

Defence against disease

Revision notes • IB Biology C3.2: pathogens, skin and clotting, innate and adaptive immunity, HIV, antibiotics, zoonoses, vaccines, herd immunity and COVID-19 data.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Defence against disease **Spec C3.2**

Pathogens as the cause of infectious diseases **Spec C3.2.1**

A **pathogen** is a disease-causing organism. Pathogens are the cause of **infectious diseases**: diseases that can be passed from one host to another. A broad range of organisms can infect humans, but the term pathogen is typically reserved for four groups.

Groups of pathogen	
Group	Example disease
Viruses	COVID-19, HIV/AIDS, rabies
Bacteria	Tuberculosis, cholera
Fungi	Athlete's foot
Protists	Malaria

Archaea are not known to cause any diseases in humans, even though many live in and on the human body.

Nature of science: careful observation

Careful observation can lead to important progress. In 19th-century Vienna, a doctor observed that childbed fever (an infection after childbirth) was far more common on a ward where doctors came straight from dissecting bodies; making them wash their hands in a chlorinated solution cut deaths sharply. In London, mapping cholera cases during an epidemic showed that they clustered around one water pump, linking the disease to contaminated water. Both led to breakthroughs in the control of infectious disease.

Skin, mucous membranes and blood clotting **Spec C3.2.2, C3.2.3**

Primary defence

The **primary defence** stops pathogens entering the body in the first place.

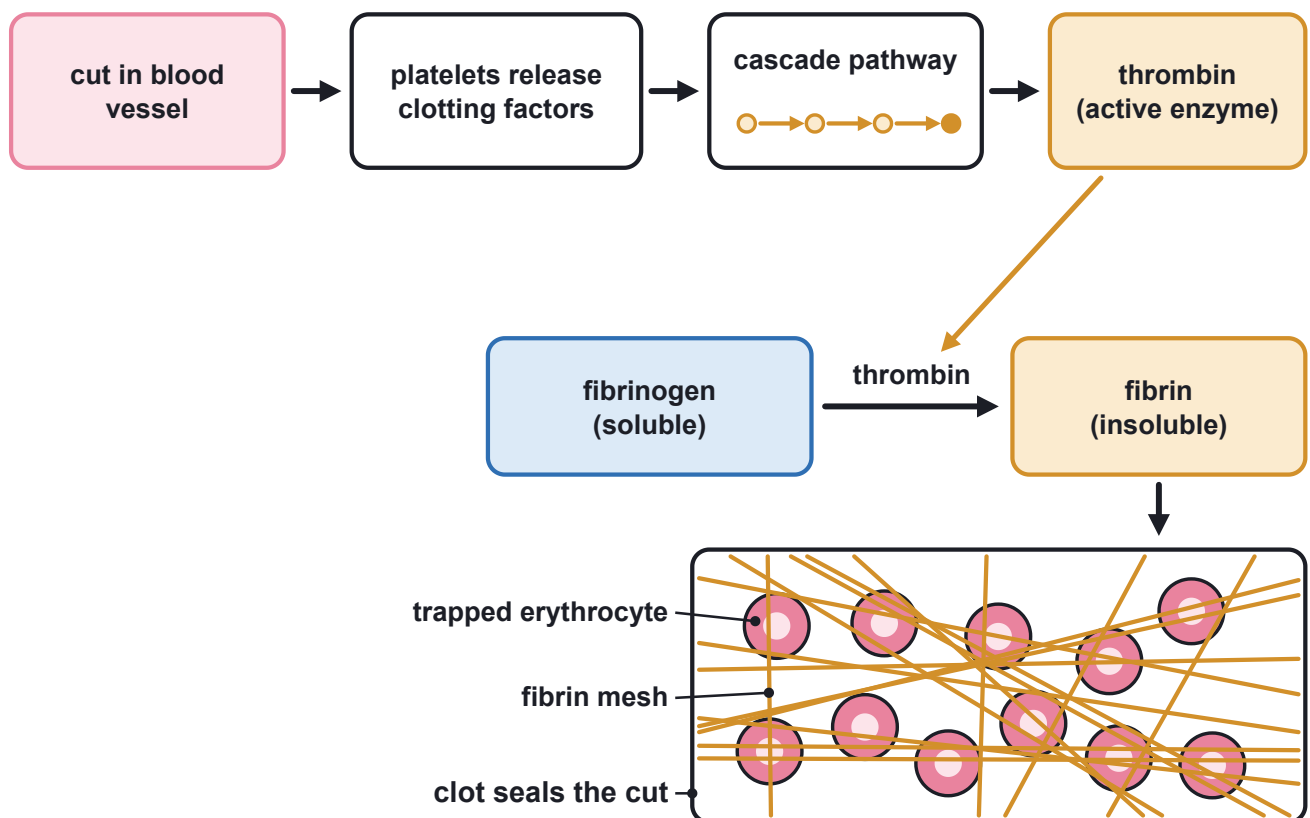
- **Skin as a physical barrier**: the outer layer is made of tough, dead cells packed with keratin, which pathogens cannot easily penetrate. Dead cells are constantly shed, taking microorganisms with them.
- **Skin as a chemical barrier**: secretions from sebaceous and sweat glands contain fatty acids and lactic acid, making the skin surface acidic, and contain antimicrobial chemicals that inhibit the growth of many bacteria and fungi.
- **Mucous membranes** line the airways, gut, urinary and reproductive tracts. They are thinner than skin but secrete sticky mucus that traps pathogens. In the airways, cilia sweep mucus up to the

throat to be swallowed. Mucus, tears and saliva contain lysozyme, an enzyme that digests bacterial cell walls.

Sealing of cuts by blood clotting

A cut in the skin breaks the primary barrier, so it must be sealed quickly. **Blood clotting** does this.

1. Platelets at the site of the cut release clotting factors.
2. The clotting factors start a cascade pathway: a series of reactions, each activating the next, which amplifies the signal.
3. The cascade produces active **thrombin**, an enzyme.
4. Thrombin rapidly converts soluble fibrinogen (a plasma protein) into insoluble **fibrin**.
5. Fibrin forms a mesh of fibres that traps erythrocytes, forming a clot that seals the cut.



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Blood clotting: a cascade produces **thrombin**, which converts soluble fibrinogen into insoluble fibrin.

Exam tip: Students are not required to draw or label diagrams of skin, and no further clotting details beyond platelets, clotting factors, the cascade, thrombin, fibrinogen, fibrin and trapped erythrocytes are required.

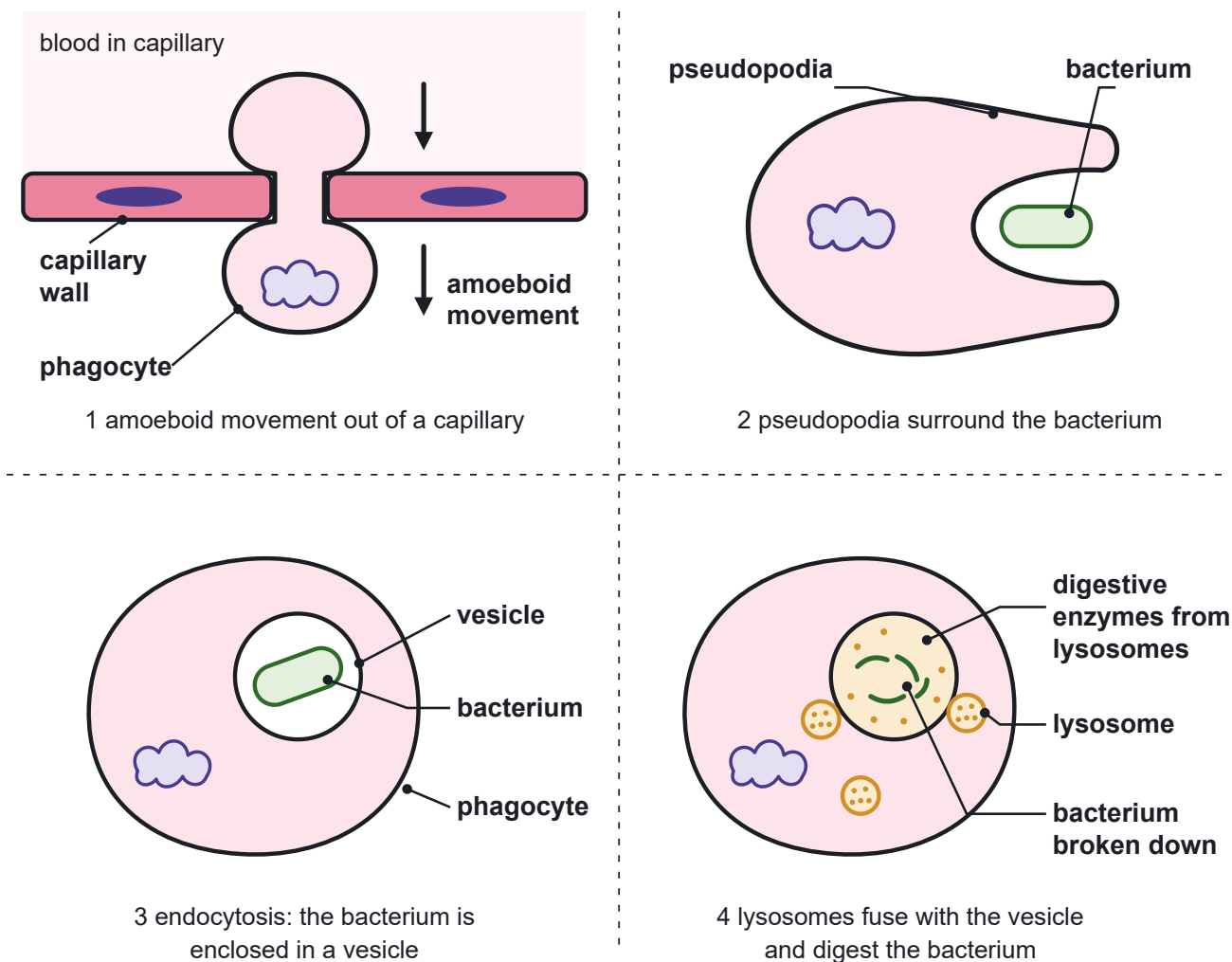
Innate and adaptive immunity, and phagocytes Spec C3.2.4, C3.2.5

Innate and adaptive immune systems		
Feature	Innate immune system	Adaptive immune system
What it responds to	Broad categories of pathogen	Particular pathogens, in a specific way
Change during life	Does not change during an organism's life	Builds up a memory of pathogens encountered
Effect of a second infection	Same response as the first time	Response becomes faster and more effective
Cells	Phagocytes	Lymphocytes (B-cells and T-cells)

Both systems work together: the innate system responds immediately to any infection, while the adaptive system takes longer the first time but produces a targeted response with long-term **memory**.

Infection control by phagocytes

1. Phagocytes circulate in the blood. At a site of infection they squeeze out of capillaries through gaps between the wall cells by **amoeboid movement**.
2. They move through the tissue to the pathogens and recognize them as foreign.
3. The phagocyte engulfs the pathogen by **endocytosis**, enclosing it in a vesicle.
4. Lysosomes fuse with the vesicle and release enzymes that digest the pathogen.



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Phagocytosis: **amoeboid movement**, engulfing by **endocytosis**, then digestion by enzymes from **lysosomes**.

Exam tip: Phagocytes are the only components of the innate immune system you need to know. Use the words **amoeboid movement**, **endocytosis** and **lysosomes** in answers.

Lymphocytes, antigens and antibody production Spec C3.2.6, C3.2.7, C3.2.8, C3.2.9

Lymphocytes

Lymphocytes are the cells of the adaptive immune system. They both circulate in the blood and are contained in lymph nodes. An individual has a very large number of different **B-lymphocytes** (B-cells), each able to make one specific type of antibody. Lymphocytes cooperate to produce antibodies.

Antigens

An **antigen** is a recognition molecule that triggers antibody production. Most antigens are glycoproteins or other proteins, usually located on the outer surfaces of pathogens. Each antibody has a binding site with a shape complementary to one antigen.

Antigens on the surface of erythrocytes (for example the A and B antigens of the ABO blood groups) may stimulate antibody production if transfused into a person with a different blood group. For example, a Rhesus-negative person given Rhesus-positive blood makes antibodies against the Rhesus (D) antigen. In the ABO system, a person already has antibodies against the A or B antigen they lack (a person with group A has anti-B), so a mismatched transfusion makes the donated erythrocytes clump (agglutinate).

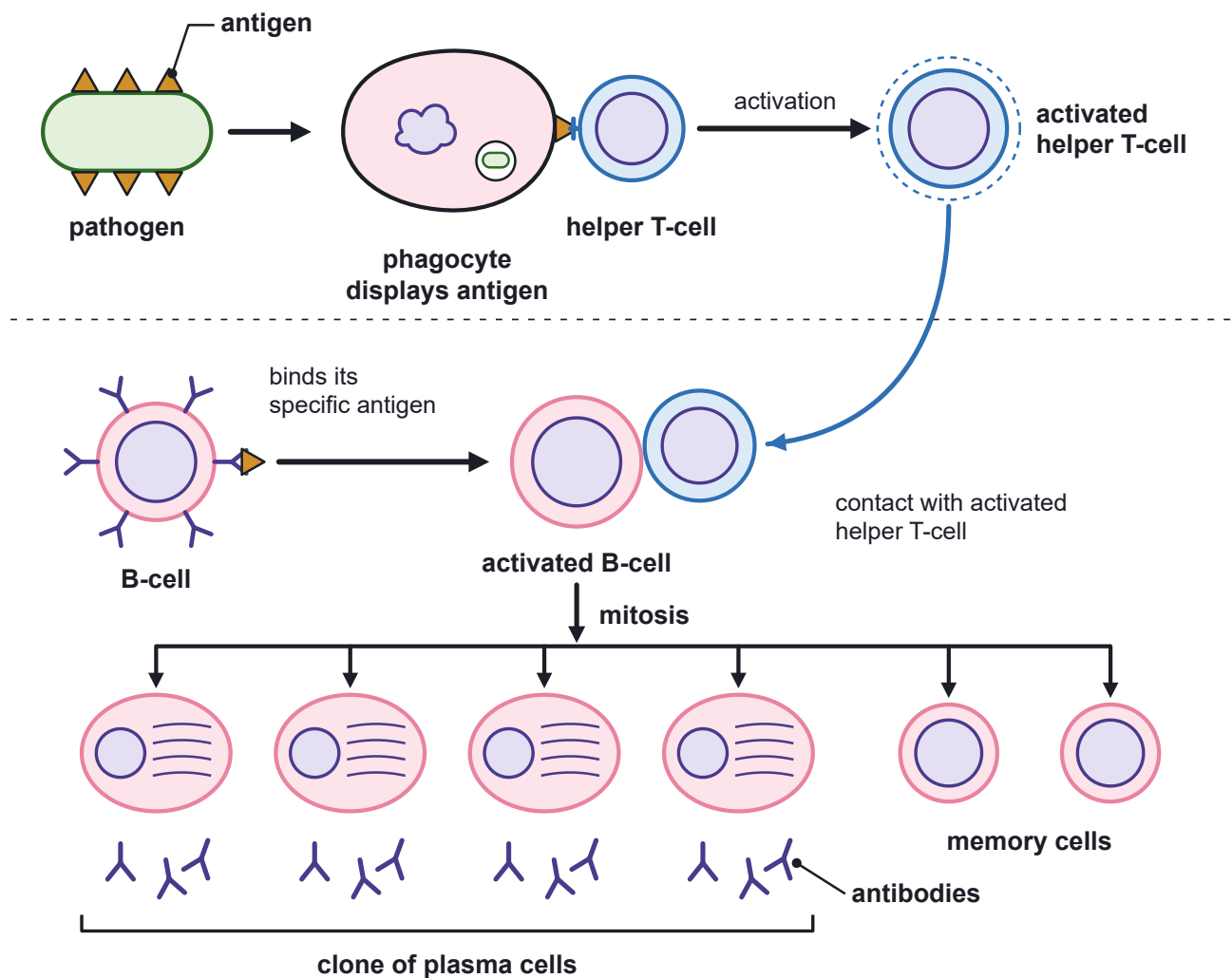
Activation of B-lymphocytes

There are antigen-specific B-cells and antigen-specific **helper T-cells**. B-cells produce antibodies and become memory cells only when they have been activated. Activation requires both:

- direct interaction of the B-cell with its specific antigen, and
- contact with a **helper T-cell** that has also become activated by the same type of antigen (helper T-cells are activated when they bind the antigen, for example displayed on the surface of a phagocyte that has engulfed the pathogen).

Clones of plasma cells

Only a relatively small number of B-cells respond to a specific antigen. To produce sufficient quantities of antibody, activated B-cells first divide by **mitosis** to produce large numbers of **plasma B-cells** (plasma cells), all capable of producing the same type of antibody. This group of identical cells is a **clone**. Plasma cells have extensive rough endoplasmic reticulum and secrete antibodies into the blood.



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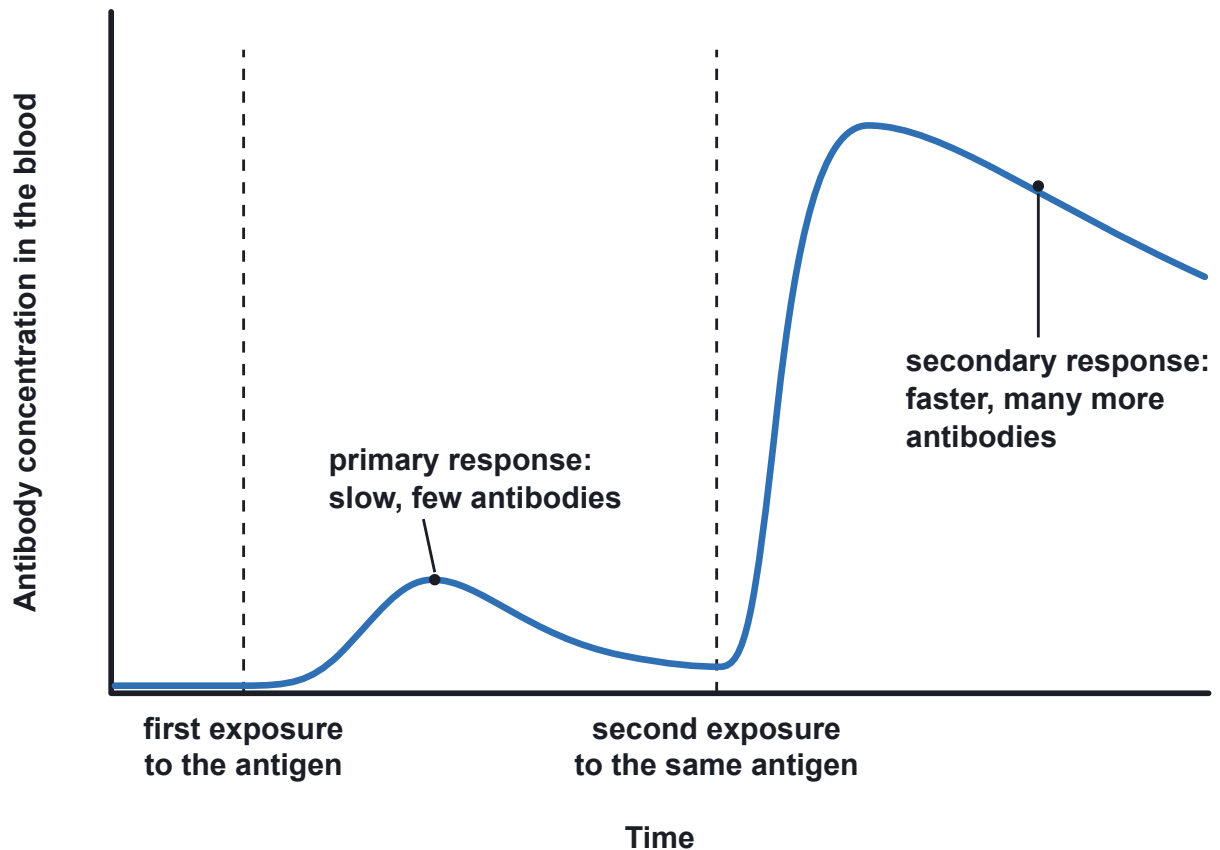
A B-cell is activated by its **specific antigen** and by contact with an **activated helper T-cell**, then divides by mitosis into a clone of plasma cells and memory cells.

Common mistake: Antibodies are made by plasma cells, not by helper T-cells or phagocytes. Helper T-cells activate B-cells but do not make antibodies.

Immunity, vaccines and herd immunity Spec C3.2.10, C3.2.16, C3.2.17

Immunity and memory cells

Immunity is the ability to eliminate an infectious disease from the body. It is due to the long-term survival of lymphocytes capable of making the specific antibodies needed to fight the infection: these are **memory cells**. On a second infection by the same pathogen, memory cells are activated quickly and divide to form plasma cells, so antibodies are produced faster and in greater quantities. The pathogen is usually eliminated before symptoms develop.



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The secondary response is faster and larger because **memory cells** survive from the first exposure.

Vaccines and immunization

A **vaccine** contains antigens, or nucleic acids (DNA or RNA) with sequences that code for antigens. Antigens may be on killed or weakened pathogens, or be purified pathogen proteins. With an mRNA vaccine, the person's own cells use the RNA to make the antigen. Either way, the vaccine stimulates a primary immune response and the development of memory cells, so the person gains immunity to a specific pathogen **without causing the disease**. Immunization is the process of making a person immune, usually by vaccination.

Herd immunity

Members of a population are interdependent in building **herd immunity**. If a sufficient percentage of a population is immune to a disease, an infected person is unlikely to meet a susceptible person, so transmission is greatly impeded and epidemics are prevented. This protects people who cannot be vaccinated, such as newborn babies or people with weakened immune systems. The more transmissible the pathogen, the higher the percentage that must be immune.

Exam tip: Nature of science: vaccines are tested rigorously and the risks of side effects are minimal but not nil. The media often report research while evaluation by other scientists is still happening, so distinguish pragmatic truths from certainty.

HIV transmission and AIDS Spec C3.2.11, C3.2.12

Transmission of HIV in body fluids

HIV does not survive long outside the body, so it is transmitted in **body fluids** that pass directly from one person into another's blood or mucous membranes. Mechanisms of transmission include:

- unprotected sexual intercourse (semen and vaginal fluids)
- sharing hypodermic needles between intravenous drug users (blood)
- transfusion of blood or blood products that have not been screened for HIV
- from mother to baby across the placenta, during childbirth or in breast milk

Infection of lymphocytes and AIDS

HIV infects only certain types of lymphocyte, mainly **helper T-cells**, which it enters and eventually kills. Over several years, the number of helper T-cells falls. Because B-cells need contact with activated helper T-cells to be activated, the reduction in these lymphocytes **limits the ability to produce antibodies**.

The person can no longer fight **opportunistic infections**: infections by pathogens that a healthy immune system would normally control, such as tuberculosis and pneumonia. This condition is AIDS (acquired immunodeficiency syndrome).

Common mistake: HIV does not infect all lymphocytes or directly destroy B-cells. Say it kills helper T-cells, so fewer B-cells are activated and fewer antibodies are made.

Antibiotics and antibiotic resistance Spec C3.2.13, C3.2.14

How antibiotics work

Antibiotics are chemicals that block processes occurring in bacteria but not in eukaryotic cells. Because these processes or structures differ between prokaryotes and eukaryotes, antibiotics can be used to treat bacterial infections without harming the patient's cells.

Examples of bacterial targets	
Process in bacteria	Why human cells are unaffected
Synthesis of the bacterial cell wall (for example blocked by penicillin)	Animal cells have no cell wall
Protein synthesis by 70S ribosomes	Human cytoplasmic ribosomes are 80S, with a different structure
Other bacterial enzymes, for example in DNA replication	Eukaryotic enzymes have different structures

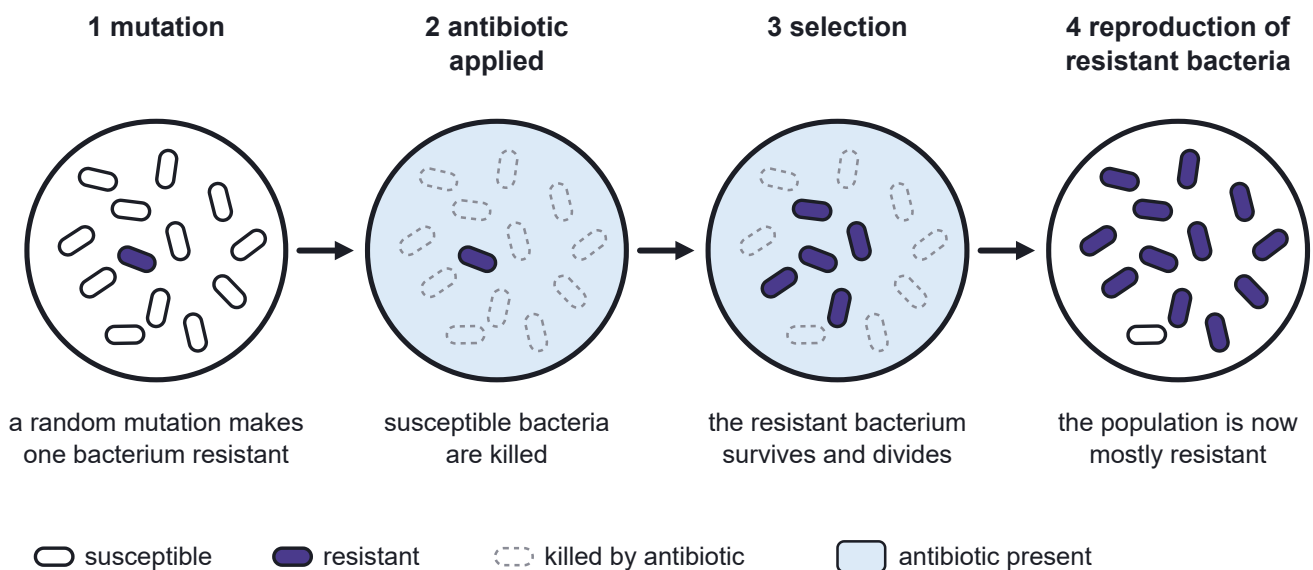
Why antibiotics fail against viruses

- Viruses have **no metabolism of their own**: they have no cell wall, no ribosomes and no enzymes for respiration or protein synthesis for antibiotics to block.
- Viruses use the host cell's own processes to replicate, and blocking these would harm the host's cells.

Evolution of resistance

1. A random mutation gives a bacterium a gene for resistance to an antibiotic, or the gene is gained from another bacterium on a plasmid.
2. When the antibiotic is used, susceptible bacteria are killed but resistant bacteria survive: **natural selection**.
3. Resistant bacteria reproduce rapidly by binary fission, passing on the resistance gene.
4. Repeated use of different antibiotics selects strains with resistance to several antibiotics: multiresistant bacteria.

Careful use of antibiotics is necessary to slow the emergence of multiresistant bacteria: prescribing them only for bacterial infections, completing the prescribed course, avoiding routine use in livestock, and good hygiene in hospitals to stop resistant strains spreading.



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Evolution of antibiotic resistance by **natural selection**: mutation, antibiotic applied, selection, reproduction of resistant bacteria.

Exam tip: Nature of science: new techniques open new avenues of research. Searching chemical libraries (large collections of compounds) is now yielding new antibiotics.

Zoonoses and evaluating COVID-19 data Spec C3.2.15, C3.2.18

Zoonoses

Zoonoses are infectious diseases that can transfer from other species to humans. Many human infectious diseases are zoonoses, and their modes of infection are varied.

Examples of zoonoses

Disease	Pathogen	Mode of infection
Tuberculosis (bovine)	Bacterium (Mycobacterium bovis)	From cattle, through drinking unpasteurized milk or breathing in droplets from infected animals. Most human tuberculosis is now spread from person to person by a related species, Mycobacterium tuberculosis.
Rabies	Virus	Through a bite from an infected mammal, such as a dog or bat, as the virus is in the saliva
Japanese encephalitis	Virus	Through the bite of a mosquito that has fed on infected pigs or wading birds
COVID-19	Virus (SARS-CoV-2, a coronavirus)	Its closest known relatives are coronaviruses found in horseshoe bats. Most evidence points to spillover from animals, possibly through an intermediate host, but the exact route into humans has not been confirmed. It now spreads between humans in respiratory droplets and aerosols.

COVID-19 is an infectious disease that has **recently transferred from another species**, with profound consequences for humans: millions of deaths worldwide, overwhelmed health services, and major social and economic disruption. The IB guide treats it as a zoonosis; how the virus first reached people is still being investigated, so avoid stating a single proven source in answers.

Evaluating COVID-19 data

Pandemic data (cases, hospital admissions, deaths, vaccination rates) are often compared over time or between groups. Two calculations are used:

$$\text{percentage change} = (\text{final value} - \text{initial value}) \div \text{initial value} \times 100$$

$$\text{percentage difference} = |\text{value A} - \text{value B}| \div ((\text{value A} + \text{value B}) \div 2) \times 100$$

Maths skill: Percentage change compares one quantity at two times, so it has a starting value to divide by and a sign (+ for an increase, – for a decrease). Percentage difference compares two values where neither is the starting point, for example two groups or two countries at the same time, so you divide by the mean of the two and the answer is always positive. If a question says 'relative to' one value, divide by that value instead and say so.

Percentage change and percentage difference

Practice data: in one city, weekly COVID-19 hospital admissions fell from 250 to 90 over two months. In the final week, the admission rate was 12 per 100 000 among unvaccinated adults and 3 per 100 000 among vaccinated adults. Calculate the percentage change in admissions, and the percentage difference between the admission rates of the two groups.

1. Percentage change = $(90 - 250) \div 250 \times 100$
2. = $-160 \div 250 \times 100 = -64\%$
3. Mean of the two rates = $(12 + 3) \div 2 = 7.5$ per 100 000
4. Percentage difference = $|12 - 3| \div 7.5 \times 100 = 9 \div 7.5 \times 100 = 120\%$
5. Relative to unvaccinated adults only: $(3 - 12) \div 12 \times 100 = -75\%$

Answer: Admissions fell by 64%. The percentage difference between the two admission rates is 120%; put another way, the rate in vaccinated adults was 75% lower than in unvaccinated adults.

Exam tip: When evaluating pandemic data, consider sample size, how cases were tested and recorded, whether the groups differ in age or health, and that correlation does not prove causation. Linking question: false-positive and false-negative test results can distort case numbers.

Quick check

1. Which four groups of organism is the term pathogen usually reserved for?
2. Which enzyme converts fibrinogen into fibrin?
3. What two things are needed to activate a B-lymphocyte?
4. Why do antibiotics not work against viruses?
5. Name three zoonoses given in the IB guide besides COVID-19.

Quick check answers

Defence against disease

1. Viruses, bacteria, fungi and protists.
2. Thrombin.
3. Direct interaction with its specific antigen, and contact with a helper T-cell activated by the same antigen.
4. Viruses have no metabolism of their own, so there are no bacterial processes to block; they use the host cell's processes.
5. Tuberculosis, rabies and Japanese encephalitis.