Edexcel International A Level (IAL) Biology

Your notes

Immunity

Contents

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Tuberculosis

- A disease is an **illness or disorder** of the **body or mind** that leads to **poor health**
- Each disease is associated with a set of **signs and symptoms**
- **Infectious diseases** are caused by pathogens and are transmissible, meaning that they can be spread between individuals within a population
  - Pathogens may include certain species of **bacteria**, some **fungi** and **all viruses**
    - Note that not all viruses are pathogenic to humans!
- An example of a pathogen is the bacteria ***Mycobacterium tuberculosis*** which causes the disease **tuberculosis,** also known as **TB**

Transmission of TB

- When infected people with the active form of TB **cough** or **sneeze**, the ***Mycobacterium tuberculosis*** bacteria enter the air in tiny **droplets** of liquid released from the lungs
- TB is transmitted when uninfected people **inhale** these droplets
  - TB spreads more quickly among people living in **overcrowded conditions**
- Once inside the lungs, TB bacteria are **engulfed by phagocytes**
- The bacteria may be able to **survive** and **reproduce** while inside phagocytes
  - Individuals with a healthy immune system will not develop TB at this stage
  - This is known as the **primary infection**
- Over time the infected phagocytes will become **encased** in structures called **tubercles** in the lungs where the bacteria will remain **dormant**
- It is possible for the bacteria to become **activated** and **overpower the immune system** at a later stage, such as during an HIV infection when the immune system is **compromised;** the person will then **develop TB**
  - This is known as the **active phase** of TB
  - The length of time between infection and developing the disease can vary from a few weeks to a few years
- The **first symptoms** of TB will include developing a **fever, fatigue, coughing** and **lung inflammation**
- If left untreated the bacteria will cause **extensive damage** to the lungs which can result in death due to **respiratory failure**
- TB may also **spread** to other parts of the body where it can lead to **organ failure** if not treated promptly

HIV

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Transmission of HIV

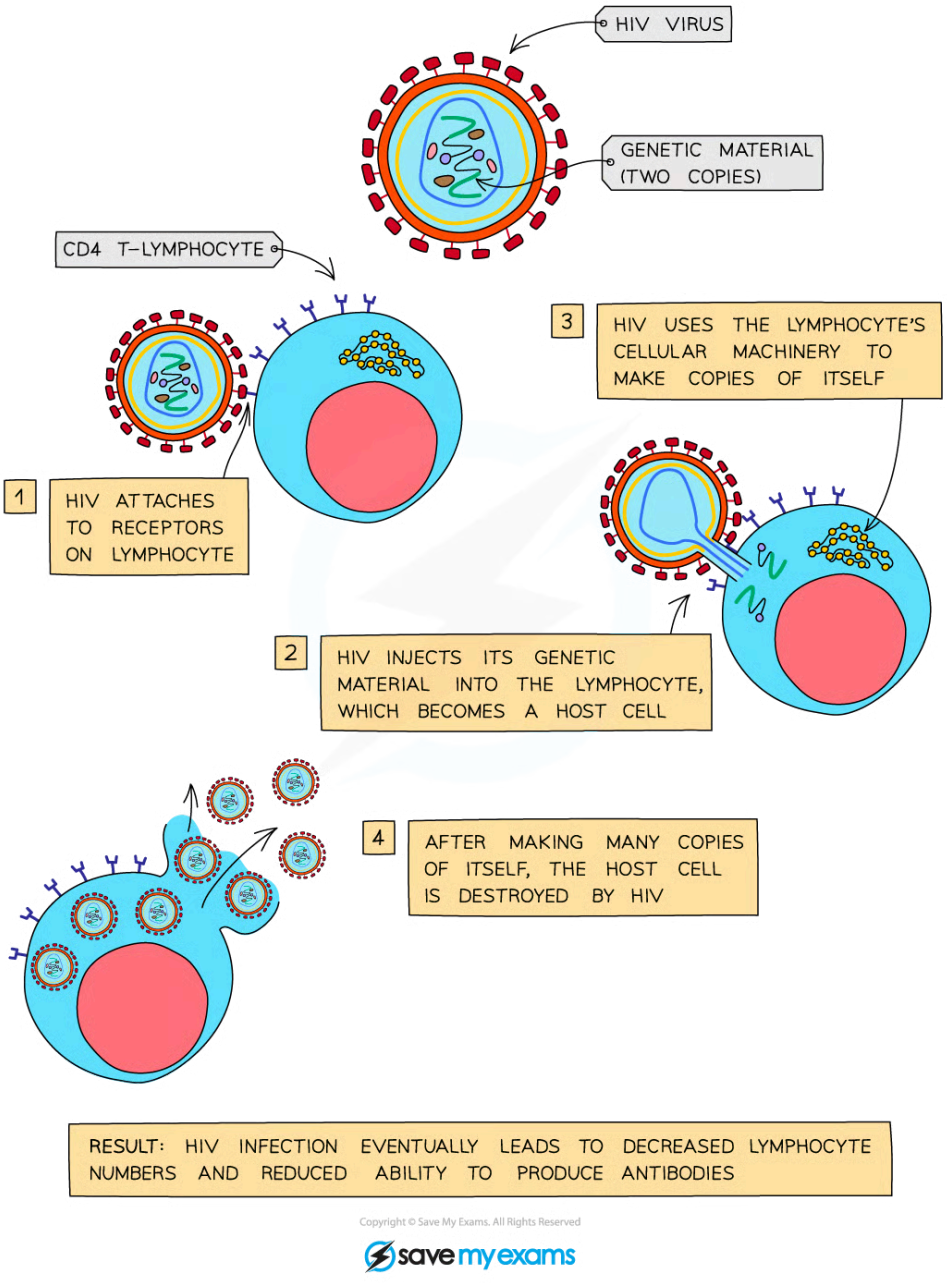
- HIV is the human immunodeficiency virus
  - Be careful **not** to refer to it as the HIV virus, as that would mean that you would be using the word 'virus' twice!
- HIV contains RNA and is a retrovirus
- HIV can be transmitted in body fluids in the following ways
  - Sexual intercourse
  - Blood donation
  - 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

Replication of HIV

- When the virus enters the bloodstream it infects **helper T cells**, a type of **white blood cell** that is normally responsible for activating antibody-producing B cells
  - It enters the helper T cells by **attaching** to a receptor molecule on the host cell membrane
  - The **capsid enters** the helper T cell and **releases the RNA** it contains
  - The viral RNA is used as a template by **reverse transcriptase enzymes** to produce a **complementary strand of DNA**
  - Once this **single-stranded DNA** molecule is turned into a **double-stranded molecule** it can be successfully inserted into the host DNA
  - From here it uses the **host cell's enzymes** to produce more viral components which are assembled to form **new viruses**
  - These **bud from the host cell** and enter the blood, where they can infect other helper T cells and repeat the process
- At this stage, the individual is **HIV positive** and may experience flu-like symptoms
- This is known as the **acute HIV syndrome** stage
- After the initial infection period, during which HIV replication is rapid, the replication rate drops and the individual enters the **asymptomatic** or **chronic** stage
  - During this period the person will not show any symptoms, often for years
- Gradually the virus **reduces the number of helper T cells** in the immune system

- B cells are no longer activated
- **No antibodies are produced**
- The patient begins to suffer from HIV-related symptoms and are now in the **symptomatic disease** stage of the infection

- The lack of T helper cells decreases the body's ability to fight off infections, eventually leading to the final stage of an HIV infection, which is known as **advanced AIDS** (Acquired immune deficiency syndrome)



HIV attaches to helper T cells (also called CD4 T-lymphocytes) and uses their cell machinery to replicate. This leads to decreased lymphocyte numbers which then affects

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the body's ability to respond to infection. Note that HIV should not be referred to as the 'HIV virus' as it is here.

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Symptoms of AIDS

- Immediately after infection with HIV a patient often suffers **mild flu-like symptoms**
  - These symptoms pass and for a period of time **infected people might not know they are infected**
- After several months or years, the viral DNA replicated by the HIV particles becomes active
- Virus particles gradually **destroy and reduce the number of helper T cells** present in a host
- This is detrimental as helper T cells play an important role in the specific immune response
  - They stimulate B cells, the production of antibodies and increased rates of phagocytosis
- As a patient can no longer produce antibodies against pathogens, they are immunocompromised and **unable to fight off infections**
- They begin to suffer from diseases that would usually cause very minor issues in healthy individuals
  - These diseases are described as **opportunistic**
  - *Tuberculosis* (TB) is a common example
- An HIV infection will progress to **AIDS** when
  - An individual starts suffering from constant **opportunistic infections**
  - The helper T cell count **drops** below a critical level
- The length of time that it takes for an HIV infection to progress to AIDS can vary between individuals but the disease will follow a standard sequence of symptoms
  - Initially an AIDS sufferer will only have **mild infections** of the mucous membranes due to the low helper T numbers
  - Over time, however, **infections will become more severe** e.g. diarrhoea, TB
  - During the final stages of AIDS a person will suffer from **a range of more serious opportunistic infections**
- It is these opportunistic diseases that cause an individual with advanced AIDS to **die**
- **Several factors** affect how quickly HIV will progress into AIDS and how long a person with AIDS will survive
  - The number of existing infections
  - The strain of HIV the person is infected with
  - Their age

- Access to healthcare

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Examiner Tips and Tricks

Try not to confuse the terms HIV and AIDS. Many people use them interchangeably when they actually mean different things.

- HIV is a virus
- AIDS is the disease caused by HIV

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Pathogens: Routes of Entry

- In order for a pathogen to cause disease it must **enter** the body of the host
  - **Body openings,** e.g. the mouth, eyes, and urinary tract, provide easy access for pathogens to enter
  - Pathogens may enter **directly into the bloodstream** through breaks in the skin
- Pathogens may be transmitted in a variety of ways

Vectors

- These are **living organisms** that carry pathogens and **transmit** them between hosts
- **Insects**, such as flies and mosquitoes, are common vectors for diseases like malaria and yellow fever

Inhalation

- **Droplets** from the respiratory tract will be **suspended in the air** when an infected person coughs, sneezes or talks
- These droplets **contain pathogens** that can be **inhaled** by healthy people
- The airways provide an **entry point** into the respiratory system of a new host and another infection occurs, e.g. flu, measles, tuberculosis

Ingestion

- Pathogens can enter through the **digestive** system when we **ingest contaminated** food or drink
- This is especially probable if food is **undercooked**, as heat destroys most of the pathogens
- These pathogens can make their way through the lining of the gut and cause disease (e.g. cholera, *Salmonella* poisoning)

Indirect contact

- **Inanimate objects** can contain large numbers of pathogens that may be transferred between hosts
  - An infected individual may touch or cough on an object which is later touched by a healthy individual who transfers the pathogens to their mouth or nose by touching their face
- Examples include bedding, towels, and surfaces

Direct contact

- Pathogens that spread this way will require some part of the host, e.g. skin, body fluids, to come into **direct contact** with a healthy individual
- Pathogens that spread by this route can then pass through the **mucous membranes** and enter the bloodstream, e.g.
  - When shaking hands with another person who then puts their hand to their nose or mouth
  - During sexual transmission
- Examples include HIV, ebola, syphilis

Inoculation

- This typically occurs when a pathogen enters the body through **broken skin**, providing it with a **direct route** into the bloodstream
- Transmission could be through sexual contact, sharing needles during drug use, or bites or scratches from infected animals
- Examples include hepatitis B, HIV, tetanus, and rabies

Barriers to Pathogenic Entry

Skin

- The skin provides a **physical barrier** against infection
- If the skin is damaged it leaves the exposed tissue beneath vulnerable to pathogens
- The **blood clotting mechanism** of the body plays an important role in preventing pathogen entry in the case of damage to the skin
- Blood clotting takes time, however, so a few pathogens may still enter before a clot forms

Microorganisms of the gut and skin

- Collectively these **harmless** microorganisms are known as the **gut** or **skin flora**
- They **compete** with pathogens for resources, thereby **limiting** their numbers and therefore their ability to infect the body

Stomach acid

- The **hydrochloric acid** that makes up a large part of the gastric juices in the stomach creates an **acidic environment** that is **unfavourable** to many pathogens present on food and drink
- Sometimes a few of these pathogens may survive and make their way to the intestines where they infect the gut wall cells and cause disease

Lysozyme

- Secretions of the **mucosal surfaces,** e.g. tears, saliva, and mucus, contains an enzyme called **lysozyme**

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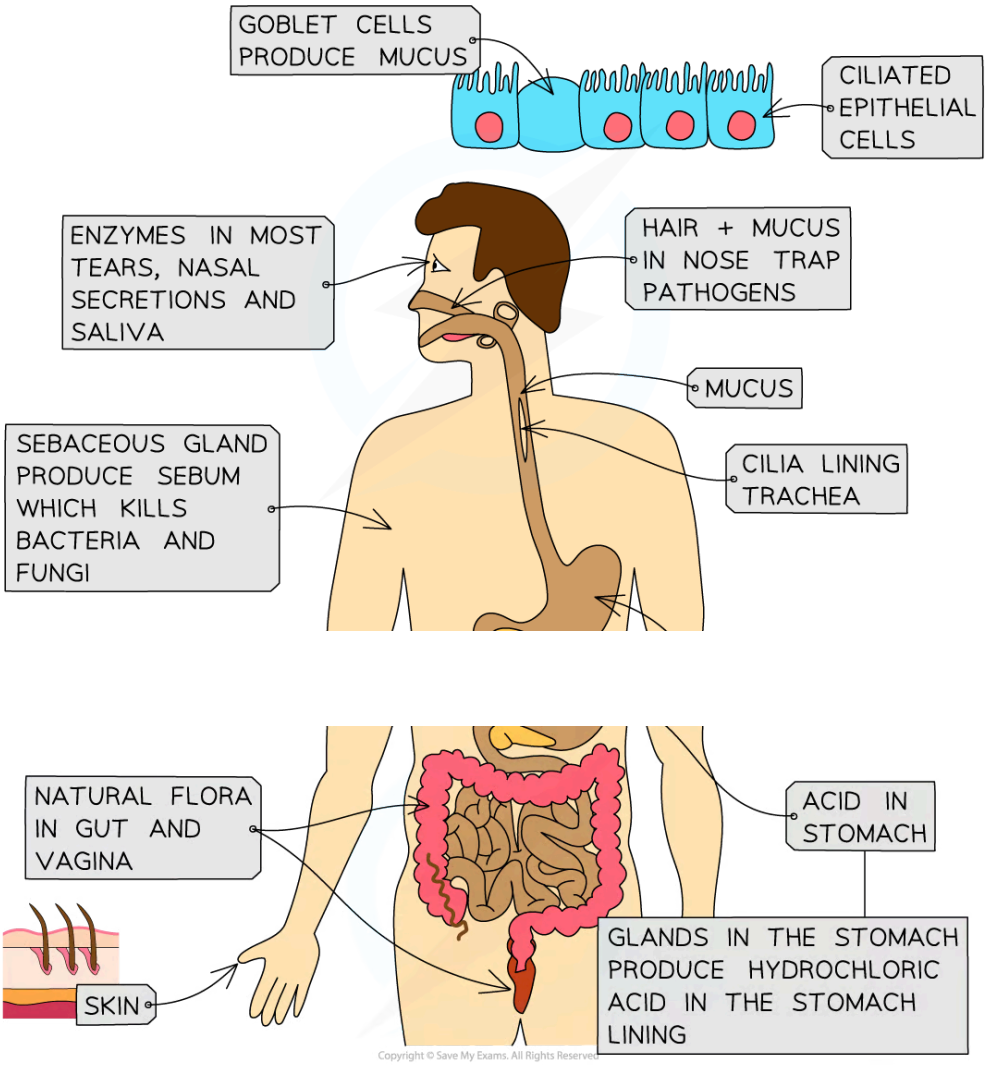
- This enzyme will **damage bacterial cell walls**, causing them to burst, or lyse



The body has various barriers that prevent the entry of pathogens

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Non-specific Immune Responses

- There are two types of immune response in the body once a pathogen enters
  - **Non-specific**
    - This response is the same, regardless of the pathogen that invades the body
  - **Specific**
    - This is a response specific to a particular pathogen
    - The immune system is able to recognise specific pathogens due to the presence of **antigens** on their cell surface
      - Antigens are molecules such as **proteins** or glycoproteins located on the surface of cells; their role is to act as an ID tag, **identifying a cell as being 'self' or 'non-self'**
        - Pathogens have **non-self antigens**, so the immune system recognises them as **not belonging to the body**
- When a pathogen invades tissue the non-specific immune response begins immediately; this includes
  - Inflammation
  - Interferons
  - Phagocytosis

Inflammation

- The surrounding area of a wound can sometimes become **swollen, warm and painful** to touch; this is **inflammation**
- Body cells called **mast cells** respond to tissue damage by secreting the molecule **histamine**
  - Histamine is a **chemical signalling molecule** that enables **cell signalling**, or communication between cells
- Histamine stimulates the following responses
  - Vasodilation increases blood flow through capillaries
  - **Capillary walls become 'leaky'**, or **more permeable**, allowing fluid to enter the tissues and creating swelling
    - Some plasma proteins leave the blood when the capillaries become more permeable
  - **Phagocytes** leave the blood and enter the tissue to **engulf foreign particles**

- Cells release **cytokines**, another cell signalling molecule that triggers an immune response in the infected area

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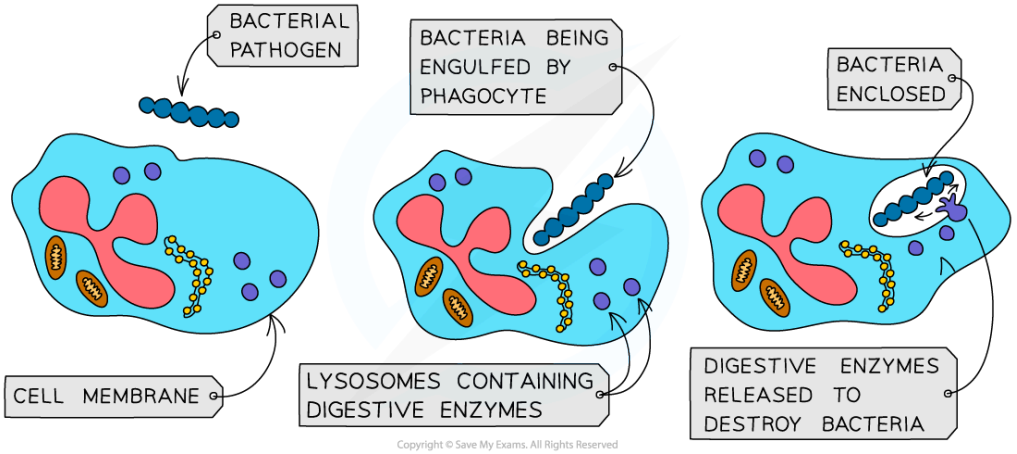
Interferons

- Cells infected by viruses produce **anti-viral proteins** called **interferons**
- Interferons **prevent viruses from spreading** to uninfected cells
  - They **inhibit** the production of viral proteins, preventing the virus from replicating
  - They **activate** white blood cells involved with the **specific immune response** to destroy infected cells
  - They **increase the non-specific immune response** e.g. by promoting inflammation

Phagocytosis

- **Phagocytes** are a type of white blood cell responsible for **removing dead cells and invasive microorganisms**; they do this by engulfing and digesting them
  - The process of engulfing and digesting is known as **phagocytosis**
- Phagocytes travel throughout the body and can leave the blood by **squeezing through capillary walls**
- During an infection they are released in **large numbers**
- Mode of action
  - **Chemicals** released by pathogens, as well as chemicals released by the body cells under attack, e.g. histamine, **attract phagocytes** to the site where the pathogens are located
  - They move towards pathogens and **recognise the antigens** on the surface of the pathogen as being **non-self**
  - The **cell surface membrane** of a phagocyte extends out and around the pathogen, **engulfing it** and trapping the pathogen within a **phagocytic vacuole**
    - This part of the process is known as **endocytosis**
  - Enzymes are released into the phagocytic vacuole when **lysosomes fuse** with it
  - These digestive enzymes, which includes lysozyme, **digest the pathogen**
  - After digesting the pathogen, the phagocyte will **present the antigens** of the pathogen on its cell surface membrane
    - The phagocyte becomes what is known as an **antigen presenting cell**
  - The presentation of antigens **initiates the specific immune response**



Phagocytes engulf pathogens in the process of phagocytosis, enclosing them in a phagocytic vacuole. Lysosomes fuse with the vacuole, releasing enzymes which digest the pathogen

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Specific Immune Responses

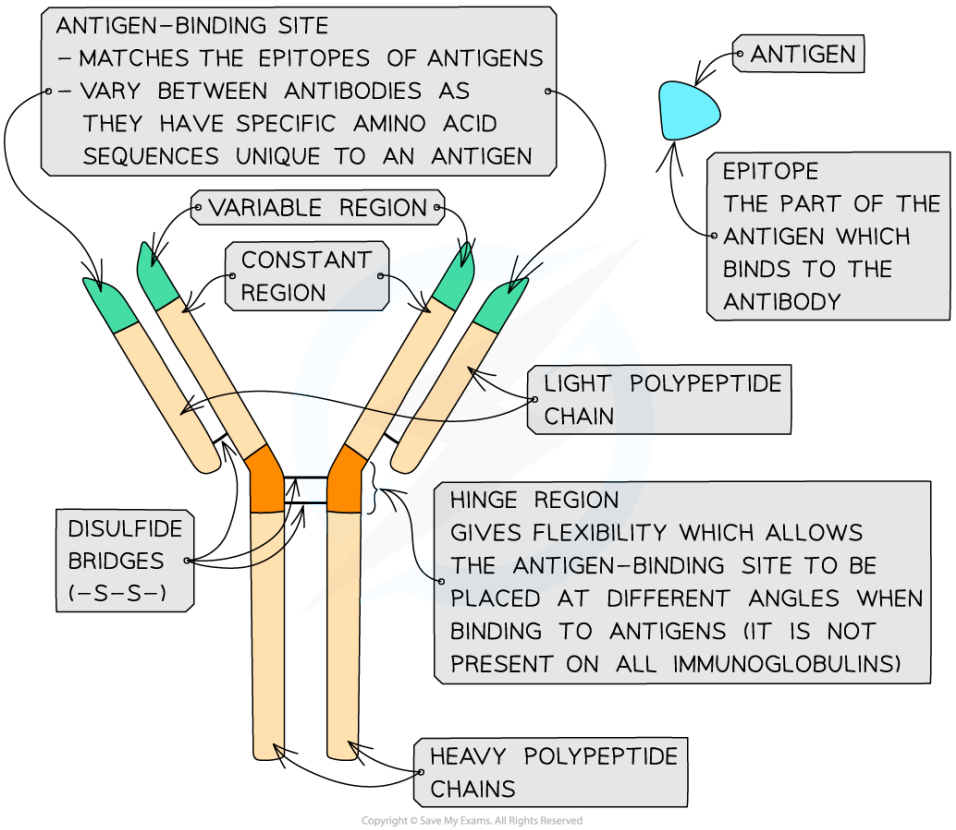
Antigens

- Every cell in the human body has **markers** on its cell surface membrane that **identify** it
- Microorganisms such as bacteria and viruses also have their own unique markers
- These markers are called **antigens** and they allow **cell-to-cell recognition**
  - Antigens are found on cell surface membranes, bacterial cell walls, or the surfaces of viruses
  - Some glycolipids and glycoproteins on the outside of cell surface membranes act as antigens
- Antigens can be either **self antigens** or **non-self antigens**
  - Antigens **produced by the organism's own body cells** are known as **self antigens**
    - Self antigens **do not** stimulate an immune response
  - Antigens **not produced by the organism's own body cells** are known as **non-self antigens**
    - Non-self antigens **stimulate an immune response**
    - E.g. the antigens found on pathogenic bacteria and viruses, or on the surface of a transplanted organ
- After pathogens are engulfed by phagocytosis, phagocytes transfer the antigens of the digested pathogen to their cell surface membrane, becoming **antigen presenting cells**
  - Antigen presenting cells such as macrophages **activate the specific immune response**
    - This occurs when the white blood cells of the specific immune response, known as lymphocytes, **bind to the presented antigens** with specific receptors on their cell surface membranes
    - Note that **macrophages are a type of phagocytic white blood cell**

Antibody structure

- Antibodies are secreted by specialised white blood cell known as **plasma cells**
- Antibodies are Y-shaped molecules sometimes known as **immunoglobulins**
- Antibodies consist of **four polypeptide chains; two 'heavy'** chains attached by **disulfide bonds** to **two 'light'** chains
  - 'Heavy' chains are long while 'light' chains are short
- Each polypeptide chain has a **constant region** and **variable region**

- The **constant regions do not vary** within a class of antibody
  - There are 5 classes of mammalian antibodies, each with different roles
- The amino acid sequences in the **variable region** are different for each antibody
  - The variable region is where the antibody binds to an antigen to form an **antigen-antibody complex**
  - At the end of the variable region is a site called the **antigen binding site**
    - The antigen binding sites **vary** greatly, giving the antibody its **specificity** for binding to **antigens**
- The **'hinge' region,** where the disulfide bonds join the heavy chains, gives flexibility to the antibody molecule, allowing the antigen binding site to be placed at different angles when binding to antigens
  - This region is not present in all classes of antibodies
- Antibodies can be either **membrane-bound** or **secreted directly** into the blood
  - Membrane-bound antibodies are **attached to the surface of lymphocytes**
  - The membrane-bound antibodies have an **extra section of polypeptide chain within their heavy chains** which forms the attachment to lymphocytes



Antibodies are Y-shaped molecules consisting of four polypeptide chains. Note that the term epitope here refers to the part of the antigen that is recognised by the immune

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system; the variable regions of the antibody are **complementary** *to the epitope of the antigen, allowing them to bind*

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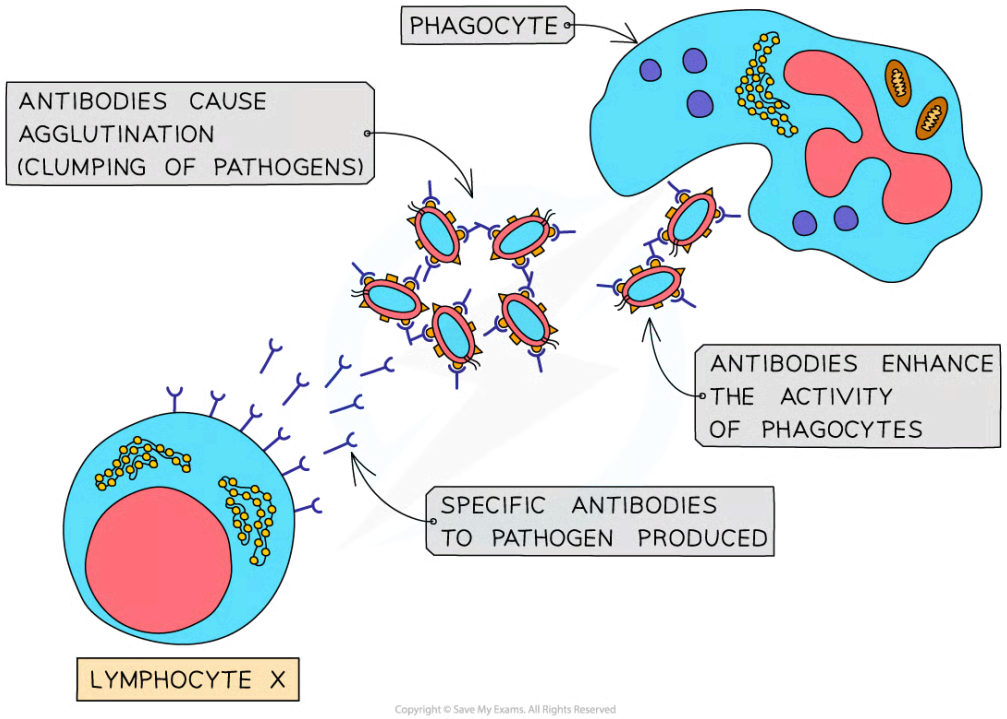
Antibody function

- Antibodies bind to **specific antigens** that trigger the specific immune response
- Antibodies function to disable pathogens in several ways
  - Pathogens enter host cells by binding to them using receptors on their surface; antibodies can **bind to these receptors**, **preventing pathogens from infecting host cells**
  - Antibodies can act as **anti-toxins** by binding to toxins produced by pathogens, e.g. the bacteria that cause diphtheria and tetanus; this neutralises the toxins
  - Antibodies cause pathogens to clump together, a process known as **agglutination**; this reduces the chance that the pathogens will spread through the body and makes it possible for phagocytes to engulf a number of pathogens at one time



Antibodies cause agglutination, which makes it difficult for the pathogens to infect host cells. This also makes it easier for the phagocytes to engulf the trapped pathogens

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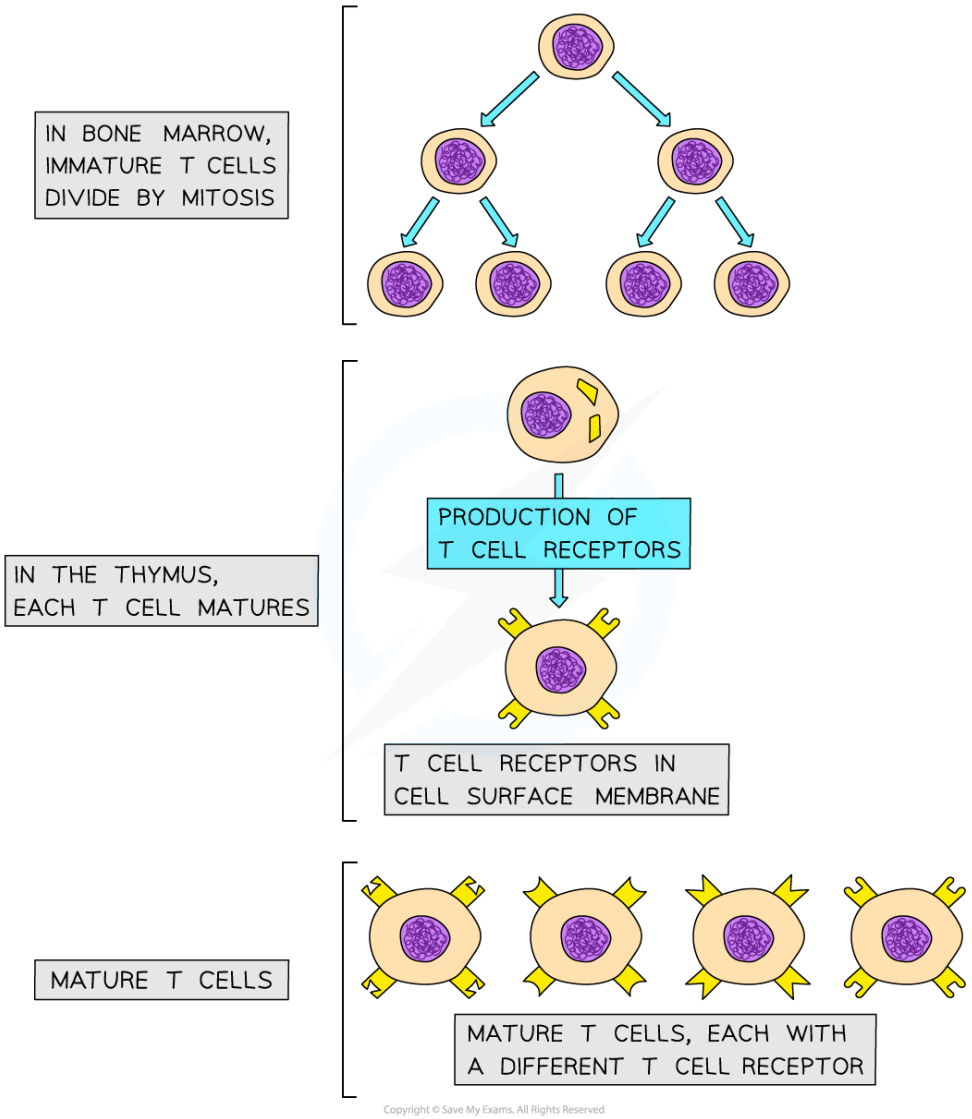
Lymphocytes: Types & Roles

- There are two types of **lymphocyte** that play a particular role in the specific immune response
  - T cells
  - B cells
- Note that lymphocytes are a type of **white blood cell**

T cells

- **T cells**, sometimes known as T lymphocytes, are produced in the bone marrow and finish maturing in the **t**hymus, which is where the **T** in their name comes from
- Mature **T cells** have specific cell surface receptors called **T cell receptors**
- These receptors have a **similar structure to antibodies** and are each **specific to a particular type of antigen**



Mature T cells have many different types of receptor on the cell surface membrane; these receptors will bind to different antigens on antigen presenting cells

- T cells are **activated** when they encounter and **bind to their specific antigen** on the surface of an antigen presenting cell
  - This **antigen-presenting** cell might be a **macrophage,** an **infected body cell**, or the **pathogen** itself
- These activated T cells **divide by mitosis** to increase in number
  - Dividing by mitosis produces **genetically identical cells**, or **clones**, so all of the daughter cells will have the **same type of T cell receptor** on their surface
- There are **three main types** of T cell
  - **T helper cells**
    - Release chemical signalling molecules that help to **activate B cells**

- Release chemical signalling molecules that help to **activate T killer cells**
- Release chemicals called cytokines, that **label pathogens and infected cells for phagocytosis**

- **T killer cells**
  - Bind to and **destroy infected cells** displaying the relevant specific antigen
- **T memory cells**
  - **Remain in the blood** and enable a faster specific immune response if the same pathogen is encountered again in the future

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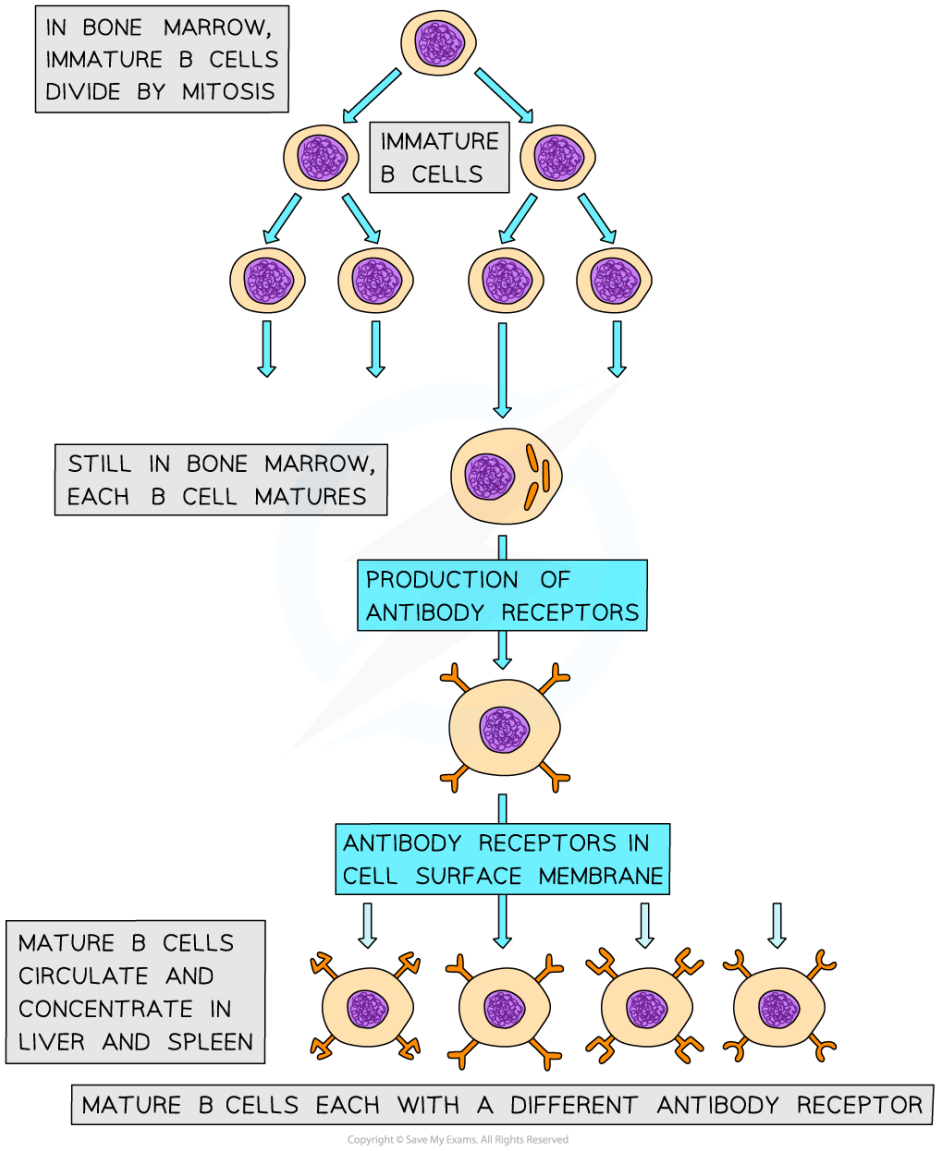
B cells

- **B cells,** also known as B lymphocytes, are a second type of white blood cell in the specific immune response
  - B cells remain in the **b**one marrow as they mature, hence the **B** in their name
- B cells have many **specific receptors** on their cell surface membrane
  - The receptors are in fact **antibodies**, and are known as **antibody receptors**
  - Each B cell has a **different type of antibody receptor**, meaning that each B cell can **bind to a different type of antigen**



Mature B cells each have different types of antibody receptors on their cell surface membrane

- If the corresponding antigen enters the body, B cells with the correct cell surface antibodies will be able to **recognise** it and bind to it
  - When the B cell binds to an antigen it forms an **antigen–antibody complex**
- The **binding of the B cell to its specific antigen**, along with the **cell signalling molecules produced by T helper cells**, **activates** the B cell
- Once activated the B cells divide repeatedly by mitosis, producing many clones of the original activated B cell
- There are **two main types of B cell**
  - **Effector cells,** which differentiate into **plasma cells**
    - Plasma cells produce specific antibodies to combat non-self antigens

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- **Memory cells**
  - Remain in the blood to allow a faster immune response to the same pathogen in the future

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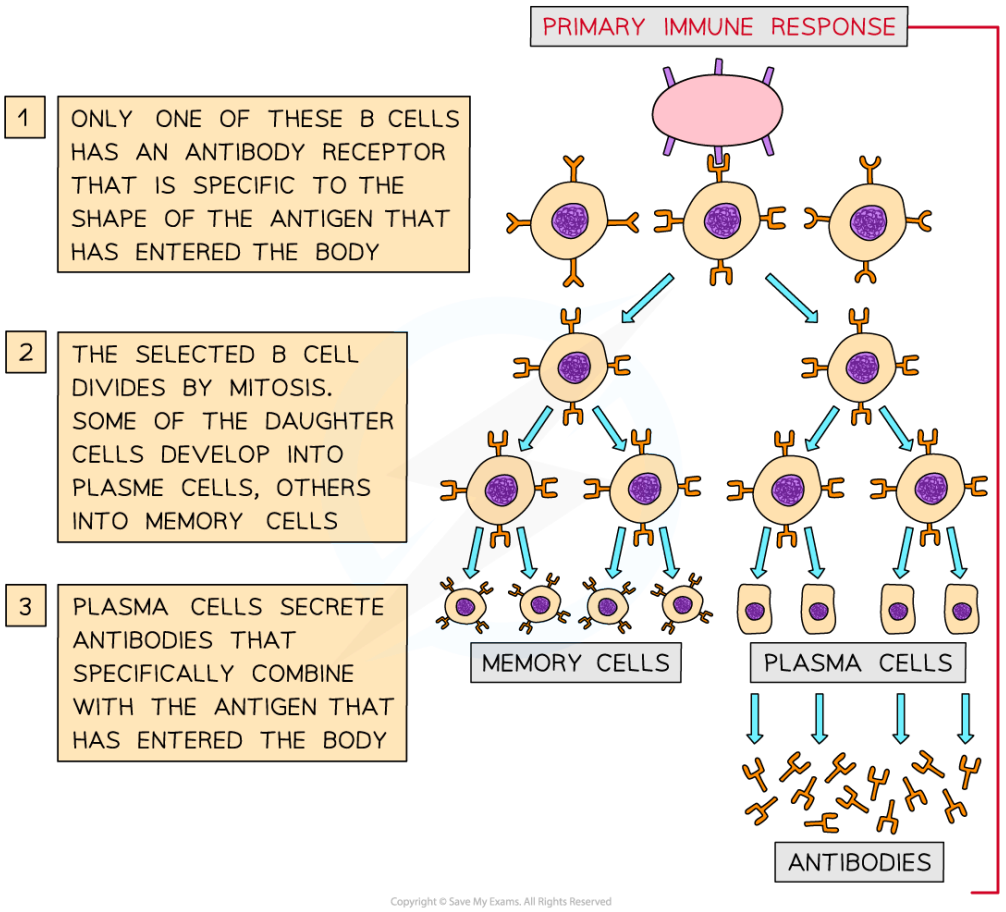

During a primary immune response B cells divide by mitosis to form plasma cells and memory cells. Note that a primary response occurs the first time an individual comes into contact with a particular pathogen

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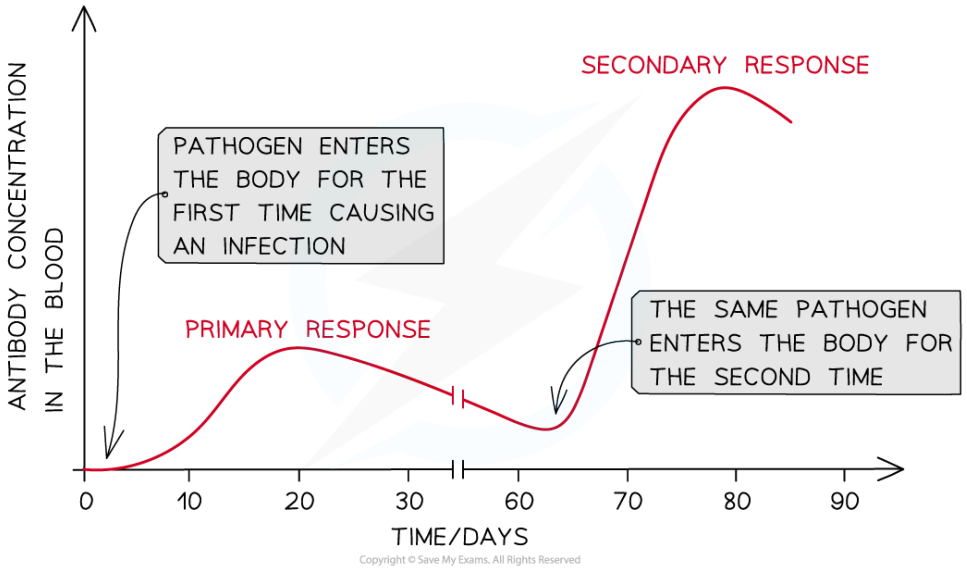
Developing Immunity

Developing immunity

- The immune system is **activated** when a **new antigen is encountered**
- This launches a **primary immune response** consisting of a **non-specific immune response** followed by a **specific immune response**
  - The primary response occurs the **first time** an antigen is encountered by the immune system
- Since it is the first time the immune system has encountered the antigen, the numbers of **T and B cells with the correct membrane receptors** present in the blood will be **low**
- It will **take time** for the correct T and B cells to be activated and to divide and differentiate into different cell types
  - It can take several days before **plasma cells** develop and are able to start producing **antibodies** against an antigen
  - This is the reason why an infected person will **experience symptoms** of the disease the first time they contract it
- Both T and B cells produce **memory cells** during the primary response, which will remain in the blood after an infection is over
  - The presence of memory cells means that a person is said to be **immune** to the pathogen
- Should the immune system encounter the same antigen again in the future it will launch a **secondary immune response** which will be much **faster** and **stronger** than the primary response
  - Memory cells are present in larger quantities than the mature lymphocytes at the start of the primary response, so the correct memory cells are able to detect an antigen, activate, divide by mitosis, and differentiate much more quickly
  - Antibodies are produced **more quickly** and in **larger quantities** in a secondary response
- This will often eliminate the pathogen **before the infected person can show symptoms**



The secondary response is much larger and faster than the primary response due to the presence of memory cells in the blood

Active immunity

- **Active immunity** is acquired when an antigen enters the body triggering a specific immune response
- Active immunity can be
  - **Natural**; acquired through exposure to pathogens
  - **Artificial;** acquired through vaccination
- In both cases the body **produces memory cells,** giving the person **long-term immunity**

Passive immunity

- **Passive immunity** is acquired without an immune response; antibodies are gained from another source, not produced by the infected person
- Passive immunity can be
  - **Natural**
    - Foetuses receive antibodies across the **placenta** from their mothers
    - Babies receive antibodies in breast milk
  - **Artificial**
    - People can be given an **injection / transfusion** of antibodies e.g. the tetanus antitoxin
    - The antibodies will have been collected from people or animals whose immune system had been triggered by a vaccination to produce antibodies

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- As the person's immune system has not been activated, there are **no memory cells** that can enable antibody production in a secondary response; if a person is reinfected they would need another infusion of antibodies

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Comparing Active & Passive Immunity Table

Feature	Active	Passive
Production of antibodies	Are produced by the body	Not produced by the body
Time before antibodies appear in blood	1–2 weeks	immediate
Presence of memory cells	yes	no
Induced by:		
Natural	Exposure to pathogen	Antibodies received from another organism (e.g. via the placenta or colostrum / breast milk)
Artificial	Vaccination	Antibodies manufactured and injected or transfused into organism (e.g. monoclonal antibodies delivered by blood transfusion)

Vaccines

- A **vaccine** contains **antigens** that are intentionally put into the body to induce **artificial active immunity**
  - Vaccines can contain dead or weakened pathogens, less harmful strains of a pathogen, antigens alone, or a piece of genetic material that codes for the antigens
- Vaccines are administered either by injection or by mouth
- **Vaccinations** produce long-term immunity as they cause **memory cells** to be created.
- The immune system recognises the antigen when re-encountered and produces antibodies in a faster, stronger **secondary response**
  - This is the main reason why vaccinated individuals typically do not show symptoms of the diseases they were vaccinated against
- **Antigenic variation** can mean that vaccinations need to be constantly modified to keep up with the changes to a pathogen's antigens

- Antigenic changes are the result of mutation

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Pathogens vs Hosts: An Evolutionary Race

- Vertebrates have evolved over millions of years to have immune systems that are capable of dealing with a wide range of different pathogens
- **Pathogens**, however, have also evolved and have developed different ways of **evading their host's immune system**
- This battle between host and pathogen is known as an **evolutionary race**; each organism develops new ways in which to have an advantage over the other
  - This evolutionary race is sometimes referred to as an **evolutionary arms race**
- Evasion mechanisms developed by pathogens serve as support for this theory

HIV evasion mechanisms

- The virus **kills helper T cells** after it infects them which reduces the number of cells that could detect the presence of the virus and activate the production of antibodies
- HIV shows **antigenic variability** due to the high mutation rate in the genes coding for antigen proteins
  - This forms **new strains** of the virus which each require a new primary immune response
    - Memory cells for one strain **will not recognise** the antigens of another strain
- The virus **prevents** infected cells from **presenting their antigens** on the cell surface membrane, making it very difficult for the relevant white blood cells to recognise and destroy the infected cells

Mycobacterium tuberculosis evasion mechanisms

- Once engulfed by phagocytes in the lungs the bacteria produce substances that will **prevent a** lysosome from fusing with the phagocytic vacuole
  - This prevents the bacteria from being broken down by digestive enzymes, leaving them to **multiply** within the phagocyte
- As with HIV the bacteria can **disrupt antigen presentation** in infected phagocytes, making it difficult for the immune system to recognise and destroy these cells