranes and division, and many antibiotics work because of these differences.

The prokaryotic plan

A typical bacterium such as *Escherichia coli* is a rod about 1 µm wide and 2 µm long (1 µm, one micrometre, is 10^{-6} m). From the outside in, it has an optional capsule, a cell wall (made of peptidoglycan in bacteria), a plasma membrane and the cytoplasm. Respiration happens on the plasma membrane, because there are no mitochondria, and photosynthetic bacteria have no chloroplasts. The DNA is usually one circular chromosome packed into a region called the nucleoid, with no membrane around it. Small extra DNA circles, plasmids, often carry genes for antibiotic resistance. Ribosomes are 70S. Flagella, when present, rotate like propellers. The cell divides by binary fission, and because no membrane separates DNA from ribosomes, an mRNA is translated while it is still being made. Unit 2 (*Bacterial morphology and cell structure*) covers each of these parts.

The eukaryotic plan

Eukaryotic cells are usually 10–100 µm across, although a yeast cell is only about 5 µm. The nucleus is bounded by a double membrane, the nuclear envelope, with pores; inside are several linear chromosomes wound on histone proteins, and a nucleolus where ribosomes are assembled. The cytoplasm holds 80S ribosomes, free or on the rough endoplasmic reticulum (ER), the Golgi apparatus, lysosomes and vacuoles, mitochondria for respiration and, in algae, chloroplasts. A cytoskeleton of actin filaments and microtubules lets the cell change shape, move material inside it and swallow food by phagocytosis, as an amoeba does. Eukaryotic flagella and cilia have the "9 + 2" arrangement of microtubules and beat like whips. Membranes contain sterols: ergosterol in fungi, cholesterol in animals. Cells divide by mitosis, and many also reproduce sexually through meiosis.

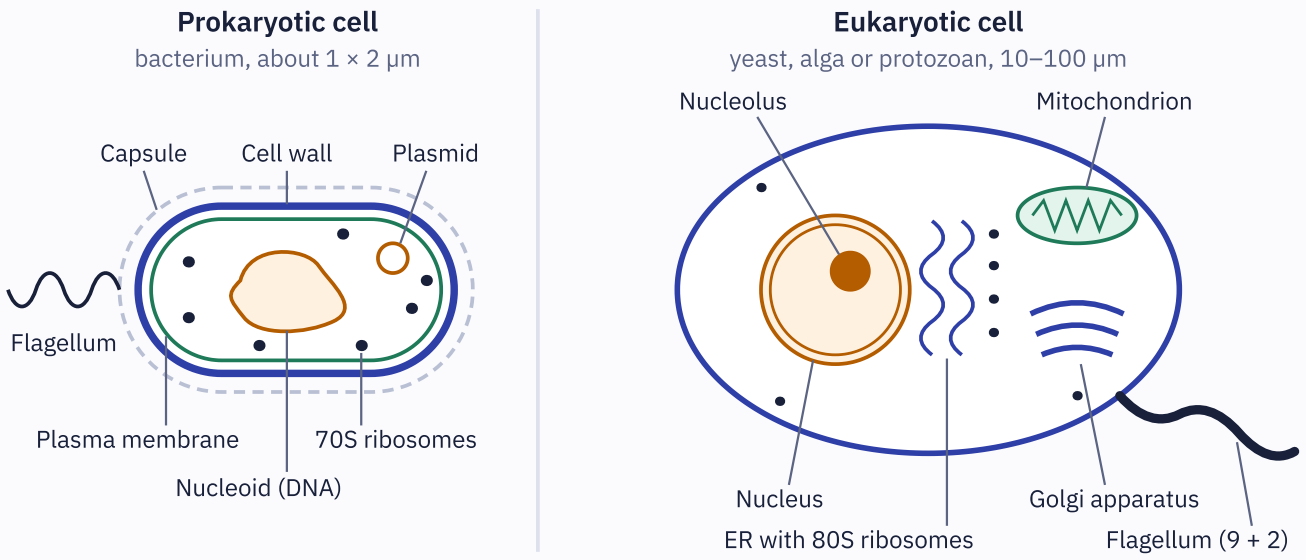


Figure 1.2.1 The two cell plans (not to scale: the eukaryotic cell is usually ten or more times wider). Notice that the prokaryote's DNA has no membrane around it, while the eukaryote's nucleus, mitochondrion, ER and Golgi are all bounded by membranes.

Side by side

FEATURE	PROKARYOTE	EUKARYOTE
Typical size	0.2–2 µm wide	10–100 µm
Nucleus	None; DNA in a nucleoid	Membrane-bound, with nucleolus
Chromosomes	Usually one, circular; no histones in bacteria	Several, linear, on histones
Ribosomes	70S (50S + 30S)	80S (60S + 40S); 70S inside mitochondria and chloroplasts

FEATURE	PROKARYOTE	EUKARYOTE
Membrane-bound organelles	Absent	Mitochondria, ER, Golgi, lysosomes, chloroplasts
Site of respiration	Plasma membrane	Mitochondria
Cell wall	Peptidoglycan in bacteria; absent in *Mycoplasma*	Chitin (fungi), cellulose (algae), none (protozoa)
Sterols in membrane	Absent (except *Mycoplasma*)	Present
Flagella	About 20 nm thick, rotate	About 200 nm thick, 9 + 2 microtubules, whip-like
Endocytosis, cytoplasmic streaming	Absent	Present
Division	Binary fission	Mitosis; meiosis in sexual reproduction
Gene expression	Transcription and translation coupled; introns rare	Separated by the nuclear envelope; introns common

Where archaea fit, and why the difference matters

Archaea have the prokaryotic plan but are a separate domain (Chapter 1.4). Their membrane lipids are joined by ether links (bacteria and eukaryotes use ester links), their walls never contain peptidoglycan, and many wrap their DNA on histone-like proteins. So "prokaryote" describes a cell plan, not one family tree.

Mitochondria and chloroplasts have their own circular DNA and 70S ribosomes, and they divide by fission. This supports the endosymbiont theory: they descend from bacteria that an early eukaryotic cell engulfed.

The differences also give selective toxicity, the basis of antimicrobial drugs (Unit 5, *Antibiotics and how they act*). Penicillin blocks peptidoglycan synthesis, which human cells do not need. Streptomycin and tetracycline act on 70S ribosomes and largely spare 80S ones. Amphotericin B binds ergosterol, so it damages fungal membranes more than human ones.

WORKED EXAMPLE

Question (6 marks). A coccus is a sphere 1 μm in diameter; a yeast-like eukaryotic cell is a sphere 10 μm in diameter. (a) Find the surface-area-to-volume ratio of each. (b) A nutrient molecule diffuses from the membrane to the centre. Using $t \approx x^2/(2D)$, where x is the distance and D the diffusion coefficient (take $D = 1 \times 10^{-10}$ m²/s, a round value for a small molecule in cytoplasm), estimate the time in each cell. (c) What do the answers say about cell size?

1. For a sphere of radius r, surface area $A = 4\pi r^2$ and volume $V = (4/3)\pi r^3$, so $A/V = 3/r$.
2. Coccus: $r = 0.5$ μm, so $A/V = 3 \div 0.5 = 6$ μm^{-1}. Eukaryotic cell: $r = 5$ μm, so $A/V = 0.6$ μm^{-1}. The coccus has 10 times more membrane per unit volume to take in food.
3. Coccus: $x = 0.5$ μm $= 5 \times 10^{-7}$ m, $x^2 = 2.5 \times 10^{-13}$ m², $t = 2.5 \times 10^{-13} \div (2 \times 10^{-10}) = 1.25 \times 10^{-3}$ s, about 1 ms.
4. Eukaryotic cell: $x = 5$ μm $= 5 \times 10^{-6}$ m, $x^2 = 2.5 \times 10^{-11}$ m², $t = 2.5 \times 10^{-11} \div (2 \times 10^{-10}) = 0.125$ s.
5. Time grows with the square of distance: 10 times the radius gives 100 times the time. A small prokaryote can rely on diffusion and grow fast; a large eukaryotic cell needs internal membranes, vesicle transport and a cytoskeleton to move material.

EXAM TRAPS

- 30S + 50S makes 70S, not 80S. The svedberg (S) measures how fast a particle sediments in a centrifuge, which depends on shape as well as mass, so S values do not add.
- Prokaryotes do have ribosomes (70S). Mitochondria and chloroplasts also have 70S ribosomes.
- "Blue-green algae" (cyanobacteria) are prokaryotes. Fungi are eukaryotes but not plants: chitin walls, no chlorophyll.
- A nucleoid is not a nucleus: it has no membrane.
- *Mycoplasma* has no cell wall but has sterols in its membrane, a favourite exception.

CHECK YOURSELF

– REMEMBER **Give the sedimentation coefficients of prokaryotic and eukaryotic ribosomes and their subunits.** 2 marks

Prokaryotic 70S = 50S + 30S. Eukaryotic (cytoplasmic) 80S = 60S + 40S.

– REMEMBER **Name three structures found only in eukaryotic cells.** 3 marks

Any three: nucleus with nuclear envelope, mitochondria, endoplasmic reticulum, Golgi apparatus, lysosomes, 9 + 2 flagella.

– UNDERSTAND **Why does penicillin kill bacteria but not human cells?** 2 marks

It blocks the synthesis of peptidoglycan, the bacterial wall polymer. Human cells have no peptidoglycan, so the drug has no target in them.

– APPLY **Find the A/V ratio of a spherical coccus 2 µm in diameter and compare it with a 1 µm coccus.** 3 marks

r = 1 µm, A/V = 3/r = 3 μm^{-1}. The 1 µm coccus has 6 μm^{-1}, twice as much surface per unit volume.

– ANALYZE **A cell has no nucleus, 70S ribosomes, no peptidoglycan, ether-linked membrane lipids and DNA on histone-like proteins. Which domain is it in, and which features rule out the others?** 4 marks

Archaea. No nucleus and 70S ribosomes rule out Eukarya; ether-linked lipids and no peptidoglycan rule out Bacteria.

– UNDERSTAND **Give two pieces of evidence for the endosymbiont theory.** 2 marks

Mitochondria and chloroplasts have their own circular DNA and 70S ribosomes, and they divide by fission like bacteria.

BEYOND THE SYLLABUS

The line between the two plans is less sharp than textbooks show. *Thiomargarita magnifica*, a bacterium described in 2022 from Caribbean mangroves, is about a centimetre long and keeps its DNA inside membrane-bound sacs. Asgard archaea from deep-sea sediments carry genes once thought to be found only in eukaryotes, and are studied as the closest living relatives of the first eukaryotic cell. Search "Asgard archaea" or "bacterial cytoskeleton FtsZ MreB". This is not for the exam.

Key terms of this lesson

TERM	MEANING OR FORMULA	CHAPTER
Biogenesis	Living cells arise only from living cells (Pasteur's swan-neck flasks, 1861)	1.1
Koch's postulates	Microbe in every case; grown in pure culture; culture causes the disease; microbe re-isolated	1.1
Prokaryote vs eukaryote	No nucleus, 70S ribosomes vs nucleus, organelles, 80S ribosomes	1.2
Surface-to-volume ratio	$A/V = 3/r$ for a sphere of radius r	1.2
Diffusion time	$t \approx x^2/(2D)$	1.2

Glossary (terms used in this lesson)

Abiogenesis The old idea that life arises from non-living matter; also called spontaneous generation.

Acid-fast Holding carbol fuchsin even when washed with acid, because of a waxy, mycolic-acid-rich wall.

ANI Average nucleotide identity between two genomes; 95–96% or more suggests one species.

Biogenesis The principle that living cells arise only from living cells.

Capsule A loose layer of polysaccharide or polypeptide outside the cell wall.

Endospore A tough, dormant structure formed inside some bacteria that survives heat and drying.

Koch's postulates Four criteria for proving that a particular microbe causes a particular disease.

Nucleoid The region of a prokaryotic cell that holds the chromosome, with no membrane around it.

The full unit book

Every chapter of Unit 1, the unit summary, the exam question bank with model answers and the full glossary: Microbiology · Unit 1 · Foundations: Microbial World and Microscopy (one file, works offline).

Sources and further reading

- Willey, Sandman and Wood, *Prescott's Microbiology*, McGraw-Hill: history, cell structure, microscopy, staining and taxonomy (from memory; check the edition you are prescribed).
- Tortora, Funke and Case, *Microbiology: An Introduction*, Pearson (from memory; check).
- Madigan and colleagues, *Brock Biology of Microorganisms*, Pearson (from memory; check).
- Pelczar, Chan and Krieg, *Microbiology*, Tata McGraw-Hill, 5th edition (from memory; check).
- *Ananthanarayan and Paniker's Textbook of Microbiology*, Universities Press: staining methods as used in Indian medical laboratories (from memory; check).
- Dubey and Maheshwari, *A Textbook of Microbiology*, S. Chand (from memory; check).
- Whitman, Coleman and Wiebe (1998), "Prokaryotes: the unseen majority", *Proceedings of the National Academy of Sciences*: the source of the 4–6 × 10^{30} estimate in Chapter 1.3 (from memory; check).
- OpenStax, *Microbiology* (2016), Chapter 2, "How We See the Invisible World", read in the SUNY and Lumen Learning edition: courses.lumenlearning.com/suny-microbiology. Used for light-microscope magnification limits and TEM section thickness.
- Central TB Division, Government of India, Technical and Operational Guidelines, Annexure 1 (Ziehl–Neelsen sputum smear method and grading): tbcindia.mohfw.gov.in.

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