Unit 2

Life and Life Process

This unit online, with its interactives:
science-playground.com/s/9a2

Leave a piece of roti in a closed tin in the rainy season, and after three or four days a gray fur grows over it, dotted with tiny black pins. Nobody put it there. It grew from spores far too small to see, which float in the air of every kitchen and land on everything. Those black pins are packed with more spores, millions of them, ready to start the same fur on the next piece of food.

The fur is a mold called ***Mucor***, one of the living things too small to see one at a time that we call **microorganisms**. This unit is about them: what the science of microbes studies and why it matters, how a virus, a bacterium and a yeast make more of themselves, and the whole life of *Mucor*, the mold on the roti, with the good and the harm it does.



Figure 2.1 *A pin mold (Mucor) growing over kitchen scraps on a compost heap. Each thread ends in a tiny black ball, a sporangium full of spores.*
Photo: Thiedbold, CC BY-SA 4.0

2.1 Microbiology

Microorganisms (also called **microbes** or germs) are living things so small that most of them can be seen only with a microscope. They include **bacteria**, **fungi** such as yeasts and molds, **protozoa** such as *Amoeba*, microscopic **algae**, and the **viruses**, which are not cells at all. The science that studies them, their structure, how they live and multiply, and what they do to us and to the world, is **microbiology** (Greek *mikros*, small; *bios*, life; *logos*, study).

Microbes come in very different sizes. A micrometer (µm) is a thousandth of a millimeter, and a nanometer (nm) is a thousandth of a micrometer.

Microbe	Typical size	Seen with
A virus (bacteriophage T4)	about 200 nm (0.2 µm) long	an electron microscope only
A bacterium (*E. coli*)	about 2 µm long, 0.5–1 µm wide	a good light microscope
A yeast cell	about 5–10 µm across	a light microscope
Amoeba proteus	about 500 µm (half a millimeter)	a hand lens, just about
A colony of *Mucor*	its threads are about 10–20 µm wide, but millions together make a fur you can see	the naked eye

A grain of rice is about 6 mm long, so 3,000 *E. coli* laid end to end would just reach along it, and about 30,000 phages would.

Branches of microbiology

Microbiology is now so large that it is split by the microbes studied:

- **Bacteriology**, the study of bacteria;
- **Virology**, the study of viruses;
- **Mycology**, the study of fungi (*mykes*, fungus);
- **Protozoology**, the study of protozoa, and **phycology**, the study of algae.

It is also split by where the knowledge is used: **medical microbiology** (germs that cause disease, and how to fight them), **immunology** (how the body defends itself), **agricultural microbiology** (microbes of soil, crops and animals), **food microbiology**, **industrial microbiology** (using microbes to make things) and **environmental microbiology** (microbes in water, soil, air and waste).

Importance of microbiology

Most microbes do no harm, and many are vital. Knowing them helps us use the useful ones and fight the harmful ones.

In medicine. Microbiology found the causes of diseases such as tuberculosis, cholera, typhoid and COVID-19, and so how each spreads and how to stop it: boiling water, washing hands, keeping flies off food. It gave us **antibiotics** (penicillin came from a mold, *Penicillium*) and **vaccines**. Bacteria now make medicines too: since 1982, hu-

man insulin for people with diabetes has been made by *E. coli* carrying the human insulin gene.

In agriculture. *Rhizobium* bacteria in the root nodules of beans, peas and lentils turn nitrogen from the air into a form plants can use, so legumes enrich the soil. Microbes rot dung and leaves into compost and humus. Microbiology also finds the fungi, bacteria and viruses that cause crop diseases, such as late blight of potato and rust of wheat, and ways to control them.

In food. Many of Nepal's foods are made by microbes. Lactic acid bacteria turn milk into *dahi* and mustard leaves into *gundruk*; *Bacillus* bacteria ferment soybeans into *kinema*; yeasts and molds in ***marcha*** (*murcha*), the starter cake, turn cooked millet or rice into *jaand* and *chhyang*. Yeast makes bread and *sel roti* batter rise. Microbiology also explains why food spoils and how drying, salting, boiling, pickling and cold slow the microbes down.

In industry. Microbes grown in huge tanks make alcohol, vinegar, citric acid, vitamins, enzymes for washing powders and cheese, and many medicines.

In the environment. Bacteria and fungi are the great **decomposers**: they break down dead plants and animals and return their nutrients to the soil. Without them, the forest floor would be piled high with dead leaves. Microbes clean sewage in treatment plants, and in a gobar gas (biogas) plant, bacteria turn dung into methane for cooking.

In research. The bacterium *E. coli* and baker's yeast are the two best-studied living things on Earth. Much of what we know about genes, how DNA is copied and how cells divide was first found in them.

Check 1

Which of these is a use of microbes in agriculture?

a making *sel roti* batter rise
b making insulin
c fixing nitrogen in the root nodules of legumes
d cleaning sewage

Check 2

A scientist who studies how the mold *Mucor* reproduces works in which branch of microbiology?

a bacteriology
b virology
c mycology
d immunology

A STORY FROM SCIENCE

The first microbe ever drawn was a mold

In 1665, the English scientist Robert Hooke published *Micrographia*, a book of drawings of what he saw through his microscope: a flea, the eye of a fly, and thin slices of cork, where he first used the word “cell”. One of its plates shows a tiny forest of stalks, each ending in a round head, that he found growing on the red sheepskin cover of a small book. It was a pin mold, *Mucor*: the first microorganism known to have been drawn and printed. About ten years later, in 1676, the Dutch cloth merchant Antonie van Leeuwenhoek, looking through tiny single lenses he ground himself, saw “very little animalcules” swimming in rainwater, and in 1683 in the scrapings from his own teeth. They were protozoa and bacteria. Two hundred years after that, Louis Pasteur in France and Robert Koch in Germany proved that microbes cause fermentation and disease, and microbiology became a science of its own.

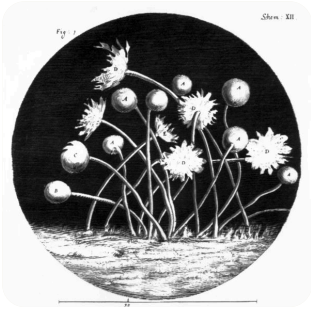


Figure 2.2 *Hooke’s drawing of the mold he found on a sheepskin book cover, from Micrographia (1665). The round heads are sporangia; the ragged ones have burst and are shedding their spores.*
Photo: Robert Hooke, Public domain

2.2 Mode of reproduction of virus, bacteria and fungi

Every living thing makes more of its own kind. A microbe usually does it **asexually**: one parent alone makes offspring that are copies of itself, so the offspring have the same genes. That is quick: when food is plentiful, a microbe can go from one cell to millions in a day. Here are three very different ways of doing it.

h. **Think:** A cook says, “If I leave rice out for 2 hours instead of 1 hour, there will be twice as many bacteria in it.” If the bacteria divide every 20 minutes, how many times more are there really after 2 hours than after 1 hour?

Found a mistake? Please tell us.

iv. Asexual and sexual reproduction in *Mucor*

4. Answer the following questions

a. What is microbiology? Name its branches based on the microbes studied.

b. Write any five points on the importance of microbiology.

c. Describe the lytic cycle of a bacteriophage with a labeled diagram.

d. Explain binary fission in *E. coli* with diagrams.

e. Describe budding in yeast with a diagram.

f. Describe the asexual reproduction of *Mucor*.

g. Describe the sexual reproduction of *Mucor* with labeled diagrams.

h. Draw a labeled diagram of the life cycle of *Mucor*, showing both its asexual and sexual cycles.

i. Write any three advantages and three disadvantages of *Mucor*.

j. **Think:** A student says, "A virus is the smallest living thing, so it must reproduce by binary fission, like bacteria." What is wrong with this?

5. Numerical problems

a. An *E. coli* cell divides every 20 minutes. Starting with one cell, how many cells will there be after 4 hours?

b. A sample of milk has 500 bacteria in it. They divide every 30 minutes. How many bacteria will it have after 3 hours?

c. A culture of bacteria grew from 1,000 cells to 64,000 cells in 2 hours. Find its generation time.

d. A bacterium divides every 25 minutes. How long will one bacterium take to become 1,024 bacteria?

e. A phage infects a bacterium, and after 30 minutes the cell bursts, releasing 150 phages. If each of these infects a new bacterium and each of those cells releases 150 phages, how many phages are there after 1 hour, and how many bacteria have been killed?

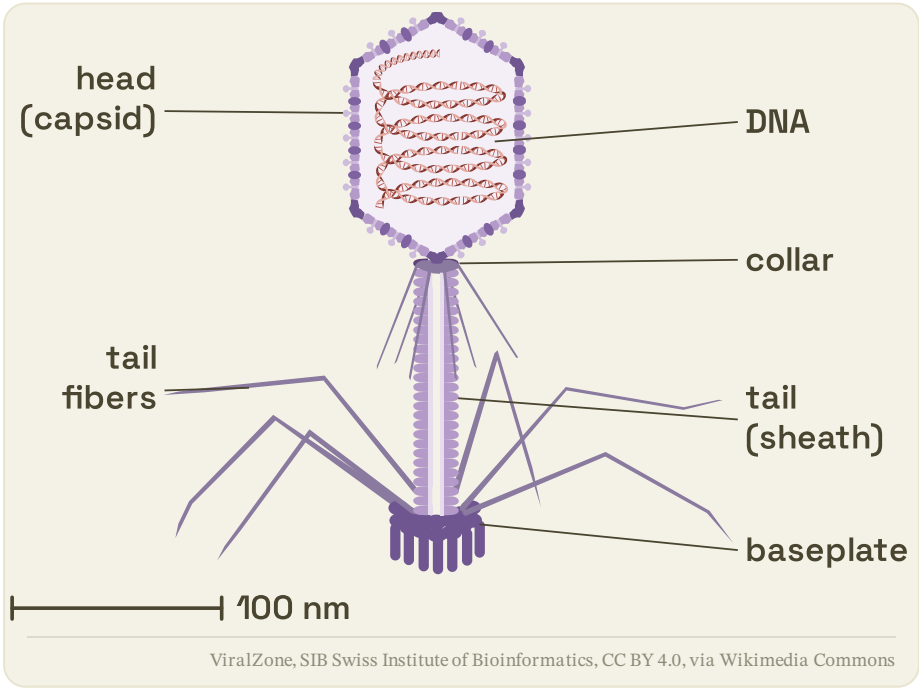
f. Yeast in a bowl of sugar solution doubles every 2 hours. If there are 50,000 cells at 7 a.m., how many are there at 3 p.m. the same day?

g. In a lab, one *E. coli* (doubling every 20 minutes) and one yeast cell (doubling every 100 minutes) are each put in their own flask of food at the same time. How many of each will there be after 200 minutes? How many times more bacteria than yeast cells?

Reproduction in viruses: the lytic cycle of a bacteriophage

A virus has no cell, no food store and no machinery for making anything. Outside a living cell it does nothing at all. It can multiply only by getting inside a living **host cell** and making the cell build new viruses for it. So a virus doesn't really reproduce the way a cell does: it is copied, by its host.

A **bacteriophage**, or **phage** ("bacteria eater"), is a virus that infects bacteria. The best-studied one, **phage T4**, infects *E. coli*, the bacterium that lives in our gut. It looks like a tiny landing craft: a six-sided **head** (the capsid, a coat of protein) holding its **DNA**, a **collar**, a hollow **tail** with a springy **sheath** around it, a **baseplate**, and six long, bent **tail fibers**, like legs.



ViralZone, SIB Swiss Institute of Bioinformatics, CC BY 4.0, via Wikimedia Commons

Figure 2.3 *Bacteriophage T4, cut open. Its DNA is coiled tightly inside the protein head; the tail is a hollow tube inside a sheath, and the tail fibers are what it lands on a bacterium with.*

When a phage meets the right bacterium, it multiplies by the **lytic cycle**, named after the last step, when the bacterium bursts (*lysis*, breaking open). The cycle has five steps.

1. Attachment (adsorption). The phage drifts until it bumps into an *E. coli* cell. Its tail fibers grip particular molecules on the cell's outer surface, its **receptors**, like a

key fitting a lock. A phage can attach only to the kind of bacterium whose receptors fit its fibers, so phage T4 infects *E. coli* but not the bacteria in curd.

2. Penetration (injection). The baseplate settles on the cell wall, and the tail sheath contracts, driving the hollow inner tube through the wall like a syringe's needle. An enzyme at the tube's tip, lysozyme, digests a small hole in the wall. The phage's DNA passes down the tail into the cell. The empty protein coat stays outside, a "ghost".

3. Biosynthesis (replication). Within minutes, the phage's genes take over the cell. The phage makes an enzyme that chops up the bacterium's own DNA, so the cell stops making its own things. The cell's ribosomes, enzymes and food store now make what the phage DNA orders: many copies of the phage DNA, and the proteins for heads, tails and fibers.

4. Maturation (assembly). The parts put themselves together. Heads are built and filled with a copy of the DNA; tails join the heads; fibers attach last. About 20 minutes after infection, the cell is crowded with complete new phages.

5. Release (lysis). Phage genes now make a protein that punches holes in the cell membrane and an enzyme (lysozyme) that digests the cell wall. Weakened, the cell bursts and dies, releasing all its new phages at once. Each is ready to attach to another *E. coli* and start the cycle again.

At 37 °C, the whole cycle takes phage T4 only about 25 to 30 minutes, and each burst cell releases roughly 100 to 150 new phages; the worked examples here mostly use **100**, a round number. That is why phages spread so fast: one phage, one cell; then a hundred phages, a hundred cells; then ten thousand.

> CAREFUL
> **Five steps or six?**
>
> Some books split the lytic cycle into six steps (attachment, penetration, transcription, biosynthesis, maturation, lysis) and some into four. The steps are the same process divided differently. In an exam, the five above, in this order, with what happens in each, will always earn the marks.

Reproduction in bacteria: binary fission in *E. coli*

A bacterium reproduces by **binary fission** (*binary*, two; *fission*, splitting): one cell grows and splits into two equal daughter cells. Each daughter gets a copy of the parent's DNA, so both are genetically the same as the parent. Here is how *E. coli* does it.

c. In binary fission of *E. coli*, the wall that grows across the middle of the cell is called the:

a columella b septum
c capsid d bud scar

d. Yeast reproduces asexually by:

a binary fission b budding
c sporangiospores d conjugation

e. The hyphae of *Mucor* are:

a septate and uninucleate b septate and diploid
c aseptate and multinucleate d aseptate and uninucleate

f. The sterile, dome-shaped central part of a *Mucor* sporangium is the:

a suspensor b gametangium
c columella d zygophore

g. A zygospore of *Mucor* is formed by the fusion of:

a two sporangiospores b two hyphae of the same strain
c two gametangia of + and − strains d a sporangium and a columella

h. One bacterium divides every 20 minutes. How many bacteria are there after 1 hour?

a 3 b 6
c 8 d 20

2. Give reasons

a. A virus is called an obligate parasite.

b. A bacterium infected by a phage in the lytic cycle dies.

c. The two daughter cells formed by binary fission are genetically identical to the parent.

d. *Mucor*'s hyphae are called coenocytic.

e. Bread kept in a closed box in a damp, warm room grows mold faster than bread kept in a fridge.

f. The zygospore of *Mucor* helps it survive bad conditions.

3. Differentiate between

i. Binary fission and budding

ii. Sporangiospore and zygospore

iii. Gametangium and suspensor

IN SHORT

- **Microbiology** is the study of microorganisms: bacteria, fungi, protozoa, microscopic algae and viruses. Its branches include bacteriology, virology, mycology and immunology; it matters in medicine, agriculture, food, industry, the environment and research.
- A **bacteriophage** multiplies by the **lytic cycle**: attachment, penetration (only the DNA enters), biosynthesis (the host's DNA is destroyed, phage DNA and proteins are made), maturation (assembly) and release (lysis). For T4 it takes about 25–30 minutes and releases roughly 100–150 phages.
- **Binary fission** in *E. coli*: the circular DNA is copied, the copies move apart, a septum grows across the middle and the cell splits into two equal, identical cells, about every 20 minutes at best. $N = N_0 \times 2^n$.
- **Budding** in yeast: a bud grows out of the mother, the nucleus divides through the neck, a wall forms and the smaller bud breaks away, leaving a bud scar. Buds that stay attached form a pseudomycelium.
- *Mucor* has a coenocytic, haploid mycelium. **Asexually**, sporangiophores carry sporangia, in which sporangiospores form round a columella. **Sexually**, + and − strains conjugate: progametangia, gametangia and suspensors, then a diploid, thick-walled **zygospore**, which undergoes meiosis on germination and gives a germ sporangium of haploid spores.
- *Mucor* decomposes dead matter and helps ferment foods and make enzymes, but it spoils food and fruit, causes allergies, and some species cause mucormycosis.

Exercise

1. Choose the correct option

a. The branch of microbiology that studies fungi is:

- a bacteriology
- b phycology
- c mycology
- d virology

b. The correct order of the steps of the lytic cycle is:

- a penetration, attachment, maturation, biosynthesis, release
- b attachment, penetration, biosynthesis, maturation, release
- c attachment, biosynthesis, penetration, release, maturation
- d biosynthesis, attachment, penetration, maturation, release

1. The DNA is copied. *E. coli* has a single, circular chromosome, a loop of DNA about 4.6 million base pairs long, packed into a tangle called the **nucleoid**. It has no nucleus around it. The chromosome is copied, starting from one point on the loop, to make two identical loops.

2. The copies move apart. As the cell grows longer, the two loops move apart, towards opposite ends of the cell.

3. A septum forms. A ring of protein (made of FtsZ) forms round the middle of the cell, just inside the membrane. The membrane and the cell wall start to grow inward along this ring, like a drawstring being pulled tight. The new wall growing across the middle is the **septum**.

4. The cell divides. The septum closes across the cell, cutting it into two cells, each with its own DNA, its own share of ribosomes and cytoplasm, and a new rounded end. The two daughter cells separate.

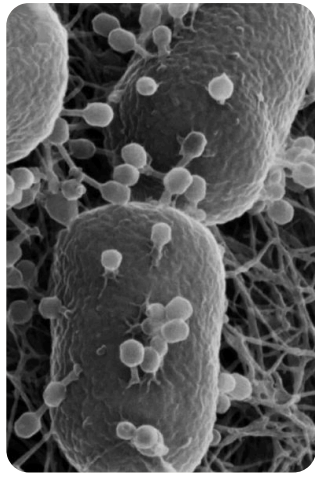


Figure 2.4 *E. coli cells covered in T4 phages, seen with a helium ion microscope. Each round dot on a short stalk is a phage's head on its tail, attached to the cell. Each bacterium is less than a micrometer wide.*

Photo: Miika Leppänen, in McGenity and others (2020), CC BY-SA 4.0

WORKED EXAMPLE

One phage, three cycles

One phage infects an *E. coli* in a culture with plenty of bacteria. Each lytic cycle takes 30 minutes and every burst releases 100 phages, each of which infects a new cell. How many phages are there after 90 minutes?

Answer

90 minutes ÷ 30 minutes = **3 cycles**.
After cycle 1: $1 \times 100 = 100$ phages.
After cycle 2: $100 \times 100 = 10{,}000$ phages.
After cycle 3: $10{,}000 \times 100 = 1{,}000{,}000$ phages.
In general, after n cycles, $N = N_0 \times b^n$, where b is the burst size: $N = 1 \times 100^3 = 10^6$.
About a million phages, from one, in an hour and a half (as long as there are a million bacteria for them to infect).

Notice that there is no spindle and no stages like the mitosis of our own cells: a bacterium's single chromosome needs only to be copied and pulled apart. That is one

Check 3

In which step of the lytic cycle is the bacterium's own DNA broken down?

a attachment
b penetration
c biosynthesis
d release

Check 4

What enters the bacterium during penetration?

a the whole phage
b only the phage's DNA
c only the protein coat
d the tail fibers

DID YOU KNOW?

Not every phage kills at once

Some phages, such as phage lambda, can choose another path, the **lysogenic cycle**: instead of taking over the cell, the phage's DNA joins the bacterium's own DNA and is copied quietly along with it every time the cell divides, for many generations. Only later, when the cell is stressed, does it break out into a lytic cycle. Phages that can only kill, like T4, are called **virulent**; those that can do both are called **temperate**.

DID YOU KNOW?

Phages as medicine

Phages were discovered by Frederick Twort in England in 1915 and Félix d'Hérelle in France in 1917. Because each kind attacks only one kind of bacterium and leaves our own cells alone, doctors in Georgia have used them as medicine for about a hundred years, and in Poland for decades. Today, as more bacteria resist antibiotics, doctors around the world are testing **phage therapy** again, sometimes as a last hope for a patient no antibiotic can cure.

reason fission is so fast. In warm broth with plenty of food, at 37 °C, *E. coli* divides about every **20 minutes**. The time between one division and the next is the **generation time** (or doubling time), because each time, the number of bacteria doubles.

So starting from N_0 bacteria, after n generations the number is

$$N = N_0 \times 2^{n} \qquad \text{where} \qquad n = \frac{\text{time passed}}{\text{generation time}}$$

DID YOU KNOW?

Why bread molds faster in the monsoon

Molds need water to grow: a cut loaf stays fresh for days in dry winter air but grows mold in two or three days in the monsoon. Cold slows it down too, which is why cooked food keeps better in a fridge: at 4 °C, *Mucor* grows very slowly, though it doesn't die.

Check 9

Which of these is NOT a disadvantage of *Mucor*?

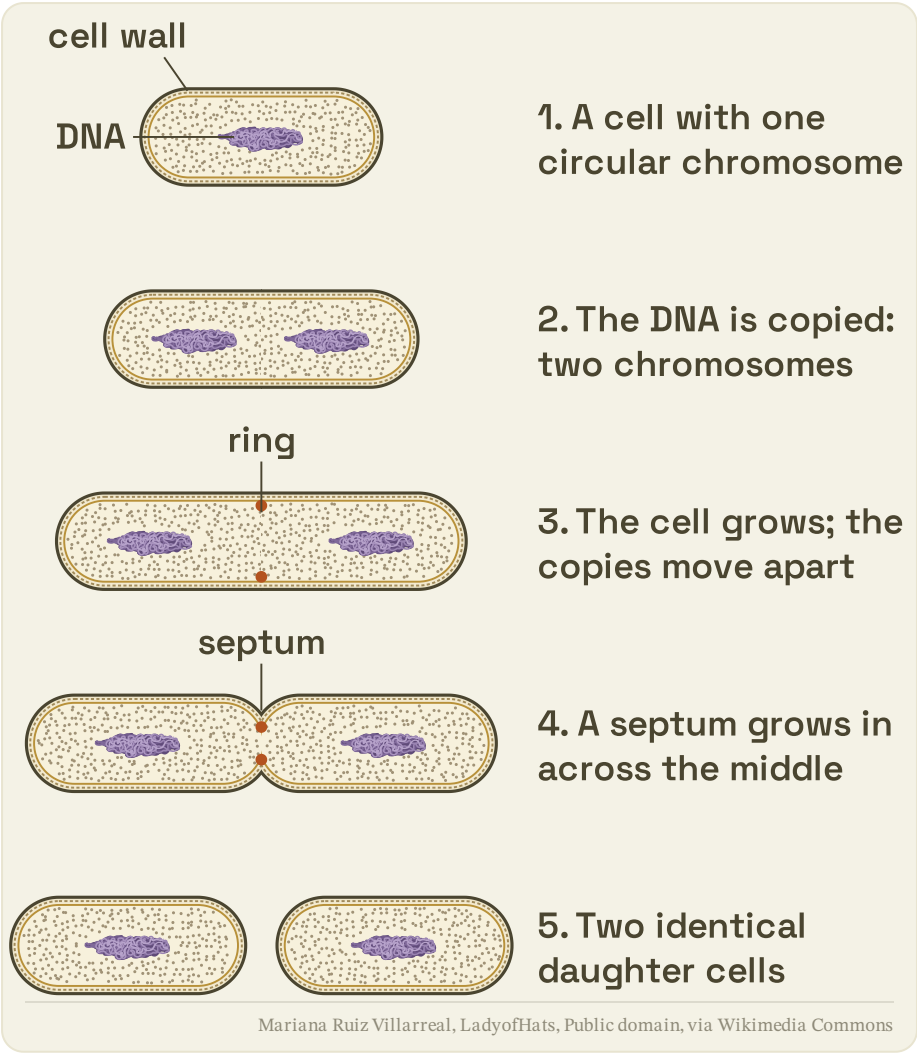
a spoiling bread and fruit
b causing mucormycosis
c helping to make alcohol from starch in *marcha*
d causing allergies

Blakeslee's discovery of the two strains was made in this group.

Disadvantages

1. **Spoils food.** *Mucor* rots bread, roti, fruits, vegetables, jam, cheese and stored grain. Its enzymes soften and sour the food, and it gives off off-flavors. Moldy food should be thrown away, not scraped clean, since the hyphae run deep inside.
2. **Damages crops after harvest.** *Mucor piriformis* causes a soft rot of apples and pears in storage, and other species rot strawberries, citrus, mangoes and yams.
3. **Causes mucormycosis.** A few *Mucor* species, with *Rhizopus* and other relatives, can infect people whose defenses are weak, especially people with poorly controlled diabetes, cancer patients, or patients on high doses of steroids. The disease, **mucormycosis** (sometimes called "black fungus" for the black, dead tissue it causes), usually starts in the nose and sinuses and can spread to the eyes and brain. It is rare but very serious: about half of the patients with the sinus form die. In 2021, during the COVID-19 pandemic, more than 40,000 cases were reported in India by the end of June, many in diabetic patients treated with steroids, and cases were reported in Nepal too. It doesn't spread from person to person.
4. **Allergies.** Its spores in the air of damp, moldy rooms can trigger sneezing and asthma in some people.
5. **Infects animals.** Some species infect cattle, pigs and poultry.

Advantages of *Mucor*	Disadvantages of *Mucor*
decomposes dead matter and recycles nutrients	spoils bread, fruit, vegetables and stored grain
helps ferment starters such as *marcha*, and foods such as *sufu*	rots fruit in storage
makes enzymes, such as microbial rennet for cheese	causes mucormycosis in people with weak immunity
ferments plant waste into alcohol	its spores cause allergies and asthma
breaks down some soil pollutants	infects some farm animals



Mariana Ruiz Villarreal, LadyofHats, Public domain, via Wikimedia Commons

Figure 2.5 *Binary fission in E. coli. The circular DNA (the nucleoid) is copied, the copies move apart as the cell grows, a septum grows inward across the middle, and the cell splits into two identical daughter cells.*

WORKED EXAMPLE

Bacteria in a lunch box

A single *E. coli* cell lands in warm dal at noon. If it divides every 20 minutes, how many bacteria are there at 3 p.m.?

Answer

Time passed = 3 hours = 180 minutes.

$$n = \frac{180}{20} = 9 \text{ generations}$$

$$N = N_0 \times 2^{\,n} = 1 \times 2^{9} = 512$$

512 bacteria after 3 hours. Three more hours (9 more generations) would give $512 \times 512 = 262{,}144$.

WORKED EXAMPLE

Finding the generation time

A culture has 300 bacteria at the start and 4,800 bacteria two hours later, all the time growing as fast as it can. Find the generation time.

Answer

$$\frac{N}{N_0} = \frac{4{,}800}{300} = 16 = 2^{4}$$

So the bacteria doubled **4 times** in 120 minutes, and

$$\text{generation time} = \frac{120 \text{ min}}{4} = 30 \text{ min}$$

The generation time is 30 minutes.

Check 7

Which part of *Mucor* is diploid?

a the hypha
b the sporangiospore
c the zygospore
d the gametangium

Check 8

A gametangium and a suspensor are both cut from:

a the sporangiophore
b the progametangium
c the zygospore
d the columella

2.4 Advantages and disadvantages of Mucor

Mucor is a nuisance in the kitchen, but in the wider world it does a great deal of good as well.

Advantages

1. **Decomposer.** With bacteria and other fungi, *Mucor* breaks down dead plant matter, dung and spoiled food, returning carbon, nitrogen and minerals to the soil, where plants can use them again. It is one of the first molds to grow on fresh, sugary dead matter.
2. **Fermented foods and drinks.** Molds of the *Mucor* group help make starter cultures for alcoholic drinks in Asia. A 2020 study of dry starter cakes from North East India, *marcha* from Sikkim among them, found *Mucor circinelloides* the most common mold, alongside *Rhizopus* and others; these molds break the starch of the grain into sugar, which the yeasts then ferment into alcohol. In China, *Mucor* species grow over cubes of tofu to make the cheese-like *sufu*.
3. **Enzymes.** Molds of this group make useful enzymes: one, formerly called *Mucor miehei*, is grown in tanks to make a rennet that curdles milk into cheese without using calves' stomachs, and enzymes for processing fats. *Mucor* species also make enzymes that break down starch and proteins.
4. **Alcohol and other products.** *Mucor indicus* can ferment sugars from plant waste into alcohol (ethanol) as well as yeast does, so it is being studied for making fuel from straw and stalks. Some species store oils rich in useful fatty acids.
5. **Cleaning up.** *Mucor* species can break down some pollutants in soil, such as certain oil residues, and their dead hyphae soak up metals from waste water.
6. **Research.** *Mucor* has helped scientists study how fungi grow, how they switch between threads and yeast-like cells, and how + and − strains find each other:

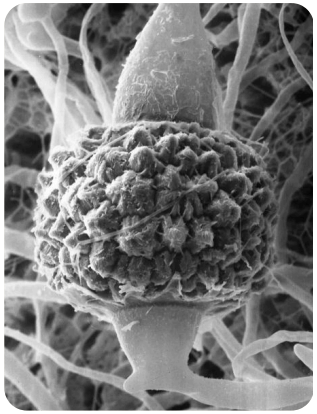


Figure 2.9 *A zygospore of Mucor mucedo seen with a scanning electron microscope: the thick, warty wall, with a suspensor above and below it.*
Photo: zygolife, CC BY-SA 2.0

CAREFUL
Isogamy, not male and female

The two gametangia that fuse look alike, so *Mucor*'s sexual reproduction is called **isogamous** (equal gametes). The + and − strains are not male and female: the signs only mean "able to mate with the other one".

A STORY FROM SCIENCE
How Blakeslee found the two strains

For many years, botanists were puzzled by bread molds. Some cultures made zygospores freely; most never did, however well they were fed. In 1904, Albert Blakeslee, a young American botanist at Harvard, grew pure cultures, each from a single spore, and set them out in pairs on dishes. Most pairs never formed zygospores. But some pairs did, always along the line where their mycelia met. He found that every culture belonged to one of two strains, and only a meeting of the two made zygospores. Since nothing showed which was male, he called them simply + and −, the names still used today.

WORKED EXAMPLE
How long to a million?

How long does it take one bacterium, dividing every 20 minutes, to become more than a million?

Answer
We need 2^n to be more than 1,000,000. Doubling from 1: $2^{10} = 1{,}024$, so $2^{20} = 1{,}024 \times 1{,}024 = 1{,}048{,}576$, just over a million.
Time = 20 generations × 20 minutes = 400 minutes = **6 hours 40 minutes**.
That's why cooked food left out overnight in summer is not safe to eat, even when it still smells fine.

CAREFUL
Real bacteria don't double forever

$N = N_0 \times 2^n$ holds only while there is plenty of food and space. A real culture first has a **lag** while the bacteria get used to their new food, then doubles steadily (the **log phase**, where the formula works), then levels off as food runs out and wastes build up (the **stationary phase**), and finally dies off. The numericals in this unit are all about the doubling stretch.

Check 5
A bacterium divides every 30 minutes. Starting from one cell, how many cells are there after 2 hours?

a 4
b 8
c 16
d 32

Reproduction in fungi: budding in yeast

Yeast (baker's and brewer's yeast is *Saccharomyces cerevisiae*) is a fungus made of a single, egg-shaped cell about 5–10 µm long. Unlike a bacterium, it is a **eukaryote**: it has a nucleus, mitochondria and a large vacuole. When it has sugar to feed on, it reproduces asexually by **budding**:

1. A bud appears. A small bulge, the **bud**, pushes out from one point on the cell wall of the parent (mother) cell. Cytoplasm flows into it.

2. The nucleus divides. The nucleus moves to the narrow **neck** between mother and bud and divides by mitosis. In yeast, the nuclear envelope stays whole all the time:

the nucleus stretches through the neck into an hourglass shape and pinches in two, leaving one nucleus in the mother and one in the bud.

3. The bud grows. The bud takes in cytoplasm, mitochondria and part of the vacuole, and grows almost as big as its mother.

4. The bud separates. A wall forms across the neck, and the bud breaks away as a new yeast cell. It leaves a ring-shaped mark, a **bud scar**, on the mother's wall. A mother cell can bud again and again, each time from a new place, until it has produced about 20 to 30 daughters.

If the buds don't separate, and each bud starts budding before it breaks away, the cells form a chain or a branched cluster. This chain of cells looks a little like a hypha and is called a **pseudomycelium** (a false mycelium).

Budding differs from fission in one way you can see: the two cells are **unequal**. The mother keeps her old wall and her scars; the bud starts small and new. With plenty of sugar, at about 30 °C, a yeast population doubles in about 1½ to 2 hours, much more slowly than *E. coli*, because a eukaryotic cell has far more to copy and sort.

	Binary fission (*E. coli*)	Budding (yeast)
The parent	is a prokaryote: no nucleus	is a eukaryote: has a nucleus
How the DNA is shared	one circular chromosome copied and pulled apart; no spindle	the nucleus divides by mitosis
The two cells	equal in size	unequal: a big mother and a small bud
The parent	disappears into its two daughters	lives on and buds again, keeping a scar each time
Time to double (best conditions)	about 20 minutes	about 1½ to 2 hours

Sexual reproduction by conjugation

When food runs short or the colony meets another one, *Mucor* can reproduce sexually. *Mucor mucedo* is **heterothallic**: its mycelia come in two strains, called **+ (plus)** and **− (minus)**. They look exactly alike; there is no male or female. A mycelium can mate only with a mycelium of the other strain.

1. **Zygophores meet.** When + and − hyphae grow near each other, each gives off chemical signals (hormones) that make the other grow short side branches, the **zygophores**, towards it. The tips touch and press together.
2. **Progametangia form.** The tips of the touching zygophores swell into club-shaped **progametangia**, each filled with cytoplasm and many nuclei.
3. **Gametangia are cut off.** A cross wall forms near the tip of each progametangium, cutting it into two parts: the end part, the **gametangium**, and the stalk behind it, the **suspensor**. Each gametangium is a multinucleate cell, one from the + strain and one from the − strain.
4. **Fusion.** The wall between the two gametangia dissolves, and their contents mix. Nuclei from the + gametangium pair with nuclei from the − one and fuse, making **diploid** (2n) nuclei. This fusion of two gametangia is **conjugation**, and the fused cell is a zygote.
5. **The zygospore forms.** The fused cell swells into a round **zygospore** (it forms inside a wall called the **zygosporangium**, and many books use the two names for the same thing). Its wall becomes thick, black and covered in warts. Held between the two empty suspensors, it can lie resting for months, through dryness and cold that would kill the mycelium.
6. **Germination.** When conditions are good again, the diploid nuclei divide by **meiosis**, making haploid nuclei again, and the zygospore cracks open. Out grows a short hypha, the **germ sporangiophore** (promycelium), with a **germ sporangium** at its tip, full of haploid spores. Released, each spore grows into a new mycelium of the + or the − strain, and the cycle begins again.

So the zygospore is the only diploid stage in *Mucor*'s whole life; every other stage is haploid. And while asexual spores make copies, the zygospore mixes the genes of two different strains, so its offspring are new combinations.

Vegetative reproduction

If the mycelium is broken, each piece of hypha with some nuclei can grow into a new mycelium. This is **fragmentation**.

Asexual reproduction by sporangiospores

When the mycelium has fed well, it reproduces asexually, which is the way *Mucor* usually multiplies:

1. Some hyphae grow straight up into the air. Each upright hypha is a **sporangiophore** (“spore-case bearer”).
2. The tip of the sporangiophore swells into a round head, the **sporangium**. Cytoplasm and many nuclei stream up into it.
3. A dome-shaped wall forms across the sporangium, separating a central sterile part, the **columella**, from the outer part. The outer cytoplasm divides into a great many small pieces, each with one or a few nuclei, and each piece grows a wall: these are the **sporangiospores** (or simply spores). They are haploid and are made by mitosis, so they have the same genes as the mycelium.
4. As the spores ripen, the sporangium turns from white or yellow to gray-black. Its thin wall breaks, the spores are set free, and the wind carries them away. A small frill of the broken wall, the **collar**, is often left round the base of the columella.
5. A spore that lands on damp food swells and puts out a **germ tube**, which grows and branches into a new mycelium.

Each sporangium can hold thousands of spores, and a single colony can carry many thousands of sporangia. That is why molds turn up everywhere: their spores are in almost every breath of air.

Some *Mucor* species have two more asexual tricks. When food or water runs short, parts of a hypha fill with cytoplasm, round off behind cross walls and grow thick walls: these **chlamydospores** survive bad times and grow into a new mycelium when things improve. And in some species growing in sugary liquid with little air, the hyphae break into round cells that multiply by budding, like yeast.

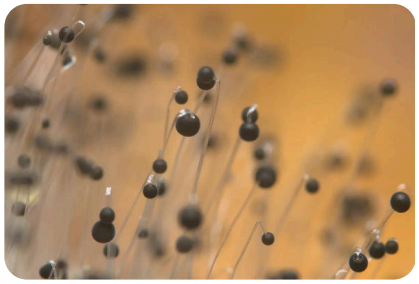


Figure 2.8 *Sporangiophores of Mucor, each ending in a black, ripe sporangium. Each ball is less than a fifth of a millimeter across.*

Photo: Michael Antoni, CC BY-SA 4.0

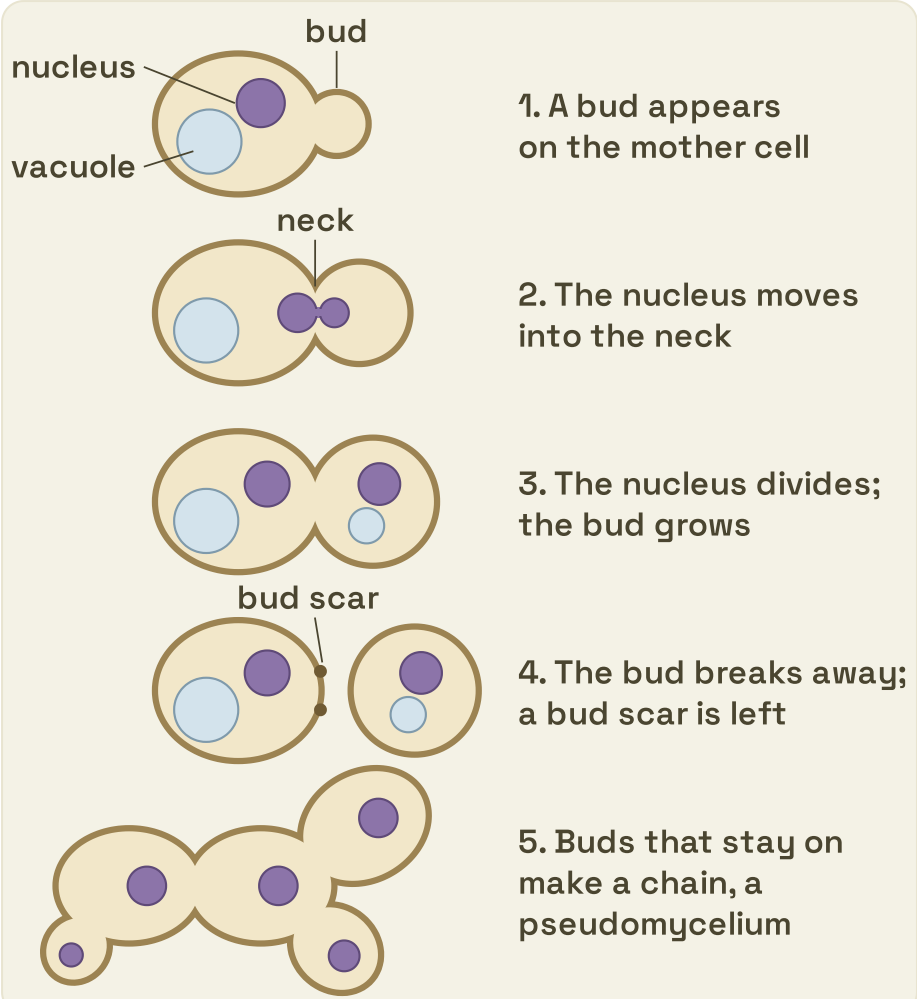


Figure 2.6 *Budding in yeast. A bud grows out of the mother cell; the nucleus divides through the narrow neck, one nucleus going into the bud; a wall forms across the neck and the bud breaks away, leaving a bud scar. Buds that stay attached and bud again form a chain, a pseudomycelium.*

WORKED EXAMPLE

Yeast in a bread dough

A dough has 50 million yeast cells in every gram when it is set to rise. If the yeast doubles every 90 minutes, how many cells are there in each gram after 6 hours?

Answer

$$n = \frac{6 \times 60}{90} = \frac{360}{90} = 4 \text{ generations}$$

$$N = 50{,}000{,}000 \times 2^4 = 50{,}000{,}000 \times 16 = 800{,}000{,}000$$

800 million yeast cells in each gram. (Real dough rises long before the yeast has had time to double many times: the bubbles come from the carbon dioxide each cell makes as it ferments the sugar.)

Check 6

Which feature shows that budding, not binary fission, is happening?

a the parent's DNA is copied

b the offspring have the same genes as the parent

c a small outgrowth forms on the parent and grows before it separates

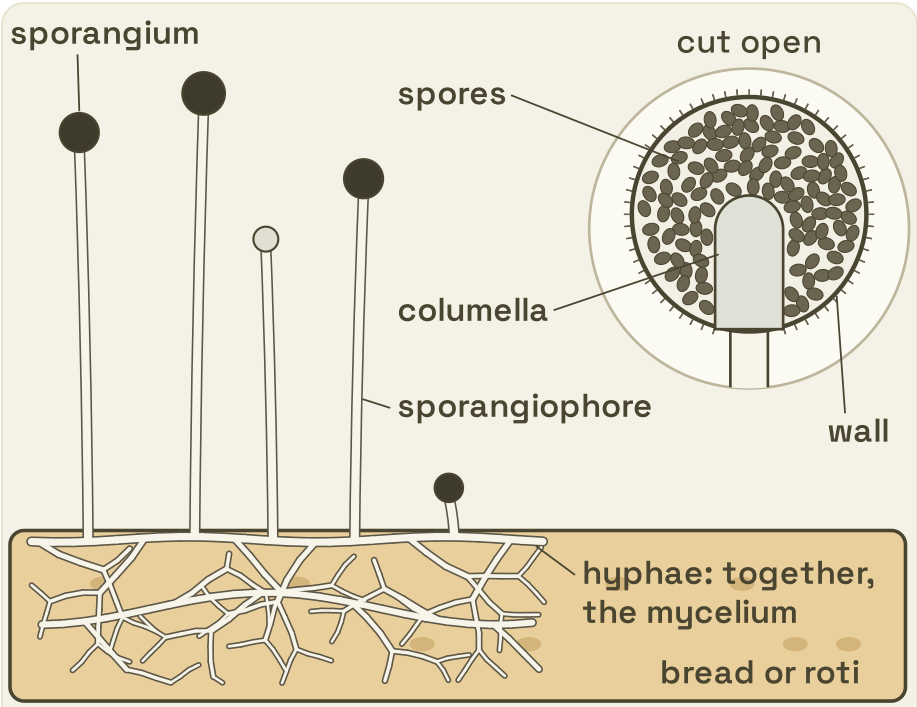
d the process is asexual

2.3 Life cycle of Mucor

Mucor is a common mold, often called pin mold or black bread mold. It grows on damp bread and roti, rotting fruit and vegetables, dung, and soil: wherever there is dead, moist food rich in sugar and starch. It is a **saprophyte**: its threads release enzymes that digest the food outside them, and then absorb the dissolved nutrients. *Mucor mucedo* is the species most books describe.

The body of Mucor

The body of *Mucor* is a **mycelium**, a cotton-like network of fine, branched, white threads called **hyphae**. Each hypha is a tube with a thin wall containing chitin, filled with cytoplasm and many small nuclei. *Mucor*'s hyphae have no cross walls (septa) dividing them into cells: each branched hypha is one long, continuous cell with hundreds of nuclei in it. Such a body is called **coenocytic** (*koinos*, shared; *kytos*, cell). Cross walls form only where reproductive parts are cut off from the rest. Every nucleus in the mycelium is **haploid**: it has one set of chromosomes (n).



Mucor drawn after Brefeld (Dodel-Port Atlas) and Meyers Konversations-Lexikon (public domain)

Figure 2.7 *Mucor growing on bread. Its hyphae run along and into the bread, making a mycelium; upright hyphae, the **sporangiophores**, each carry a round **sporangium** full of spores, around a dome-shaped **columella**. There are no rhizoids.*

CAREFUL

Mucor has no rhizoids

Some books draw *Mucor* with root-like **rhizoids** and with **stolons** (hyphae arching over the surface to root again). Those belong to *Rhizopus*, a close relative and the other common bread mold. *Mucor*'s sporangiophores grow straight from the mycelium, one at a time, with no rhizoids at their base. If you are asked to draw *Mucor*, leave the rhizoids out; if a question shows rhizoids, it is about *Rhizopus*.

Mucor reproduces in three ways: **vegetatively** (fragmentation), **asexually** (spores) and **sexually** (conjugation).