BIOZONE

HSC | BIOLOGY
MODULES 5 - 8

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CHAPTER 3

DNA and Polypeptide Synthesis

Key terms

anticodon
base-pairing rule
coding strand
codon
denaturation
DNA
exon
fibrous protein
gene
gene expression
genetic code
globular protein
intron
mRNA
peptide bond
polypeptide
primary structure
protein
proteome
quaternary structure
ribosome
rRNA
secondary structure
template strand
terminator sequence
tertiary structure
transcription
tRNA
translation

Activity number

Inquiry question: *Why is polypeptide synthesis important?*

DNA in prokaryotes and eukaryotes

Key skills and knowledge

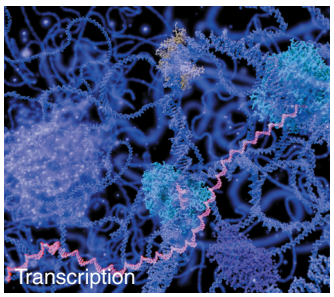
☐ 1 Construct representations to model and compare the forms in which DNA exists in prokaryotes and eukaryotes to include: **54-57**

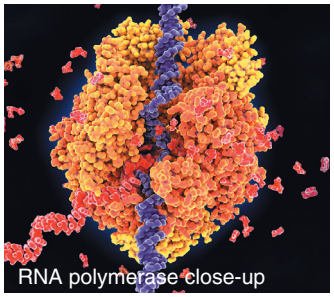
i Where the DNA is located and how it is packaged.

ii The size of the genome, number of chromosomes, and presence or absence of extra-chromosomal DNA.

iii The shape/form of the chromosome and the way the genetic information is organised.


DNA model


Transcription


RNA polymerase close-up

Polypeptide synthesis

Key skills and knowledge

☐ 2 Describe the structure of the three types of RNA (mRNA, tRNA, and rRNA) and their functional roles in polypeptide synthesis. Compare and contrast RNA and DNA. **46 58**

☐ 3 Use a model to describe how nucleic acids encode the instructions for the synthesis of proteins in cells, including reference to the relationship between the base sequence in a nucleic acid and the order of the amino acids in a polypeptide chain. **59**

☐ 4 Describe the genetic code, including the 4-letter alphabet and the 3-letter triplet code (codon) of base sequences, and the non-overlapping, linear nature of the code. **60**

☐ 5 Assess the importance of mRNA and tRNA in transcription and translation. Describe the steps involved in gene expression including transcription, RNA processing (eukaryotic cells), and translation. Identify where in the cell each of these steps occurs. **61-63**

☐ 6 Analyse the function and importance of polypeptide synthesis in cells, e.g. through the analysis of gene expression profiles. **64**

☐ 7 Assess how genes and environment affect phenotypic expression including: **65-68**

i How genetic make-up (genotype), environmental factors, and epigenetic factors contribute to produce the phenotype of an organism.

ii The role of mutations in altering phenotype.

☐ 8 PRAC Investigate continuous variation in a population sample for a characteristic determined by multiple genes, e.g. height, hand span, foot length. **69**

Investigating the structure and function of proteins

Key skills and knowledge

☐ 9 Recall how a polypeptide is synthesised from amino acid monomers. Explain how the properties of amino acids determine how they interact and how these interactions create the hierarchical levels of structure that produce a functional protein. **70 72**

☐ 10 PRAC Create a model to investigate the hierarchical nature of protein structure. **72**

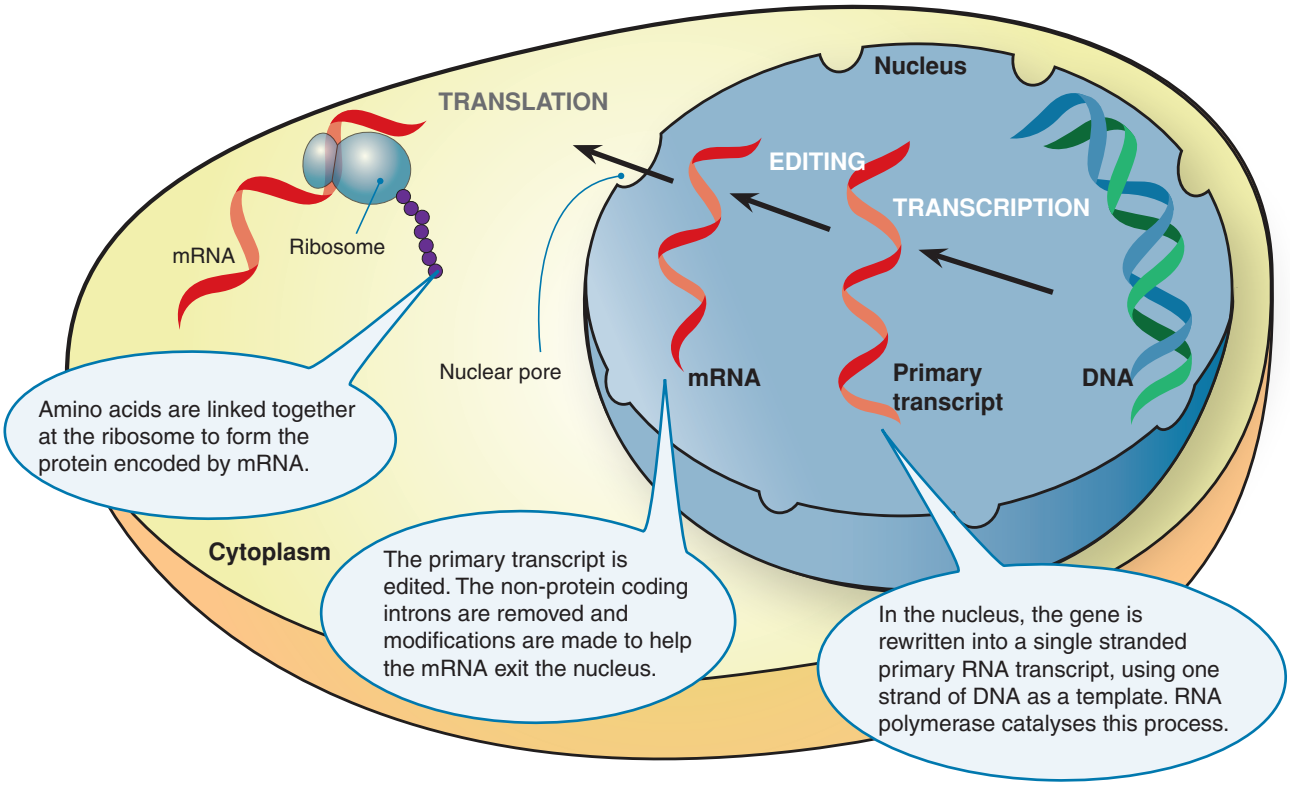
☐ 11 PRAC Investigate the properties of amino acids using chromatography. **71**

☐ 12 Explain how protein shape is related to function and compare the functional roles of globular and fibrous proteins. Identify and describe the diverse roles of proteins making up an organisms's proteome. **73-75**

59 What is Gene Expression?

Key Idea: Genes are sections of DNA that code for proteins. Genes are expressed when they are transcribed into messenger RNA (mRNA) and then translated into a protein.
Gene expression is the process by which the information in a gene is used to synthesise a protein. It involves **transcription** of the DNA into mRNA and **translation** of the mRNA into protein. Eukaryotic genes include non-protein coding regions called introns. These regions of intronic DNA must be edited out before the mRNA is translated by the ribosomes. Transcription of the genes and editing that primary transcript to form the mature mRNA occurs in the nucleus. Translation of the protein by the ribosomes occurs in the cytoplasm.

A summary of eukaryotic gene expression



1. What is a gene? _____

_____

2. (a) What does gene expression mean? _____

_____

(b) What are the three stages in gene expression in eukaryotes and what happens in each stage?

(i) _____

(ii) _____

(iii) _____

3. The photograph right shows an SEM of a giant polytene chromosome. These chromosomes are common in the larval stages of flies, which must grow rapidly before changing to the adult form. They form as a result of repeated cycles of DNA replication without cell division. This creates many copies of genes. Within these chromosomes, visible 'puffs' indicate regions where there is active transcription of the genes.

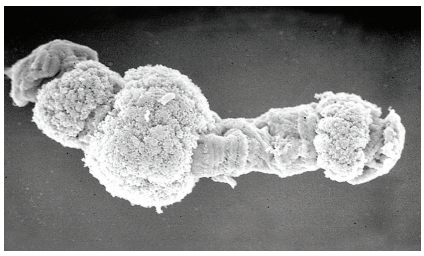
(a) What is the consequence of active transcription in a polytene chromosome?

_____

(b) Why might this be useful in a larval insect? _____

_____

_____



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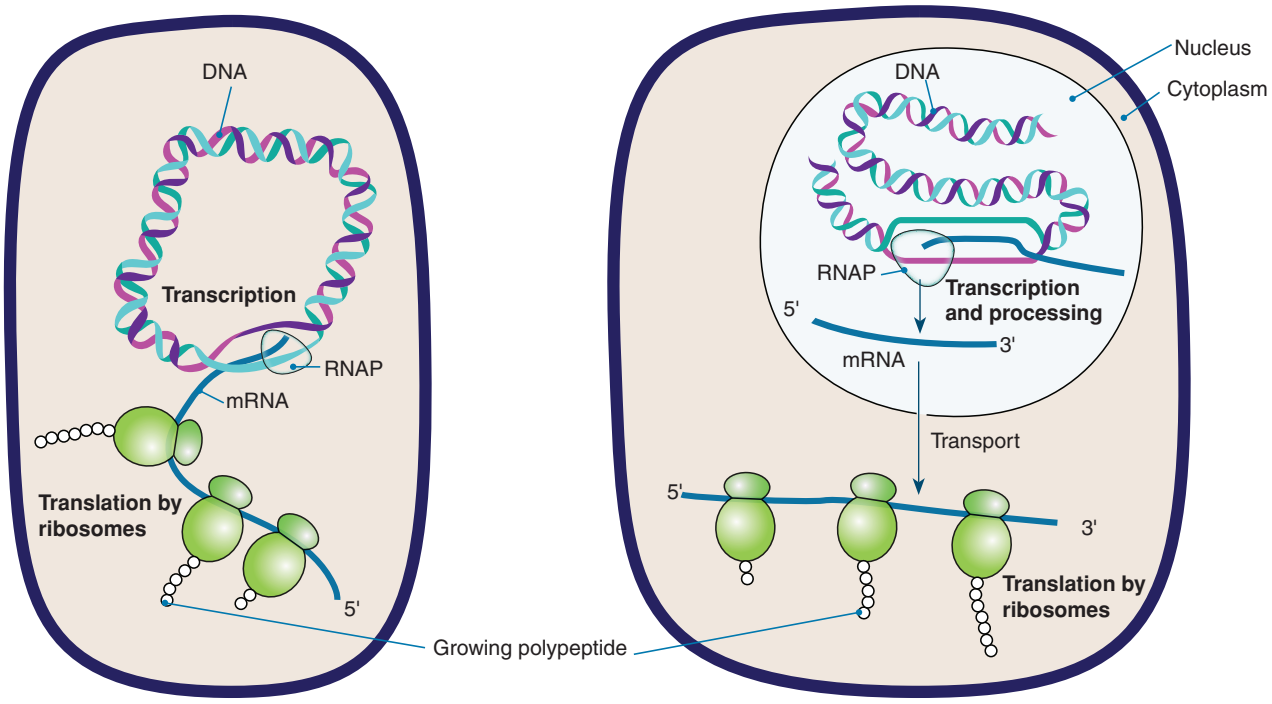
Comparing gene expression in prokaryotes and eukaryotes

In both prokaryotes and eukaryotes, genes are transcribed by the enzyme RNA polymerase (**RNAP**) and translated by ribosomes. However, there are important differences. In eukaryotes, the primary transcript must be edited and processed before exiting the nucleus to the cytoplasm. In prokaryotes, there is no nucleus and ribosomes begin translating a gene while it is still being transcribed.



Prokaryote **Eukaryote**

4. For the following triplets on a DNA template strand, state the codon sequence for the mRNA that would be synthesised:

   Triplets on the DNA: T A C T A G C C G C G A T T T

   Codons on the mRNA: _____

   Triplets on the DNA: T A C A A G C C T A T A A A A

   Codons on the mRNA: _____

5. What is the significance of the promoter and terminator regions on the DNA? _____

   _____

6. Why might a cell employ several RNA polymerases to produce multiple RNA transcripts of a gene at any one time?

   _____

   _____

7. Based on the diagram above, describe two differences between gene expression in prokaryotes and eukaryotes:

   (a) _____

   _____

   (b) _____

   _____

8. Based on the diagram above, how is gene expression in prokaryotes and eukaryotes similar? _____

   _____

9. What benefit might there be to the way in which prokaryotes can begin translation while a gene is still being transcribed?

   _____

   _____

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104 Applications of DNA Profiling

Key Idea: DNA profiling has many forensic applications, from identifying criminal offenders to saving endangered species.

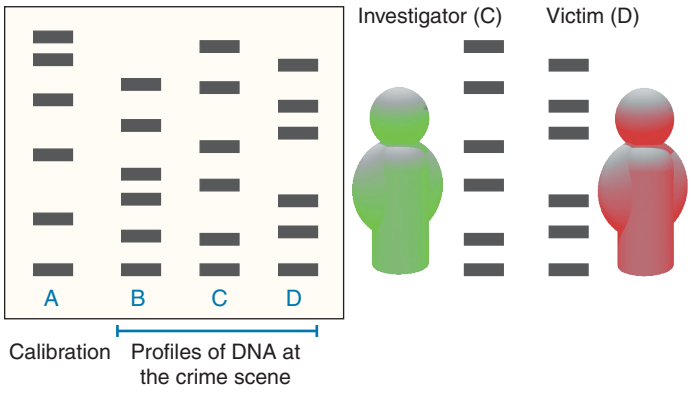
The use of DNA as a tool for solving crimes such as homicide is well known, but it can also has several other applications. DNA evidence has been used to identify body parts, solve cases of industrial sabotage and contamination, for paternity testing, and even in identifying animal products illegally made from endangered species.

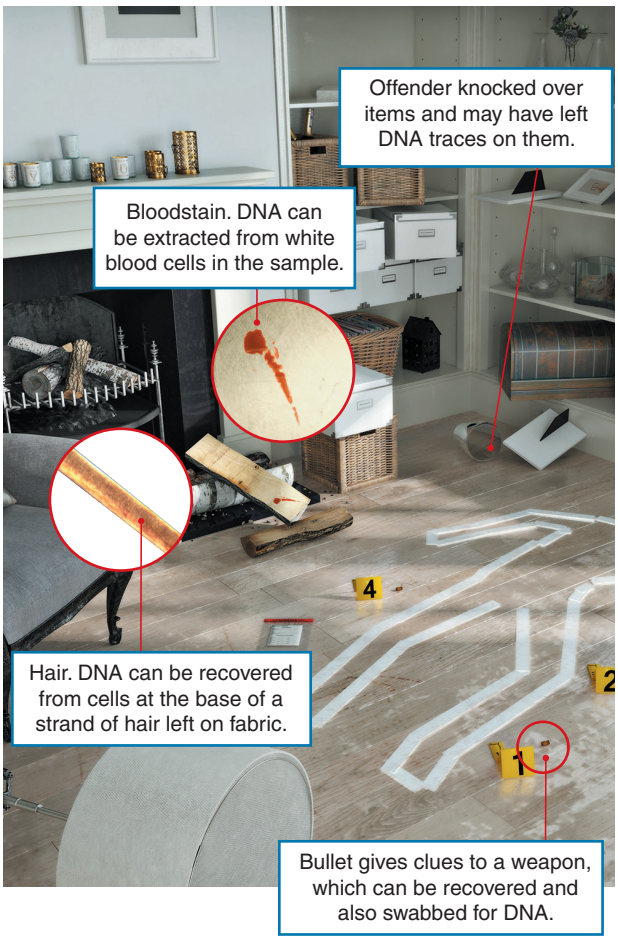
Using DNA to solve crimes

Although it does not make a complete case on it own, DNA profiling (in conjunction with other evidence) is one of the most powerful tools in identifying offenders or unknown tissues.

A lot of DNA is found at crime scenes and the information collected can be used to help identify the criminal. However, not all of the DNA collected will be from the criminal. Other DNA could belong to the victim, people who came to their aid (e.g. paramedics) or the police investigators (if they have not taken correct precautions).

In the example (right) the criminal who broke into this home has left behind several samples of their DNA. Samples of material that may contain DNA are taken for analysis. At a crime scene, this may include blood and body fluids as well as samples of clothing or objects that the offender might have touched. Samples from the victim and the investigator are also taken to eliminate them as a possible source of contamination (below). In this example the DNA of the people who live in the house will also be collected so their profiles can be eliminated. A calibration or standard is run so the technician knows the profile has run correctly.

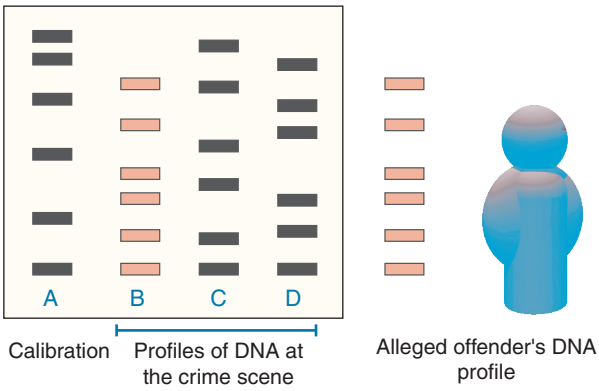




There are two different ways an offender can be identified through DNA profiling.

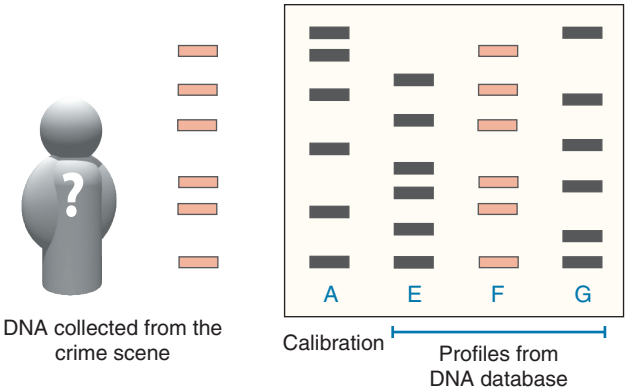
1. If a person is suspected of a crime, a sample of their DNA can be taken (e.g. blood sample) and compared to DNA evidence collected at the crime scene. A match indicates they are the offender. If there is no match, the person can be cleared as a suspect.
2. In cases where the suspect is unknown, biological evidence from the crime scene is analysed and the profile is compared to known offender profiles in DNA databases. The profile may match that of a known offender.

1 A person is suspected of the crime



Match! The alleged offender's profile matches the DNA collected at the crime scene.

2 The offender is unknown



Match! The DNA collected from the crime scene matches the profile of a known offender in the database.

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Paternity testing

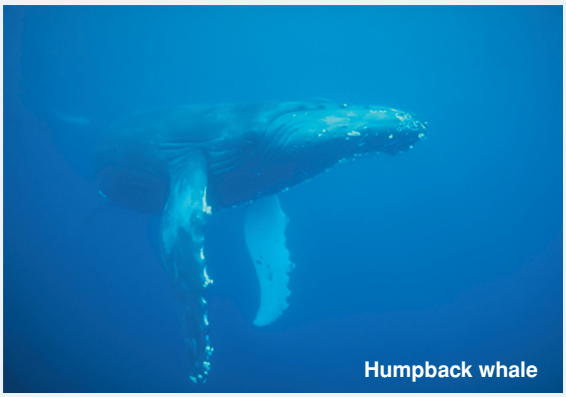
DNA profiling can be used to determine paternity (and maternity) by looking for matches in alleles between parents and children. It is used in cases such as child support or inheritance. DNA profiling can establish the certainty of paternity (and maternity) to a 99.99% probability of parentage.

Every STR allele is given the number of its repeats as its name, e.g. 8 or 9. In a paternity case, the mother may be 11, 12 and the father may be 8, 13 for a particular STR. The child will have a combination of these. The table below illustrates this:

DNA marker	Mother's alleles	Child's alleles	Father's alleles
CSF1PO	7, 8	8, 9	9, 12
D10S1248	14, 15	11, 14	10, 11
D12S391	16, 17	17, 17	17, 18
D13S317	10, 11	9, 10	8, 9

The frequency of the each allele occurring in the population is important when determining paternity (or maternity). For example, DNA marker CSF1PO allele 9 has a frequency of 0.0294 making the match between father and child very significant (whereas allele 12 has a frequency of 0.3446, making a match less significant). For each allele, a paternity index (PI) is calculated. These indicate the significance of the match. The PIs are combined to produce a probability of parentage. 10-13 different STRs are used to identify paternity. Mismatches of two STRs between the male and child is enough to exclude the male as the biological father.

Whale DNA: tracking illegal slaughter


Humpback whale

Under International Whaling Commission regulations, some species of whales can be captured for scientific research and their meat can be sold legally. Most whales, including humpback and blue whales, are fully protected and to capture or kill them is illegal.

Between 1999 and 2003, researchers used DNA profiling to investigate whale meat sold in markets in Japan and South Korea. They found 10% of the samples tested were from fully protected whales including western grey whales and humpbacks. They also found that many more whales were being killed than were being officially reported.

1. Why are DNA profiles obtained for both the victim and investigator? _____

_____

_____

2. Study the profile on the right.

   (a) Is the alleged offender innocent or guilty?_____

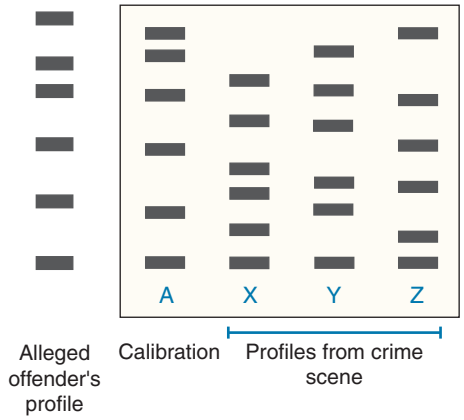
   (b) Explain your decision: _____

_____

_____

_____

_____



3. For the STR D10S1248 in the example above, what possible allele combinations could the child have?

_____

4 A paternity test was carried out and the abbreviated results are shown right:

DNA marker	Mother's alleles	Child's alleles	Man's alleles
CSF1PO	7, 8	8, 9	9, 12
D10S1248	14, 15	11, 14	10, 11
D19S433	9, 10	10,15	14, 16
D13S317	10, 11	9, 10	8, 9
D2S441	7, 15	7, 9	14, 17

   (a) Could the man be the biological father? _____

   (b) Explain your answer: _____

_____

_____

_____

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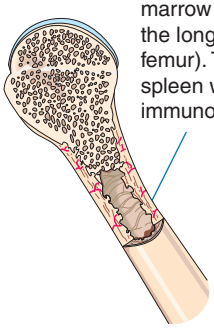
172 The Adaptive Immune Response

Key Idea: The adaptive immune response launches a specific immune response to antigens. It involves B cells and T cells.

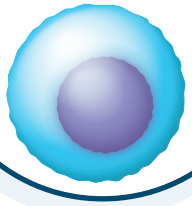
Recall that the innate immune response responds the same way for every antigen it encounters. In contrast, the adaptive immune response reacts uniquely to each specific type of antigen it encounters. The adaptive immune response targets both extracellular antigens (e.g. bacteria) and intracellular antigens (e.g. viruses). There are two main components of the adaptive immune system: the humoral immune response and the cell mediated immune response. The **humoral immune response** is associated with the serum (the non-cellular part of the blood) and involves the action of antibodies secreted by **B cells** (B lymphocytes). The **cell-mediated immune response** is associated with the production of lymphocytes called **T cells** (T lymphocytes). Antigens are recognised by T cells only after antigen processing (opposite).

Lymphocyles and their functions

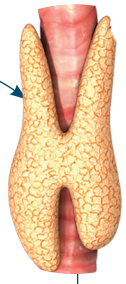
Bone marrow
B cells mature in the bone marrow in the shaft of the long bones (e.g. the femur). They migrate to the spleen where they become immunocompetent.



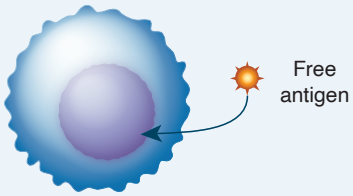
Stem cell
Stem cells in the bone marrow and fetal liver give rise to T cells and B cells.



Thymus gland
The thymus gland is located above the heart. It is large in infants but becomes smaller with age. Immature T cells move to the thymus to mature before migrating to other lymphatic organs.

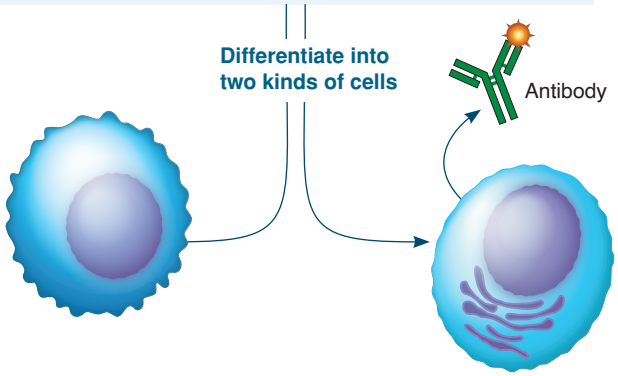


B CELLS



B cells recognise and bind antigens. Each B cell recognises one specific antigen. Helper T cells recognise specific antigens on B cell surfaces and induce their maturation and proliferation. A mature B cell may carry as many as 100,000 antigenic receptors embedded in its surface membrane. B cells defend against bacteria and viruses outside the cell and toxins produced by bacteria (free antigens).

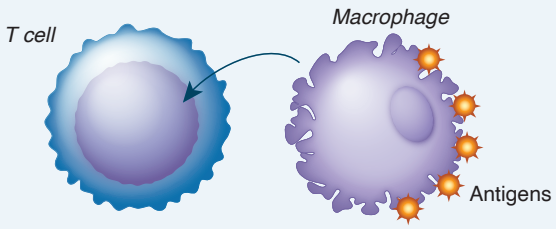
Differentiate into two kinds of cells



Memory cells
Some B cells differentiate into long-lived memory cells (see Clonal Selection). When these cells encounter the same antigen again (even years or decades later), they rapidly differentiate into antibody-producing plasma cells.

Plasma cells
When stimulated by an antigen (see Clonal Selection), some B cells differentiate into plasma cells, which secrete **antibodies** into the bloodstream. The antibodies then inactivate the circulating antigens.

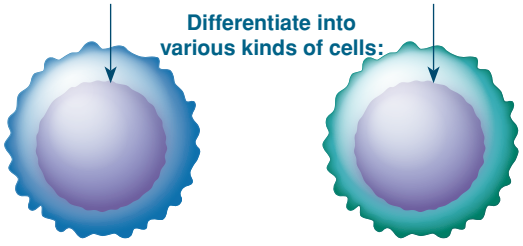
T CELLS



T cells respond only to antigen fragments that have been processed and presented by specialised antigen-presenting cells (dendritic cells and macrophages). They defend against:

- Intracellular bacteria and viruses
- Protozoa, fungi, flatworms, and roundworms
- Cancerous cells and transplanted foreign tissue

Differentiate into various kinds of cells:



T helper cell activates T killer cells and other helper T cells. They are needed for B cell activation.

T killer cell destroys target cells on contact. Recognises tumour or virus-infected cells by their surface markers. They are also called cytotoxic T cells.

There are also other types of T cells:
T memory cells have encountered specific antigens before and can respond quickly and strongly when the same antigen is encountered again.
T regulator cells control the immune response by turning it off when no more antigen is present. They are important in the development of self tolerance.

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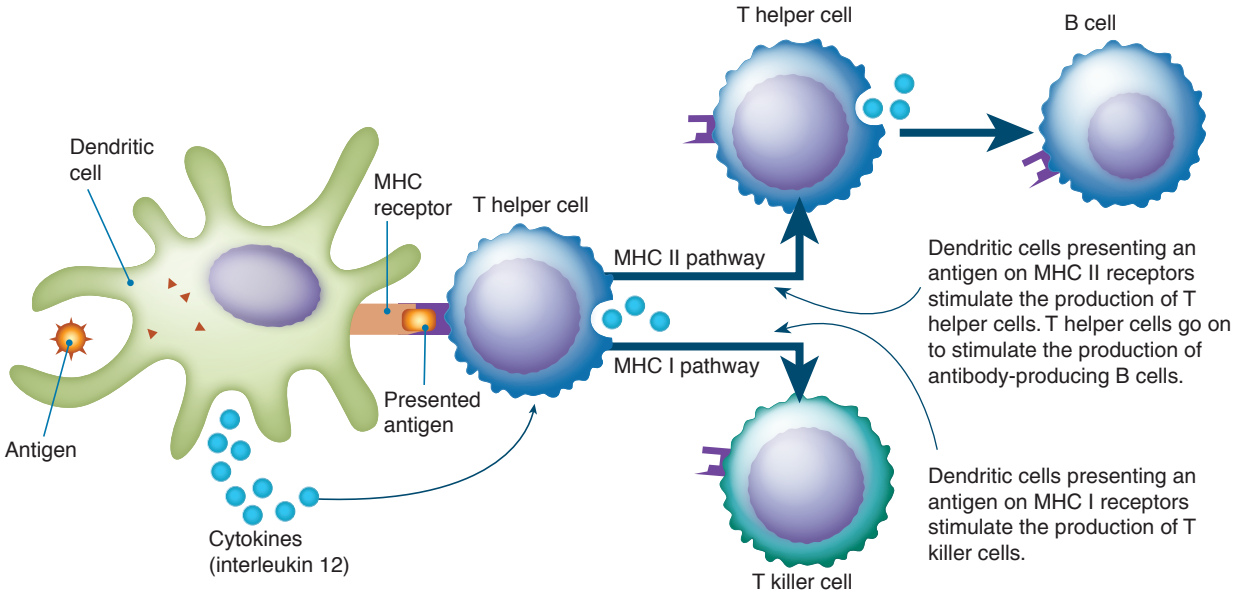
Dendritic cells stimulate the activation and proliferation of lymphocytes



- Dendritic cells (as well as macrophages and B cells) are specialised antigen-presenting cells (APC). Most nucleated cells have MHC I receptors but APC have both MHC I and MHC II receptors, making them so-called "professional" APC.
- Immature dendritic cells originate in the bone marrow and migrate to the lymph nodes. When the dendritic cell encounters an antigen, it presents it to a T helper cell (above). This stimulates the T helper cell to secrete chemicals called cytokines. Cytokines stimulate the activation and increase in number of T cells, activating the immune system against that specific antigen.

1. Describe the nature and general action of the two major divisions in the immune system:

   (a) Humoral immune system: _____

   _____

   _____

   (b) Cell-mediated immune system: _____

   _____

   _____

2. Explain how an antigen causes the activation and proliferation of T cells and B cells, including the role of dendritic cells:

   _____

   _____

   _____

   _____

3. In what way do dendritic cells act as messengers between the innate and the adaptive immune systems?

   _____

   _____

6. Describe the function of each of the following cells in the immune system response:

   (a) T helper cells: _____

   (b) T killer cells: _____

7. Suggest why the thymus gland is largest in infants: _____

   _____

   _____

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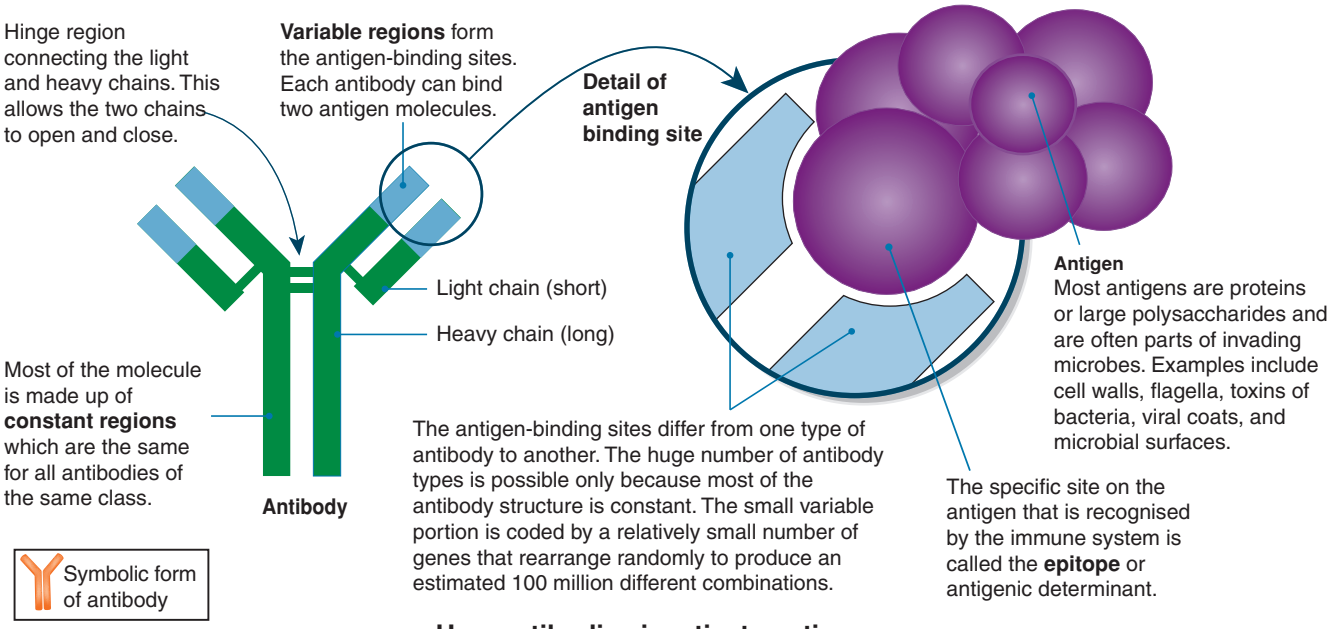
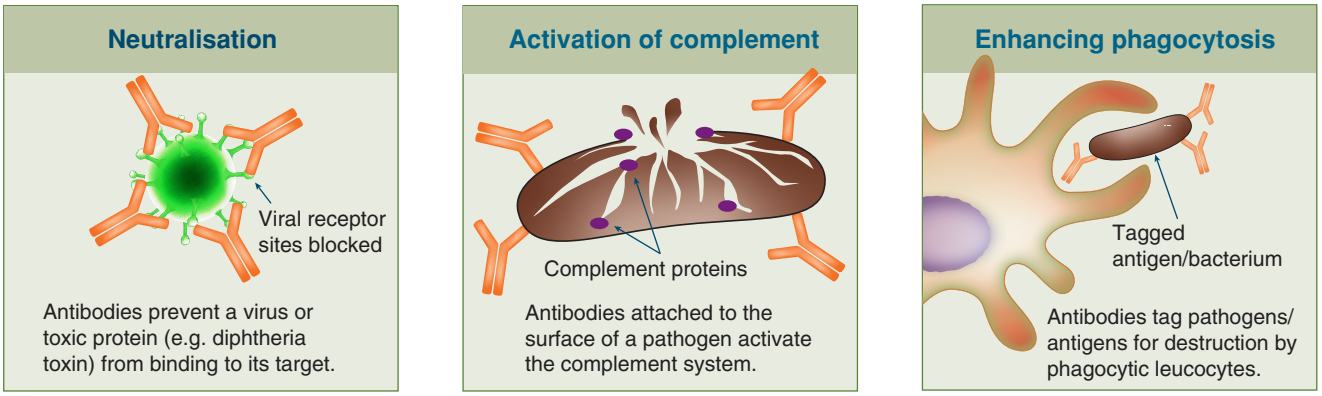
176 Antibodies

Key Idea: Antibodies are large, Y-shaped proteins, made by B cells, which destroy specific antigens.

Antibodies and antigens play key roles in the response of the immune system. Recall that antigens are foreign molecules which promote a specific immune response. Antigens include pathogenic microbes and their toxins, as well as substances such as pollen grains, blood cell surface molecules, and the surface proteins on transplanted tissues. **Antibodies** (also called immunoglobulins) are proteins made in response to antigens. They are secreted from plasma B cells into the plasma where they can recognise, bind to, and help destroy antigens. There are five classes of antibodies, each plays a different role in the immune response. Each type of antibody is specific to only one particular antigen.



How antibodies inactivate antigens



1. Describe the structure of an antibody, identifying the specific features of its structure that contribute to its function:

2. Use the diagram above to describe three ways in which antibodies help the immune system' to stop infection:

(a)

(b)

(c)

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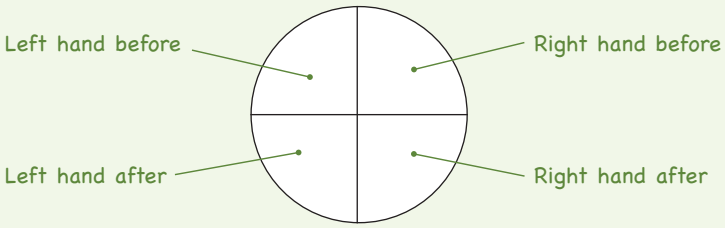
180 The Effectiveness of Hand Washing

Key Idea: Hand washing is an important and simple method to prevent the spread of disease, but must be properly done. We as humans spend much of our time manipulating objects with our hands, so it follows that our hands are covered with the microorganisms found in our environment. These microbes can then be easily transferred by touch to our mouths, such as when eating, or to other people, such as when we hand them an object. Hand washing after contact with potentially contaminated material reduces the chance of transmitting microbes to our internal environment or to others. In the investigation below you will obtain primary data on the effectiveness of handwashing.

Investigation 12.1 Investigating the effectiveness of handwashing

See appendix for equipment list.

1. The class will be divided into thirds. One third will wash their hands with warm water. One third will wash their hands with soap and warm water and one third will use hand sanitiser. Your teacher will place you into one of these groups. **Do not wash your hands until step 5!**
2. Each person in the group should take a nutrient agar plate and use a marker pen to label the edge of the lid of the plate with name, the incubation temperature (e.g. 30°C), and which group you are in.
3. Then use the marker pen to divide the plate lid into quarters and label them as shown below:



4. Open the lid and press the tips of your middle and fore fingers from your left hand in the "Left hand before" quarter. Hold them there for 5 seconds. Then press the tips of your middle and fore fingers from your right hand in the "Right hand before" quarter. Hold them there for 5 seconds. Close the lid.
5. Now wash your hands using the regime assigned to your group (water, soap and water, hand sanitiser). Dry your hands if needed with a clean paper towel.
6. Open the lid of the agar plate again and press the tips of your middle and fore fingers from your left hand in the "Left hand after" quarter. Hold them there for 5 seconds. Then press the tips of your middle and fore fingers from your right hand in the "Right hand after" quarter. Hold them there for 5 seconds. Close the lid and seal it with clear tape.
7. Incubate the plate at your chosen incubation temperature, lid down, for 24 hours.
8. Retrieve the agar plates and observe the four different quarters. Count and record the number of bacterial colonies on the plate in each half (before and after). Do this for all the plates in your assigned group. If you only have a small number in your group, just enter the data you have. Calculate the mean number the colonies before and after (below).
9. Compare your means with means from the other groups in the class.

1. (a)

Your technique: _____	Plate number										Mean
Number of colonies before washing hands											
Number of colonies after washing hands											

(b) Handwashing technique: _____ Mean colonies before: _____ Mean colonies after: _____

(c) Handwashing technique: _____ Mean colonies before: _____ Mean colonies after: _____

2. Which technique appears to have the greater ability to remove bacteria from your hands? Explain why:

_____

_____

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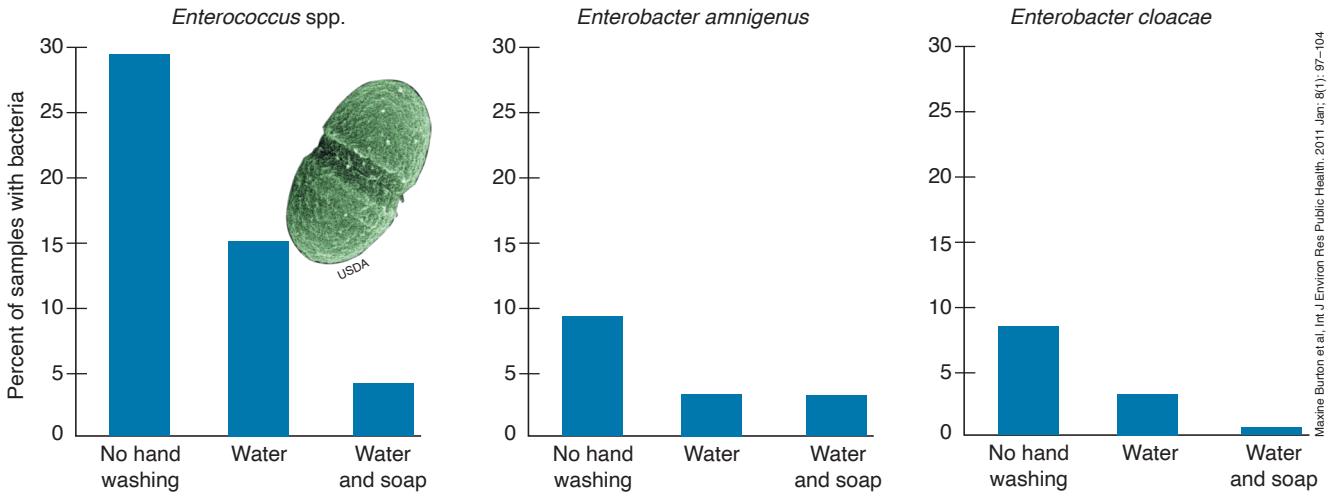
Testing the effectiveness of hand washing

- A 2011 study performed the following experiment on the effectiveness of hand washing.
- Twenty volunteers deliberately contaminated their hands by contact with hard surfaces such as hand rails and door knobs in public areas.
- They were then randomly allocated to one of three groups: no hand washing, hand washing with tap water, or handwashing with soap and tap water. No instructions were given as to how to hand wash or for what length of time. Volunteers simply washed their hands as they would normally.
- Swabs were then taken from the volunteers' hands and transferred to agar plates. These were incubated at 35°C for 48 hours. This procedure was carried out 24 times for each volunteer for a total of 480 samples.
- The results are shown below. The bacteria found all occur in the intestines of animals (collectively called faecal coliforms).



Questions 3-5 are with reference to the study above:

3. (a) Was hand washing an effective way to remove bacteria from the hands? _____

   (b) Which was the most effective method of removing bacteria from the hands? _____

4. Which bacterium was most common on the hands? _____

5. Why do you think the researchers gave no handwashing instructions to the volunteers? _____

6. Use your data and the experiment above to explain why hand washing is an important part of controlling the spread of disease, especially in a epidemic or pandemic situation (e.g. the Covid-19 pandemic).

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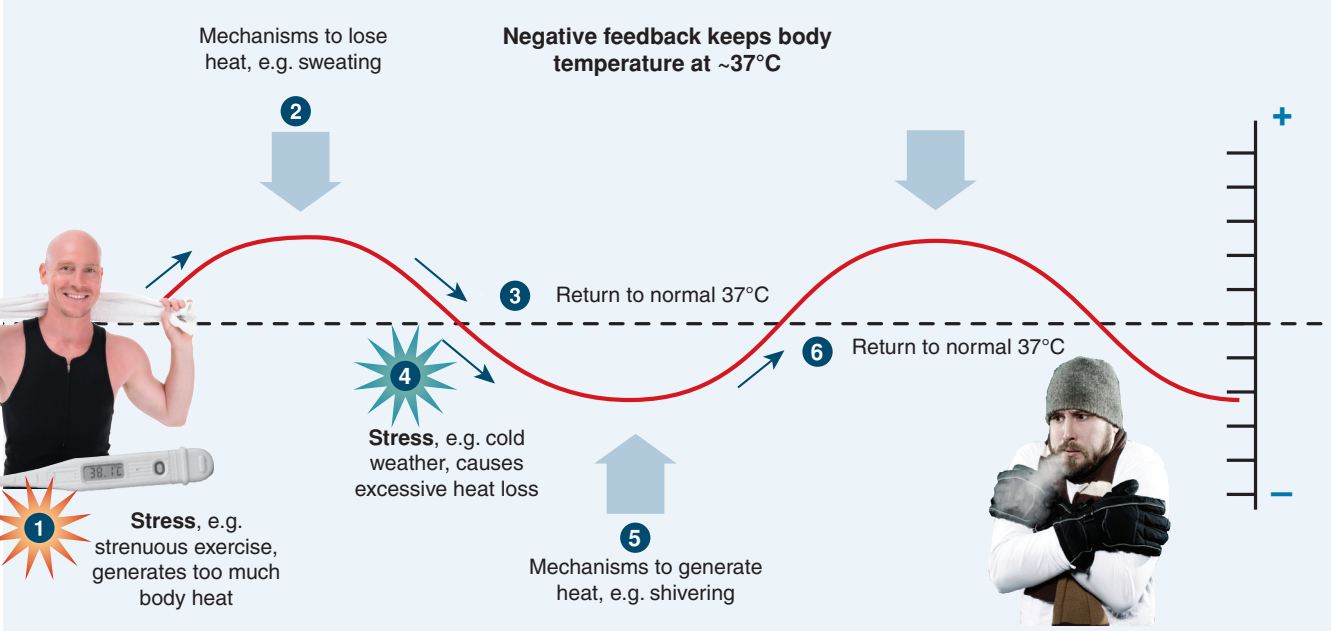
190 Feedback Mechanisms

Key Idea: Feedback mechanisms can stabilise biological systems or exaggerate deviations from the median condition. There are two types of feedback mechanisms used in the body, each producing specific outcomes. Negative feedback maintains a stable internal environment, as occurs in the regulation of body temperature. Positive feedback exaggerates any changes in the internal environment, usually to achieve a specific outcome quickly, e.g. blood clotting.

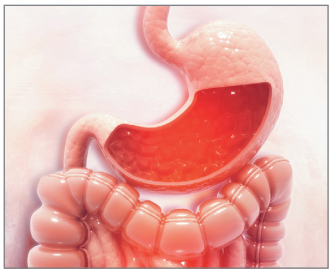
Negative (counterbalancing) feedback

- Negative (or counterbalancing) feedback is a control system that maintains the body's internal environment at a relatively steady state. Negative refers to the sign used in mathematical models of feedback.
- Negative feedback has a stabilising effect by discouraging variations from a set point. When variations are detected by the body's receptors, negative feedback returns internal conditions back to a steady state (below).
- Most physiological (and environmental) systems achieve homeostasis through negative feedback.



CDC

We know when we are too cold but we are unaware of most of the negative feedback operating in our bodies. Yet it keeps our body systems stable.



Food in the stomach activates stretch receptors, stimulating gastric secretion and motility. As the stomach empties, the stimulus for gastric activity declines.

Negative feedback controls almost all the body's functioning processes including heart rate, blood glucose, blood pressure, and pituitary secretions.

Maintaining a stable blood glucose is an important homeostatic function regulated by negative feedback involving two antagonistic hormones.

1. How does the behavior of a negative feedback system maintain homeostasis? _____

2. Why do you think it is important that the regulation of the body's critical functions depends on negative feedback?

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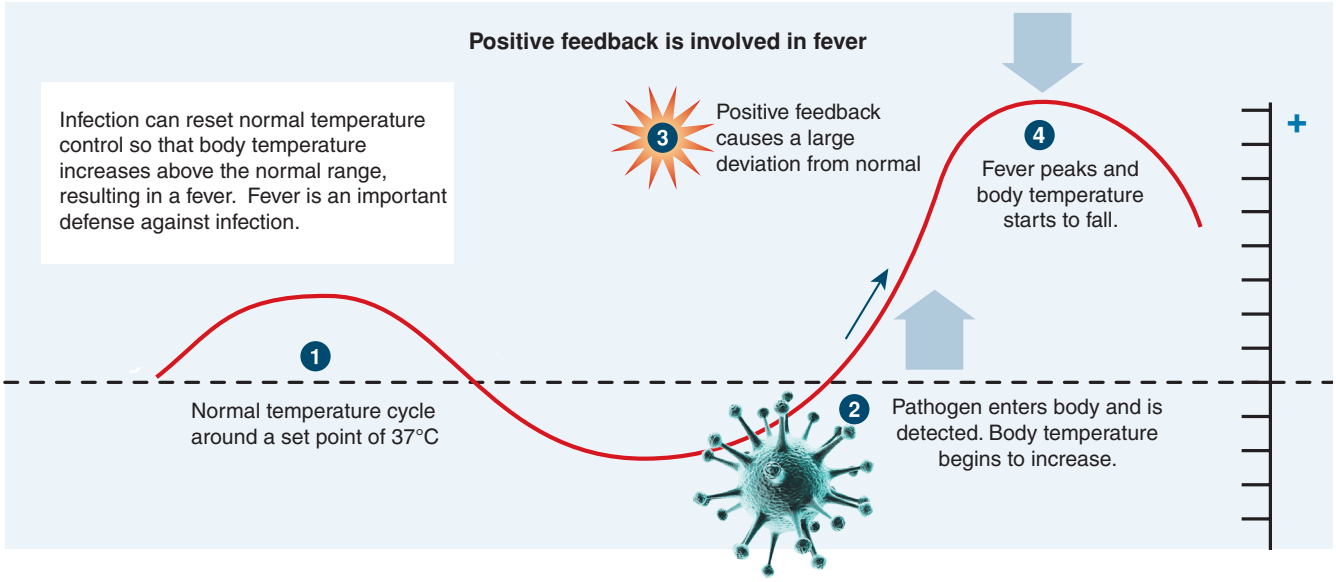
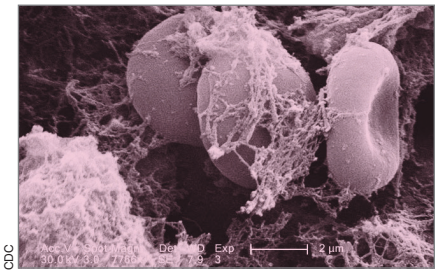
Positive feedback

- Positive feedback mechanisms amplify (increase) a response in order to achieve a particular result. Examples of positive feedback include fruit ripening, fever, blood clotting, childbirth (labour) and lactation (production of milk).
- A positive feedback mechanism stops when the end result is achieved (e.g. the baby is born, a pathogen is destroyed by a fever, or ripe fruit falls off a tree). Positive feedback is less common than negative feedback in biological systems because the escalation in response is unstable. Unresolved positive feedback responses (e.g. high fevers) can be fatal.





Positive feedback is involved in blood clotting. A wound releases chemicals to activate platelets in the blood. Activated platelets release chemicals to activate more platelets, so a blood clot is formed.

Ethylene is a gaseous plant hormone involved in fruit ripening. It accelerates ripening in nearby fruits, so these also ripen, releasing more ethylene. Too much ethylene causes over-ripening.

Childbirth involves positive feedback. Pressure of the baby's head causes release of a hormone that increases contractions even more. The feedback loop ends when the baby is born.

3. (a) Why is positive feedback much less common than negative feedback in body systems? _____

_____

(b) How can positive feedback lead to a runaway response in the body? _____

_____

_____

(c) Why can positive feedback be dangerous if it continues on for too long? _____

_____

_____

(d) How is a positive feedback loop normally stopped? _____

_____

(e) Predict what could happen if a person's temperature continued increasing during a fever (did not peak and fall)?

_____

_____

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