iii. Vaccine and antibiotic

iv. Primary response and secondary response

4. Answer the following questions

a. Describe the role of the skin in the defense of the body.

b. How does the mucous membrane of the respiratory tract protect the body? Draw a labeled diagram of the ciliated lining of the windpipe.

c. What is phagocytosis? Describe its steps.

d. What is an antibody? How are antibodies produced, and how do they help to destroy germs?

e. What is immunity? Describe the kinds of acquired immunity with an example of each.

f. What is vaccination? Write its importance. Name four vaccines in Nepal's immunization program and the diseases they prevent.

g. What are antibiotics? Write their advantages and disadvantages.

h. What is antibiotic resistance? How does it develop, and how can it be slowed down?

5. Apply and think

a. Chickenpox has an R_0 of about 10. A school has 800 students. At least how many of them must be immune to stop chickenpox spreading through the school?

b. Pemba cut his hand on a rusty nail in a cowshed. At the health post he was given an injection of anti-tetanus serum (ready-made antibodies) and his first dose of the tetanus vaccine. Why both? Which kind of immunity does each give?

c. **Think:** Sushant has a runny nose and a sore throat. He asks the pharmacist for "a strong antibiotic, so I get better quickly". What should the pharmacist tell him, and why?

d. **Think:** Simran says, "I was vaccinated against measles, so it doesn't matter to me whether other children are vaccinated." Do you agree? Give two reasons.

Found a mistake? Please tell us.

Unit 5

Applied Biology

This unit online, with its interactives:
science-playground.com/s/9a5

Every breath you take carries a few dust specks, pollen grains and bacteria into your nose. Every handful of food has bacteria on it; every scratch on your knee lets some in. Thousands of the germs around you could make you ill, and a few could kill. Yet most of the time you stay well, and when you do fall ill (a cold, a stomach upset, chickenpox), you usually get better on your own within days, and you seldom catch the same disease twice. All the while your body is defending itself, at its surface and in its blood, and remembering every germ it has beaten.

In this unit you will follow those defenses from the outside in: the skin and the sticky lining of your airways, which keep most germs out; the white blood cells that eat the germs that get in, and the antibodies that mark them; the immunity that remembers, and the vaccines that teach it safely; and the antibiotics that help when the body can't win alone, with the danger that comes from using them carelessly.

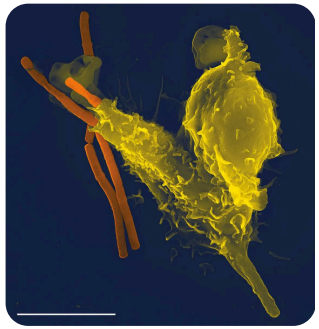


Figure 5.1 *A white blood cell (a neutrophil, yellow) catching anthrax bacteria (orange), seen through a scanning electron microscope, colored by the scientist. The white line is 5 µm: the cell, stretched out as it crawls, is about 12 µm long.*
Photo: Volker Brinkmann, CC BY 2.5

5.1 Role of skin and mucous membrane in defense mechanism of human body

Germs and the body's three lines of defense

A **pathogen** is a living thing (or a virus) that causes disease: certain bacteria (the ones that cause typhoid, cholera and tuberculosis), viruses (flu, measles, COVID-19, rabies), fungi (ringworm, thrush), protozoa (malaria, amoebic dysentery) and parasitic worms. They get in through the mouth with food and water, through the nose with the air, through cuts and bites in the skin, and through the other openings of the body.

The body's defense against them is called its **defense mechanism**, and it works like the defense of an old city such as Bhaktapur: walls and gates to keep enemies out, guards inside who attack anyone who climbs over, and an army that learns each enemy and comes back stronger. Biologists group it into **three lines of defense**.

Line	What it is	Examples	Works against
First line	barriers at the surface that keep germs out	skin, mucous membranes, mucus and cilia, tears, saliva, stomach acid	every germ alike
Second line	defenders inside that attack any germ that gets past	phagocytes (eating white blood cells), inflammation, fever	every germ alike
Third line	defenders that recognize one particular germ and remember it	lymphocytes and the antibodies they make	one germ at a time

The first two lines are the same for every germ and are ready from birth: they are called **non-specific** or **innate** defenses. The third line is **specific**: it is aimed at one germ, it takes days to get going the first time, and it remembers. That third line is what we mean by immunity in 5.3.

The skin: a wall of dead cells

The **skin** covers about 1.5 to 2 square meters of an adult's body, and is its biggest organ. Its outer layer, the **epidermis**, is made of layers of cells that are pushed up from below, fill with a tough protein called **keratin**, flatten and die. The surface you touch is about fifteen to twenty layers of these dead, flat, keratin-filled cells, packed and

> **viruses**. Advantages: it cures bacterial diseases and makes surgery safe. Disadvantages: side effects, allergy, and **resistance**, which careless use speeds up.

Exercise

1. Choose the correct option

a. Which of these is part of the first line of defense of the body?

- a antibodies
- b neutrophils
- c mucus in the nose
- d memory cells

b. The tiny hairs that sweep mucus up the windpipe are:

- a villi
- b cilia
- c flagella
- d pseudopodia

c. Which white blood cells are the most numerous, and first to arrive at an infection?

- a neutrophils
- b lymphocytes
- c eosinophils
- d basophils

d. The immunity a baby gets from its mother's milk is:

- a natural active immunity
- b natural passive immunity
- c artificial active immunity
- d artificial passive immunity

e. Which of these is a toxoid vaccine?

- a BCG
- b oral polio vaccine
- c tetanus vaccine
- d measles-rubella vaccine

f. Penicillin was discovered in 1928 by:

- a Edward Jenner
- b Alexander Fleming
- c Élie Metchnikoff
- d Selman Waksman

2. Give reasons

a. Smokers often suffer from a cough and chest infections.

b. Pus forms in an infected wound.

c. Vaccination is better than treatment.

3. Differentiate between

i. Innate immunity and acquired immunity

ii. Active immunity and passive immunity

IN SHORT

- The body defends itself in **three lines**: barriers at the surface (first), phagocytes, inflammation and fever (second), both **non-specific** and **innate**; and lymphocytes and antibodies (third), **specific**, with memory.
- **Skin**: a tough wall of dead, keratin-filled cells, constantly shed, dry, slightly acid (sebum and sweat), with friendly bacteria. It protects only while unbroken.
- **Mucous membranes** line the body's openings; **goblet cells** make **mucus**, which traps germs and contains lysozyme and antibodies. In the **windpipe**, **cilia** sweep the mucus up to the throat (the **mucociliary escalator**), where it is swallowed or coughed out. Smoke damages the cilia. Tears, saliva and stomach acid help.
- **White blood cells** defend the body in the blood and tissues. **Inflammation** (redness, heat, swelling, pain) brings them to an infection; pus is mostly dead neutrophils.
- **Phagocytosis**: phagocytes (**neutrophils**, and **macrophages** from monocytes) eat germs in five steps: **chemotaxis, adherence, ingestion** (pseudopodia, **phagosome**), **digestion** (lysosomes, **phagolysosome**), **release** of waste.
- An **antigen** is a foreign molecule that starts an immune response; an **antibody** (immunoglobulin) is a Y-shaped protein of four chains, made by **plasma cells** from **B lymphocytes**, that binds one antigen. Antibodies **neutralize**, **agglutinate**, mark germs for phagocytes and burst them. **Memory cells** remember.
- **Immunity** is innate or acquired; acquired immunity is **active** (own antibodies, slow, long-lasting: after illness or a **vaccine**) or **passive** (ready-made antibodies, immediate, short: from the mother, or antivenom and antiserum). The **secondary response** is faster, higher and longer than the primary.
- A **vaccine** (dead or weakened germ, a part of it, or a toxoid) gives active immunity without the disease (Jenner, 1796). It protects the person and others (**herd immunity**, needing a share $1 - 1/R_0$ immune), and wiped out smallpox (1980). Nepal's program vaccinates every child free.
- An **antibiotic** is a substance from a microbe, or made on its pattern, that kills or stops bacteria (penicillin: Fleming, 1928). It attacks the cell wall, 70S ribosomes or DNA copying, which human cells lack; it has **no effect on**

glued together like the tiles of a roof. Under the epidermis is the **dermis**, with blood vessels, nerves, hair roots, and the **sweat glands** and **sebaceous (oil) glands** that open onto the surface.

The skin keeps germs out in several ways.

1. **A tough physical barrier.** Most bacteria and viruses can't get through unbroken skin: its dead cells have nothing for a virus to infect, and keratin is hard to digest.
2. **Constant shedding.** The dead surface cells flake off all the time, tens of thousands every minute, and germs sitting on them are shed with them. The whole epidermis is renewed roughly every month or two.
3. **Dryness.** Most bacteria need water to multiply, and the surface of the skin is fairly dry.
4. **Acid.** Sweat and the oil of the skin (**sebum**) make the skin's surface slightly acid, about pH 5, an **acid mantle** in which many bacteria grow poorly. Some of the fatty acids in sebum kill bacteria and fungi directly, and sweat carries proteins that kill bacteria.
5. **Friendly bacteria.** Harmless bacteria live on everyone's skin. They use up the space and food there, and some make substances that stop other bacteria, so dangerous ones find it hard to settle.

The skin protects only while it is whole. A cut, a burn, a crack in dry heels, an insect bite or a dirty needle opens the wall. That is why a wound is washed with clean water and soap and kept covered, and why the mosquitoes that bite through skin can carry malaria, dengue and Japanese encephalitis straight into the blood.

Check 1

Why is a burn that has destroyed a large area of skin so dangerous, even after the pain has gone?

a the burn makes the blood acid

b without the skin's barrier, bacteria can easily get into the tissues below

c burned skin makes too much sweat

d the skin's friendly bacteria become harmful

Mucous membranes: a sticky lining at every opening

Wherever the body opens to the outside, at the nose, mouth, throat and windpipe, the gut, the urinary and reproductive passages, and the inside of the eyelids, it is lined not by skin but by a soft, moist **mucous membrane**. (Some handouts and question papers write "mucus membrane". *Mucous* is the word that describes the lining, and

mucus is the liquid it makes. In an exam, write *mucous membrane*: it is the term biology books and dictionaries use.)

A mucous membrane is a thin layer of living cells (an **epithelium**) kept wet by **mucus**, a slippery, sticky liquid made by **goblet cells** scattered among the other cells (they are shaped like a goblet, a wine cup, swollen with mucus at the top). Mucus defends the body in three ways:

- it **traps** dust, pollen and germs like flypaper, so they never reach the living cells beneath;
- it carries **chemicals that kill germs**, such as **lysozyme**, an enzyme that breaks down the cell walls of many bacteria;
- it carries **antibodies** of a kind called IgA, which stick to germs and stop them from attaching to the lining (you will meet antibodies in 5.2).

The mucous membrane of the respiratory tract

About 10,000 liters of air pass through your nose and windpipe every day, and with it dust, smoke, pollen and germs. The respiratory tract has a defense at every step.

- **The nose.** Hairs just inside the nostrils catch large dust specks. The nasal passages are narrow and twisting, so the air swirls against their wet, mucus-covered walls and most particles stick there. A tickle in the nose sets off a **sneeze**, which blows the mucus and what it caught out at high speed.
- **The windpipe (trachea) and the bronchi.** Their lining is a **ciliated epithelium**: tall cells, each with about two hundred tiny hairs called **cilia** on its free surface, with goblet cells among them. The cilia stand in a thin layer of watery liquid, and over them lies a blanket of mucus. Each cilium beats very fast, about twelve to fifteen times a second, with a quick, stiff stroke toward the throat and a slow, bent return. The cilia of neighboring cells beat one after another, in waves, like wind passing over a field of rice, and together they push the mucus blanket, with everything trapped in it, **up** toward the throat, about half a centimeter to a centimeter a minute. This moving carpet is called the **mucociliary escalator**.
- **The throat.** The mucus that arrives in the throat is swallowed without our noticing, and the strong acid in the stomach kills most of the germs in it. Anything that does reach the lower airways sets off a **cough**, a blast of air that throws mucus up and out.

The escalator is easily damaged. **Tobacco smoke** slows the cilia and, over years, destroys them, so a smoker's mucus is no longer carried up: it pools in the airways, and the only way to clear it is to cough (the morning "smoker's cough"), and germs settle

Check 8

Why does using an antibiotic make resistant bacteria more common?

a the antibiotic changes the bacteria's DNA to make them resistant

b it kills the bacteria that aren't resistant, so the few resistant ones survive and multiply

c the body makes antibodies that protect the bacteria

d resistant bacteria eat the antibiotic and grow faster

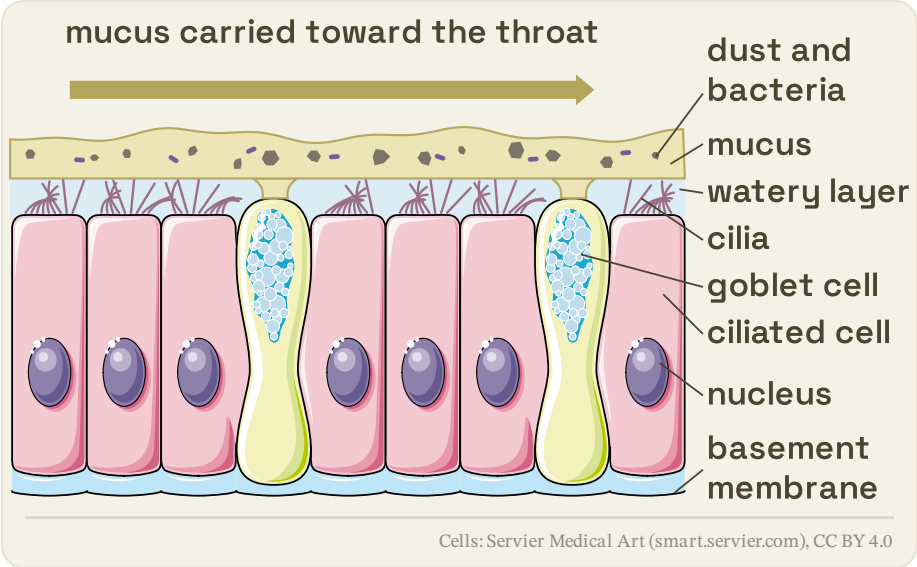
directly caused about 1.14 million deaths in 2021, and forecast more than 39 million such deaths between 2025 and 2050, the most of all in South Asia. In Nepal, as elsewhere, some strains of typhoid, tuberculosis and hospital infections already resist the usual drugs, so patients need costlier medicines that have more side effects, and sometimes nothing works.

What makes it worse: taking antibiotics for colds and flu; buying them at a pharmacy without a doctor's prescription; skipping doses, or stopping them on your own before the doctor said; sharing them or keeping leftovers for next time; giving them to healthy chickens, goats and fish to make them grow faster; and poor hygiene and sanitation, which spread resistant bacteria from person to person.

What everyone can do:

- Use antibiotics **only when a doctor prescribes them**, and never demand them for a cold or flu.
- **Take them exactly as prescribed**: the right dose, at the right times, for as long as the doctor says. Don't stop or change them on your own; if you feel worse or have side effects, ask the doctor.
- **Never share** them or use leftovers.
- **Prevent infections** in the first place: wash hands with soap, drink safe water, keep food clean, and get vaccinated.

> CAREFUL
> **"Finish the course"**
>
> Many books and posters say "always finish the course of antibiotics", as if every last pill must be swallowed whatever happens. Doctors now treat some infections with shorter courses than before, and they sometimes change or stop a medicine (after a side effect, or when a test shows it isn't needed). So the advice today (the UK's NHS, for one) is to **take antibiotics exactly as the doctor or pharmacist tells you, and only ones prescribed for you**: don't stop early, skip doses, or save or share them on your own. In an exam, write "complete the full course prescribed by the doctor; don't stop it early on your own": that is the same advice, and it scores.



Cells: Servier Medical Art (smart.servier.com), CC BY 4.0

Figure 5.2 *The lining of the windpipe (trachea), cut through, much enlarged. Goblet cells make the mucus; the cilia of the ciliated cells, beating in the watery layer beneath it, push the mucus blanket and the dust and bacteria trapped in it up toward the throat. The cells are about 50 µm tall; each cilium is about 6 µm long.*

in it and cause bronchitis and pneumonia more often. **Smoke from wood and dung fires** in a kitchen without a chimney does the same, which is one reason why women and children in such homes in Nepal suffer more chest infections. Cold, dry air also slows the cilia, and some viruses, such as those of flu and the common cold, infect and kill the ciliated cells themselves, so a cold is often followed by a cough that takes weeks to go.



Figure 5.3 *The lining of a small airway seen from above through a scanning electron microscope: each tuft is the cilia of one ciliated cell; the bare surface between the tufts is the top of other cells, among them the ones that make mucus.*

Photo: Charles Daghlian, Public domain

Check 2

In the windpipe, which way do the cilia move the mucus, and why?

a down into the lungs, where white blood cells destroy the germs
b up to the throat, where it is swallowed or coughed out
c round and round, so the germs can't settle
d out through the walls of the windpipe into the blood

Other barriers at the openings

- **Tears** wash the eyes and contain lysozyme, and each blink wipes the eye clean.
- **Saliva** washes the mouth and contains lysozyme too.
- **Stomach acid** (hydrochloric acid, about pH 2) kills most germs swallowed with food, water and mucus. A few, such as the bacteria of cholera and typhoid when swallowed in large numbers, survive it.
- **Urine** flushes the urinary passage, and the vagina is kept acid by its friendly bacteria.
- **Friendly bacteria** in the gut and on every mucous membrane take up the space and food that harmful ones would need. A long course of antibiotics, which kills many of them, can let harmful ones take over (see 5.4).

A STORY FROM SCIENCE

Fleming's cold

In November 1921, the Scottish doctor **Alexander Fleming** had a cold. Out of curiosity he put a drop of his own nasal mucus onto a dish of bacteria, and a few days later saw that the bacteria round the drop had dissolved away. He went on to find the same germ-killing substance in tears, saliva and egg white, and named it **lysozyme**. It was too weak to cure dangerous infections, but it trained his eye: seven years later, when a mold dissolved the bacteria on another of his dishes, he knew at once what he was looking at (see 5.4).

5.2 Role of blood in defense mechanism of human body

Germs that get past the skin and the mucous membranes meet the defenders carried by the blood: the **white blood cells** (**leukocytes**). Unlike red cells, they have a nucleus, and they are not trapped in the blood vessels: they can squeeze out between the cells of a capillary's wall, crawling like an amoeba, to reach an infection in the tissues.

Disadvantages of antibiotics

- **Side effects.** Antibiotics kill the friendly bacteria of the gut along with the harmful ones, so diarrhea is common, and fungi such as *Candida* may overgrow (thrush). Some cause other harm: streptomycin can damage hearing, tetracycline stains the growing teeth of young children.
- **Allergy.** Some people are allergic to an antibiotic, most often penicillin: a rash, and rarely a sudden, dangerous reaction (anaphylaxis). A doctor asks about allergies before giving one.
- **They don't act on viruses**, and taking them when they aren't needed brings only the side effects.
- **Antibiotic resistance.** Above all, every use of an antibiotic helps bacteria become resistant to it, so that it no longer cures the infection.

Antibiotic resistance

Among millions of bacteria, a few, by chance, carry a change in their DNA (a mutation) that lets them survive an antibiotic: an enzyme that breaks it, a pump that throws it out, a wall it can't reach. When the antibiotic is used, the others die and these few survive, and with no competitors they multiply. Bacteria can also pass genes for resistance to one another, even to other kinds of bacteria, on small rings of DNA called **plasmids**. The more an antibiotic is used, and the more carelessly, the faster resistant bacteria spread.

WORKED EXAMPLE

How fast do the survivors multiply?

A course of an antibiotic, taken carelessly (doses skipped, or stopped before the doctor said), leaves one resistant bacterium alive among the dead. In good conditions it divides every 30 minutes. If all its descendants survive, how many are there after 10 hours?

Answer

Number of divisions = 10 hours × 60 ÷ 30 = **20**.
Each division doubles the number, so after 20 divisions: $2^{20} = 1{,}048{,}576$.
So one survivor becomes about **a million** resistant bacteria in ten hours, and none of them will die from that antibiotic. (In the body the immune system and the shortage of food slow this down, but the survivors still take over.)

Resistant infections are among the gravest health problems of our time. A large worldwide study (published in 2024) estimated that bacteria resistant to antibiotics

- **Copying DNA.** Some antibacterial medicines, such as ciprofloxacin, stop the enzymes bacteria use to copy their DNA.

An antibiotic that kills bacteria is **bactericidal** (penicillin); one that only stops them multiplying, so the white blood cells can finish them, is **bacteriostatic** (tetracycline). A **broad-spectrum** antibiotic acts on many kinds of bacteria (tetracycline); a **narrow-spectrum** one on a few (penicillin, mostly on one group).

CAREFUL

Antibiotics don't work on viruses

Viruses have no cell wall, no ribosomes of their own and no metabolism: they use the cell's. So antibiotics do nothing against viral diseases such as the common cold, flu, most sore throats, most diarrhea in children, measles and COVID-19. Taking them for a cold only harms: side effects, and resistance in the bacteria that live in you. A doctor may sometimes give an antibiotic during a viral illness, but that is for a bacterial infection that has come with it or is likely to.

Check 7

Penicillin can kill bacteria in a patient's blood without harming the patient's cells, because:

a human cells are too big for penicillin to enter

b it stops bacteria building their cell wall, and human cells have no cell wall

c human cells make antibodies against penicillin

d it works only outside the body

Advantages of antibiotics

- **They cure bacterial diseases** that once killed: pneumonia, typhoid, cholera, tuberculosis (with several drugs together for months), meningitis, infected wounds, infections after childbirth.
- **They make surgery and modern medicine possible.** Operations, cesarean births, kidney transplants and cancer treatment all carry a risk of infection that antibiotics control.
- **They stop the spread of some diseases**, since a treated patient soon stops passing the bacteria on.
- **They saved millions of lives** and are a big part of the reason people live much longer now than a hundred years ago.
- Some are used to treat bacterial diseases of animals and plants.

A healthy adult has about 4,000 to 11,000 white cells in each microliter (cubic millimeter) of blood, against about 5 million red cells. When there is an infection the body makes more, and a raised white cell count in a blood test is one sign a doctor looks for.

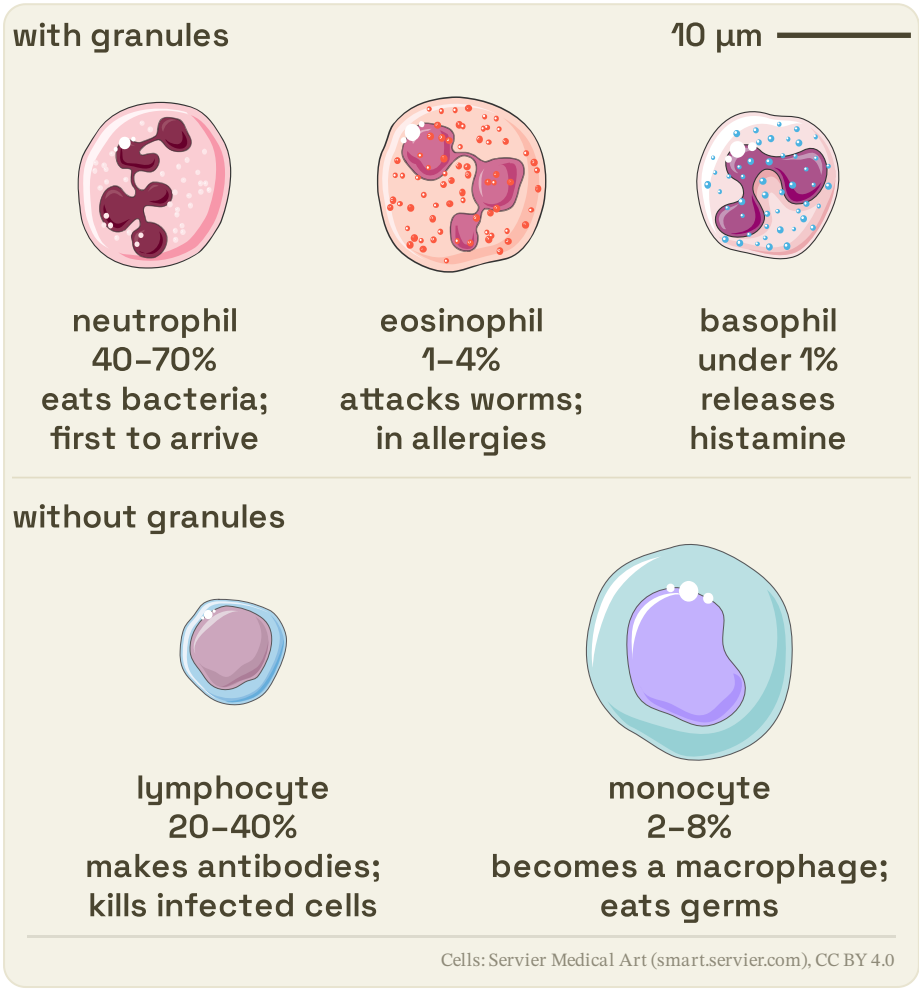


Figure 5.4 *The five kinds of white blood cell, drawn to one scale, with their share of the white cells in healthy blood and their main work in defense. Neutrophils and monocytes are the phagocytes, the cells that eat germs; lymphocytes make antibodies and kill infected cells.*

Inflammation: calling the defenders

Step on a thorn, and within an hour the place is **red, hot, swollen and painful**. This is **inflammation**, the second line of defense at work. Damaged cells, and white cells

called basophils and their cousins in the tissues, mast cells, release **histamine** and other chemicals. These widen the small blood vessels nearby, so more blood flows there (the redness and heat), and make the capillary walls leaky, so plasma and white cells pour out into the tissue (the swelling). The pressure and chemicals on nerve endings cause the pain, which makes you rest the injured part. Within hours neutrophils arrive in great numbers and start eating the bacteria.

If the fight goes on, the dead neutrophils, the bacteria they killed and broken tissue collect as a thick, yellowish liquid: **pus**. A boil or an infected wound full of pus is a battlefield, and the pus is mostly the bodies of the fallen defenders.

When germs spread through the body, the brain raises its temperature: a **fever**. A temperature of a degree or two above the usual 37 °C slows the multiplying of many bacteria and viruses and speeds up the work of white blood cells.

Phagocytosis

Phagocytosis (from the Greek *phagein*, to eat, and *kytos*, a cell) is the process by which certain white blood cells, called **phagocytes**, take in germs, dead cells and other particles, enclose them in a bag of membrane inside the cell and digest them. You met it as a kind of endocytosis in Unit 1.

There are two main phagocytes.

- **Neutrophils** are the most common white cells. They are the first to arrive at an infection, in minutes to hours, in huge numbers, and each eats a few bacteria and then dies, within a day or two. They are the main cells in pus.
- **Monocytes** circulate in the blood for a day or so, then leave it and grow into **macrophages** (“big eaters”), which live in the tissues for months. A macrophage can eat a hundred bacteria, and it also eats dead and worn-out cells (the spleen’s macrophages eat old red blood cells) and clears away the debris of an infection. Macrophages also show pieces of the germs they have eaten to lymphocytes, which helps start the third line of defense.

Phagocytosis happens in five steps.

1. **Chemotaxis (moving toward the germ).** Bacteria and damaged tissue give off chemicals. The phagocyte senses where they are strongest and crawls toward them, squeezing out of the capillaries if it must.
2. **Adherence (attaching).** The phagocyte’s membrane sticks to the bacterium. It grips best when the bacterium is coated with antibodies or other blood proteins, which act like handles.



Figure 5.8 *A sample of the penicillin mold, dried in a brass case behind glass, that Alexander Fleming gave to a colleague in 1935. It is now kept in the Science Museum, London.*

Photo: Science Museum London / Science and Society Picture Library, CC BY-SA 4.0

Antibiotic	Made by	Used against
penicillin	the fungus *Penicillium*	throat infections, pneumonia, syphilis, infected wounds
cephalosporins	the fungus *Acremonium* (*Cephalosporium*)	many infections of the chest, skin, urinary tract
streptomycin	the soil bacterium *Streptomyces griseus*	tuberculosis (the first drug that cured it, 1943)
tetracycline	*Streptomyces* bacteria	cholera, some pneumonias, acne
erythromycin	a soil bacterium, *Saccharopolyspora*	whooping cough, chest infections in people allergic to penicillin

How antibiotics work, and why they don’t harm us

Antibiotics attack parts of a bacterial cell that our cells don’t have, or have in a different form. That is why they can kill bacteria inside the body without killing the body’s cells. You saw these differences in Unit 1.

- **The cell wall.** Bacteria have a cell wall of peptidoglycan; human cells have no cell wall. Penicillin and cephalosporins stop bacteria building their wall, so a growing bacterium bursts.
- **The ribosomes.** Bacterial ribosomes are smaller (70S) than the ribosomes in the cytoplasm of our cells (80S). Streptomycin, tetracycline and erythromycin jam them, so the bacterium can’t make proteins.

5.4 Antibiotics: Introduction, Advantages and Disadvantages

What antibiotics are

Before the 1940s, a scratch from a rose thorn could kill. If bacteria got into it and spread through the blood, doctors had nothing to stop them. Pneumonia, infections after childbirth and infected wounds killed millions every year.

An **antibiotic** is a chemical substance produced by a microorganism (a bacterium or a fungus), or made in a laboratory on the same pattern, that kills bacteria or stops their growth, in amounts small enough not to harm the patient seriously. The word means "against life"; it was given this meaning by the American microbiologist **Selman Waksman** in the 1940s. Antibiotics are one kind of **antimicrobial** medicine; others act against fungi, viruses and parasites.

A STORY FROM SCIENCE

A mold on the dish

In September 1928, **Alexander Fleming** came back to his laboratory in London from a holiday and sorted through a pile of old dishes of *Staphylococcus* bacteria. On one, a blue-green mold had grown, and round it the bacteria had died, leaving a clear ring. The mold was *Penicillium*, and Fleming named the substance it released **penicillin**. He couldn't purify enough of it to use, and it was set aside for a decade. In 1940, at Oxford, **Howard Florey**, **Ernst Chain** and **Norman Heatley** purified it and showed that it cured infected mice, and in 1941 they treated their first patient. Factories in the United States soon made it by the ton, in time to save thousands of wounded soldiers in the Second World War. Fleming, Florey and Chain shared the Nobel Prize in 1945.

Some antibiotics and where they come from:

3. **Ingestion (taking it in).** The phagocyte pushes out arm-like extensions of its cytoplasm, called **pseudopodia** ("false feet"), round the bacterium. Their tips meet and join, and the bacterium is enclosed in a bag of membrane inside the cell, a **phagosome**.
4. **Digestion (killing it). Lysosomes**, the cell's bags of digestive enzymes, join the phagosome to make a **phagolysosome**. Their enzymes, and strong oxidizing chemicals the cell makes, such as hydrogen peroxide, kill the bacterium and break it down.
5. **Release (getting rid of the waste).** The leftovers that can't be digested are carried to the cell's surface and thrown out (**exocytosis**), and the phagocyte is ready to eat again.

Check 3

In phagocytosis, what is a phagosome?

a. a lysosome full of enzymes
b. an arm of cytoplasm that reaches round the bacterium
c. the bag of membrane round a bacterium that has just been taken into the cell
d. the waste a phagocyte throws out

A STORY FROM SCIENCE

The thorns in the starfish

In 1882 the Russian zoologist **Élie Metchnikoff** was in Messina, in Sicily, watching the larvae of starfish under his microscope: they are transparent, so he could see their cells move. One day, he wrote later, an idea struck him: perhaps the wandering cells he saw inside them defended the body. He stuck a few small thorns into some larvae, and by the next morning the thorns were surrounded by crowds of the moving cells. They were named **phagocytes**, "eating cells". For years other scientists thought only chemicals in the blood fought germs, and the argument was fierce. In 1908 Metchnikoff shared the Nobel Prize with Paul Ehrlich, who had worked on the chemicals: both were right.

Antibody production

Phagocytes eat almost any germ, but they don't learn. The third line of defense does, and it is the work of the **lymphocytes**.

Every germ carries on its surface particular molecules, mostly proteins and sugars, that are foreign to the body. A molecule that the body recognizes as foreign and that

starts an immune response is called an **antigen**. The outer protein of a virus, the cell wall of a bacterium, the toxin a bacterium releases and the pollen that causes hay fever are all antigens.

There are two main kinds of lymphocyte, both made in the bone marrow.

- **B lymphocytes (B cells)** make antibodies.
- **T lymphocytes (T cells)**, which mature in a gland in the chest called the **thymus**, either direct the response (**helper T cells**) or kill the body's own cells that have been infected by a virus (**killer T cells**). HIV, the virus that causes AIDS, destroys the helper T cells, which is why people with untreated AIDS die of infections a healthy body would beat.

An **antibody** is a Y-shaped protein, made by B cells, that sticks to one particular antigen and helps to destroy it. Antibodies are also called **immunoglobulins** (Ig). Each one is made of four protein chains, two long **heavy chains** and two short **light chains**, held together in the shape of a Y. The tips of the two arms are the **antigen-binding sites**. Their shape fits one antigen, as a key fits one lock, and each kind of B cell makes antibodies with one shape only. Your body has millions of different kinds of B cell, each with its own shape, ready before any germ arrives.

When a germ gets in, antibodies are made in these steps.

1. **Recognition.** Among the millions of B cells, the few whose antibodies fit the germ's antigen bind to it. Helper T cells, which have been shown pieces of the germ by macrophages, recognize it too and switch those B cells on.
2. **Multiplying.** The chosen B cells divide again and again, making a large group (a **clone**) of identical cells, all with the right antibody.
3. **Plasma cells.** Most of them become **plasma cells**, packed with rough endoplasmic reticulum, which pour out antibodies into the blood, each one thousands of antibodies every second.
4. **Memory cells.** Some become **memory cells**, which live for years, sometimes for life, and remember the antigen.

Antibodies then destroy germs in several ways:

- **Neutralization:** they cover the parts of a virus that it uses to enter cells, or the active part of a toxin, so the virus can't infect and the toxin can't harm.
- **Agglutination:** each antibody has two arms, so it can hold two germs at once; many antibodies glue many germs into a **clump**, which can't spread and is easy for phagocytes to eat.



Figure 5.7 *At the District Public Health Office's immunization clinic in Pokhara, a health worker checks a baby's vaccination card before the next dose.*

Photo: Department of Foreign Affairs and Trade, CC BY 2.0

CAREFUL

Vaccines are safe

After a vaccine a child may have a sore arm, a little swelling or a mild fever for a day or two: signs that the immune system is responding. Serious reactions are very rare, far rarer than the harm the diseases do. Some claims spread on social media, such as that vaccines cause autism, have been checked in studies of millions of children and found to be false. And vaccines don't "use up" or weaken a child's immunity: a child meets thousands of antigens every day in food, dust and play.

Check 6

A three-week-old baby can't yet have the measles vaccine. How can vaccinating the people around her protect her?

a the vaccine passes from them to her through the air

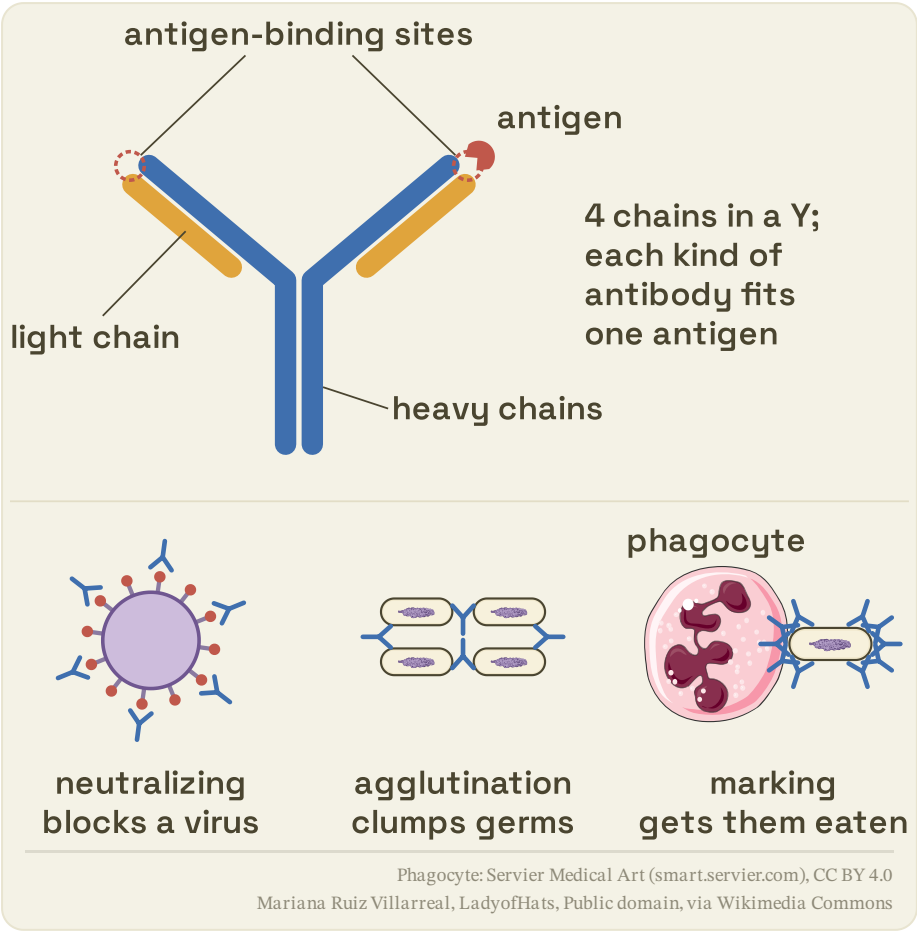
b their antibodies pass to her when they hold her

c if almost everyone around her is immune, measles can't spread to reach her

d the vaccine makes the measles virus weaker everywhere

Age	Vaccines
At birth	BCG (tuberculosis)
6 weeks	pentavalent (diphtheria, whooping cough, tetanus, hepatitis B, Hib) 1; OPV 1 (polio, by mouth); PCV 1 (pneumococcus); rotavirus 1 (by mouth)
10 weeks	pentavalent 2; OPV 2; PCV 2; rotavirus 2
14 weeks	pentavalent 3; OPV 3; fIPV 1 (polio, a small dose injected into the skin)
9 months	MR 1 (measles and rubella); PCV 3; fIPV 2
12 months	Japanese encephalitis
15 months	MR 2; typhoid conjugate vaccine (TCV)
Girls in Grade 6 (out-of-school girls at 10 years)	HPV (against the virus that causes most cervical cancer)
Pregnant women	Td (tetanus and diphtheria), to protect the mother and the newborn from tetanus

Nepal added the typhoid vaccine in 2022, with a campaign in April that vaccinated more than seven million children from 15 months to 14 years old, and the HPV vaccine in February 2025, with a campaign that reached about 1.46 million girls, 94 in every 100 of those it aimed at: girls in Grades 6 to 10, and girls aged 10 to 14 who weren't in school. Since then it is a yearly vaccine for girls in Grade 6, and for 10-year-old girls who aren't in school.



Phagocyte: Servier Medical Art (smart.servier.com), CC BY 4.0
Mariana Ruiz Villarreal, LadyofHats, Public domain, via Wikimedia Commons

Figure 5.5 *An antibody: four protein chains in a Y, with an antigen-binding site at the tip of each arm. Below, three ways antibodies help to destroy germs. One antibody is about 10 nm (a hundredth of a micrometer) across, far smaller than the virus and bacteria it marks: the drawings below are not to scale.*

- **Marking for phagocytes (opsonization):** a germ coated with antibodies is gripped and eaten by phagocytes much faster.
- **Bursting the germ:** antibodies stuck to a bacterium switch on a group of blood proteins (**complement**) that punch holes in its membrane, so it bursts.

The first time the body meets a germ, all this takes about a week, and meanwhile the germ multiplies and you fall ill. The memory cells are why the second time is different, as you will see in 5.3.

CAREFUL

Antigen and antibody

The two words sound alike, but they are opposite partners. The **antigen** is the foreign molecule, on or from the germ. The **antibody** is the body's own protein, made by B cells, that sticks to it. A useful memory aid: the anti**gen gen**erates the antibody response; the anti**body** is made by the **body**.

Check 4

Which cells make antibodies?

a neutrophils
b red blood cells
c plasma cells, which come from B lymphocytes
d macrophages

Check 5

A single antibody can hold two bacteria at once. Which way of destroying germs depends on this?

a neutralization
b agglutination
c phagocytosis
d fever

5.3 Immunity and Vaccination: Introduction and Importance

Immunity

Immunity is the body's ability to resist a disease, by preventing the germ from getting in or by destroying it, or its toxin, before it can cause illness. A child who has had chickenpox is immune to chickenpox: the germ may enter again, but it is destroyed before it can make the child ill.

Immunity is of two kinds.

Innate (natural, inborn) immunity is the defense we are born with: the skin and mucous membranes, the phagocytes, inflammation and fever. It works against all germs alike, starts at once, and doesn't improve with practice or remember a germ.

Acquired (adaptive) immunity is the defense the body gains during life against particular germs, through antibodies and lymphocytes. It is specific, and it has a **memory**. It is acquired in four ways.

than a share $1 - \frac{1}{R_0}$ of the people are immune, each case passes it on to fewer than one other person on average, and the disease dies out.

WORKED EXAMPLE

How many must be immune?

Measles is one of the most catching diseases: one person with measles can pass it to 12 to 18 others who aren't immune. Taking $R_0 = 15$, what share of the people must be immune to stop it spreading? And for a disease with $R_0 = 4$?

Answer

Share needed $= 1 - 1 \div R_0$.

- Measles, $R_0 = 15$: $1 - 1 \div 15 = 1 - 0.067 = 0.933$, about **93%**.
- $R_0 = 4$: $1 - 1 \div 4 = 1 - 0.25 = 0.75$, that is **75%**.

So against measles, more than nine in every ten people must be immune, which is why every child gets two doses of the MR vaccine, and why measles comes back as soon as vaccination slips. A disease that spreads less easily is stopped with a smaller share immune.

YOUR TURN

Polio

For polio, R_0 is about 6. What share of the people must be immune to stop it spreading?

Answer

$1 - 1 \div 6 = 1 - 0.167 = 0.833$: about **83%**, a little over eight people in ten.

Nepal's national immunization program

Nepal began immunizing children in 1979, with BCG and DPT, and its **National Immunization Program** now gives vaccines against 14 diseases, free, at health posts, hospitals and outreach clinics. The vaccines must be kept cold, between 2 and 8 °C, from the factory to the child's arm, through a chain of refrigerators, cold boxes and vaccine carriers on porters' backs and mules: the **cold chain**.

The schedule as of 2026 (it changes as new vaccines are added, so a health post has the latest card):



Figure 5.6 *Edward Jenner (1749–1823), the English doctor who tested the first vaccine, against smallpox, in 1796.*

Photo: Wellcome Collection, CC BY 4.0

The importance of vaccination

- **It protects the person.** A vaccinated child is very unlikely to catch the disease, or gets it only mildly. Vaccines prevent diseases that kill or disable: measles, whooping cough, diphtheria, tetanus, polio, tuberculosis in young children, pneumonia, rotavirus diarrhea, typhoid, Japanese encephalitis, and, with the HPV vaccine, most cancers of the cervix.
- **It protects others: herd immunity.** A disease spreads from person to person. If enough people are immune, an infected person meets too few people who can catch it, the chains of infection break, and the disease dies out. This protects those who can't be vaccinated, such as newborn babies and people too ill to be vaccinated. Protection of the unvaccinated by the immunity of the people around them is called **herd immunity**.
- **It can wipe out a disease.** Smallpox is gone. Wild polio survives only in a few places; the WHO's South-East Asia Region, which includes Nepal, was certified free of polio in 2014.
- **It saves money and suffering.** Preventing a disease costs far less than treating it, and children who aren't sick don't miss school and parents don't miss work.
- **It reduces the use of antibiotics.** Fewer infections mean fewer antibiotics, and so less antibiotic resistance (see 5.4).

How many people must be immune for herd immunity? It depends on how easily the disease spreads, measured by its $\mathbf{R_0}$ ("R-nought"): the number of people one infected person passes it to, on average, in a population where nobody is immune. If more

	Active immunity: the body makes its own antibodies	Passive immunity: ready-made antibodies are given
Natural	after catching a disease and recovering (measles, chickenpox)	a mother's antibodies pass to her baby across the placenta, and in breast milk, above all the first milk, **colostrum**
Artificial	after a **vaccine**	an injection of antibodies made in another person or an animal: **antivenom** for a snakebite, rabies immunoglobulin after a dog bite, anti-tetanus serum

Active immunity	Passive immunity
The person's own B cells make the antibodies.	Antibodies made elsewhere are given.
Takes one to two weeks to develop.	Works at once.
Memory cells are made, so it lasts long, often years or for life.	No memory cells: the antibodies are broken down, and protection fades in weeks to months.
Used to **prevent** disease (vaccines).	Used for **immediate** protection or treatment (after a snakebite or a dog bite), and protects newborn babies.

The first and the second meeting with a germ

When the body meets an antigen for the first time, the **primary response** is slow: for the first several days there are no antibodies against it at all, while the right B cells are found and multiply. Antibodies then rise for one to two weeks, not very high, and slowly fall. Meanwhile the germ has had days to multiply, and the person is ill.

When the same antigen comes again, months or years later, the memory cells are waiting. The **secondary response** starts within a day or two, the antibody level rises much faster and higher, often tens or even hundreds of times higher, and it stays high for much longer. The germ is usually destroyed before it has multiplied enough to cause illness: the person may never know they met it.

WORKED EXAMPLE

Choose the immunity

Name the kind of immunity in each case. a. A girl recovers from measles and never catches it again. b. A farmer in Chitwan bitten by a cobra is given antivenom. c. A baby is protected from measles in her first months by her mother's antibodies. d. A child is given the measles-rubella vaccine at nine months.

Answer

a. **Natural active**: her own body made the antibodies and memory cells, during the illness.

b. **Artificial passive**: the antivenom is antibodies made in horses, given ready-made. It works at once, which is what a snakebite needs, but gives no lasting protection.

c. **Natural passive**: her mother's antibodies crossed the placenta before birth. They fade over the first months of life, which is one reason the measles vaccine is given at nine months.

d. **Artificial active**: the vaccine makes her own body produce antibodies and memory cells.

DID YOU KNOW?

Why you catch colds again and again

If immunity remembers, why do people catch a cold every year? Because colds are caused by more than 200 different viruses, mostly rhinoviruses of about 160 types, each with its own antigens: immunity to one doesn't protect against the others. Flu viruses change their surface antigens a little every year, which is why a new flu vaccine is made each year.

Vaccination

A **vaccine** is a preparation of a dead or weakened germ, a harmless part of it, or its inactivated toxin, which, when given to a person, makes the body produce antibodies and memory cells against that germ, without causing the disease. Giving a vaccine, by injection or by mouth, is **vaccination** or **immunization**. It gives **artificial active immunity**: the body's first meeting with the germ is a safe one, so its first real meeting with the disease is a second meeting, and gets the fast, strong secondary response.

Kind of vaccine	What it contains	Examples in Nepal's program
Live, weakened (attenuated)	the living germ, weakened so it multiplies a little but can't cause the disease in a healthy person	BCG (tuberculosis), oral polio (OPV), measles-rubella (MR), rotavirus, Japanese encephalitis
Killed (inactivated)	the whole germ, killed	polio vaccine by injection (fIPV, a small "fractional" dose into the skin)
Toxoid	the germ's toxin, made harmless by chemicals	tetanus and diphtheria (in Td and the pentavalent vaccine)
Subunit or conjugate	only one part of the germ, its antigen, sometimes joined to a protein to make it stronger	hepatitis B, Hib, pneumococcal (PCV), typhoid (TCV), HPV
mRNA	instructions for the body's own cells to make one antigen of the germ for a short time	some COVID-19 vaccines

A STORY FROM SCIENCE

The milkmaid's cows

Smallpox once killed hundreds of thousands of people a year, and left many survivors blind or scarred. In the 1790s an English country doctor, **Edward Jenner**, heard what milkmaids said: those who had caught **cowpox**, a mild disease, from the cows they milked never caught smallpox. On 14 May 1796 he took matter from a cowpox sore on the hand of a milkmaid, Sarah Nelmes, and put it into two small cuts on the arm of James Phipps, the eight-year-old son of his gardener. James had a slight fever and recovered. On 1 July Jenner inoculated him with matter from a smallpox sore, and he didn't fall ill. (No doctor today would test on a child that way.) The Latin for cow, *vacca*, gave the words **vaccine** and **vaccination**. In 1980, after a worldwide vaccination campaign, the World Health Assembly declared smallpox **eradicated**: the first human disease ever wiped out. The last natural case was in Somalia in 1977.