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6.3 Defence Against Infectious Disease

IB Biology - Revision Notes

6.3.1 Skin

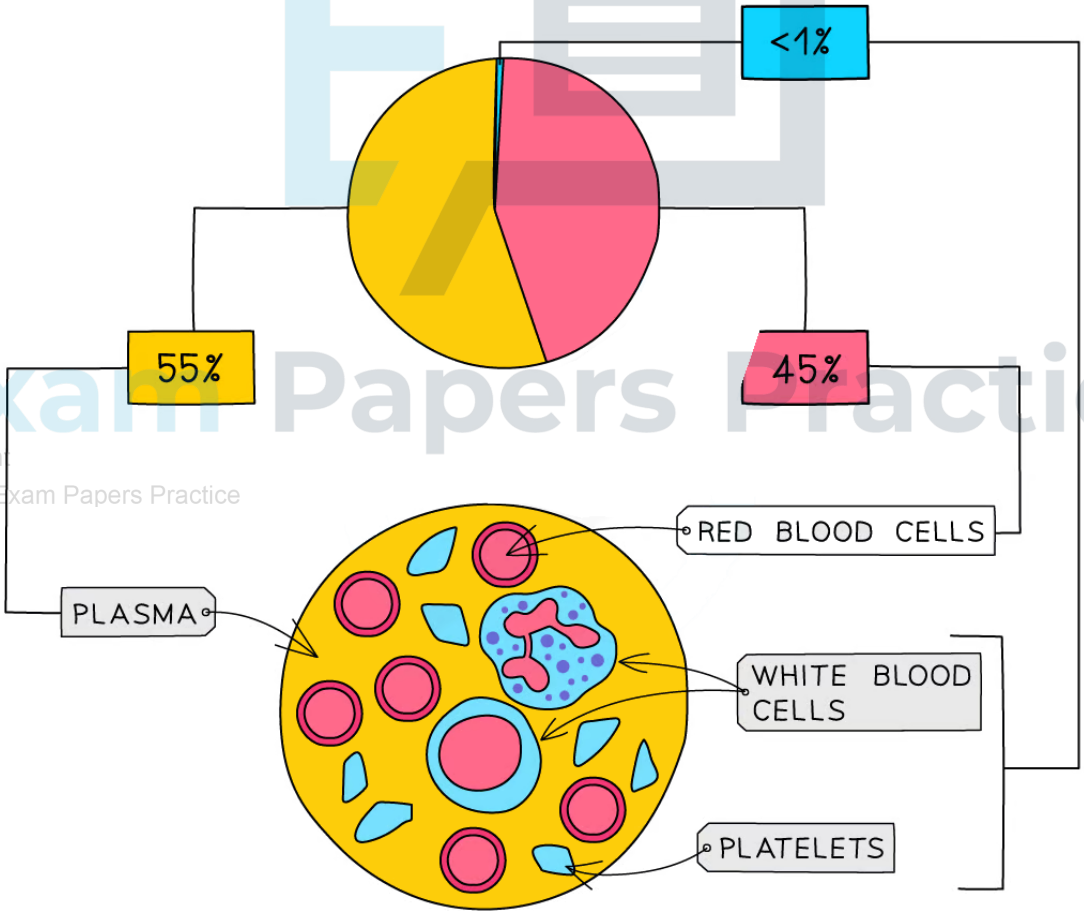
Skin

- The **skin and mucous** membranes form a **primary defence** against pathogens that cause infectious disease
- **Skin** is the largest organ of the body and is covered in **microorganisms** that usually cause no issues, as they can't enter the body. Skin provides:
  - A **tough physical barrier** that prevents entry of pathogens into our bodies
  - Cuts in the skin are sealed by formation of **blood clots** to prevent entry of pathogens
  - **Chemical protection** through the production of **sebum** from the sebaceous glands of the hair follicles
    - Sebum is a chemical responsible for maintaining a **low skin pH** which inhibits the growth of microorganisms
- **Mucous membranes** are found lining vulnerable areas which may be a route for pathogens into the body
  - This includes the **airways**, areas around the **reproductive organs** (foreskin and vagina) and the **digestive system**
- The membranes contain goblet cells which produce mucus containing **glycoproteins**
  - Microorganisms and particles become **trapped** by the mucus and are then either **swallowed** (into the stomach) or **expelled**, therefore preventing infection
  - Mucus also contains **lysozyme enzymes** which have **antibacterial** properties, providing more protection from invading microorganisms

6.3.2 Blood Clotting

Platelets

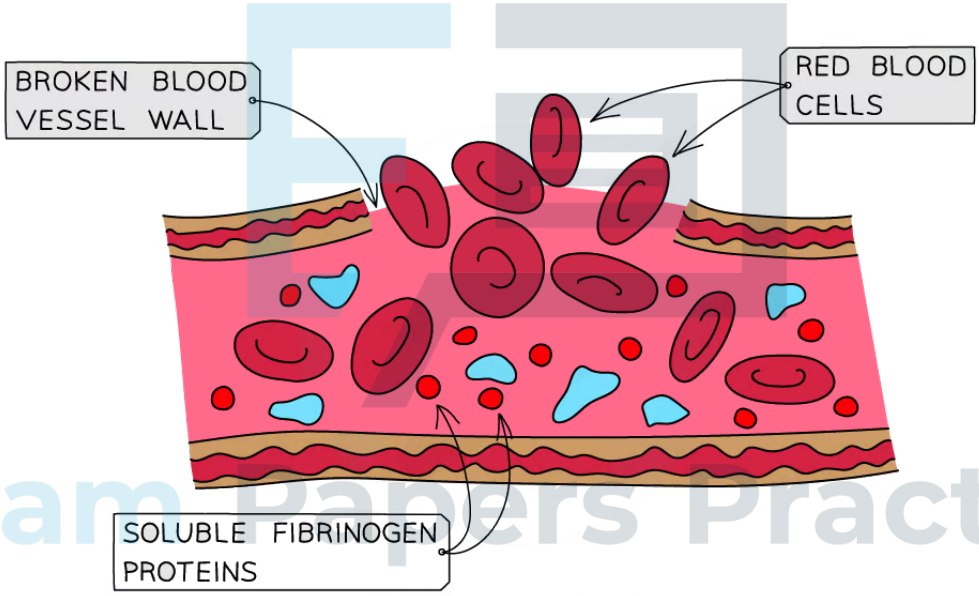
- When the skin is cut, microorganisms have an entry point to get into the body
  - The first line of defence is compromised
- In order to minimise the risk of substantial **blood loss** and entry of **unwanted microorganisms**, the blood starts to clot to **seal the wound**
- In response to **blood vessel damage**, platelets form a temporary **plug** to stem bleeding
  - Platelets are **cellular fragments** that make up one component of the blood
- They release chemicals called **clotting factors** that trigger a **chemical cascade** which results in blood clotting

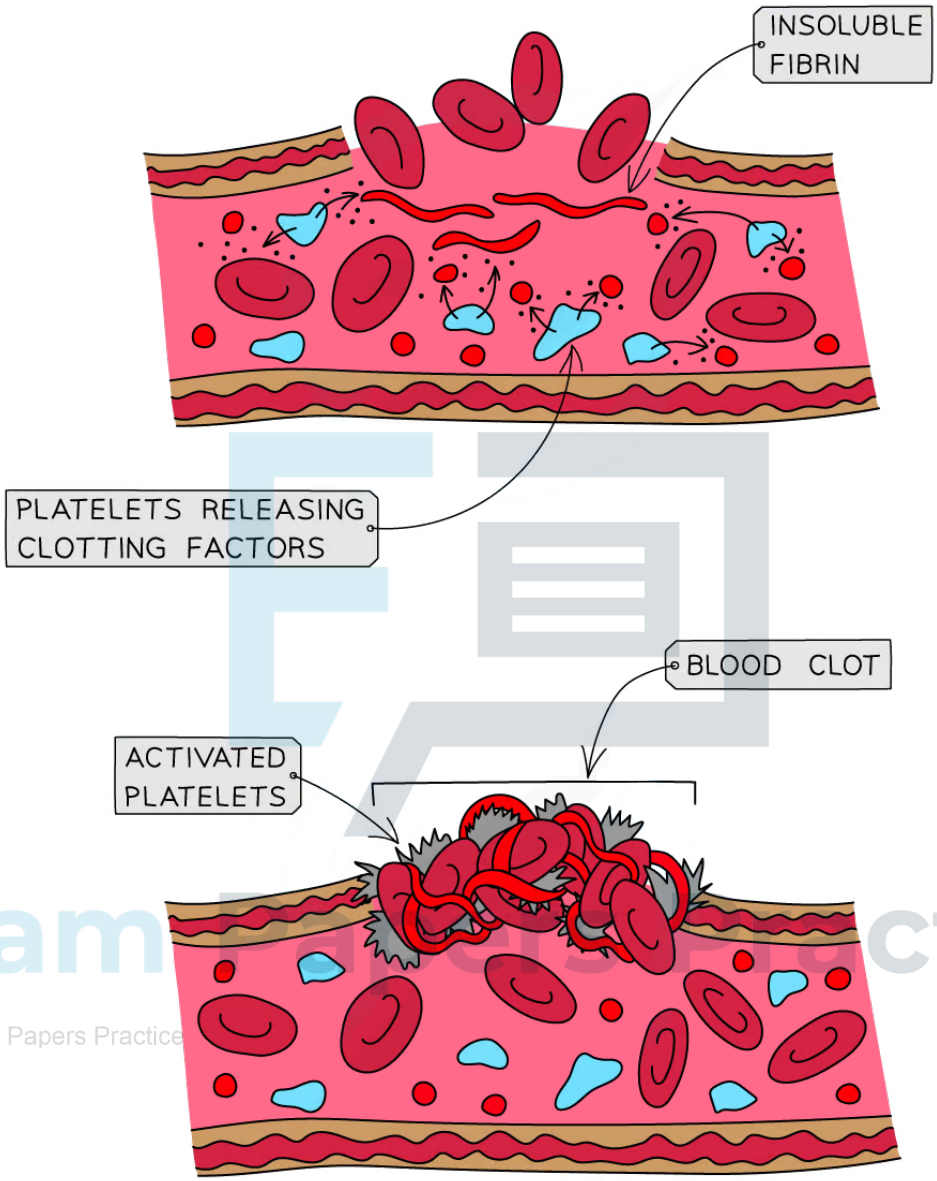


The blood is made up of 4 key components including plasma, red blood cells, white blood cells and platelets

Blood Clotting Proteins

- The chemical cascade, triggered by the clotting factors, involves a large number of steps and several plasma proteins
  - First of all, the **clotting factors** stimulate the release of the enzyme **thrombin**
  - Thrombin catalyses the conversion of the soluble protein **fibrinogen** into **fibrin**, which is insoluble
  - Fibrin forms a **mesh** that traps more platelets and blood cells to prevent entry through the wound
    - A small initial stimulus is **amplified** to produce a large amount of fibrin so that the wound is quickly sealed
  - Exposure to air results in the hardening of the mesh to create a **scab**





Blood clot formation

Clotting in Coronary Arteries

Causes of blood clots in the coronary arteries

- A blood clot in the coronary arteries is called **coronary thrombosis**
- Several factors may **increase the risk** of coronary thrombosis developing:
  - **Atherosclerosis in the coronary arteries** results in a build-up of layers of fatty material (plaque) causing **damage to the endothelium wall**
    - Bulging of **the lumen** of the artery causes a blockage which reduces the space for blood flow
    - Deposition of **calcium ions** can worsen the situation by hardening the endothelium
    - **Lesions** can also sometimes form due to **ruptures** in the atheroma

Consequences of blood clot formation in the coronary arteries

- **Occlusion** of the **coronary arteries** is a common problem that can lead to significant health issues such as **coronary heart disease**
- The coronary arteries deliver **oxygen** and **nutrients** to the cardiac muscle tissue
- If a blood clot forms in the coronary arteries, it can cause **blockages**
- A blockage means that the tissue beyond that point is deprived of oxygen and nutrients, so it is unable to **respire aerobically**
- As a result, cells are unable to produce a **sufficient amount of ATP** which inhibits normal cardiac muscle contraction resulting in **irregular** and **uncoordinated** movement called **fibrillation**
  - If not rectified, either naturally or through medical intervention, fibrillation could lead to **death**
- A **heart attack** (myocardial infarction) may also occur in situations where the blood supply is completely inhibited so that the cardiac muscle tissue starts to die
  - This can be fatal

Risk factors for coronary thrombosis

- There are several factors which have shown a clear **correlation** with increased chances of coronary thrombosis or heart attacks
- The main risk factors for include:
  - **Genetic factors**
  - **Age and sex**
  - **High blood pressure**
  - **Smoking**
  - **High concentrations of low-density lipoproteins (LDLs)**
  - **Diabetes**
  - **Obesity**
  - **Lack of exercise**

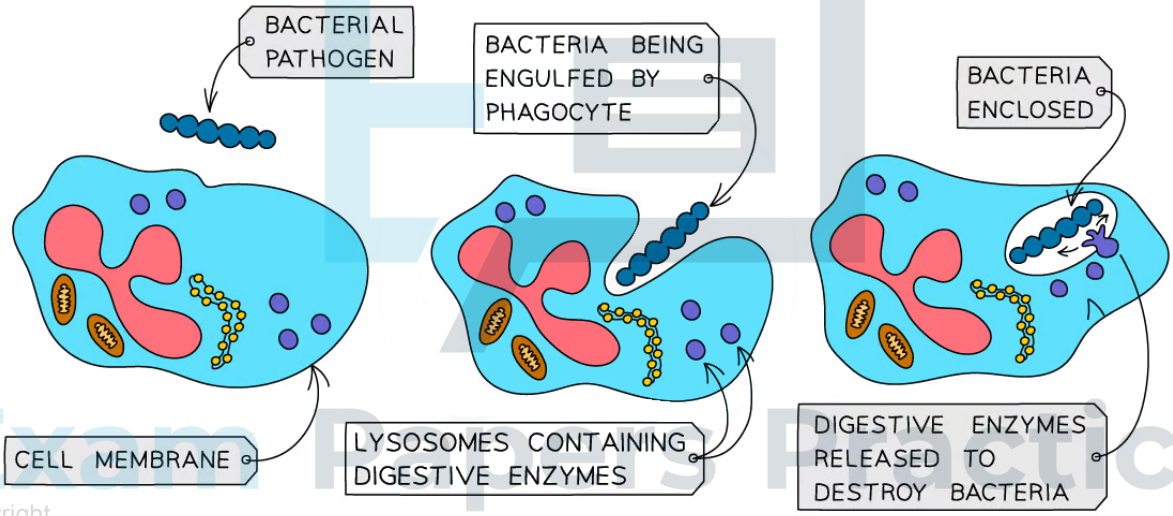
Exam Tip

Remember, **correlation does not prove causation**: There are many contributing factors which will affect the likelihood of developing a coronary thrombosis, as a result, we cannot say that any single factor is **causative**. We can say that there is a **correlation** between that factor and the incidence of coronary thrombosis

6.3.3 White Blood Cells

White Blood Cells

- **Phagocytes** are white blood cells that are produced continuously in the **bone marrow**
- They are responsible for **removing dead cells and invasive microorganisms**; a **non-specific immune response**
- Phagocytes move to the site of infection and attach to pathogens
- The **cell surface membrane** of the phagocyte extends out and around the pathogen, **engulfing it** by **endocytosis**
- They then digest the pathogen using **enzymes** which are stored within **lysosomes** (in their cytoplasm)



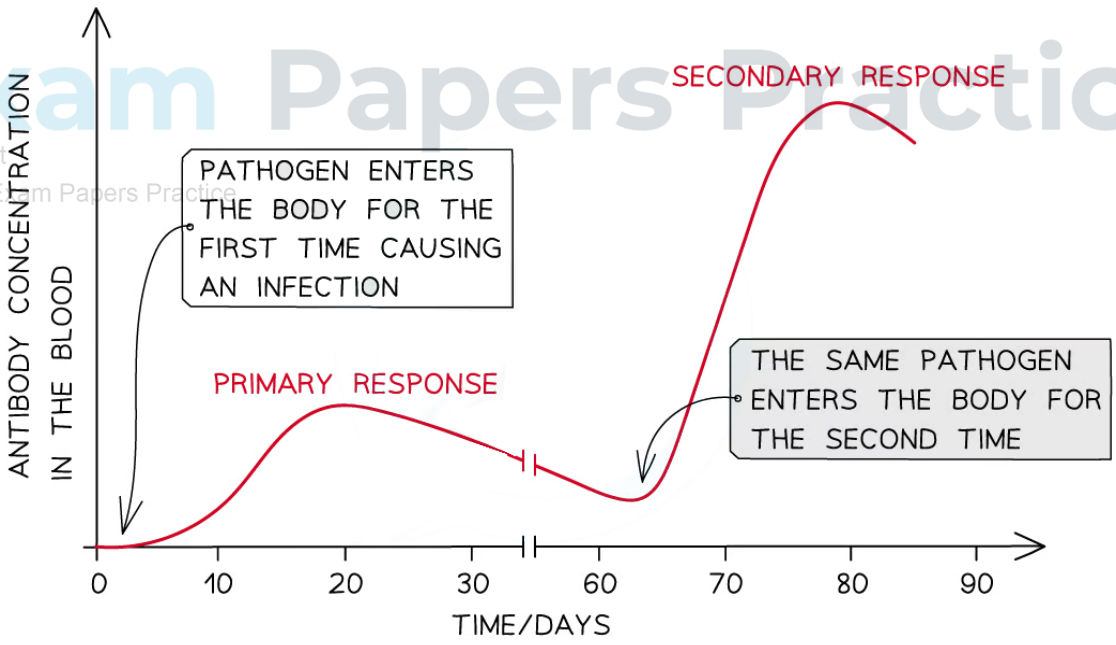
Phagocytic cells ingest pathogens and digest them using enzymes

Antibody Production

- Pathogens possess protein molecules on their cell membranes called **antigens**
- When a **lymphocyte** is exposed to a specific foreign antigen, it will produce specific **antibodies**
  - It is known as a **specific immune response** because one lymphocyte will respond to just **one type of antigen**

- Antibodies have two functional regions:
  - A hypervariable functional region that binds to antigens on pathogens
  - A functional region which aids the body in fighting the pathogen by **labelling the pathogen** (making it easier for phagocytes to find and engulf) and by **preventing virus cells from binding** to receptors on host cells (meaning they cannot enter the cell)

- When activated by a pathogen, lymphocytes clone themselves to produce **plasma cells** which are capable of mass **antibody production**
- Antibodies are only short-lived, degrading within weeks or months and the plasma cells that produced them are lost soon after
- However, **inactive long-living memory cells** are produced which remain in the blood for a long period of time to give **immunity**
- Memory cells allow for the **rapid production of antibodies** after secondary infection
  - If the same pathogen infects for a second time, the inactive **memory cells** will become active and divide to produce **plasma cells** at a rapid rate
  - These plasma cells are able to supply a **large number of antibodies at a rapid rate** to fight the pathogen before symptoms appear



Memory cells allow for the rapid production of antibodies

Effects of HIV on Antibody Production

- **Human Immunodeficiency Virus** is a retrovirus made up of several key components including **RNA** and the enzyme, **reverse transcriptase,** which is used to produce DNA in the host cell
- HIV infects the body and attacks a type of lymphocyte cell called a **T-helper cell**
- T-helper cells are a key component in the production of antibodies, so HIV **inhibits the bodies capacity to produce antibodies**
- In the **early stages of infection**, antibodies are produced to fight HIV, these can be **detected in blood tests**
    - The individual is said to be **HIV positive**

The development of AIDS

- As the **infection progresses**, the ability to produce antibodies significantly reduces
- This renders the immune system unable to fight off other pathogens and so the individual becomes **prone to infection** from other **opportunistic pathogens**
- When the individual is suffering from **several diseases** or conditions at the same time, they are said to have **acquired immune deficiency syndrome** (AIDS)
- **Progression of HIV,** from the initial infection to the development of AIDS, can be slowed down using **anti-retroviral drugs**
    - Due to highly successful drugs, many HIV positive individuals are able to live full-quality lives with normal life expectancies

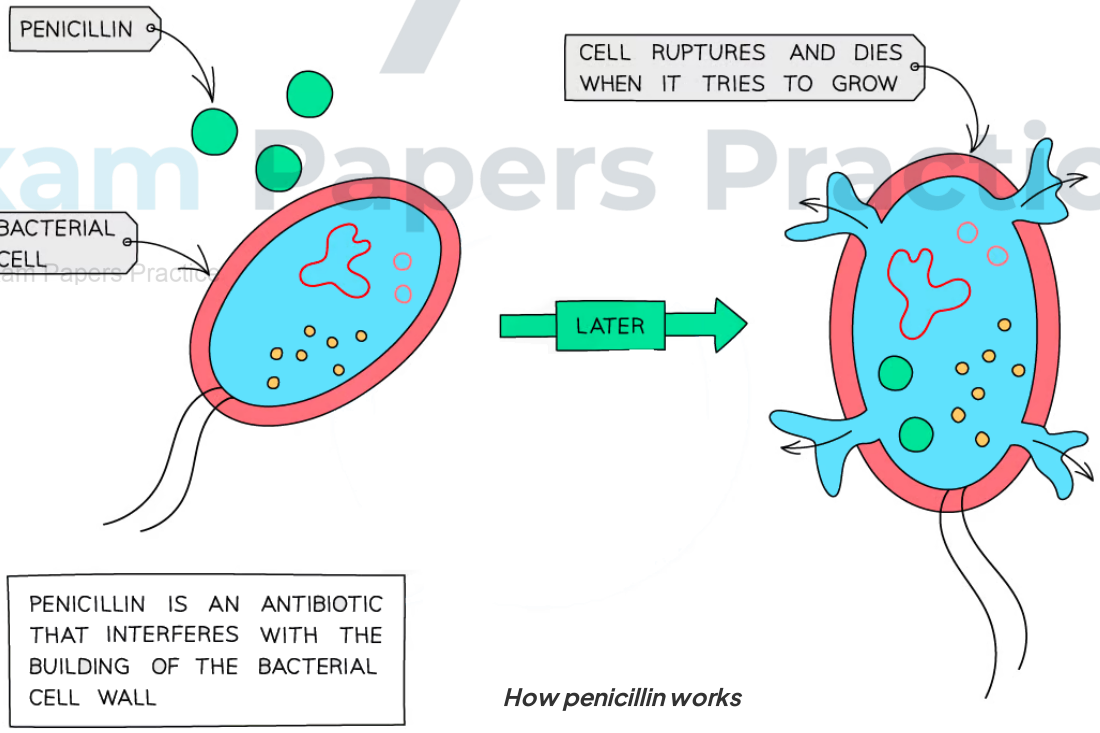
Transmission of HIV

- HIV is unable to survive outside of the human body and so is mainly **transmitted by the direct exchange of body fluids**
    - Viruses need host cells in order to replicate
- This means HIV can be transmitted in the following ways:
    - **Sexual intercourse**
    - **Blood donation**
    - **Sharing of needles** used by intravenous drug users
    - From mother to child **across the placenta**
    - Mixing of blood between mother and child **during birth**
    - From mother to child **through breast milk**

6.3.4 Antibiotics

Antibiotics

- **Antibiotics** are **drugs** that **inhibit the growth** of microorganisms
  - Most antibiotics **kill or stop the growth of bacteria** (prokaryotes) but do not harm the cells of the infected organism
  - This is because they block specific processes that occur in **prokaryotic cells** but **do not have the same effect on eukaryotic cells**
- Processes that might be targeted include:
  - Transcription
  - Translation
  - DNA replication
  - Ribosome function
  - Cell wall formation
- Some antibiotics are derived from living organisms such as saprotrophic fungi
  - **Penicillin** is produced by certain fungi in the genus *Penicillium*
  - When growing in the wild the antimicrobial secretions of the fungus helps it to **compete** by killing nearby saprotrophic bacteria
- Antibiotics can also be made synthetically (in a laboratory)

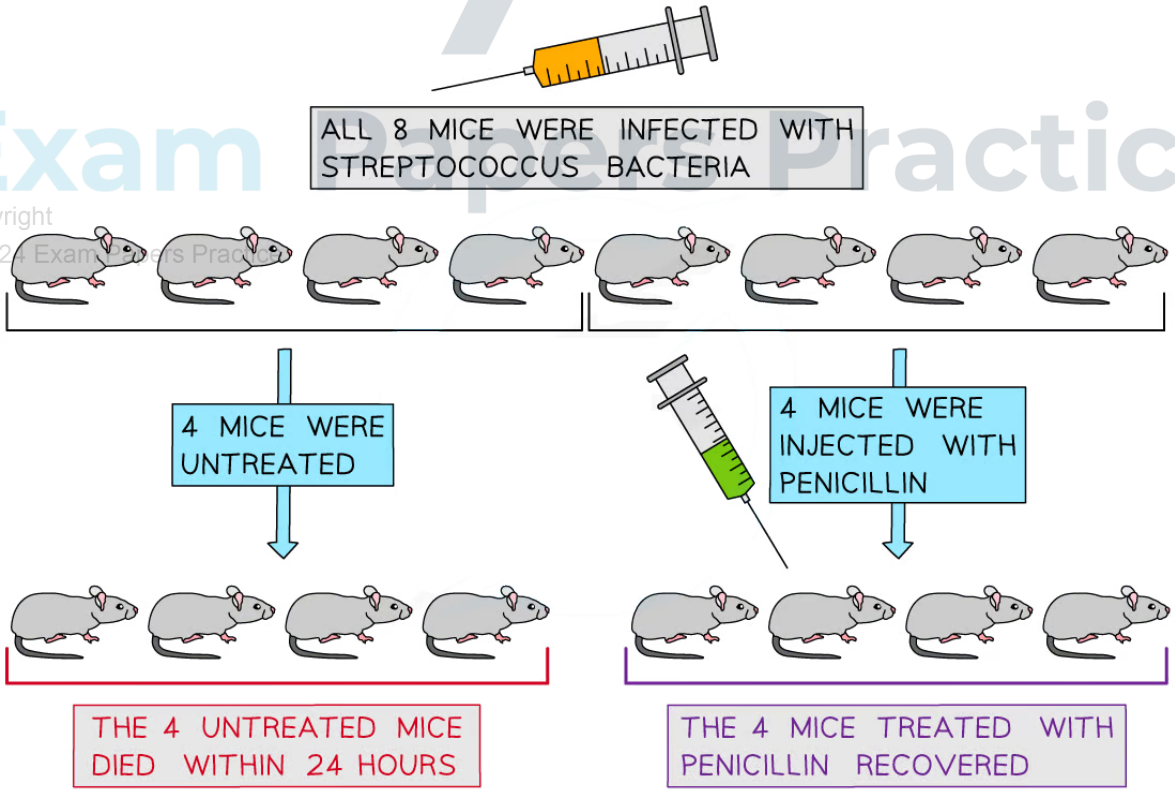


How penicillin works

- Penicillin is not effective against **all bacteria** (eg. *tuberculosis*) because the bacteria may have:
  - **Thicker cell walls** which reduce permeability
  - **Enzymes which breakdown penicillin**
- There are many different examples of antibiotics which are effective against a range of bacterial diseases

Florey & Chain's Experiments

- **Howard Florey and Ernst Chain** carried out experiments to test penicillin on bacterial infections in mice in the 1930s
- First of all, they developed a technique for **purifying and concentrating** penicillin from liquid cultures of *Penicillium*
  - The method they used was very **inefficient** and only produced small quantities of the antibiotic
- Secondly, they showed that Penicillin was effective in preventing bacterial growth on agar plates
- After they had collected this evidence, Florey and Chain used mice to show the effect of penicillin at the level of an organism
  - In order to carry out these tests on mice, the mice first needed to be **infected** with a known bacterial pathogen. A deadly ***Streptococcus* bacteria** was used to develop pneumonia in 8 mice
  - Of these 8 mice, 4 were **injected with penicillin** and 4 were left **untreated**
  - In less than 24 hours, the 4 untreated mice had **all died** whereas those that were treated with penicillin **survived**



Florey and Chain showed that penicillin could aid the recovery of mice infected with Streptococcus bacteria

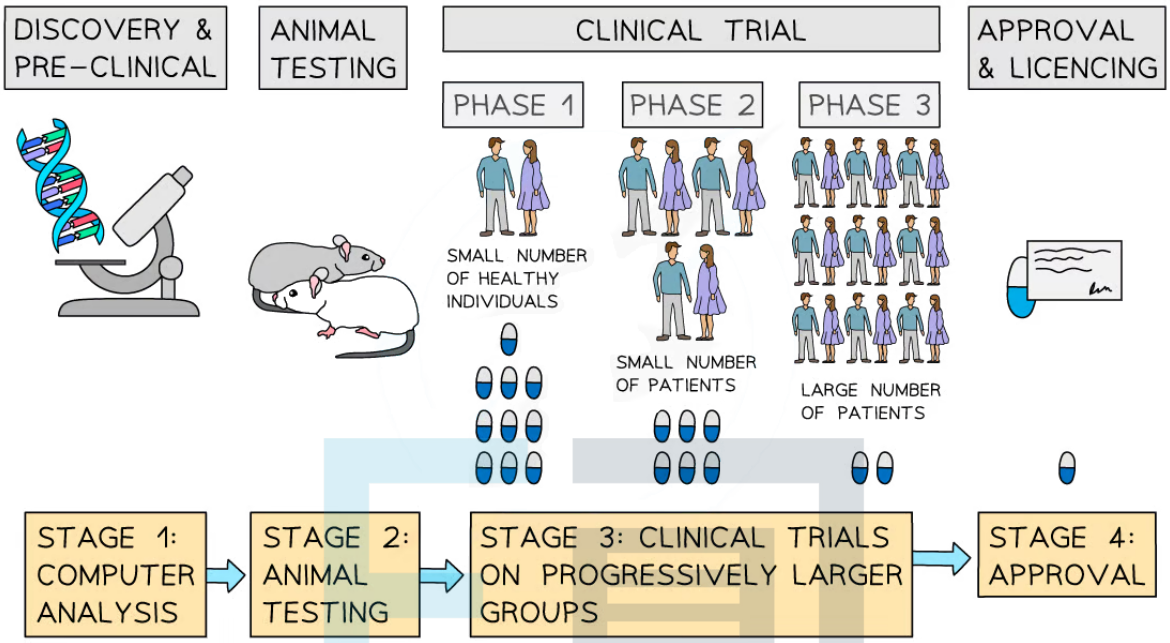
Human tests

- After successful trials using penicillin to treat mice, Florey and Chain were ready to begin testing **human patients**
- It took some time to build up a **large enough supply of penicillin** using their purification techniques
- They then started treatment on their first patient, a policeman who was suffering from a life-threatening bacterial infection resulting from a scratch on his face
- The patient showed improvement but unfortunately, the supply of penicillin was **not enough to complete the treatment** and so the man died of his infection
- Following this, a series of other patients were treated with varying success and Florey and Chain realised that they needed to produce much larger quantities of penicillin than their current capacity
- Larger scale testing and treatment (using penicillin) became possible after an **American pharmaceutical company started mass production**
- It was after this that the true level of efficacy for penicillin was established

Florey & Chain's Experimental Technique

NOS: Risks associated with scientific research; Florey and Chain's tests on the safety of penicillin would not be compliant with current protocols on testing

- New drugs carry new risks as scientists can not always predict how the body may **respond** to the drug, whether the drug will be **effective** or how significant any **side effects** might be
- Before drugs become licenced and available for use, they must go through a rigorous series of tests and trials to **minimise the risks**
- A summary of the procedure is as follows:
  - Initially, after a computer analysis has been carried out on the structure of the drug, trials are carried out with **animals** to see the effect on a whole organism level
  - Next, a **small number of healthy humans** will trial the drug to measure the **toxicity**
  - If these first 2 stages are successful, testing will be carried out on a progressively larger number of **patients** suffering from the target disease
    - In this final stage, the aim is to establish how **effective** the drug is and collect as much information as possible about **side effects**
  - Once the clinical trials are complete, the new drug can be **approved and licenced** for medical use
  - The process usually takes **years** to reach the approval stage
- When Florey and Chain carried out their trials with penicillin, these protocols for safe testing were not in place and their work was only carried out over a matter of **months**
  - This meant that some patients received **treatment very rapidly** for infections that were previously incurable, however, there was a **huge risk** that the new drug, penicillin, could have caused **significant side effects**



New drugs go through a series of tests and trials in order to be approved for medical use

Previous drugs trials

- Carefully designed drugs testing protocols do now exist, but serious problems can still arise
  - **Thalidomide** was a drug that was used in the 1950s to treat a variety of conditions including some cancers and leprosy
    - It was found that thalidomide provided an effective cure for **morning sickness** and so pregnant women were prescribed thalidomide as a treatment
    - The effects of the drug **on a foetus** had **not been tested** and in subsequent years, babies were born with a **range of disabilities** including the absence of limbs, sensory impairment and disfigurement, amongst others
    - It took several years for the link to be made between Thalidomide and the disabilities of the thousands of children who were born
    - Thalidomide was **withdrawn** from use in the early 1960's

  - A drugs trial was carried out in 2006 to test an experimental **leukaemia drug, TGN1412**
    - The drug had **successfully passed the animals trials** where it was given to monkeys, so it moved to the next stage of testing
    - Eight healthy volunteers took part in the trial and after an hour of receiving the drug, six of them were rushed to **intensive care with multiple organ failure**
    - Although they all recovered, the **long term effects** on their immune systems are unknown
    - This is one of the most infamous clinical trial emergencies of modern day

Viruses

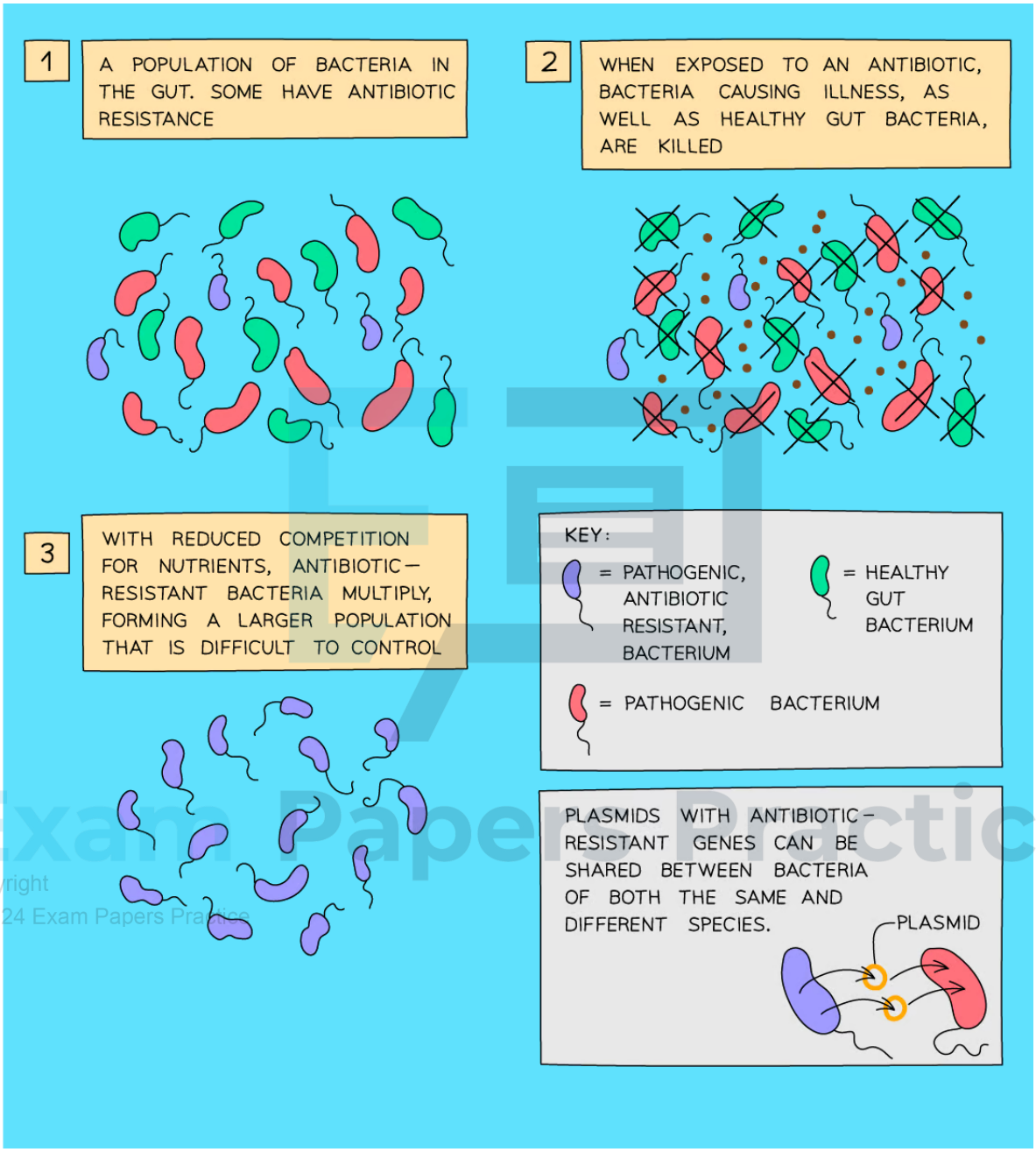
Antibiotics and viruses

- Antibiotics are ineffective against **viruses** as they are **non-living**
- Viruses are **particles** and not cells
  - They have **no metabolism** or cell structure and therefore cannot be targeted in any of the ways that antibiotics target a bacterial cell
- When a virus **replicates**, it uses the **host cell's mechanisms** for transcription, translation and other metabolic pathways, so not even these processes can be targeted as antibiotics do not bind to the proteins that host cells use in these processes
  - Drugs that would target these processes would **damage the host cells** and cause even more harm
- **Antivirals** are drugs that target viral **enzymes** without harming the host cell

6.3.5 Antibiotic Resistance

Antibiotic Resistance

- Within a bacterial population, there is **variation** caused by **mutations** (as occurs in populations of all species)
- A chance mutation might cause some bacteria to become **resistant** to an antibiotic (eg. penicillin)
- When the population is treated with this antibiotic, **the resistant bacteria do not die**
- This means the resistant bacteria can continue to reproduce with **less competition from the non-resistant bacteria**, which are now dead
- Therefore the **genes for antibiotic resistance are passed on** with a much greater frequency to the next generation
  - As bacteria only have one copy of each gene, a mutant gene will have an immediate effect on any bacterium possessing it
- Over time, the whole population of bacteria becomes **antibiotic-resistant** because the antibiotic-resistant bacteria are best suited to their environment
- This is an example of **evolution by natural selection**
- Some pathogenic bacteria have become **resistant to penicillin** as they have acquired **genes that code for the production of the enzyme β-lactamase** (also known as penicillinase), which breaks down penicillin



Bacteria evolve rapidly as they reproduce quickly and acquire random mutations – some of which confer resistance

The future of antibiotic resistance

- Antibiotic-resistant strains are a major problem in human medicine
- New resistant strains are constantly emerging due to the **overuse of antibiotics**
  - By using antibiotics frequently, humans exert a **selective pressure** on the bacteria, which supports the evolution of antibiotic resistance
- Scientists are trying hard to find **new antibiotics** that bacteria have not yet been exposed to, but this process is expensive and time-consuming
- Some strains of bacteria, such as methicillin-resistant *Staphylococcus aureus* (MRSA), can be **resistant to multiple antibiotics** and they create infections and diseases which are very difficult to treat
- When antibiotics were discovered, scientists thought they would be able to **eradicate** bacterial infections, but less than a century later a future is being imagined where many bacterial infections cannot be treated with current medicines

Measures to avoid antibiotic resistance

- Antibiotic resistance in bacteria is an example of natural selection that humans have helped to develop through **incorrect use or overuse** of antibiotics
- Implementation of certain measures can help to avoid antibiotic resistance. These measures may include:
  - Avoiding prescription of antibiotics for **non-serious or non-bacterial infections**
  - **Completing the full prescribed course** of antibiotics to ensure the infection is completely cleared
  - Maintaining **high standards of hygiene** in the hospital environment
  - Minimising use of antibiotics for routine treatment to animals in **agriculture**
  - Development of **new types of antibiotic**