# C3.2 Defence against disease

## Guiding Questions

How do body systems recognize pathogens and fight infections?

What factors influence the incidence of disease in populations?

Pathogens are viruses, bacteria and other small organisms that can cause disease. Our first defence against pathogens is to prevent them from entering the body, our skin and mucous membranes acting as barriers. When a pathogen is able to enter the body, we have a two-layered immune system that responds to fight the infection. Our innate immune system consists of white blood cells called phagocytes that recognize pathogens as foreign and engulf them by endocytosis resulting in their digestion.

True immunity is built up over time by our adaptive immune system. This component of our immune system chemically recognizes the specific molecules that make up pathogens. These molecules are called antigens. A type of white blood cell called lymphocytes cooperates in the presence of specific antigens. This leads to cell cloning of specific lymphocytes to fight off the pathogens that carry the identified antigen. One important component of this response is the production of proteins called antibodies. Long-lived memory lymphocytes remain after an infection, providing long-term immunity.

There are many factors that influence the incidence of disease in populations. We only began to understand the causes of diseases about two hundred years ago. Since then, great advances have been made in disease prevention, especially in the way that human wastes are treated and sanitary conditions have been improved for water sources and preparing foods. Identification and treatments for viral diseases have been the most difficult to understand, with many viral diseases remaining and spreading in the population. Vaccines are our best protection against viruses, but there are challenges to their acceptance in some human populations. Bacterial diseases have been successfully treated by antibiotics, but their overuse is leading to the emergence of antibiotic-resistant strains of bacteria.

## C3.2.1 – Infectious diseases are caused by pathogens

| **C3.2.1 – Pathogens as the cause of infectious diseases** |
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| Students should understand that a broad range of disease-causing organisms can infect humans. A disease-causing organism is known as a pathogen, although typically the term is reserved for viruses, bacteria, fungi and protists. Archaea are not known to cause any diseases in humans.<br><br>**NOS:** Students should be aware that careful observation can lead to important progress. For example, careful observations during 19th-century epidemics of childbed fever (due to an infection after childbirth) in Vienna and cholera in London led to breakthroughs in the control of infectious disease. |

**Pathogens** are disease-causing organisms. Pathogens are any viruses, bacteria, fungi and protists that result in disease upon entry into the body. The vast majority of these



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types of organisms are (thankfully) not pathogenic to humans. There are some that are only pathogenic to other animals, which explains why cats, dogs and farm animals are susceptible to their own diseases. Most of these diseases will not transmit to humans, although there are exceptions.

This community water pump was responsible for 616 deaths in the 1854 cholera outbreak in London, UK.

### Nature of Science

Meticulous observations can lead to breakthroughs. In 1854, there was a major cholera outbreak in a suburb of London, UK. The *Vibrio cholerae* bacteria that causes cholera is found in the faeces of infected individuals. It was common practice in the 1800s for residents to empty human waste into areas in front of their homes. The bacteria moved down through the soil and infected a drinking well used by many in the community. A physician by the name of John Snow suspected cholera was being transmitted in water supplies. He created a map of all known infections and found one particular well had been used by all the infected people. The well was closed, and the number of cholera infections fell. The information and map created by Snow formed the basis of modern epidemiology studies that trace outbreaks of disease.

Pathogenic organisms are not inherently "evil". They just happen to use human tissues as food and shelter. Their means of growth and secretions, however, can cause us harm. We have begun to learn a great deal about pathogenic organisms and have devised treatments for both before and after infection. Improvements in public health policies also help prevent the spread of pathogenic organisms. Throughout most of recorded history, humans had no real knowledge of the presence of pathogens and blamed infectious diseases on factors that now seem almost nonsensical to us. We must always remember that we live in an age where science is providing information not available to us even one or two generations ago.

### Nature of Science

In the mid-1800s, a physician called Ignaz Semmelweis, in Vienna, Austria, began to study a lethal disease commonly known as childbed fever. The disease had alarmingly high rates of infection and death in Vienna's maternity wards. Semmelweis began to note a difference in infection rates between two maternity wards. One ward was staffed by midwives and the other by physicians and medical students. The rate of infection and death on the physicians' ward was much higher than the ward staffed by midwives. Semmelweis began to narrow down and eliminate specific differences between the two wards, besides who staffed them. The one difference that proved to be consequential was that the physicians had often carried out autopsies before helping women in childbirth. Semmelweis postulated that the physicians were carrying small "particles" that caused disease from the autopsies to the pregnant women. He ordered the physicians to wash their hands with a chlorine solution before treating patients, and there was an immediate improvement in infection rate in the maternity ward.

*i* Modern classification systems place all living organisms in one of three domains. One of these three domains is Archaea, comprising small single-celled prokaryotic cells that are fundamentally different from bacteria. No member of the Archaea domain is known to cause a human disease.



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# C3.2.2 – Skin and mucous membranes as the first line of defence

| C3.2.2 – Skin and mucous membranes as a primary defence |
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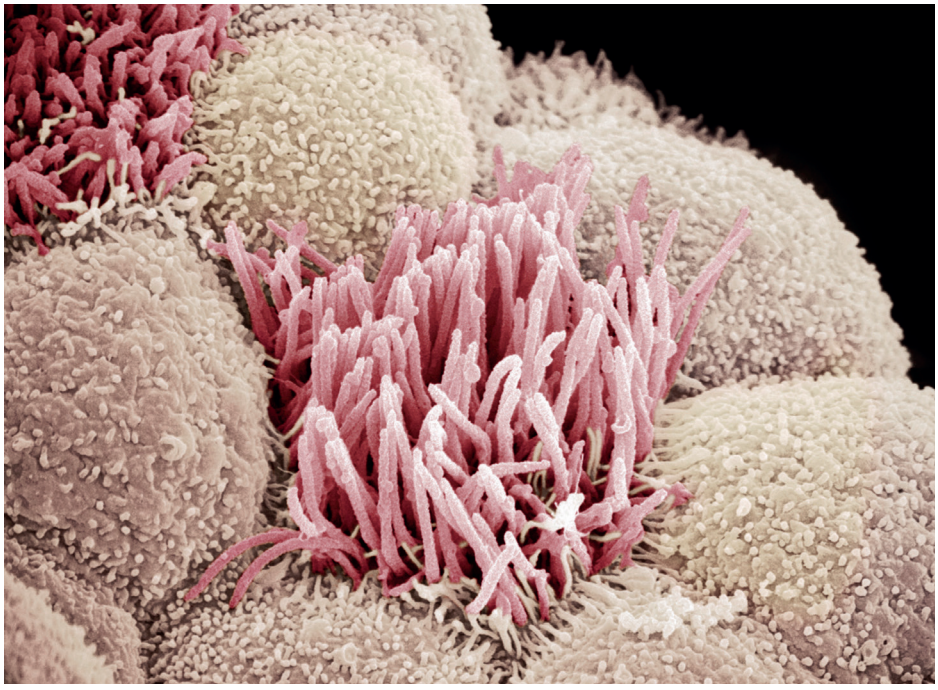
| The skin acts as both a physical and chemical barrier to pathogens. Students are not required to draw or label diagrams of skin. |

The best way to stay healthy is to prevent pathogens from having the opportunity to cause disease. One way to do this is to try to stay away from sources of infection. This is why it is still common to isolate (or quarantine) people who have highly transmittable diseases. Obviously, it is not possible to isolate yourself from every potential source of infection. Therefore, the human body has evolved some ingenious ways of making it difficult for pathogens to enter and start an infection. One of those ingenious ways is your skin.

Think of your skin as having two primary layers. The underneath layer is called the **dermis** and is very much alive. It contains sweat glands, capillaries, sensory receptors and dermal cells, which give structure and strength to the skin. The layer on top of this is called the **epidermis**. This epidermal layer is constantly being replaced as the underlying dermal cells die and are moved upwards. This layer of mainly dead cells forms a physical barrier against most pathogens because it is not truly alive. As long as our skin remains intact, we are protected from most pathogens that can enter living tissues. This is why it is important to clean and cover cuts and abrasions of the skin when they do occur.



A false-colour scanning electron micrograph (SEM) of the mucous membrane lining of the trachea. The large white cells are called goblet cells and they secrete mucus. Hair-like cilia (in pink) are also visible.

Pathogens can enter the body at the few locations that are not covered by skin. These entry points are lined with tissue cells that form a **mucous membrane**. The cells of mucous membranes produce and secrete a lining of sticky mucus. This mucus can trap incoming pathogens and so prevent them from reaching cells that they could



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infect. Some mucous membrane tissue is lined with **cilia**. Cilia are hair-like extensions capable of a wave-like movement. This movement carries trapped pathogens up and out of mucous-lined tissues such as your trachea. Table 1 shows some common areas that have a mucous membrane.

**C3.2 Table 1** Areas of the body that have a mucous membrane

| Area with a mucous membrane | What it is and does |
|---|---|
| Trachea | The tube that carries air to and from the lungs |
| Nasal passages | Tubes that allow air to enter the nose and then the trachea |
| Urethra | A tube that carries urine from the bladder to the outside |
| Vagina | The reproductive tract leading from the uterus to the outside |

According to an article published by the National Institutes of Health (NIH), bacteria outnumber their human hosts by about 10 to 1 cells. In a typical human adult, bacteria therefore account for about 2% of the human's body mass.

## C3.2.3 – Blood clotting minimizes blood loss and infection

**C3.2.3 – Sealing of cuts in skin by blood clotting**

Include release of clotting factors from platelets and the subsequent cascade pathway that results in rapid conversion of fibrinogen to fibrin by thrombin and trapping of erythrocytes to form a clot. No further details are expected.

When small blood vessels such as capillaries, arterioles and venules are damaged, blood escapes from the closed circulatory system. Often the damaged blood vessels are in the skin, and so pathogens are then able to enter the body. Our bodies have evolved a set of responses to create a clot that "seals" the damaged blood vessels, so preventing excessive blood loss and helping prevent pathogens from entering the body.

Circulating in the blood plasma are a variety of molecules called **plasma proteins**. These proteins serve many purposes, including some that are involved in clotting. Two of the clotting proteins are **prothrombin** and **fibrinogen**. These two molecules are always present in blood plasma, but remain inactive until "called to action" by events associated with bleeding. Also circulating in the bloodstream are cell fragments known as **platelets**. Platelets form in the bone marrow, along with red blood cells (**erythrocytes**) and white blood cells (**leucocytes**), but do not remain as entire cells. Instead, one very large cell breaks down into many fragments, and each of the fragments becomes a platelet. Platelets do not have a nucleus and they have a relatively short cellular life span of about 8–10 days.

Consider what happens when a small blood vessel is damaged. The damaged cells of the blood vessel release chemicals that stimulate platelets to adhere to the damaged area, forming a "plug". The damaged tissue and platelets release chemicals called **clotting factors** that convert prothrombin to **thrombin**. Thrombin is an active enzyme that catalyses the conversion of soluble fibrinogen into the relatively insoluble **fibrin**. The appropriately named fibrin is a fibrous protein that forms a mesh-like network that helps to stabilize the platelet plug. More and more cellular debris becomes trapped in the fibrin mesh, and soon a stable clot has formed, preventing both further blood loss and the entry of pathogens.



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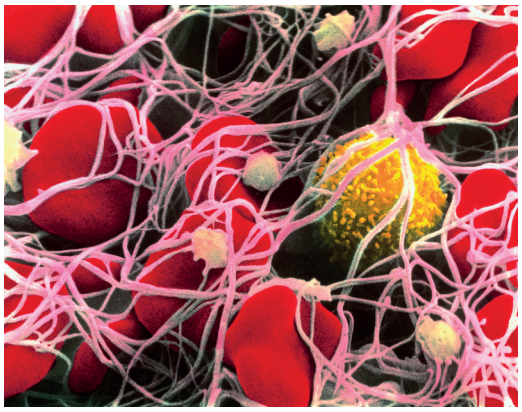

This false-colour SEM shows the formation of a blood clot. Small platelets (roughly spherical in shape and shown in pale green) have triggered the formation of insoluble fibrin protein fibres. Trapped in the fibrin are several red blood cells, platelets and one white blood cell (a larger sphere shape shown in yellow).

## C3.2.4 – A two-layered immune system: innate and adaptive

| **C3.2.4 – Differences between the innate immune system and the adaptive immune system** |
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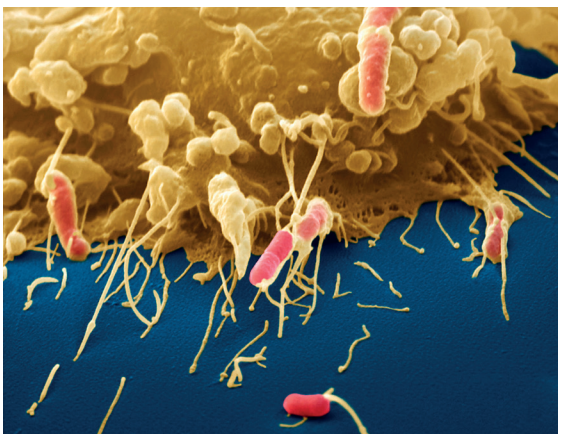
| Include the idea that the innate system responds to broad categories of pathogen and does not change during an organism's life whereas the adaptive system responds in a specific way to particular pathogens and builds up a memory of pathogens encountered, so the immune response becomes more effective. Students are not required to know any components of the innate immune system other than phagocytes. |

Humans are born with an immune system called the **innate immune system**. This first layer of the immune system responds to broad categories of pathogens and does not change during a person's lifetime. For example, the innate immune system would recognize any bacterium as a bacterium, rather than a specific species of bacterium.

The basis of the innate immune response is the ability to recognize those things that belong in the human body versus those that do not belong. In other words, it can recognize and respond to things that are "not-self". This includes bacteria, viruses, protists and fungi, and even things such as pollen and dust. The molecules of these foreign or not-self entities that can trigger an immune response are called **antigens**. The innate immune response involves activation of a group of leucocytes called **phagocytes**, which area capable of engulfing invading material by **endocytosis**.



A false-colour SEM of a large phagocyte (yellow) that has recognized a group of bacteria (pink rod shapes) as "not-self" and is in the initial stages of endocytosis.



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The second layer of human immunity is called the **adaptive immune response**. This portion of our immune response develops over time and only after exposure to specific antigens of specific pathogens. The first exposure to a specific antigen leads to a series of cellular events culminating in molecules and cells that are long-lived and have the ability to defend the body against a specific pathogen. The specific long-lived white blood cells that are formed during the first exposure are called **memory cells**. Upon a second exposure to the same pathogen, these specific memory cells can be activated quickly. They can be so effective in fighting a pathogen that a person may not even realize that they were exposed a second time. The adaptive immune response becomes more effective with age, as a person becomes exposed to more pathogens.

## C3.2.5 – The role of phagocytes

| **C3.2.5 – Infection control by phagocytes** |
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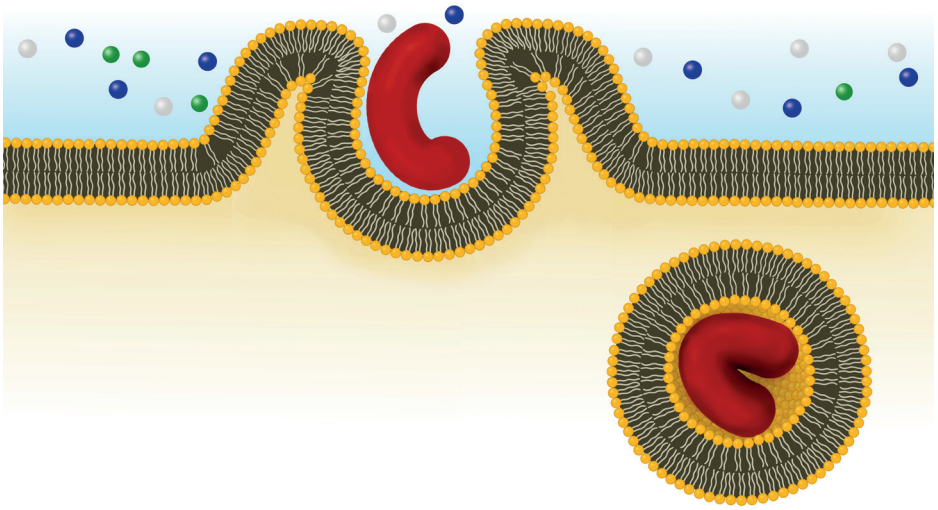
| Include amoeboid movement from blood to sites of infection, where phagocytes recognize pathogens, engulf them by endocytosis and digest them using enzymes from lysosomes. |

Phagocytes are leucocytes (white blood cells) that are capable of an action called **amoeboid movement**. Cells capable of amoeboid movement can purposefully extend sections of their plasma membrane, followed by their cytoplasm and organelles. Phagocytes use this type of motion to squeeze their way through capillaries so that they can leave and enter the bloodstream in order to move through body tissues. When a phagocyte encounters something in body tissues that contains antigens and thus is not-self, it sends out plasma membrane extensions to engulf the foreign body in a process called **endocytosis**. The foreign body is brought inside the phagocyte, where the hydrolytic enzymes of **lysosomes** digest the potential invader. This response by phagocytes is non-specific and is part of the innate immune response.



A portion of the plasma membrane of a phagocyte engulfs a bacterium by endocytosis. Two stages are shown. The bacterium ends up being encased in a vesicle that is later digested by enzymes from one or more lysosomes.



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# C3.2.6 – The role of lymphocytes

| **C3.2.6 – Lymphocytes as cells in the adaptive immune system that cooperate to produce antibodies** |
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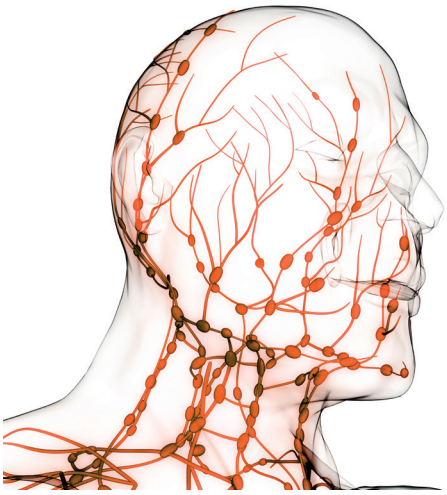
| Students should understand that lymphocytes circulate in the blood and are contained in lymph nodes. They should appreciate that an individual has a very large number of B-lymphocytes that each make a specific type of antibody. |

There are many types of leucocyte that contribute to the human immune system. Two major types are called **B-lymphocytes** and **T-lymphocytes**. Sometimes their names are shortened to just B-cells and T-cells. Lymphocytes continuously circulate in the blood stream and are also contained within our lymphatic system, especially within lymph nodes. We are going to look at the function of B-lymphocytes first, and then explore the functions of T-lymphocytes.



A diagram showing the location of lymph nodes in the neck and head area. B-lymphocytes accumulate in lymph nodes. Each lymph node has lymph vessels bringing lymph fluid in, and other lymph vessels taking lymph fluid away.

The specific leucocytes called B-lymphocytes produce protein molecules called **antibodies** as part of the adaptive immune response. There are many types of B-lymphocytes, and each type is able to synthesize a specific antibody. Each specific antibody is able to recognize and bind to a specific antigen. If you had a measles infection, you would produce one type of antibody, and if you contract a virus that gives you influenza (flu), you would produce another type of antibody. Each type of antibody is different because each type has been produced in response to a different pathogen.

**Each type of B-lymphocyte is a biological factory for synthesizing only one type of antibody.**

Antibodies are a Y-shaped proteins. At the end of each of the branches of the Y is a **binding site**. The binding sites are where an antibody attaches itself to an antigen. Because the antigen is a protein on the surface of a pathogen (such as a bacterium), the antibody thus becomes attached to the pathogen. Each of us has many different types of antibody-producing B-lymphocyte cells and each can produce only one type of antibody.

The specificity that an antibody has for a certain antigen is not unlike an enzyme's specificity for a certain substrate or a hormone's specificity for a target protein found on only certain cells.



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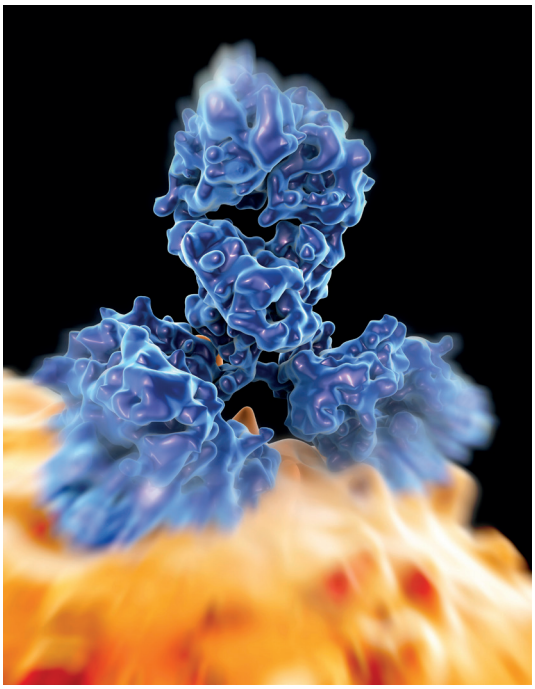

Computer artwork showing a single antibody (a blue, upside down Y shape in this picture) attached to an antigen on the surface of a pathogen.

Antibodies have specific mechanisms for fighting off infection by a pathogen. Any one antibody has two binding sites. If multiple antibodies bind to a cluster of pathogens, a clump is created because each antibody can potentially bind to two different pathogens. The antibody-bound cluster makes it easier for phagocytes to find and engulf the entire clump.

Many viruses attach to the plasma membrane of a body cell. The DNA or RNA of the virus is then injected into the cell. This cell then becomes a cellular factory to make more viruses. The protein coat of the virus, called a **capsid**, often remains on the outer plasma membrane of the cell and can be recognized by antibodies. Multiple antibodies of the same type use their binding sites to attach to proteins of the capsids. This is a way of marking the infected cell to be engulfed later by phagocytes.

## C3.2.7 – Antigens trigger antibody production

**An antigen is any substance that induces the immune system to produce antibodies. Most antigens are glycoproteins or other proteins and they are usually located on the outer covering of pathogens. These molecules, rather than the entire pathogen, are the molecular antigens that result in an immune response.**

| **C3.2.7 – Antigens as recognition molecules that trigger antibody production** |
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| Students should appreciate that most antigens are glycoproteins or other proteins and that they are usually located on the outer surfaces of pathogens. Antigens on the surface of erythrocytes may stimulate antibody production if transfused into a person with a different blood group. |

The adaptive immune response is based on many specifics:

- each type of B-lymphocyte makes a specific type of antibody
- each antibody is specific for one antigen
- each antigen is part of a specific group of molecules of a specific pathogen.

Antigens are usually proteins, and many are **glycoproteins** found embedded in the outer membrane of a pathogenic organism. This could be the plasma membrane of a bacterium or the outer cells of a protist or fungus. Viruses do not have a plasma membrane, but they do have a protein coat called a capsid and the capsid proteins act as antigens.



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Other molecules, besides those in pathogens, can be recognized as antigens by our immune system. When organs are transplanted surgically, the organ or tissue transplanted must be "matched" very carefully by comparing the proteins of the donor and recipient. Transplanted hearts, kidneys and skin are examples of organs that can be transplanted. Many proteins must be taken into consideration, and rarely is there a perfect match. The exception is when identical twins are used as both donor and recipient.

Blood transfusions should only occur after the blood types of both donor and recipient have been tested and are known to be compatible. When a blood type is indicated by the notation $AB^+$, for example, this notation is actually providing information about two blood types. One is called the ABO blood type, and the other is the Rh blood type. In this example, AB represents the ABO type, and + represents the Rh type. Blood typing is based on the presence or absence of three different antigens that are genetically inherited and found on the surface of erythrocytes. The three antigens are the A protein, B protein and Rh protein. The presence or absence of the three antigen proteins indicates a person's blood type.

| | **Antigen found on the plasma membrane of erythrocytes** |
|---|---|
| **ABO blood type** | |
| A | A protein |
| B | B protein |
| AB | A and B proteins |
| O | Neither A nor B protein |
| **Rh blood type** | |
| Positive | Rh protein |
| Negative | No Rh protein |

The antigens associated with different blood types

For example:

- a person with blood type $B^-$ has the B protein on their erythrocytes but does not have either the A protein or the Rh protein
- a person with blood type $O^+$ has neither the A nor the B protein but does have the Rh protein.

For blood transfusions to be successful a person must not receive a protein that they do not already have, as determined by their own genetics. A person with blood type $AB^+$ can receive blood from anyone because they already have all three antigens. A person with blood type $O^-$ can only receive blood from someone who also has blood type $O^-$, because they have none of the three antigens on their erythrocytes.

## Challenge yourself

**1.** For each of the potential recipients shown, state all of the blood types that they could safely receive in a blood transfusion.

**(a)** Recipient with blood type $A^+$.

**(b)** Recipient with blood type $O^+$.

**(c)** Recipient with blood type $AB^-$.

If someone receives a blood transfusion of an incompatible blood type, a transfusion reaction will occur. The reaction is an immune response to what the body identifies

Because pathogens have many antigens, a strong immune response may be a response to more than one of those antigens. In other words, more than one type of antibody can be produced in response to a single pathogen.

**In a blood transfusion, a person cannot receive any of the three possible erythrocyte antigen proteins that they do not already have. This includes the A, B and Rh antigen proteins.**

The first blood transfusions were carried out before people had any knowledge of blood types. Transfusions were even carried out using farm animals as donors. As you can imagine, sometimes this accomplished more harm than good.



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as an antigen. If someone receives type B blood and they do not genetically produce the B antigen protein, antibodies will be produced that bind to the donated cells and **agglutination** (clumping) can occur. The resulting transfusion reaction may lead to minor effects but has been known to be fatal.

## C3.2.8 – The role of helper T-lymphocytes

| **C3.2.8 – Activation of B-lymphocytes by helper T-lymphocytes** |
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| Students should understand that there are antigen-specific B-cells and helper T-cells. B-cells produce antibodies and become memory cells only when they have been activated. Activation requires both direct interaction with the specific antigen and contact with a helper T-cell that has also become activated by the same type of antigen. |

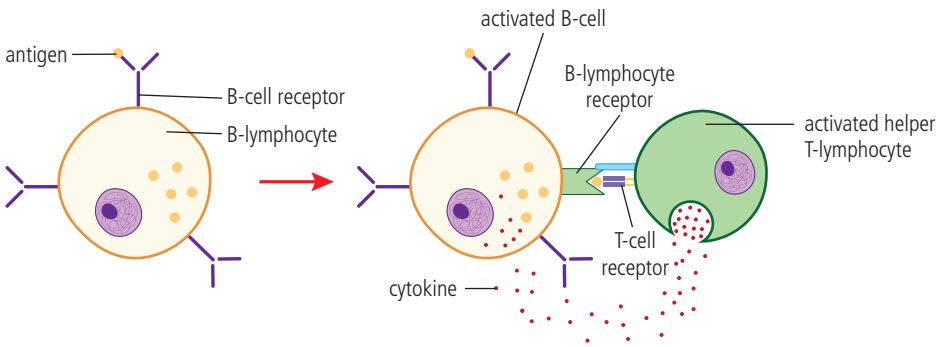
Two important types of leucocytes that respond in the adaptive immune response are **helper T-lymphocytes** (T-cells) and **B-lymphocytes** (B-cells).

Helper T-lymphocytes chemically communicate with other leucocytes, including B-lymphocytes, to signal the presence of a specific antigen.

- There are many types of helper T-lymphocytes.
- Each type can only activate a specific B-lymphocyte.
- The same antigen that activates a specific B-lymphocyte will also activate a helper T-lymphocyte.
- Helper T-lymphocytes display antigens on their own plasma membrane.
- Helper T-lymphocytes release molecules called **cytokines** after finding a specific antigen to help activate a specific B-lymphocyte.
- Some helper T-lymphocytes are long-lived and are called **memory cells**.

B-lymphocytes produce a specific antibody that binds to a specific antigen.

- There are many types of B-lymphocytes.
- Each type produces an antibody specific to one antigen.
- Each type that produces a specific antibody must be activated before it can make antibodies.
- Activation requires exposure to an antigen of the pathogen and also exposure to an activated T-lymphocyte that is displaying the antigen and releasing chemicals called cytokines.
- Some B-lymphocytes are long-lived and are called memory cells.




**C3.2 Figure 1** Activation of a B-lymphocyte by a helper T-lymphocyte. Both the B-lymphocyte and the helper T-lymphocyte have already encountered the pathogen. An antigen from the pathogen is displayed on the plasma membrane of the B-lymphocyte and on a receptor of the helper T-lymphocyte. A protein receptor on the B-lymphocyte must match a receptor on the helper T-lymphocyte. Cytokines from the helper T-lymphocyte are released and taken in by the B-lymphocyte. When all of these events have occurred, the B-lymphocyte is activated.



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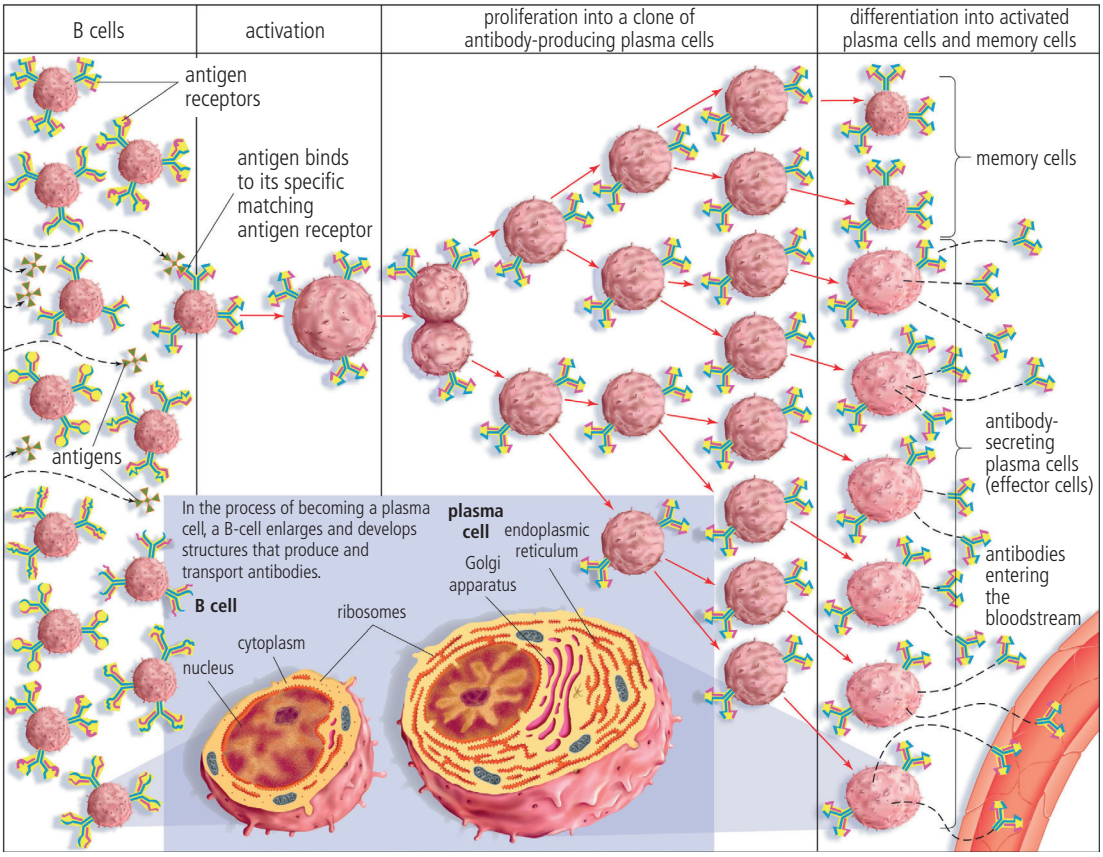
# C3.2.9 – Activation of a B-lymphocyte results in cloning

**C3.2.9 – Multiplication of activated B-lymphocytes to form clones of antibody-secreting plasma cells**

There are relatively small numbers of B-cells that 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 that are capable of producing the same type of antibody.

**The basis of the adaptive immune response is that a few specific lymphocytes of each type are present in the body at all times. When a specific cell type is needed for an immune response, activation of that cell type leads to cloning to make many copies of that type of cell.**

The helper T-lymphocytes and B-lymphocytes described in Section C3.2.8 are antigen specific. The problem is that there is an incredible number of different antigens that may require a response. The immune system can only maintain a relatively low number of each type of cell that can respond to any one antigen. When specific B-lymphocytes are needed in an immune response, they first become activated and then undergo numerous mitotic cell divisions. In effect, they create **clones** of cells that have the genetic instruction to synthesize mass quantities of the antibodies that can bind to the antigens of a pathogen.




On the left is a representation of many types of B-lymphocytes. Only one type is activated by an antigen (and helper T-lymphocyte, not shown). The activated B-lymphocyte undergoes repeated mitosis to create a small "army" of the same type of B-lymphocyte. A few of these, shown on the upper right, are memory cells and will not produce antibodies during the current infection. The rest form antibody-secreting plasma cells that produce antibodies that can be useful in body tissues or be circulated in the bloodstream. Activated B-lymphocytes become larger, and develop many ribosomes, endoplasmic reticulum and Golgi bodies, all used for antibody production and secretion.



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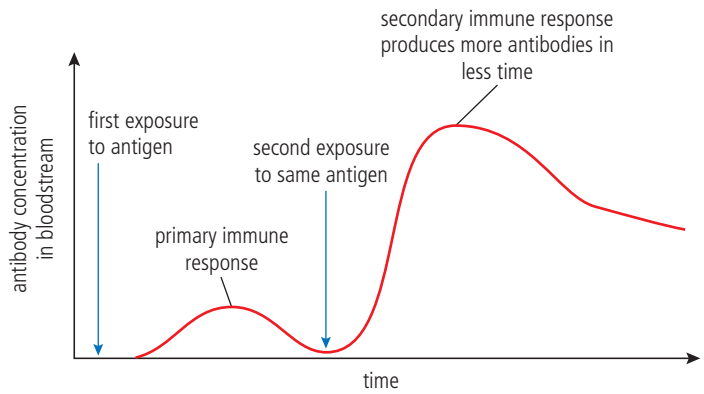
# C3.2.10 – The role of memory cells

**C3.2.10 – Immunity as a consequence of retaining memory cells**

Students should understand that immunity is the ability to eliminate an infectious disease from the body. It is due to the long-term survival of lymphocytes that are capable of making the specific antibodies needed to fight the infection. These are memory cells.

The adaptive immune response requires an initial exposure to the antigen(s) of a particular pathogen. That first response is relatively long and is called the **primary immune response**. During this first exposure there are no memory cells, as the few lymphocytes that can respond to this pathogen have not yet been activated or cloned. The length of time it takes for a primary immune response to occur varies depending on the pathogen, but there is almost always sufficient time for symptoms of disease to develop. For example, if it is the first time a person is exposed to a specific cold virus, they will have symptoms of the cold. The primary immune response is taking place while the person is experiencing the symptoms, and will eventually result in the symptoms disappearing as the pathogen is eliminated from the body.

The second or any subsequent exposure to that same cold virus will trigger a **secondary immune response**. The memory cells that were produced during the primary infection continue to circulate in the bloodstream. These very long-lived cells, now in relatively large numbers, are capable of responding to the same pathogen very quickly. It is usually so quick that symptoms of the disease do not present, or are quite minor. The secondary immune response not only occurs faster it also produces many more antibodies than the first exposure.




Antibody production by the primary and secondary immune responses. The second exposure to the same antigen may be months or years after the first exposure. The production of antibodies is quicker after a second infection, and the number of antibodies is greater.

We have no true immunity to a pathogen during the first infection, but we do have an immune system that is usually able to eliminate a new pathogen. True immunity begins with a subsequent infection as a result of the activity of memory cells.

As shown by the recent **pandemic** caused by a coronavirus (SARS-CoV-2), pathogens are easily spread across the globe. SARS-CoV-2 is not the first pathogen to have moved from country to country despite interventions to stop its spread. Some previous pandemics have been referred to as plagues.

**Sometimes the term immunity refers to the body's ability to eliminate an infectious disease during a primary immune response, when symptoms are likely to occur. This is because our immune system has both primary and secondary immune responses.**

How do animals protect themselves from threats?



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## C3.2.11 – HIV transmission

| C3.2.11 – Transmission of HIV in body fluids |
| --- |
| Include examples of the means and implications of HIV (human immunodeficiency virus) transmission. |

**HIV** is the abbreviation for a virus called **human immunodeficiency virus**. Just like any virus, HIV is very specific about which organisms and which cell types in an organism it infects. Unfortunately, the (host) cells it infects in humans is one of the key lymphocyte cell types involved in the human immune response.

HIV does not survive outside the body and is not transmitted by saliva, tears or sweat. It is also not transmitted by insects such as via mosquito bites. The fluids that can transmit HIV are blood, semen, rectal fluids, vaginal fluids and breastmilk.

The two most common ways that HIV is spread from person to person is by having unprotected sex with an infected person, and by using a hypodermic needle that has previously been used by someone who is infected. In addition, it is possible for an HIV-positive mother to infect her child during pregnancy, labour, delivery or breastfeeding. In some countries, receiving a blood transfusion can spread HIV, but this is no longer a risk in countries where blood and blood products are routinely tested for contamination. Some medical treatments, such as injections for treating haemophilia, have been known to spread HIV when the injected material was purified from human blood. In many areas of the world, these products are now produced by genetically engineered bacteria and there is no risk of transmitting HIV.

## C3.2.12 – The result of HIV infection

| C3.2.12 – Infection of lymphocytes by HIV with AIDS as a consequence |
| --- |
| Students should understand that only certain types of lymphocyte are infected and killed, but that a reduction in these lymphocytes limits the ability to produce antibodies and fight opportunistic infections. |

HIV is very specific about "choosing" which cell to infect. The host cells of HIV are known as helper T-lymphocytes or **CD4 T-lymphocytes**. CD4 is the name of the glycoproteins that are found on the plasma membrane of helper T-lymphocytes and are used by HIV in its mechanism for entering a cell.

Unfortunately for anyone infected with HIV, the helper T-lymphocytes will eventually be killed by the virus, but they are the same cells used to activate B-lymphocytes and some cells involved in an immune response (see Figure 1 on page 316). A person who has a very low helper T-lymphocyte count in their blood stream will not have a strong immune response to pathogens. This is the disease called **AIDS** or **acquired immune deficiency syndrome**. People that are HIV-positive and have progressed to AIDS are susceptible to **opportunistic infections**. These are infections that occur more often or with more severity in people with weakened immune systems. Opportunistic infections include tuberculosis, salmonella, pneumonia and several others.

*i* Deaths from HIV have greatly decreased in countries with advanced medical care where HIV-positive patients take daily doses of medicines that reduce the potential for damage to the immune system.



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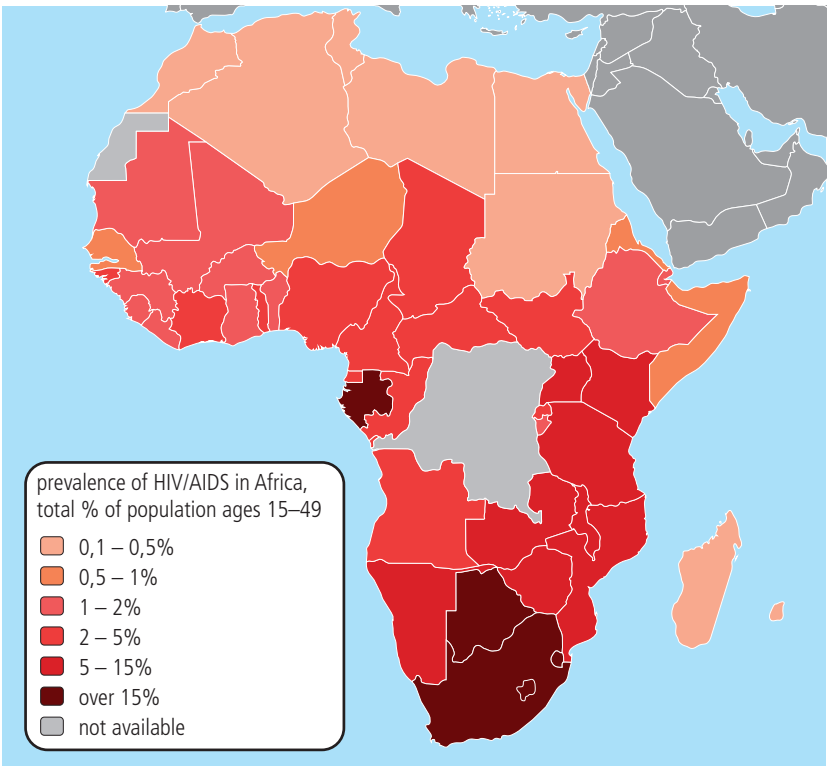


The prevalence of people infected with HIV is very unevenly distributed around the world. Many sub-Saharan African countries continue to show a high percentage of people infected. In this graphic, published in the peer-reviewed journal *Nature*, the data points are shown as much smaller, more accurate clusters than ever shown before. This can be used to help distribute resources to fight AIDS.

# C3.2.13 – Antibiotics against bacterial infections

| **C3.2.13 – Antibiotics as chemicals that block processes occurring in bacteria but not in eukaryotic cells** |
|---|
| Include reasons that antibiotics fail to control infection with viruses. |

Bacteria are **prokaryotic** cells. Humans and other animals are composed of **eukaryotic** cells (see Chapter A2.2). There are many structural and biochemical differences between prokaryotic and eukaryotic cells. For example, while protein synthesis occurs in both types of cells, the processes are different. Also, bacteria have a cell wall, a structure that is not characteristic of eukaryotic animal cells.

**Antibiotics** are chemicals that take advantage of the differences between prokaryotic and eukaryotic cells: they selectively block some of the biochemical pathways needed by bacteria while having no effect on human or other animal cells. There are many categories of antibiotics, depending on the biochemical pathway that is being targeted. One type of antibiotic selectively blocks protein synthesis in bacteria, but has no effect on eukaryotic cells' ability to manufacture proteins. Another type of antibiotic inhibits the production of a new cell wall by bacteria, thus blocking their ability to grow and divide.

*i* There are chemicals that have been developed as **antiviral medications**. These chemicals suppress a virus's ability to infect and multiply in the host's cells. Antiviral medications have become the standard of care for people with HIV and hepatitis C infections.



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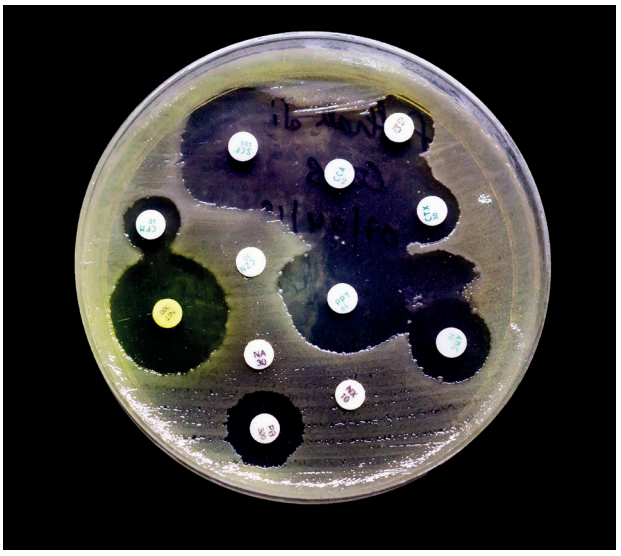
Viruses have no metabolism, which explains why antibiotics have no effect on them. Viruses make use of our own body cells' metabolism to create new viruses. Any chemical that could inhibit viral metabolic activity would also be damaging to our own body cells. Antibiotics should not be routinely prescribed for viral diseases.

## C3.2.14 – Pathogenic resistance to antibiotics

| **C3.2.14 – Evolution of resistance to several antibiotics in strains of pathogenic bacteria** |
| --- |
| Students should understand that careful use of antibiotics is necessary to slow the emergence of multiresistant bacteria.<br><br>**NOS:** Students should recognize that the development of new techniques can lead to new avenues of research; for example, the recent technique of searching chemical libraries is yielding new antibiotics. |

Bacterial resistance to antibiotics is a serious problem around the world. For too long, antibiotics have been used improperly and too frequently. The fundamental principles of evolution explain how pathogenic bacteria become resistant to any one antibiotic. When bacteria find their way into living tissues, frequently the environment is nearly perfect for their growth and cell division. Tissues are moist, full of nutrients, and relatively warm. In this type of growing environment some pathogenic bacteria can grow exponentially and double their numbers in as small a time period as 20 minutes.

Every cell division requires the DNA of a bacterial cell to replicate. Mutations occur spontaneously when DNA replicates. Most of the mutations are of no consequence, but when the DNA replication rate is very high, one or more mutations is likely to occur that is consequential. One of those random, but consequential, mutations may give a bacterial cell protection from the biochemical action of a particular antibiotic. One mutation is all that is required, as that bacterial cell will undergo binary fission repeatedly to grow into many cells. All bacterial cells that arise from the mutated cell will have the resistance to the antibiotic. In addition, the mutated strain may now cause infections in other people.



Bacterial species grown in a Petri dish showing resistance to antibiotics. The dull cloudy area is where bacteria are growing. The small white discs are impregnated with antibiotics. The clear area around many of the discs indicates that the antibiotics are preventing bacterial growth. The clear area is called a **zone of inhibition**. The presence of bacterial growth around three of the discs indicates those antibiotics that have little to no ability to prevent growth.



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### Nature of Science

A great deal of scientific research precedes the release of a new antibiotic before it can be prescribed. Antibiotics always come with directions for use that are based on this research. These directions include how long you should take the medicine for. If someone stops taking an antibiotic early, for example because their symptoms have improved, only the bacteria that are most sensitive to the antibiotic have been killed. A few resistant cells may not have been killed and can grow into a new resistant strain. You should always take an antibiotic for the full prescribed duration.

A few strains of pathogenic bacteria have emerged over the years that are resistant to several antibiotics. One example is methicillin-resistant *Staphylococcus aureus* (MRSA). This bacterial strain causes **staphylococcal infections** that are very difficult to treat. Responsible use of existing antibiotics is needed to prevent the emergence of more multiresistant bacteria. Responsible use includes:

- only prescribing an antibiotic when necessary
- taking the full course of an antibiotic, and not stopping when symptoms first subside
- reducing the spread of bacterial diseases by vaccination, hand-washing and proper food hygiene
- reducing or stopping the practice of adding antibiotics to farm animal feed.

Methods using artificial intelligence (AI) are being used to screen for new antibiotics. This involves predicting the interaction of chemicals using AI and the known chemicals in chemical libraries. Halicin, a chemical screened by AI, is a new and promising antibiotic that is being prepared for clinical trials.

### Nature of Science

The development of new techniques can lead to new lines of research. The use of chemical libraries is a new approach to antibiotic development. Chemical libraries store chemicals along with all the known information about those chemicals. Searching chemical libraries is yielding new antibiotic treatments because synergistic effects of antibiotic combinations can be explored at the molecular level.

## C3.2.15 – Zoonotic diseases

| **C3.2.15 – Zoonoses as infectious diseases that can transfer from other species to humans** |
| --- |
| Illustrate the prevalence of zoonoses as infectious diseases in humans and their varied modes of infection with several examples including tuberculosis, rabies and Japanese encephalitis. Include COVID-19 infection as an infectious disease that has recently transferred from another species, with profound consequences for humans. |

Many infectious diseases are species specific. Those that can cross species, specifically animal to human, are called **zoonotic diseases**. The pathogen may be a virus, bacterium, protist or fungus. Some examples are described below.

### Rabies

Rabies is a disease caused by a virus. Most human cases of rabies are the result of dog bites, although the dog may have received the virus from a wild animal. Cases of rabies



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occur throughout the world, but are more common in Africa and Asia. The rabies virus causes a progressive and fatal inflammation of the human brain and spinal cord. By the time symptoms begin to show in an infected person, it is too late for treatment. The best defence against rabies in humans is preventative vaccination of dogs. Seeking medical treatment shortly after a bite from a rabid animal can prevent death if the treatment is received quickly.

## Tuberculosis

Zoonotic tuberculosis is a bacterial disease caused by *Mycobacterium bovis*. Humans are exposed to this bacterium through cattle. Ingestion of unpasteurized milk and milk products and infected meat are the primary means of transmission. Airborne transmissions are also possible, especially for those that work with cattle. The main symptom is damaged lung tissue, but other human tissues are also affected. The name tuberculosis comes from growths called tubercles that occur in the lymph nodes of an infected person.

## Japanese encephalitis

Japanese encephalitis is caused by a virus that is transmitted through the bite of a species of *Culex* mosquito. The mosquito receives the virus from either a pig or wading bird. Most cases occur in southeast Asia and are quite mild, although a few cases have progressed to more serious symptoms, including coma and eventually death. There is a vaccine that prevents symptoms but it is not widely used in the rural areas where the disease is typically transmitted.

## COVID-19

COVID-19 is a disease caused by a coronavirus known as **SARS-CoV-2**. It is almost certainly zoonotic, although no specific species has yet been identified as the first to infect humans. All other known coronaviruses can be zoonotic. SARS-CoV-2 has been shown to transfer easily from humans to other animals, such as dogs, cats and deer, and many other animals have tested positive for the virus. Most researchers classify COVID-19 as an "emerging infectious disease of probable animal origin", until more is learned about its origins. The virus quickly caused a global pandemic by spreading from person to person in 2019–2020. COVID-19 symptoms vary from **asymptomatic** (no symptoms) to severe and fatal respiratory damage. Variants of the virus are continuing to emerge, resulting in increased transmission rates. Vaccines have been developed but are not readily available in all areas of the world.

Current practices of keeping very dense populations of domesticated animals can lead to both increased animal-to-animal and animal-to-human zoonotic disease transmission.



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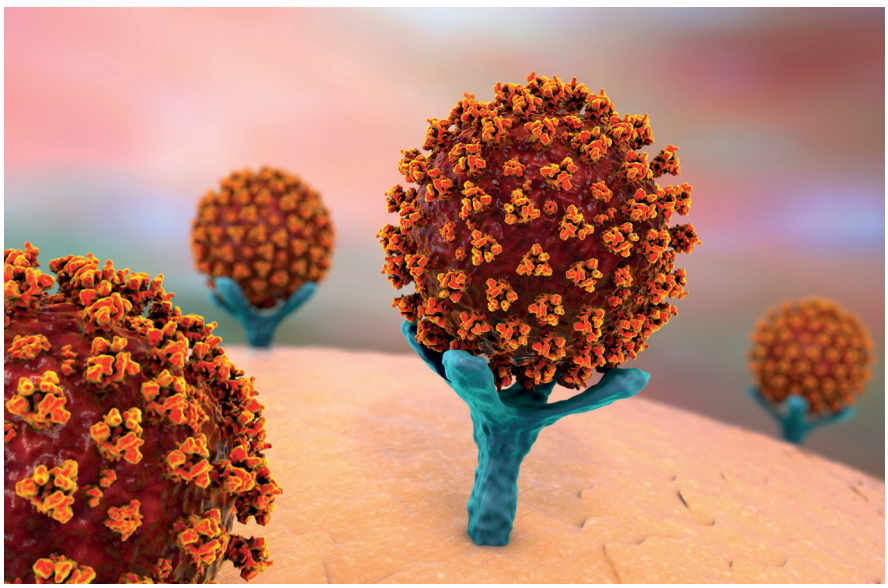
# C3.2.16 – Vaccines and immunity

**C3.2.16 – Vaccines and immunization**

Students should understand that vaccines contain antigens, or nucleic acids (DNA or RNA) with sequences that code for antigens, and that they stimulate the development of immunity to a specific pathogen without causing the disease.

In Section C3.2.10 you learned about the primary and secondary immune responses that result in the production and use of memory leucocytes. For many diseases, vaccines have been developed that act as the first exposure to a pathogen. A vaccine is typically composed of the chemical components of a pathogen after eliminating the disease-causing abilities of the pathogen. In traditional vaccine production, the pathogenic virus or bacterium is inactivated so that it cannot cause the disease. The pathogen or selected antigens from the pathogen are then injected into a person, resulting in the same immune response as if the pathogen had entered the host's body. This injection results in a primary immune response that then leaves behind memory cells that can be quickly triggered into action upon reinfection by the pathogen.

Recent advances in vaccine research and technology have led to a new approach. Instead of injecting an inactivated pathogen or antigen, the DNA or RNA molecules that code for the synthesis of specific protein antigens are injected. Body cells take in the nucleic acid and use their normal cell protein synthesis organelles and enzymes to produce antigens. These antigens, although produced by body cells, are recognized as foreign and stimulate a primary immune response without exposure to the pathogen. As with traditional vaccines, memory cells are produced to provide immunity.



A depiction of SARS-CoV-2 sitting in a protein receptor of a cell. Proteins that make the "spike" structures of the virus are synthesized by human cells after injection with one of the RNA vaccines.

TOK

Social media has become a major news source for many people. What is the responsibility of social media platforms to ensure that shared information is fact based?

As part of the COVID-19 response, RNA vaccines were rapidly developed and manufactured. The protection provided by these vaccines has been excellent, especially for reducing the more serious symptoms that can result in hospitalizations. However, acceptance of the vaccines as safe and effective tools against COVID-19 has not been universal in some countries. Widespread misinformation concerning the safety and value of the vaccines has contributed to limited acceptance.



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## C3.2.17 – The role of herd immunity

| C3.2.17 – Herd immunity and the prevention of epidemics |
| --- |
| Students should understand how members of a population are interdependent in building herd immunity. If a sufficient percentage of a population is immune to a disease, transmission is greatly impeded.<br><br>**NOS:** Scientists publish their research so that other scientists can evaluate it. The media often report on the research while evaluation is still happening, and consumers need to be aware of this. Vaccines are tested rigorously and the risks of side effects are minimal but not nil. The distinction between pragmatic truths and certainty is poorly understood. |

Many pathogenic diseases spread as a result of person-to-person contact. When a large percentage of people in a given area (a herd) achieve immunity to a disease, there is a far reduced chance of the disease spreading. Even someone with no immunity is far less likely to get the disease when **herd immunity** has been achieved. The percentage of immune people that is needed to achieve herd immunity differs depending on the disease. Generally, the more contagious a disease, the higher the percentage needs to be. Measles, a highly contagious disease, requires 92–94% of the population to be immune. It is not yet certain what percentage of people need to be immune to COVID-19 to achieve herd immunity, or even if herd immunity is achievable. COVID-19 continues to produce new variants that may or may not be recognized by the immune response from a previous variant.

### Nature of Science

Scientists publish their research so that other scientists can evaluate it. The media often report on the research while evaluation is still happening, and consumers need to be aware of this. Vaccines are tested rigorously and the risks of side effects are minimal but not nil. The distinction between pragmatic truths and certainty is poorly understood. A pragmatist can consider something to be true without needing to confirm that it is universally true.

## C3.2.18 – Evaluating COVID-19 data

| C3.2.18 – Evaluation of data related to the COVID-19 pandemic |
| --- |
| **Application of skills:** Students should have the opportunity to calculate both percentage difference and percentage change. |

There are many tools available to scientists for evaluating data. Two of the more common tools are calculating the **percentage difference** and **percentage change.** These very different calculations are often confused.

Calculating the percentage difference is useful when you are comparing two values that mean the same thing at the same time, for example if you are comparing the height of two people on the same day.

The percentage difference is the difference between two values divided by the average of the two values expressed as a percentage.



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## Worked example

Noah has a height of 176 cm and Mithun has a height of 184 cm. What is the percentage difference in their height?

### Solution

Percentage difference = (184 cm − 176 cm) / ((184 cm + 176 cm) / 2) × 100

= 8 / 180 × 100 = 4.4%

There is a 4.4% difference between their heights.

Calculating the percentage change is useful when you are comparing two values that are separated by time.

Percentage change is the difference between the new and old values divided by the old value expressed as a percentage.

## Worked example

Two years ago, Noah had a height of 160 cm. He now has a height of 176 cm. What is Noah's percentage change in height over the two years?

### Solution

Percentage change = (176 cm – 160 cm) / 160 cm × 100

= 16 cm / 160 cm × 100 = 10%

There has been a 10% increase in Noah's height.

### Challenge yourself

Herd immunity is difficult to achieve when a disease is highly contagious. How contagious a disease is represented by a value denoted as $R_0$, pronounced "R nought" or "R zero". The $R_0$ value is the estimated number of people that will be infected by a single infected person if everyone they contact is susceptible to the disease. The higher the $R_0$ number, the more contagious the disease is.

Use the data in the following table to answer the following questions.

2. What is the correlation between the $R_0$ value and the threshold percentage necessary for herd immunity?
3. Young people no longer receive a vaccine for smallpox. Suggest a reason why they do not need one.
4. In 1955, one company that produced a polio vaccine released some batches that contained active polio virus. Over 250 people contracted polio, with some resulting in paralysis. Discuss why information like this should be publicly available.
5. Calculate the percentage difference between the $R_0$ values of H1N1 and SARS-CoV-2 given in the table.



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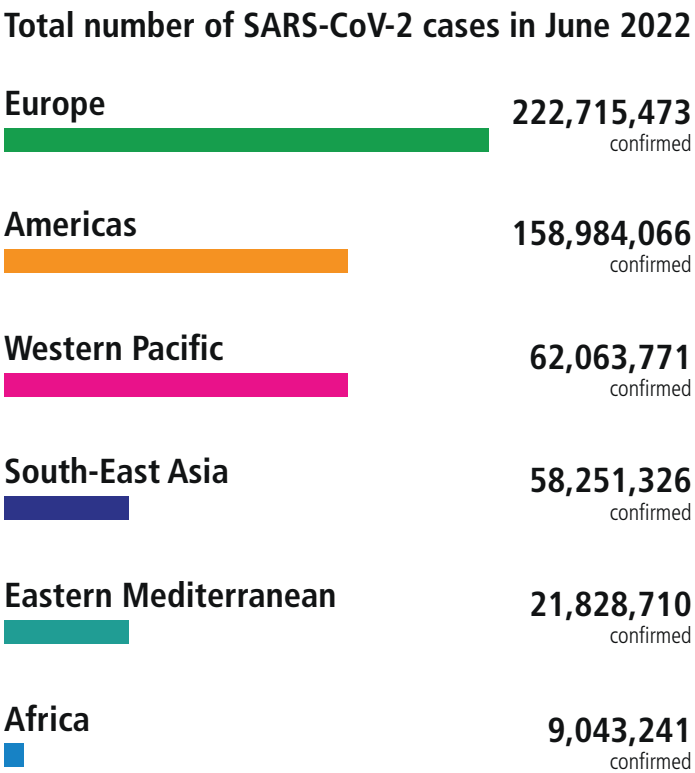
**6.** The virus causing COVID-19 has become more contagious over time as a result of mutations. The $R_0$ value of the original SARS-CoV-2 that emerged in 2019 was calculated to be 2.8 by the National Institutes of Health. Use the more recent $R_0$ value for the SARS-CoV-2 variant given in the table to calculate the percentage change in $R_0$ value.

| Infectious diseases | $R_0$ value | Herd immunity threshold |
|---|---|---|
| Smallpox | 5–7 | 80–85% |
| Mumps | 4–7 | 75–86% |
| Measles | 12–18 | 92–94% |
| Diphtheria | 6–7 | 85% |
| Pertussis | 12–17 | 92–94% |
| Polio | 4–13 | 75–92% |
| Rubella | 6–7 | 83–85% |
| H1N1 (2009 Pandemic) | 1.6 | 40% |
| SARS | 2–4 | 50–75% |
| SARS-CoV-2 (COVID-19) | 5.7 | 82.5% |

The concept of herd immunity based on how contagious a disease is. The $R_0$ and herd immunity values for SARS-CoV-2 are based on 2022 estimations.

The World Health Organization (WHO) is the United Nations agency that promotes good health practices and care throughout the world. Figure 2 shows the data collected by WHO, as of June 2022, on the number of SARS-CoV-2 cases in different areas of the world. Note, however, that testing protocols and reliability differed between the regions.




**C3.2 Figure 2** The total number of SARS-CoV-2 cases in June 2022 since virus transmission began in six WHO regions of the world.

How can false-positive and false-negative results be avoided in diagnostic tests?



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## Guiding Question revisited

How do body systems recognize pathogens and fight infections?

In this chapter you have learned:

- humans and many other animals have both innate and adaptive immune systems
- the innate immune response attempts to remove anything recognized as foreign or "not-self" without identifying it
- the adaptive immune response recognizes specific foreign entities and the response leaves behind immunity to that entity in the form of memory cells
- adaptive immunity involves recognition of molecules, called antigens, that make up pathogens
- specific helper T-lymphocytes are needed to recognize an antigen, and clone themselves to create higher numbers of that cell type
- specific B-lymphocytes are activated by helper T-lymphocytes, and produce antibodies that bind to antigens making up the pathogen
- long-lived cells of both types of lymphocyte act as memory cells to provide long-term immunity to the antigen
- vaccines are created by using inactive pathogens or nucleic acids injected into the body, which leads to the production of memory cells.

## Guiding Question revisited

What factors influence the incidence of disease in populations?

In this chapter you have learned:

- skin and mucus membranes can often prevent entry of a pathogen into the body
- HIV/AIDS is a viral disease that can greatly lower the ability of a person's body to mount an effective immune response
- antibiotics are chemicals that selectively target the growth processes of bacteria and have been instrumental in treating bacterial infections
- antibiotic misuse and overuse have led to some pathogenic bacteria becoming resistant to one or more antibiotics
- vaccines are effective in creating long-term immunity in a population
- some pathogens are known to pass from species to species and are known as zoonoses
- herd immunity is achieved for a specific pathogen when a high percentage of the population has achieved immunity, making it unlikely that a pathogen would infect an unprotected person.



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## Exercises

**Q1.** Briefly state the function of each of the following during the process of blood clotting.

**(a)** Platelets

**(b)** Fibrinogen

**(c)** Thrombin

**Q2.** Which one of these is an unsafe transfusion of blood?

**A** $O^+$ to $A^+$

**B** $A^+$ to $AB^+$

**C** $O^+$ to $O^-$

**D** $AB^-$ to $AB^+$

**Q3.** B-lymphocytes must be exposed to two things before becoming activated. What are those two things?

**Q4.** What is the cellular process that produces clones of selected lymphocytes?

**Q5.** Antibiotics will not help control a viral infection. Why?

**Q6.** Why do symptoms develop when the body undergoes a primary immune response?

**Q7.** A single pathogen can result in multiple adaptive immune responses in a person. Which answer best explains this.

**A** A pathogen may be related to a previous pathogen.

**B** A pathogen may contain many antigens recognizable by the immune system.

**C** A pathogen will always mutate inside the body.

**D** A pathogen is altered by the adaptive immune response.



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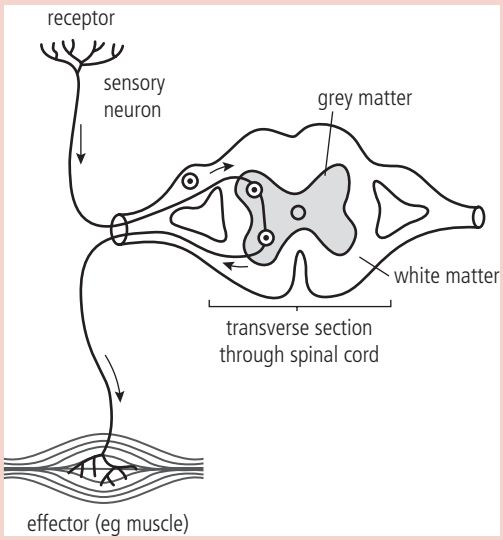
## C3 Practice questions

**1.** Annotate the diagram of the reflex arc to show the name and function of the structures labelled I and II.




(*Total 2 marks*)

**2.** The heart responds quickly to physical activity. Describe how heart rate is controlled to meet increased circulatory demands.

(*Total 2 marks*)

**3.** Bacteria are prokaryotes that sometimes act as pathogens. Describe how the body can defend itself against pathogens.

(*Total 7 marks*)

**4.** Explain the evolution of antibiotic resistance in bacteria.

(*Total 6 marks*)



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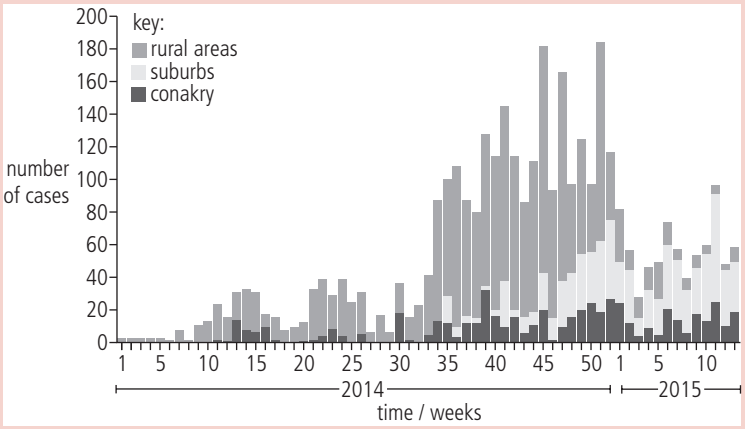
**5.** Ebola virus disease (EVD) is the disease in humans and other primates that is caused by the Ebola virus. Fruit bats are the reservoir for the virus and are able to spread the disease without being affected. Humans can become infected by contact with fruit bats or with people infected by the virus, their body fluids or equipment used to treat them.

The stacked bar graph shows the epidemiological data for EVD cases in Conakry, the capital city of Guinea, the surrounding suburbs, and rural areas in Guinea, from the beginning of January 2014 to the end of March 2015.




**(a)** Identify the week and year in which the first cases were recorded in the suburbs. (1)

**(b)** Based on the graph, compare and contrast the progress of the epidemic in the suburbs and rural areas. (3)

**(c)** Suggest **two** reasons for the overall decline in the epidemic after week 51. (2)

**(*Total 6 marks*)**



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