INTERNATIONAL SECONDARY CERTIFICATE EXAMINATION
NOVEMBER 2023

BIOLOGY: PAPER II

SOURCE MATERIAL BOOKLET FOR QUESTIONS 1, 2 AND 3

SECTION A

QUESTION 1

Read the information below. Use this information, as well as your own knowledge, to answer Question 1 in the question paper.

Africa's deadly feline predators

Africa's three famous big cats, the lion, leopard, and cheetah, have evolved into the deadliest predators on Earth. Big cats share various characteristics, such as skeletal structure, muscular bodies, powerful teeth and jaws, and sharp claws. These similar bodily structures, combined with mitochondrial DNA analysis, confirm that these cats belong to the same family: the *Felidae*.

Cats differ in other characteristics such as size, fur colour, and coat pattern, depending on their habitat and hunting habits. These physical characteristics can all be explained by genotypic variation. Variations in the gene that codes for melanin (a protein pigment responsible for fur colour) can produce a wide colour range from black to sandy brown to red.

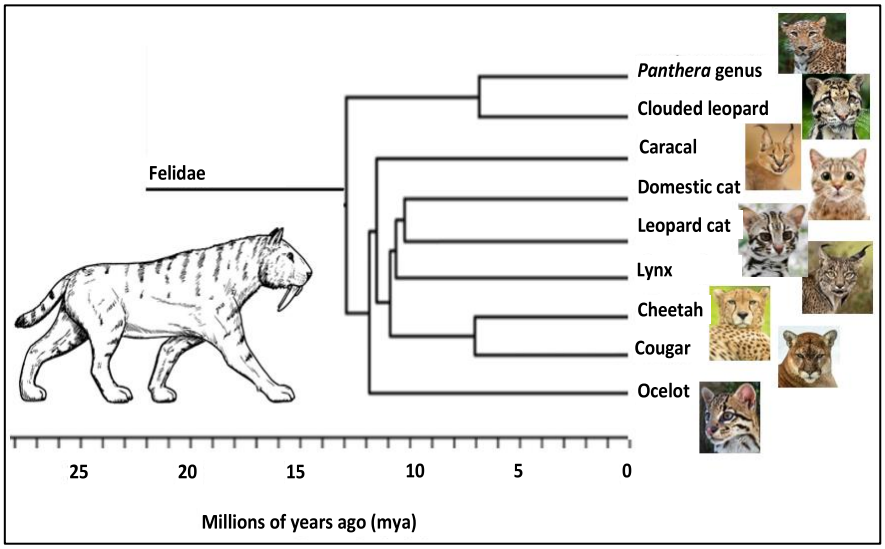
Figure 1.1 – Africa's famous cats – the lion, cheetah, and leopard

Over millions of years, the Felidae family evolved into different species, including *Panthera*, as shown in the phylogenetic tree (Figure 1.2) below.

Facts about different members of the *Panthera* genus

Members of the *Panthera* genus include lions, tigers, leopards, and jaguars. Most of the modern cats of today arose due to migrations that occurred during the two major ice ages of the past ten million years. During these ice ages the sea levels dropped, and land bridges formed between continents. This enabled the cats to migrate into several different habitats. When the ice sheets melted and sea levels rose again, the land bridges were covered. The migratory cats became isolated from their original populations. Over time, some members of *Panthera* evolved independently on different land masses to form different species, such as snow leopards and golden-brown leopards.

Figure 1.2 – Phylogenetic tree of members of the Felidae family



[Adapted: <https://commons.wikimedia.org/wiki/File:Felidae_phylogeny_(ita).png>]

Figure 1.3 – Map showing distribution of black leopards, snow leopards, and golden-brown leopards

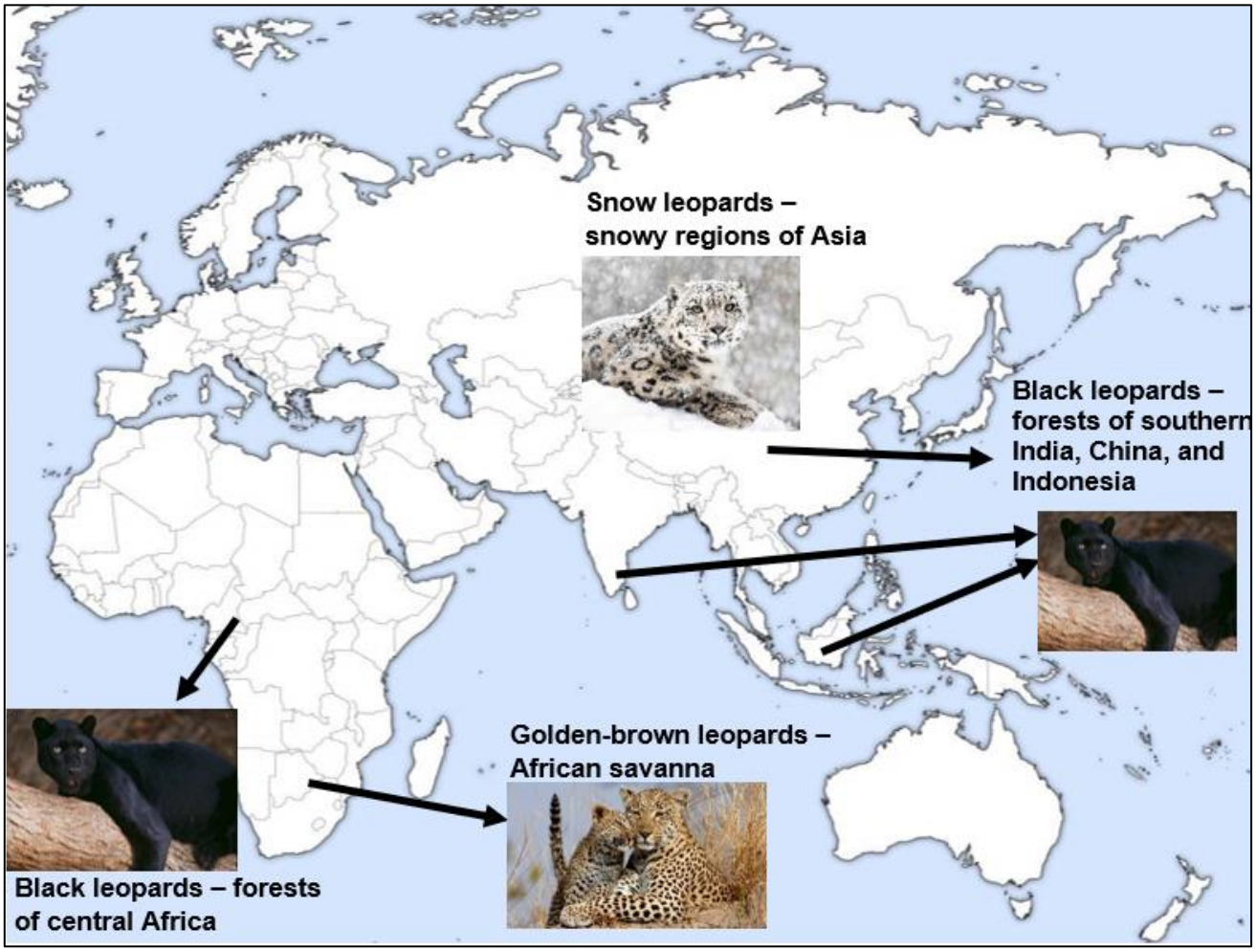


Figure 1.4 – Facts about snow leopards, golden-brown leopards, and black leopards

Snow leopards (*Panthera uncia*)

Habitat: Mountains of Central Asia – cold, dry, snow in winter.
Fur: White with black spots.

Golden-brown leopards (*Panthera pardus*)

Habitat: African savanna – grasses and scattered trees.
Fur: Golden brown with black spots.

Black leopards (*Panthera pardus*)

Habitat: 80% are found in dense forests of Asia and Africa; 20% are found in the African savanna.
Fur: Black with black spots.

Facts about the snow leopard (*Panthera uncia*)
Snow leopards have thick white fur with black spots that provides excellent camouflage when hunting prey in their snowy habitats.

Facts about the black leopard (*Panthera pardus*)
The Marvel superhero, the Black Panther, was inspired by the beautiful black leopard. This is an example of melanism in leopards. Melanism in leopards is caused by a recessive gene mutation, which causes black fur. Black leopards are more common in dense forests where light levels are lower. There is a significant decrease in the frequency of black leopards in biomes that consist of open habitats or less-dense forests with more light. In these habitats, the golden-brown leopard is more common.

Black leopards survive well in dense forests where there is no human disturbance. But melanism is a competitive disadvantage in the face of strong human impacts, such as deforestation.

Figure 1.5 – The Marvel superhero, the Black Panther

Figure 1.6 – The black leopard

[Images: <https://marvel.fandom.com/wiki/T%27Challa_(Earth-616)> <https://www.ripleys.com/weird-news/black-panthers/>]

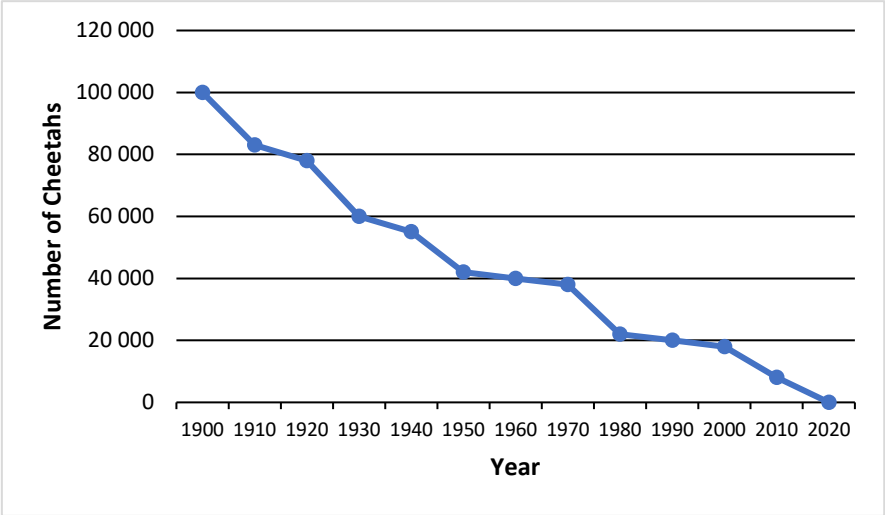
Facts about the cheetah (*Acinonyx jubatus*)
The world's fastest land animal is in a race for survival. Cheetahs are an example of the bottleneck effect. Genetic analysis of wild cheetahs shows that the cheetah population has an extremely low genetic diversity, caused by events that sharply reduced the size of their population. Scientists hypothesise that climate change about 10 000 years ago was responsible for their decline. Hunting by humans and habitat destruction are further reducing the size of their population. When this happens, inbreeding is likely to occur in this smaller population.

Cheetahs have a low natality, poor sperm quality, high cub mortality and they are sensitive to disease. If there is a sudden environmental change, it is unlikely that cheetahs will be able to adapt and evolve. This could ultimately cause their extinction.

[Adapted: <https://evolution.berkeley.edu/evo-news/will-evolution-doom-the-cheetah/>]

Figure 1.7 – A rare sighting: a female cheetah and her cubs
[Image: <https://news.cgtn.com/news>]

Figure 1.8 – The world cheetah population from 1990 to 2020



[Image: <https://flowvella.com/s/2f05/02AB69FB-C0E6-4A24-AD97-D41826B5AC61>]

The domestic cat

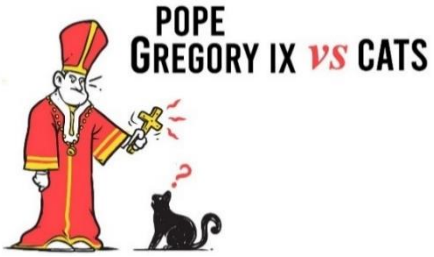
Cats in Egypt

The domestic cat originated from the African wildcat, *Felis sylvestris lybica*, a member of the *Felidae* family. Domestic cats have had a working relationship with humans for over 5 000 years. The Egyptians understood the value of cats and treated them like royalty. Cats hunted crop-destroying rats and mice for the Egyptians and in return were provided with food and protection. As the Egyptians bred more and more cats, they would have selected the ones that were more social and less territorial, but still behaved as typical cats. Domestic cats have very few genetic differences from their wild ancestors.

Cats in Europe

In the 1200s, Pope Gregory IX ordered the killing of thousands of cats in Europe because he thought they were evil. He linked cats to satanism and witchcraft.

In the 1300s, the Bubonic Plague killed millions of people in Europe. The plague was spread by fleas that lived on rats. Some people believe that killing the cats allowed the rats to thrive, making the plague even worse.



[Adapted: <https://www.historyextra.com/period/ancient-egypt/why-were-cats-so-important-in-ancient-egypt/>]
[Adapted: <https://historycolored.com/articles/7385/when-pope-gregory-ix-declared-a-war-on-cats/>]
[Adapted: <https://museumhack.com/black-cats-black-death/>]
[Adapted: <https://icatcare.org/advice/the-origins-of-cats/>]
[Adapted: <https://www.researchgate.net/figure/Dated-Felidae-phylogenetic-tree-based-on-genome-wide-pairwise-F2-statistics-calibrated_fig1_350356371>]
[Adapted: <https://theconversation.com/the-why-what-and-where-of-the-worlds-black-leopards-112674>]
[Adapted: <https://www.wildcatfamily.com/felidae-evolution/>]
[Adapted: <https://www.smithsonianmag.com/science-nature/evolution-in-black-and-white-50053448/Cats>]
[Adapted: https://sites.google.com/site/cheetahlb2013p6s/endangered-species]

QUESTION 2

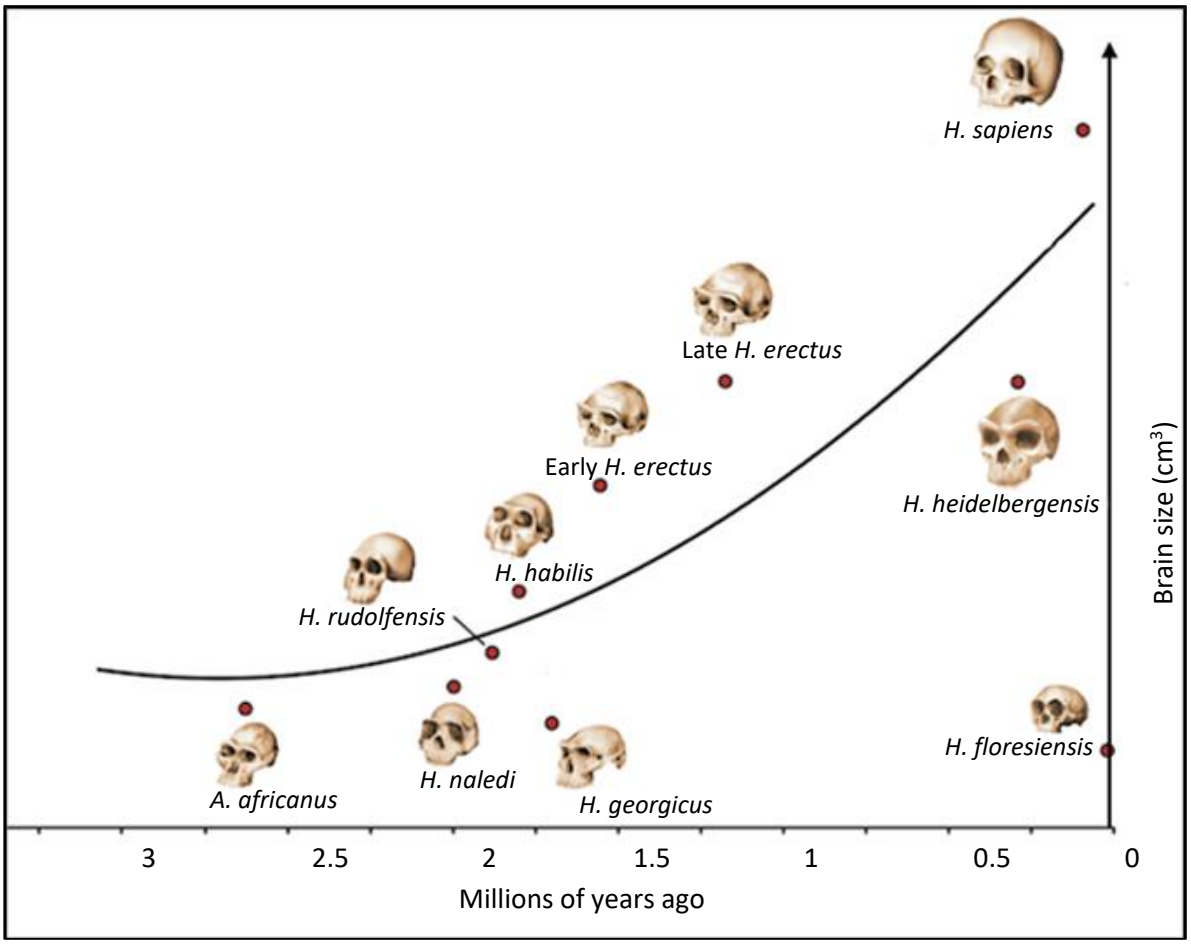
Read the information below. Use this information, as well as your own knowledge, to answer Question 2 in the question paper.

The evolution of human intelligence

Brain size and human intelligence

In humans, intelligence is commonly defined as the sum of mental capacities such as abstract thinking, understanding, communication, reasoning, learning and memory formation, action planning, and problem solving. Humans have become more intelligent over the last two million years.

Figure 2.1 – Graph showing brain size of various hominids over time



[Image adapted from: <https://ars.els-cdn.com/content/image/1-s2.0-S0168010219304882-gr1_lrg.jpg>]

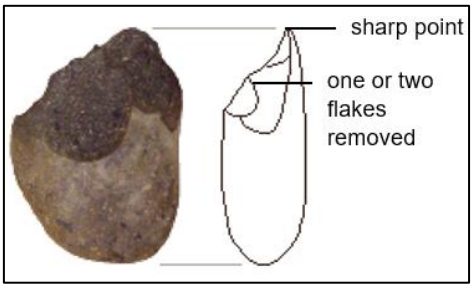
The social-brain hypothesis and human intelligence

One idea that scientists have proposed to explain the evolution of intelligence in humans is the social-brain hypothesis. This hypothesis suggests that as hominids began to live in more complex social groups, their brains became larger. Social interactions became more complex when hominids began to make tools. They used language to plan and teach each other while making and using tools. As the environment changed and became more unpredictable, bigger brains helped our hominid ancestors to work together more effectively to survive.

The importance of hominid tool making in brain development and intelligence

The stone tools that have survived in the archaeological record can tell us something about the intelligence of the people who made them. The oldest and simplest stone tools, known as Oldowan flake tools, were uncovered alongside the fossilised remains of *Homo habilis* in the Olduvai Gorge in Tanzania. *Homo habilis* made simple flake stone tools by hammering the rock with another rock until the desired shape was achieved. Efficient use of this flaking technique requires a strong precision grip and the ability to use hands in a skilful, coordinated way. It also requires an improvement in mental capabilities. *Homo habilis* used these tools to kill large animals to eat the meat.

Figure 2.2 – Oldowan flake tools



Homo erectus took this flaking process one step further to make Acheulian hand axes. The movements needed to make advanced tools were no more difficult, but they had to be executed more intelligently to produce a tool that had a fat, sturdy body with a sharp cutting edge. The advance from simple stone tools to elegant handheld axes was a massive technological leap for early hominids. These tools were used in a variety of ways, from killing animals, to stripping bark off trees, to digging holes in the ground. They have been described as the 'all-in-one tool' of the earlier Stone Age in Africa.

Figure 2.3 – Acheulian tools (hand axes)

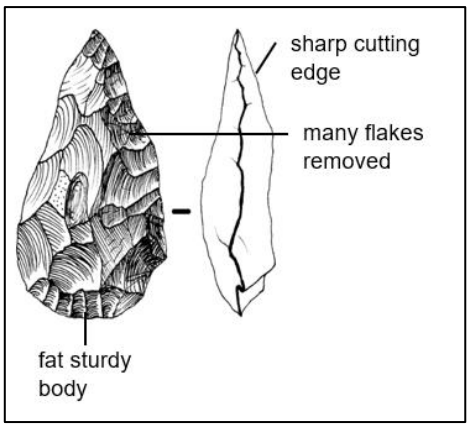
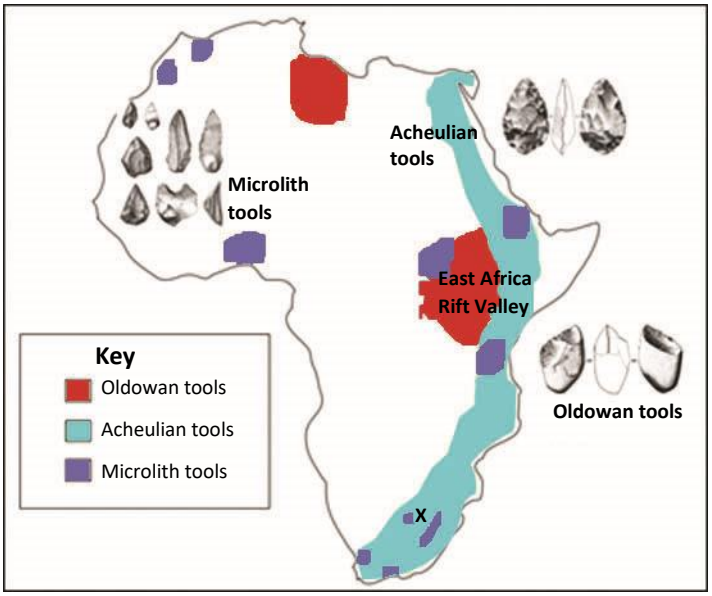


Figure 2.4 – Microlith and bone tools

[Images: <https://link.springer.com/referenceworkentry/10.1007/978-1-4419-0465-2_702>]

Homo sapiens learned how to make microliths (tiny stone tools) for a range of specific tasks. They also used bone, ivory, or deer antler to create a variety of tools that were used to hunt, and to make useful items like clothes and storage containers.

Figure 2.5 – Map of Africa showing the locations of the three types of hominid stone tools that have been discovered



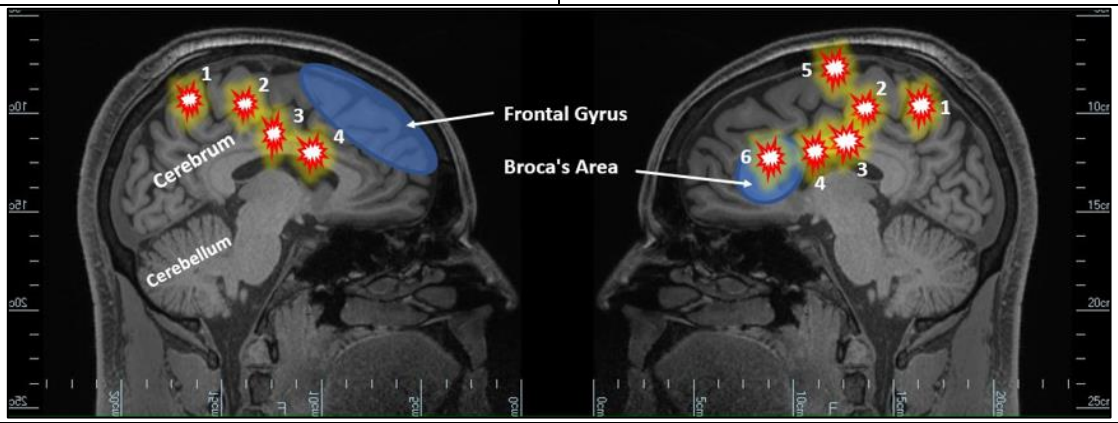
[Images: <https://earthlogs.org/tag/oldowan/> <https://ars.els-cdn.com/content/image/1-s2.0-S0168010219304882-gr1_lrg.jpg>]

Research into brain areas used for tool development

In a recent study, scientists investigated the relationship between stone toolmaking and brain function using brain imaging technology. Participants in the study were asked to use the same techniques to make stone tools that were used by early hominids. While they were making the tools, a brain scanner took images of their brains. The images show the areas in the brain's right hemisphere that were activated when people made simple Oldowan tools compared to when they made more advanced Acheulian tools.

Figure 2.6 – Brain activation during stone tool production

Brain regions 1 to 4 are activated when **Oldowan tools** are made.	Brain regions 1 to 6 are activated when **Acheulian tools** are made.



Areas 1 to 4 are involved in:	Area 5 – the frontal gyrus is involved in:	Area 6 – Broca's area is involved in:
• sensory processing • motor processing	• thinking and reasoning • speech and language	• speech

[Adapted: <https://socialsci.libretexts.org/Bookshelves/Anthropology/Physical_Anthropology/Explorations_Lab_and_Activities_Manual/11%3A_Archaic_Homo/11.03%3A_Brain_Language_Lithics>]
[Adapted: <https://elifesciences.org/digests/41250/how-humans-evolved-bigger-brains#:~:text=Brain%20size%20increased%20rapidly%20during,those%20of%20our%20closest%20relatives>]
[Adapted: <https://australian.museum/learn/science/human-evolution/homo-habilis/>]
[Adapted: <https://www.cam.ac.uk/research/news/climate-changed-the-size-of-our-bodies-and-to-some-extent-our-brains>]

The continued evolution of the human brain

The human body and brain size are still evolving. The social-brain hypothesis explains how more complex social interactions have been responsible for an increase in brain size. However, if people rely too much on others and stop thinking for themselves, their brains may get smaller. Researchers are saying that the human brain has decreased in size over the last 3 000 years, from 1 500 cm^3 to 1 400 cm^3. A large brain requires a lot of energy to maintain. If knowledge is shared or individuals have specific roles to play in a social group, brains may adapt to become more efficient by decreasing in size. Our increasing dependence on technology may cause our brains to shrink even more over the next few thousand years.

A study on naked mole rats

To see if it is possible for brains to decrease in size, scientists conducted a study on naked mole rats. Naked mole rats live in groups where every rat has a specific role to play. If naked mole rats live alone, they need to perform more than one role in order to survive.

Scientists isolated some naked mole rats, while others were kept in groups of varying sizes. After a certain length of time, the brain mass and number of brain neurons were measured in the solitary naked mole rats and in the rats living in groups. The results are shown below.

Figure 2.7 – Graph showing brain mass in social and solitary naked mole rats

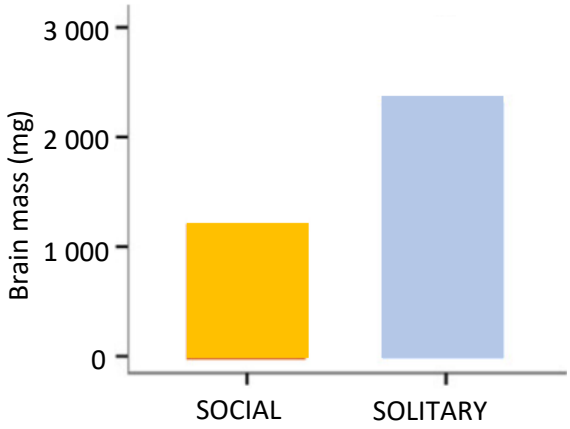
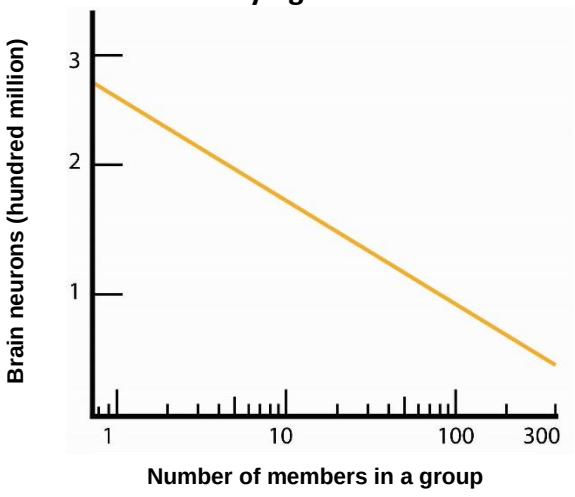


Figure 2.8 – Graph showing number of brain neurons in naked mole rats living in groups of varying sizes



[Adapted: <https://www.researchgate.net/figure/The-relationship-of-selected-neuronal-correlates-of-cognitive-capacity-and-social-group_fig5_325782771>]
[Adapted: <https://www.quantamagazine.org/how-humans-evolved-supersize-brains-20151110/>]
[Adapted: <https://www.frontiersin.org/articles/10.3389/fnins.2018.00174/full>]
[Adapted: <https://www.cam.ac.uk/research/news/climate-changed-the-size-of-our-bodies-and-to-some-extent-our-brains>]
[Adapted: <https://sunwarrior.com/blogs/health-hub/proteins-effect-brain-function-memory-health>]
[Adapted: <https://www.psychologytoday.com/us/blog/diagnosis-diet/201903/the-brain-needs-animal-fat>]
[Adapted: <https://blog.frontiersin.org/2021/10/22/when-and-why-did-human-brains-decrease-in-size-3000-years-ago-new-study-may-have-found-clues-within-ants/>]
[Adapted: https://www.researchgate.net/figure/Absolute-and-relative-brain-size-by-sociality-Bar-plots-illustrating-the-differences-in_fig3_325782771]

SECTION B

QUESTION 3

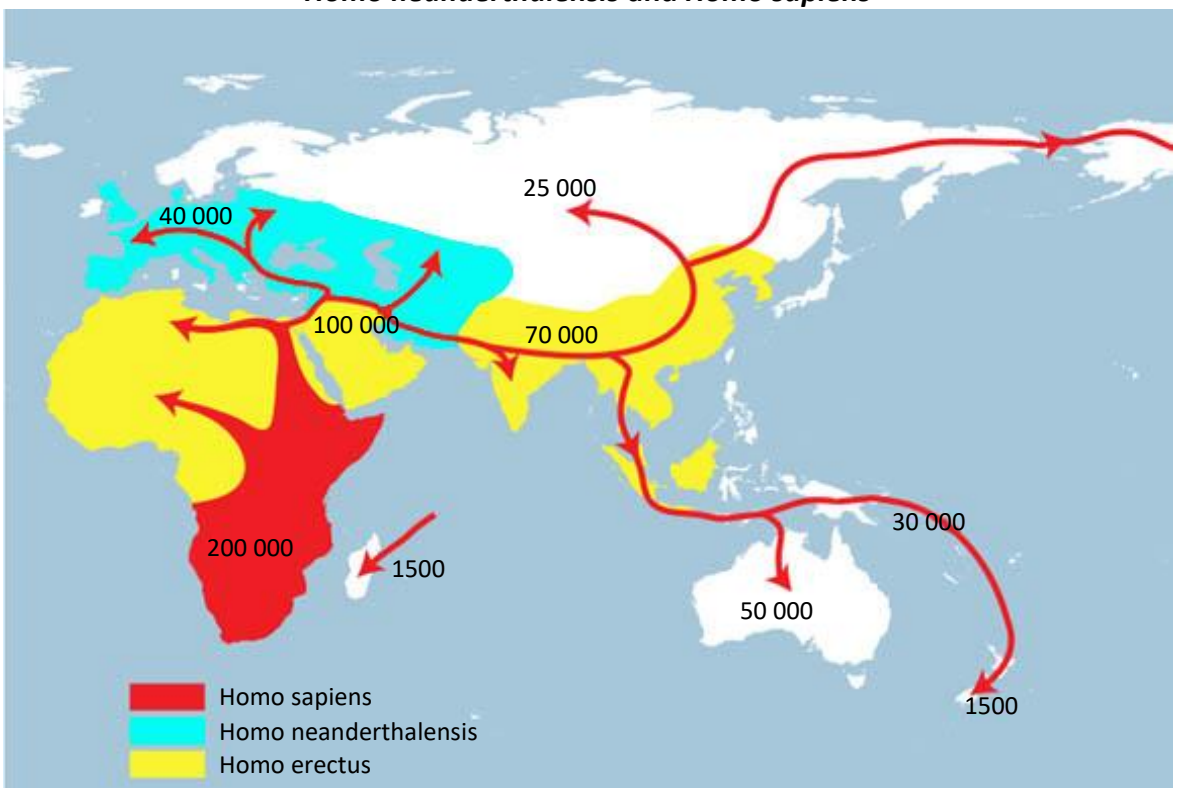
Read the information below. Use this information as well as your own knowledge to answer Question 3 in the question paper.

SOURCE A Evolution of humans and pathogens

Approximately 200 000 years ago, modern humans first appeared in Africa, and 100 000 years later, they began to migrate out of Africa. The exposure to new environments and major lifestyle shifts, such as agriculture and urbanisation, created the opportunity for human adaptation and evolution by natural selection. However, these rapid environmental changes also created new patterns of complex disease, as pathogens evolve according to the changing environment. Scientists must work to understand the evolution of pathogens so that more sustainable solutions to public health problems can be found.

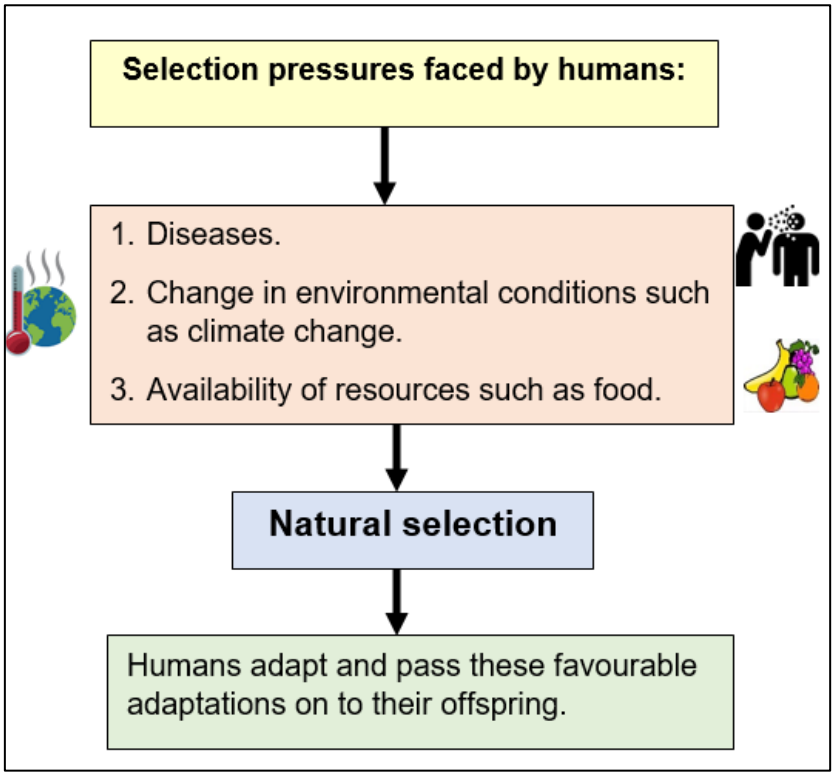
[Adapted from Nature, a scientific journal: <https://www.nature.com/articles/s41576-020-00305-9>]

Map showing successive dispersals of *Homo erectus*, *Homo neanderthalensis* and *Homo sapiens*



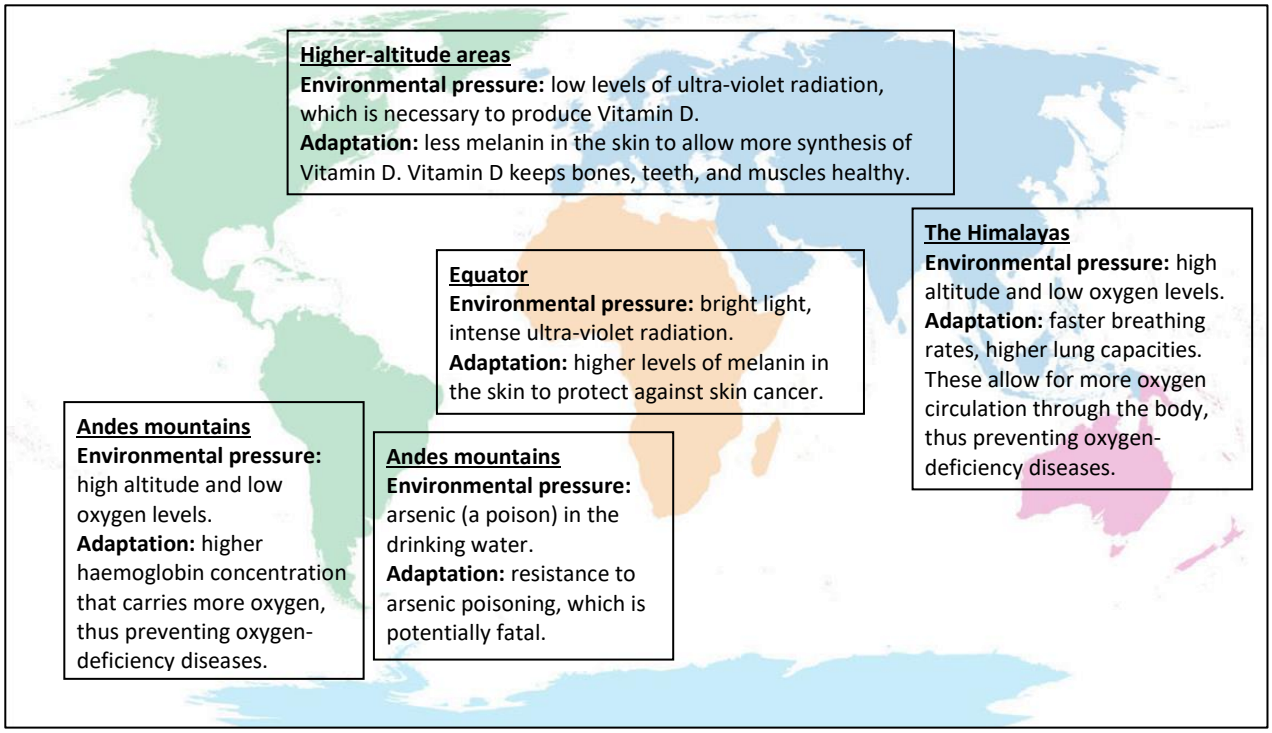
[Image: <https://en.wikipedia.org/wiki/Recent_African_origin_of_modern_humans>]

Selection pressures faced by humans and natural selection



[Adapted from National Geographic magazine, a popular source written for the public. The authors quote peer-reviewed articles, but the articles have not undergone the peer-review process. Source: <https://education.nationalgeographic.org/resource/natural-selection>]

Examples of human adaptations in different environments



[Adapted from Nature Education, a scientific journal: Schaffner, S. & 1Sabeti, P. (2008) Evolutionary adaptation in the human lineage. *Nature*]

Examples of evolution and its impact on disease

Scurvy

Over time, humans have evolved to stop producing the enzyme that makes Vitamin C in the body. Without this enzyme, humans are more likely to develop scurvy. Scurvy is a disease that can cause bleeding gums, muscle weakness, pain, and fatigue.

[Adapted from The National Library of Medicine journal article: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3352556/>]

Syphilis

This sexually transmitted disease, caused by bacteria, first appeared in Europe in 1495. Symptoms of syphilis were visible painful sores and so people avoided having intercourse with these infected people. Over time, natural selection favoured the milder form of the disease because it caused less obvious or painful symptoms.

[Adapted from the Royal Society Journal: <https://www.jstor.org/stable/4142709>]

Fire and the evolution of tuberculosis

Tuberculosis has evolved into a widespread disease. It may be because of the use of controlled fire by our hominid ancestors. When hominids started to use fire, they inhaled smoke, causing damage to their lungs. Damaged lungs increased their chances of developing tuberculosis. As fire making also encouraged more social behaviour, infections spread more easily because people were closer together.

[Adapted from a social networking site: <https://www.researchgate.net/publication/305648121_Controlled_fire_use_in_early_humans_might_have_triggered_the_evolutionary_emergence_of_tuberculosis>]

Lactose tolerance

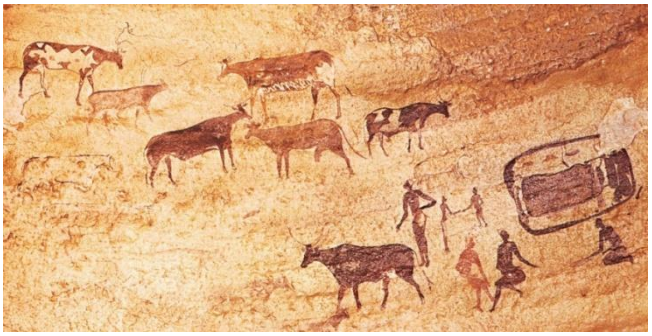
Most babies are lactose tolerant – they can easily digest lactose, a sugar found in milk. As they get older, this ability is lost, and they become lactose intolerant. Since the domestication of cattle, milk has become an important food source for humans, but lactose intolerance causes health problems. A new mutation in the lactase gene now gives some adults the ability to digest lactose. Lactose tolerance is one of the strongest signs of natural selection seen anywhere in the human genome.

[Adapted from Nature, a scientific journal: <https://www.nature.com/scitable/topicpage/evolutionary-adaptation-in-the-human-lineage-12397>]

SOURCE B Animal domestication and diseases in humans

The domestication of animals and plants began 40 000 years ago and allowed humans to settle down instead of moving from place to place in search of food. Animals are domesticated through the process of artificial selection. This agricultural lifestyle increased population density, increasing the risk of the spread of infectious disease. As animals have been domesticated, this has also promoted the evolution of disease. Many of these diseases have become the major killers of mankind: influenza, tuberculosis, malaria, smallpox, plague, and syphilis.

A rock painting in Algeria shows people herding cattle
Date: 10 000 BCE*



*BCE: Before the Common Era (previously Before Christ)

[Adapted from National Geographic Magazine: <https://education.nationalgeographic.org/resource/artificial-selection>]

SOURCE C Evolution of the immune system

A well-functioning immune system is critical for survival and the human immune system has evolved over time. Disease is a powerful source of environmental pressure and as a result, natural selection has created diversity in the human immune system. People differ in their ability to fight off infections. People with weak immune systems could be helping pathogens to evolve and become more deadly.

Early humans lived in Africa and were exposed to many potentially dangerous microbes that thrived in Africa's tropical environment. They adapted and evolved very strong immune systems, which are effective in controlling diseases an individual is exposed to.

However, a strong immune system does not always work in your favour. A modern-day example is the number of deaths caused by a severe immune response to SARS-Cov-2. Many of these deaths were not caused by the virus itself, but by the immune system's over-reaction to the virus.

[Adapted from a peer-review article published in Frontiers: <https://www.frontiersin.org/articles/10.3389/fimmu.2020.01446/full>]

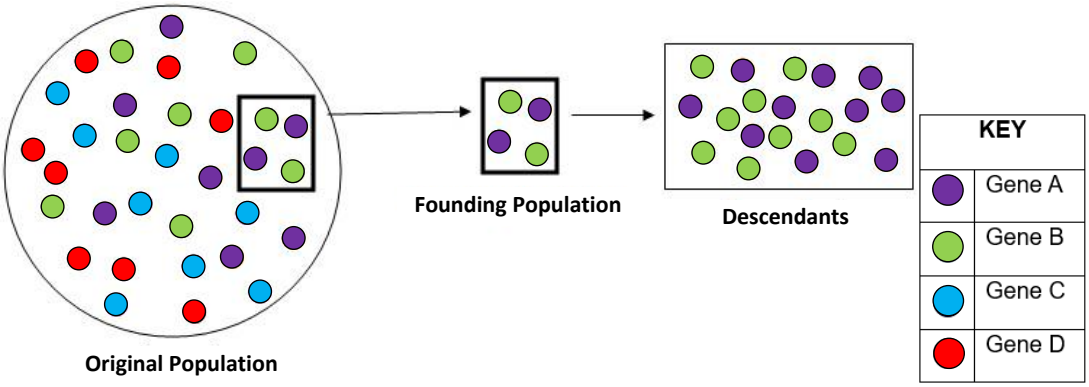
SOURCE D Management of diseases and possible unintended effects

Management of disease	Purpose of the management	Possible unintended effects
Doctors prescribe **antibiotics** to humans. 	Antibiotics are designed to kill bacteria that cause TB, gonorrhoea, and food-borne diseases.	Antibiotic resistance. Diseases become more difficult to treat. 
Farmers give their animals **antibiotics**.	Farmers want to prevent disease in their farm animals. 	Antibiotics are found in the urine of animals and contaminate drinking water, which exposes humans to excess antibiotics. Antibiotic resistance develops and becomes a threat to global health and food security.
Antiretrovirals	Stop replication of HIV 	HIV drug resistance. More HIV infections. Higher HIV death rate.

[Adapted from various scientific journals: <https://academic.oup.com/jid/article/215/9/1362/3002848?login=false>; <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5891049/>]
[Adapted from a news website: <https://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance>]

SOURCE E The founder effect

The founder effect can increase the frequency of certain rare diseases in a population.

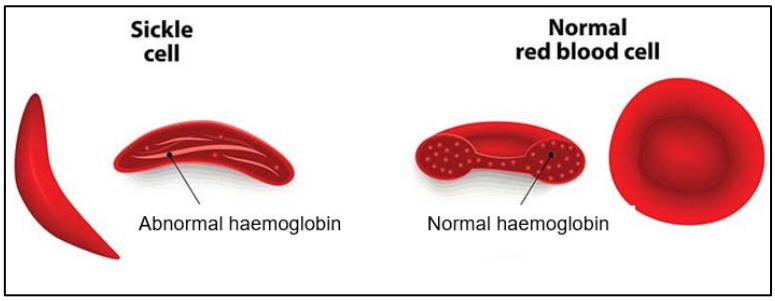


[Adapted from Wikipedia: The Free Encyclopaedia, which can be edited by the public. <https://en.wikipedia.org/wiki/Founder_effect>]

SOURCE F Malaria

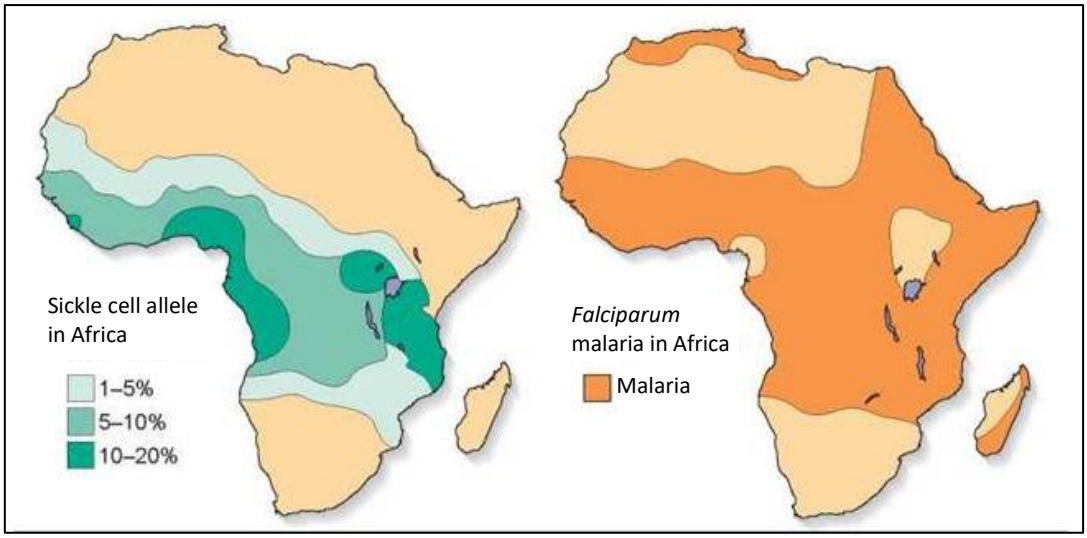
Evolutionary response in humans

Malaria is a disease caused by a parasite that is carried by mosquitoes. Malaria kills over 400 000 people per year; 90% of these deaths occur in Africa. Malaria has exerted the highest evolutionary pressure on the communities across the African continent. Humans have evolved an interesting adaptation to this deadly disease. Sickle cell trait (SCT) is caused by a mutation that changes haemoglobin in red blood cells, causing them to become sickle shaped. The malaria parasite can invade normal red blood cells, but not the sickle cells. This means that people with the sickle cell trait are protected from malaria infection. Over time natural selection has caused sickle cell carriers to become more widespread in areas of Africa where there is a high incidence of malaria.



[Adapted from a magazine article, which has not been peer reviewed: <https://www.notaloneinsicklecell.com/Global-Impact-Of-SCD/>]

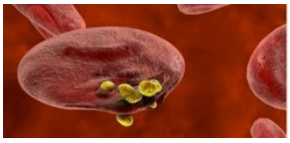
Map showing prevalence of the sickle cell trait (allele) and malaria in Africa



[Image: <https://www.weforum.org/agenda/2019/01/mankind-s-first-tool-to-fight-malaria-also-kills/>]

Evolutionary response in mosquitoes
Mosquitoes that transmit malaria have evolved resistance to the insecticides that are used to kill them.

Evolutionary response in the malaria parasite
Malaria parasites are evolving resistance to the drugs used to treat malaria.

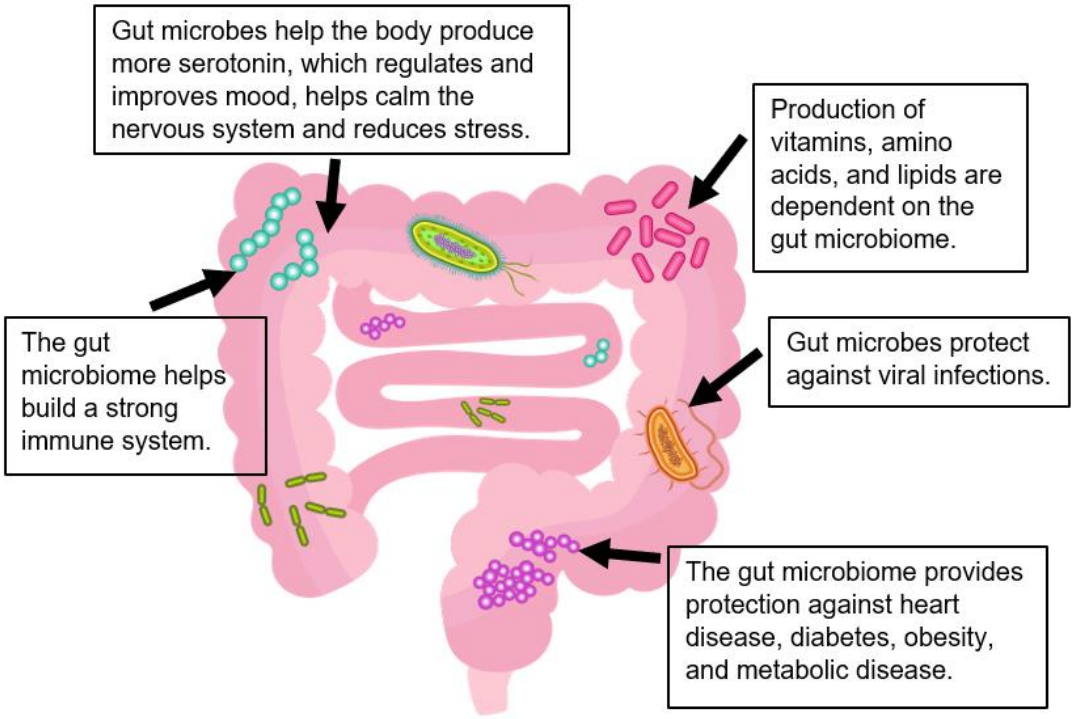


The malaria parasite infecting a red blood cell.

SOURCE G The human gut microbiome

The human gut microbiome is made up of hundreds to thousands of species of bacteria and archaeabacteria. These microorganisms can affect the health of their human hosts. Over time, human gut microbes have evolved along with their human hosts and this symbiotic relationship has benefited both human host and gut microbes.

Benefits of the human gut microbiome



[Adapted from a blog: <https://atlasbiomed.com/blog> and <https://www.health.harvard.edu/blog/diet-disease-and-the-microbiome-2021042122400>]