INTERNATIONAL BIOLOGY OLYMPIAD e. V. IBO

INSTRUCTIONS FOR THE THEORY EXAMINATIONS

PAPER 2: 1.30PM - 4.30PM

Instructions

Each paper comprises 46 questions, which will be completed on a computer.

You MUST answer ALL parts of ALL questions. For multiple-true/false tasks, answer each statement with either 'true' or 'false'. Between none and all of the statements may be true. For calculations, choose the number nearest to the correct answer. You should make your best guess if you are unsure; you will not be penalised for incorrect guesses, but may gain marks.

Each correct answer will score 1 mark. Each incorrect or missing answer will score 0 marks.

You SHOULD attempt the questions IN ORDER, and come back to any that you cannot answer at first. You can flag these by clicking the flag icon, and see your progress by opening the contents pane on the left-hand side. You may find that ideas explored in earlier questions help you answer later questions.

Some figures can be enlarged by clicking on them.

You can change the language you view the papers in by choosing an option from the top right corner.

You will need to use the information given to you in each question creatively, but you will never require advanced technical or specialised knowledge.

You MUST have the following equipment for this exam.

- Approved calculator
- Pen/pencil
- You will be provided with scrap paper. You MUST NOT bring any paper into, or out of, the exam room. A copy of this document will be available on the first page of each exam.

Regulations

You MUST NOT communicate with ANY other candidate at ANY time, whilst you are in the examination room.

You MUST NOT open ANY other windows on your computer.

You MUST NOT access ANY information that could unfairly help you whilst the examination is in progress.

If you require the assistance of a guide you should raise your hand, and remain facing forward until given further instructions.

You MUST NOT attempt to leave your computer station without the assistance of a guide.

If you experience technical problems, you MUST inform a guide IMMEDIATELY.

Good luck!

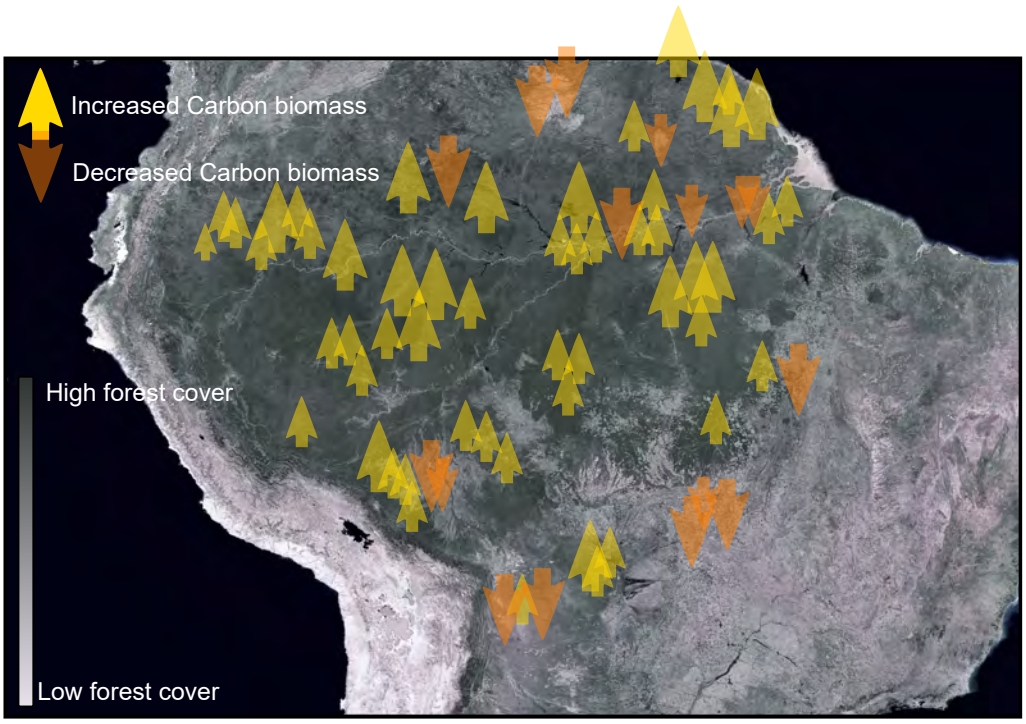
USEFUL SCIENTIFIC DEFINITIONS

WT	In all cases, WT refers to wild-type. Wild-type organisms have not been genetically manipulated, or otherwise chosen for a specific genetic property.
Knockout	Knockout refers to an organism which has had specific gene, which is stated in the question, mutated such that no functional product is produced from it.
Haplotypes	A haplotype is a combination of alleles that occur on the same DNA molecule. For example, if genes A, B, C, D, and E are located on the same chromosome, and each gene has two alleles, this genomic region can have many different haplotypes (AbCdE, abcDE, ABCde etc.). If these genes are strongly genetically linked, some haplotypes will occur in the population more often than expected by chance, i.e. specific alleles of one gene will usually co-occur with specific alleles of the linked genes. Mutations within such a region create new haplotypes, descended from the old. Meiotic crossing over within the region brakes existing haplotypes and randomly recombines alleles thus eliminating the association between alleles over time.
mmHg	Millimeters of mercury. Biologists usually use mmHg as the unit for pressure. mmHg are directly proportional to Pascals and cmH2O, but give rounder numbers in most biological situations.
Partial pressure (PGas)	Partial pressure measures the pressure that a gas would exert on its surroundings if only that gas was present. Partial pressures are noted as Pgas (e.g. Po2 = partial pressure of oxygen). For example, the total pressure of atmospheric air, at sea-level, is 760 mmHg, and oxygen makes up 21 % of all the molecules in atmospheric air. Therefore the partial pressure of oxygen in atmospheric air is Po2 = 0.21 x 760 = 160 mmHg. The partial pressure of a gas in solution, is the partial pressure that the gas would have in air which is in equilibrium with the solution. For example, the partial pressure of oxygen in a glass of water exposed to atmospheric air for a long time will also be 160 mmHg. Hence, partial pressures are used by biologists to predict the rate and direction of gas transfer and equilibrium conditions. Partial pressures are NOT directly proportional to the concentration of the gas in a solution. Concentration depends on partial pressure, solubility, temperature etc.
Expression	Many DNA genes are transcribed to produce RNA, which is translated to produce a polypeptide. This folds, and may be modified, to give a functional protein. Unless stated otherwise, the expression level of a gene describes how much functional protein it is generating through the combined action of these processes. Therefore, if expression is increased, more functional protein is being produced. This does not necessarily mean there is increased amounts of protein (it may be degraded quickly). The functional product may also need further steps to become activated.
Arrows	In scientific diagrams, arrows are taken to mean leads to, activates, becomes, or simply a label.
Flat-headed arrows	In scientific diagrams, flat-headed arrows are taken to mean inhibits, blocks, reduces.

ADAPTING TO THE ENVIRONMENT

AMAZON BIOMASS

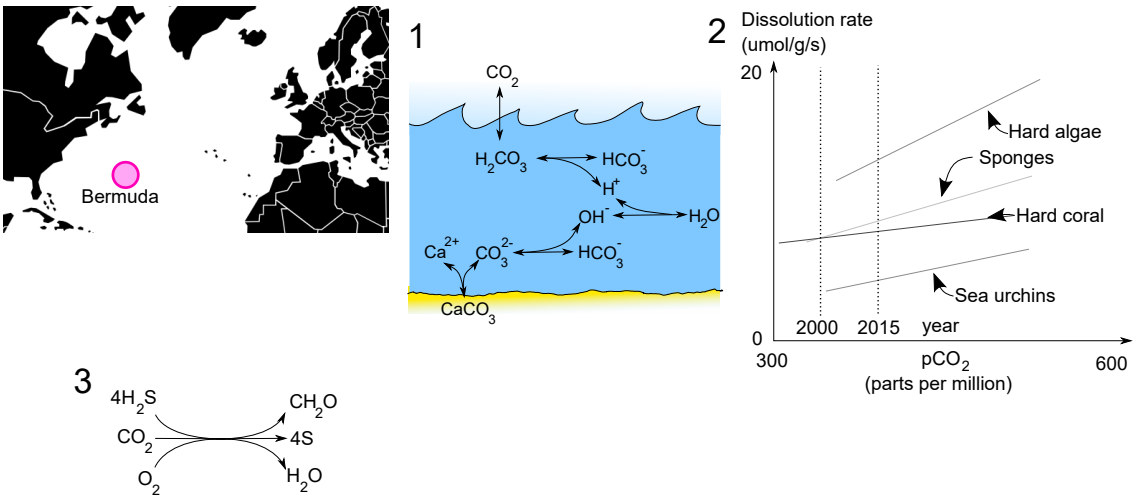
Forests sink more than 30% of anthropogenic CO_2, but the way they handle atmospheric CO_2 is changing. This map shows the change in total fixed carbon mass in the Amazon over the last decade. The Amazon rainforest is responding to climate change similarly to most rainforests.



	True	False
Excluding deforestation, rainforests have shown a net increase in carbon biomass in recent years.		
Increasing UV input, due to a thinning ozone layer, can increase carbon fixation.		
Increasing atmospheric CO_2 concentration can increase carbon fixation.		
Small increases in temperature increases the rate of photosynthetic enzymes.		

BERMUDAN CORAL

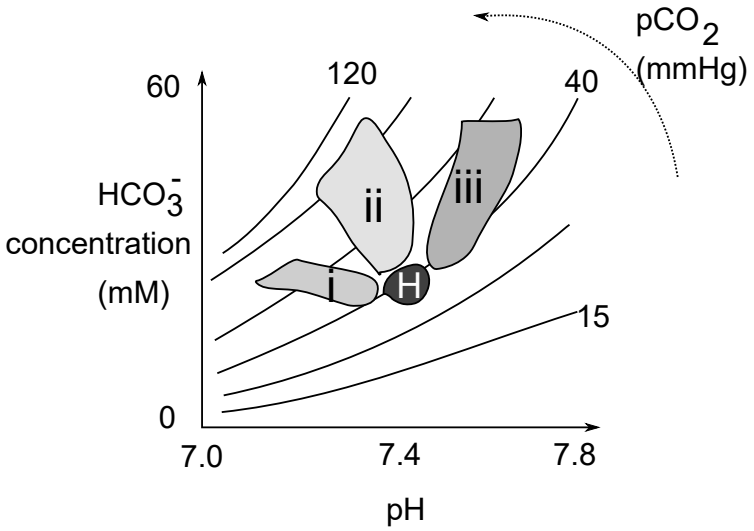
Oceans also sink more than 30% of anthropogenic carbon dioxide, which dissolves to form an acid that alters calcium carbonate solubility (1). Many marine invertebrates have calcium carbonate skeletons, which form marine sediments and reefs. The British island of Bermuda is a hub for studying coral reefs and sea trenches, so the effect of CO_2 on Bermudan sediments in seawater was measured (2). Five thousand metres below the reefs, marine bacteria fix CO_2 to grow (3).



	True	False
Anthropogenic carbon dioxide damages invertebrate skeletons.		
The structure of the Bermudan barrier reef is under threat due to changes in seawater chemistry.		
The growth of invertebrates contributes to the oceans' ability to sink carbon.		
Bacteria at hydrothermal vents use modified photosynthetic enzymes to fix carbon.		

ACIDOSIS

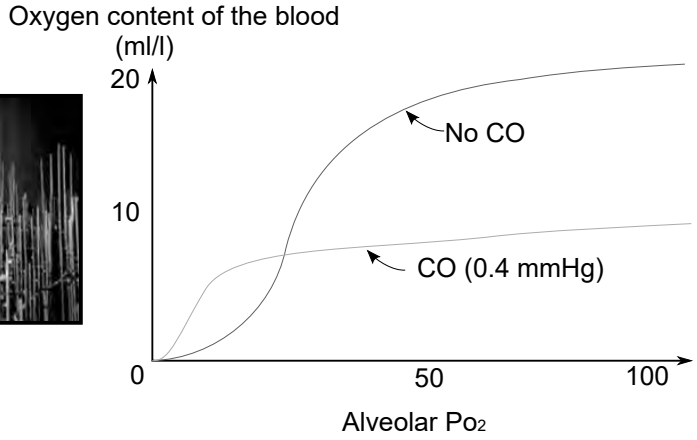
Blood pH must be tightly controlled. To achieve this, the lungs excrete CO_2 from the body and the kidneys alter blood HCO_3^- levels. The blood chemistry of healthy people (H) and people with diseases i, ii, and iii was analysed, and falls in the ranges shown.



	True	False
Disease i makes blood too acidic.		
Disease ii involves increased gas exchange in the lungs.		
Disease ii involves harmful changes in kidney function.		
Vomiting can induce the phenotype seen in iii.		

CARBON MONOXIDE POISONING

Sir John Kendrew (1917-1997) published the structure of haem-proteins, revealing how oxygen is transported in the blood.
Carbon monoxide is a poisonous gas which can enter the blood via the lungs and alters oxygen transport. In normal air, Po_2 = 100 mmHg in the lungs. After addition of CO, so Pco = 0.4 mmHg, there are equal molar amounts of CO and O_2 in the blood.

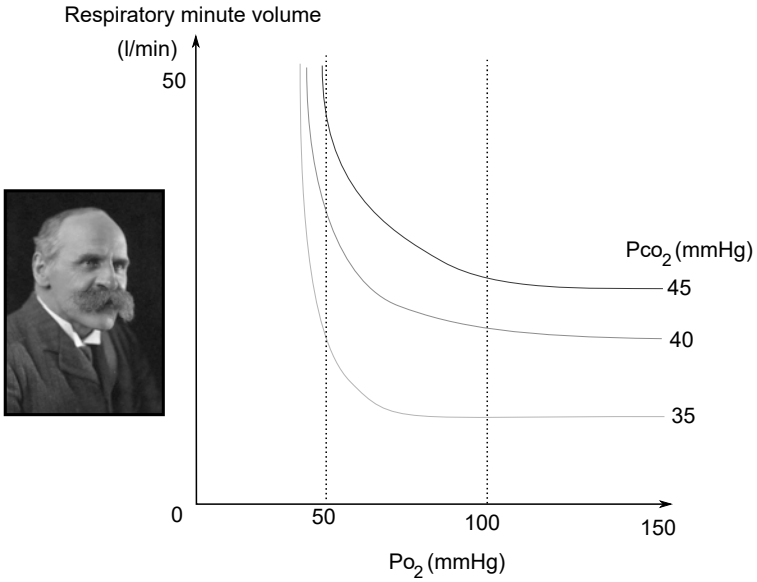


	True	False
Carbon monoxide increases the affinity ('tightness of binding') of haemoglobin for oxygen.		
0.4 mmHg of carbon monoxide reduces the solubility of oxygen in plasma.		
Carbon monoxide reduces the amount of functional heamoglobin in the blood in physiological conditions.		

	50 x greater	100 x greater	150 x greater	200 x greater	250 x greater
Choose the nearest relative affinity to the correct answer.					

ALVEOLAR GASES

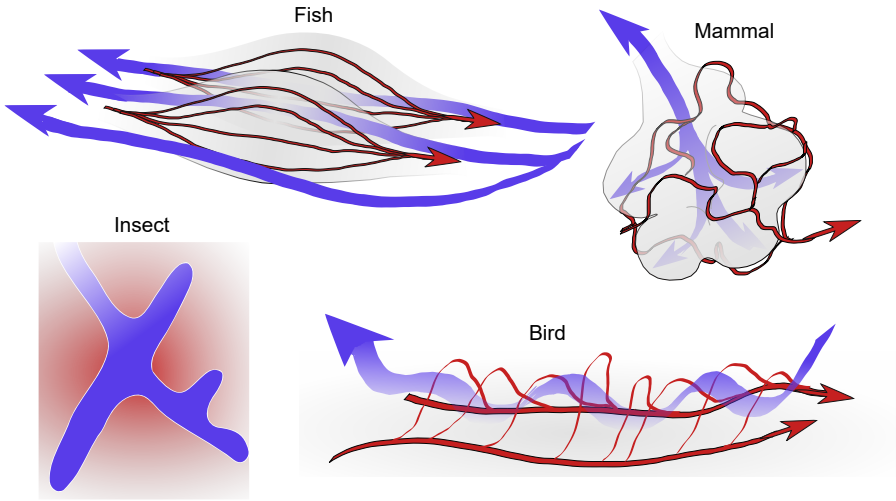
John Haldane (1892-1962) discovered many mechanisms which control gas exchange and breathing.
The effect of altering the pressure of oxygen or carbon dioxide in air sacs (alveoli) within human lungs on the volume of air breathed every minute was recorded.
Alveolar air, at sea level, usually has Po_2 = 100 mmHg, Pco_2 = 40 mmHg.



	True	False
Increasing blood acidity (lowering pH) increases breathing rate.		
Breathing rate is determined by the oxygen content of blood in normal conditions.		
At high altitude (atmospheric pressure < 50 % of sea level), falling carbon dioxide pressure in the blood has a greater impact on breathing than falling oxygen pressure.		
Total blood oxygen content changes negligibly when alveolar oxygen pressure is increased from 50 mmHg to 150 mmHg.		

ANIMAL RESPIRATORY SYSTEMS

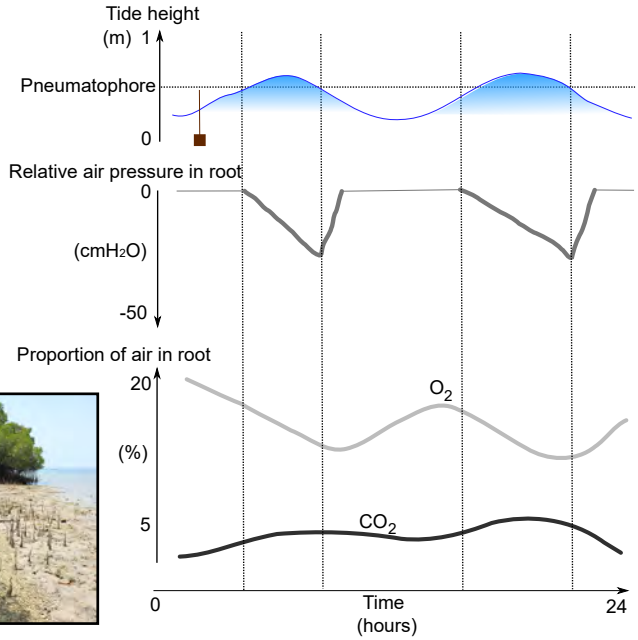
The gas exchange surfaces, and the direction of respiratory-medium and blood flow, of different animals are sketched. Mammals and birds must use respiratory muscles to drive air to these surfaces, as shown.



	True	False
Mammals require passive diffusion to exchange gases.		
Mammals extract a greater proportion of the air's oxygen than fish extract from water.		
Air must reach within micrometers of active insect cells.		
Bird lungs exchange gas with air for a greater proportion of a breathing cycle than mammals.		

AIR ROOTS

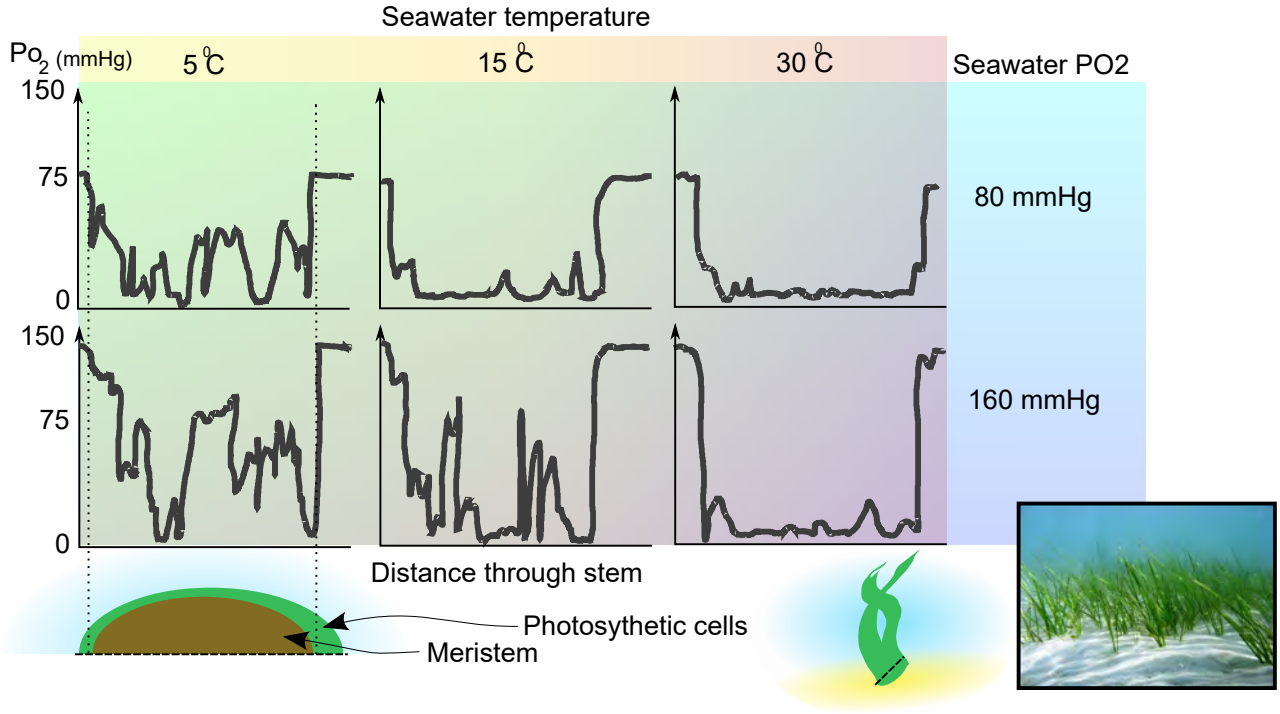
Mangrove trees grow in intertidal flats, and can have vertical roots (pneumatophores) which act like snorkels for the submerged roots. The mechanism through which they facilitate gas exchange was investigated by recording gas pressures, relative to atmospheric air, as pneumatophores are covered and uncovered by the tide.



	True	False
Air is sucked into roots when pneumatophores are revealed by falling tides.		
Respiration in the roots contributes to the air pressure changes in the roots.		
Pneumatophores supply CO_2 for photosynthesis.		
Respiration rate in the roots slows when pneumatophores are submerged.		

MERISTEM OXYGEN

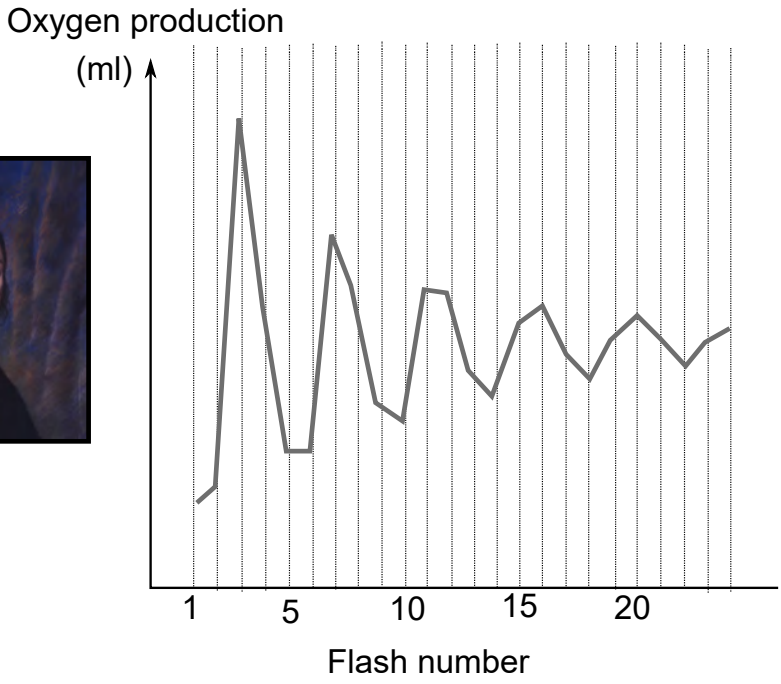
Seagrass grows rapidly from a meristem at its base. However, weak growth and death of entire seagrass meadows, have become common in recent years. The oxygen partial pressure along the diameter of a seagrass stem was recorded at different seawater temperatures and oxygen saturations.
Atmospheric Po_2 is usually = 160 mmHg.



	True	False
Rising seawater temperatures could explain the loss of seagrass meadows.		
These experiments were performed in the dark.		
The meristem has a faster metabolic rate than surrounding tissue.		
There is more CO_2 in the meristem at 30 °C, than at 5 °C.		
The meristem will receive more oxygen in rough ocean conditions than calm ocean conditions.		

PHOTOSYNTHETIC OXYGEN

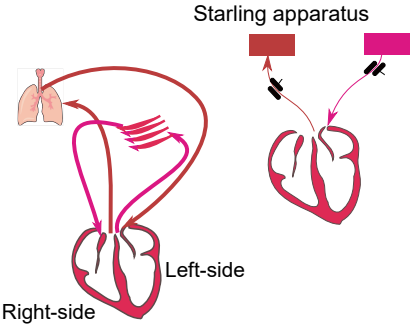
Joseph Priestley (1733-1804) discovered that plants consume CO_2. In this process they produce elemental oxygen, which he also discovered. In chloroplasts, the oxygen-evolving complex loses single electrons when exposed to light. After a specific number of electrons are lost, the complex regains electrons from water to produce oxygen, in a cycle. Consecutive pulses of light were flashed at a solution of chloroplasts, and the amount of oxygen produced from each flash was recorded.

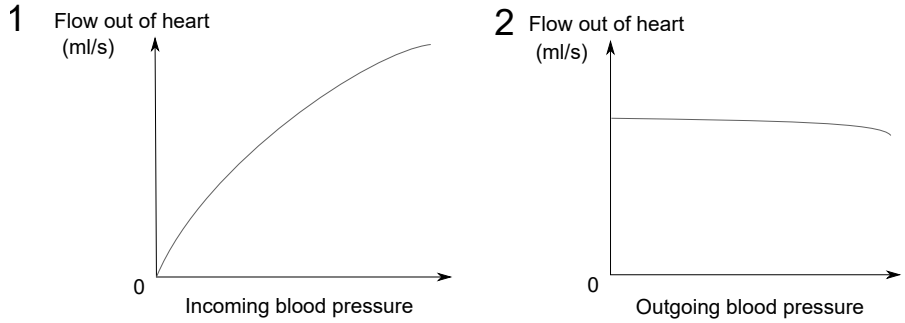


	True	False
2 light pulses are sufficient to complete the oxygen-evolving cycle.		
A maximum of 4 electrons is lost by the complex.		
At the beginning of the experiment, most complexes had already lost 1 electron.		
More oxygen is evolved for the same light exposure at the end of the experiment.		

FRANK-STARLING LAW

William Harvey (1578-1657) discovered that the heart pumps blood around the body in a circuit. Ernest Starling (1866-1927) discovered many of the fundamental properties of the circulatory system, including how cardiac output (the amount of blood pumped in a given time) is controlled. Starling completely removed a beating heart from the body, and attached it to an apparatus that allowed him to alter the pressure of incoming 'venous' (1) or outgoing 'arterial' blood (2). He then measured cardiac output.
Both the left and right-sides of the heart gave similar results.

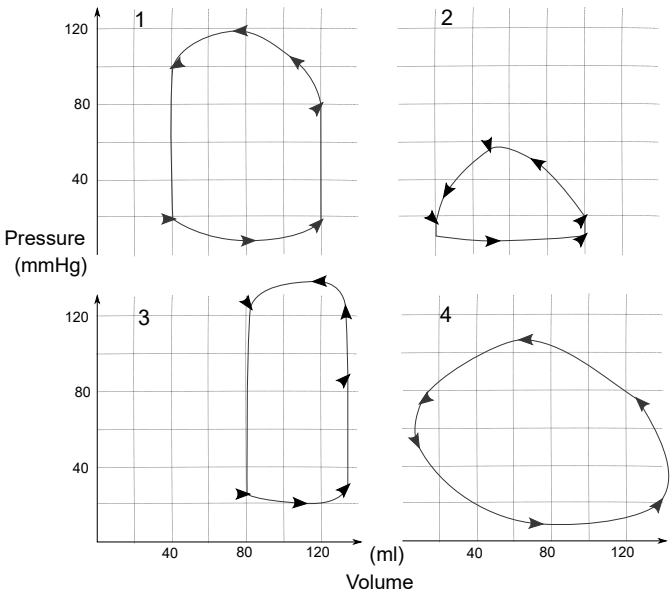


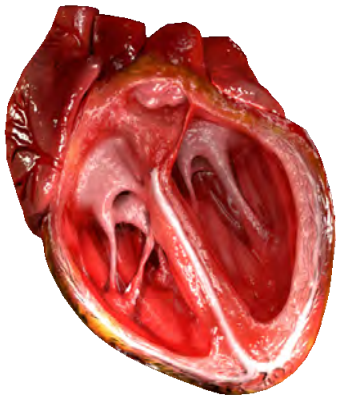


	True	False
Responses to exercise include toning (contraction of smooth muscle) of the veins.		
If outflow from the right-side of the heart increases, nervous or hormonal coordination is required for outflow from the left-side of the heart to match it.		
The energy required for the heart to beat increases as venous blood pressure increases.		
In the early stages of heart failure, cardiac output can be maintained if blood volume is increased.		

PRESSURE-VOLUME LOOPS

The pressure and volume of beating ventricles can be measured as they change with time.
Recordings (1) and (2) are from the same resting, healthy heart, beating at 60 beats per minute (bpm).
At maximum cardiac output of 28.8 l/min, the maximum ventricular volume doubles, and the minimum ventricular volume halves.
Recordings (3) and (4) are from different diseased hearts.





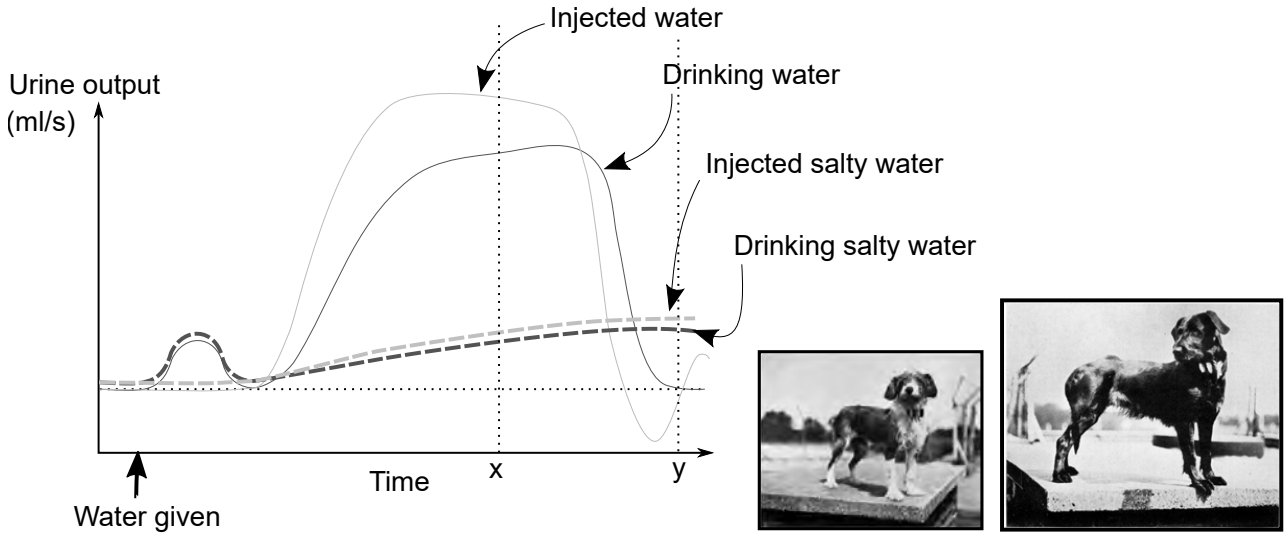
	2 l/min	5 l/min	6 l/min	7 l/min	10 l/min
Choose the nearest output to the correct answer.					

	100 bpm	125 bpm	150 bpm	175 bpm	200 bpm
Choose the nearest rate to the correct answer.					

	True	False
Recording 1 is of the right-side of the heart, recording 2 is of the left-side of the heart.		
Recording 3 indicates an aortic (arterial) obstruction.		
Recording 4 indicates leaky heart valves.		

BLOOD OSMOLARITY

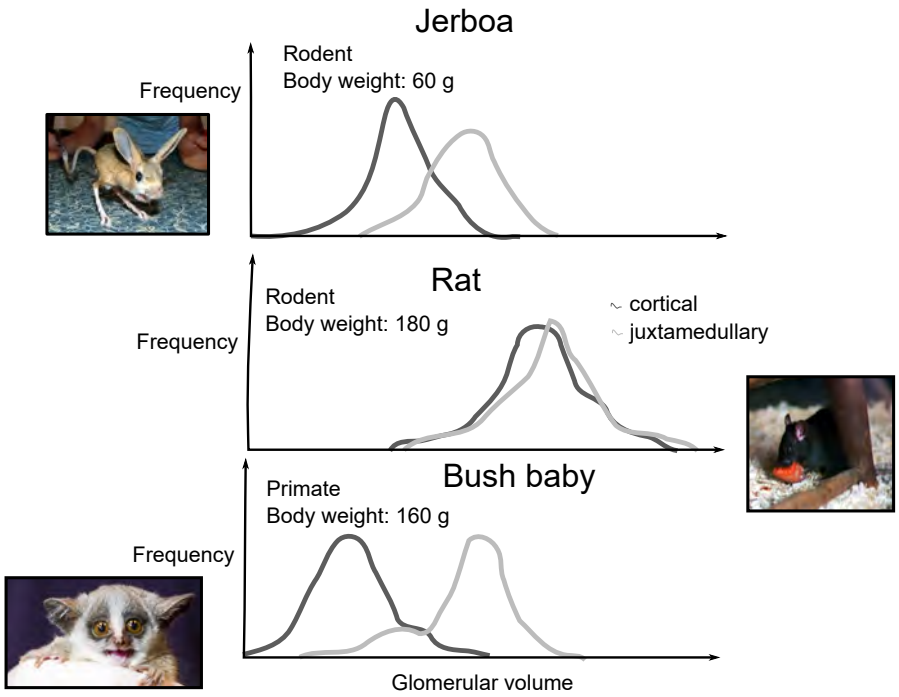
Ernest Verney (1894-1967) explained the regulation of urine production. At the indicated time, dogs (Canis lupus familiaris) were given equal volumes of fresh water, or salty water of the same concentration (osmolarity) as blood, orally or through jugular injection. The volume of urine generated was measured with a catheter.



	True	False
Blood volume is adjusted more quickly than blood osmolarity.		
Blood osmolarity receptors are the dominant regulators of urine production.		
Receptors in the gastrointestinal tract regulate the kidneys.		
Urine at time X has a higher osmolarity than urine at time Y.		

ANIMAL NEPHRONS

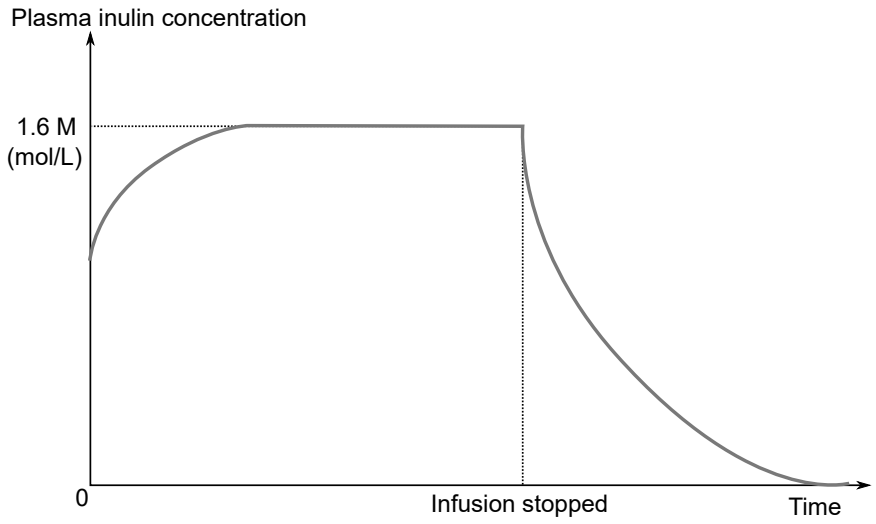
In kidneys, glomeruli are sieves which filter plasma into nephrons. Nephrons modify this fluid, and reabsorb or excrete it. The volumes of individual glomeruli, leading to two types of nephron, were measured in different animals. In all species, juxtamedullary nephrons are much fewer in number than cortical nephrons, but produce more concentrated urine.



	True	False
Glomerular volume is proportional to body size.		
Bush Babies (Galagidae) live in arid habitats.		
Jerboa (Dipodidae) and Bush baby nephron volume distribution has evolved convergently (not inherited from a common ancestor).		
In rats (Rattus), the majority of urine is derived from juxtamedullary nephrons.		

RENAL FILTRATION

Inulins are inert polysaccharides which cannot cross cell membranes. Inulins were infused into a human vein at a constant rate of 0.2 moles per minute. After infusion is stopped, a total of 25 moles of inulins were collected in the urine.



	True	False
Rate of inulin secretion is proportional to its concentration in blood.		
A drug which freely passes through cell membranes will be lost in urine at a faster rate than inulins, when at the same concentration in blood.		

	25 ml/min	50 ml/min	75 ml/min	100 ml/min	125 ml/min
Choose the volume closest to the correct answer.					

	8 l	16 l	24 l	32 l	40 l
Choose the volume closest to the correct answer.					

SALT MARSHES

Most of the best farmland, including the English fens, is low lying and threatened by rising sea levels. Spartina patens and Typha angustifolia are marsh plants. To investigate the effect of seawater exposure on these species, they were planted in saltwater marshes and freshwater marshes, with and without neighboring plants (1), or in greenhouses at six salt concentrations (2).

1

Average biomass (g/cm^2)

Neighbours	Spartina patens		Typha angustifolia	
	Salt	Fresh	Salt	Fresh
+	8	3	0	18
-	10	20	0	33

2

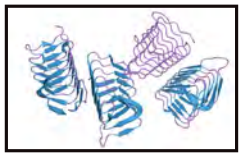
Maximum biomass (g/cm^2)	Salinity (parts per thousand)	0	20	40	60	80	100
	Spartina patens	77	40	29	17	9	0
	Typha angustifolia	80	20	10	0	0	0

	True	False
Spartina patens is more salt-tolerant than Typha angustifolia.		
Spartina patens physiology is better adapted for saltwater exposure than freshwater exposure.		
Spartina patens will become more common as sea-levels rise.		
The distribution of Typha angustifolia in habitats with graded salinity is determined by competition.		

ANTARCTIC FISH

The Royal Research Ship Sir David Attenborough and submarine Boaty McBoatface will explore British Antarctica. Life here exists below the freezing temperature of usual fish, which is determined by their osmolarity (1). Salt accounts for the majority of blood's osmolarity. Antarctic fish are therefore prone to freezing, which usually occurs by the expansion of pre-existing ice crystals in the water. Some Antarctic fish reduce their freezing point by > 2 ^{o}C by secreting antifreeze proteins into the blood (2). Additionally, Antarctic fish must have an appropriate cell membrane chemistry, to prevent their membranes from becoming too rigid at low temperatures (3).

2



Freezing point

1 (℃) 0

-0.6

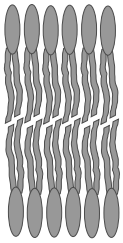
-1.9

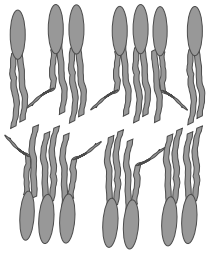
0 350 1000

Fish Seawater

Osmoles of salt

3 Saturated phospholipids





Unsaturated phospholipids

	True	False
Fish staying at great depth under floating ice shelves need to produce antifreeze proteins.		
The anti-freeze proteins function mainly by increasing the osmolarity of the fish.		
Antarctic fish have increased expression of phospholipid desaturases.		
Antarctic fish have better temperature sensors and dynamic responses to temperature than temperate fish.		

CYANOBACTERIA EVOLUTION

Scientists are uncertain how Natural Selection shapes genome size, gene number, physiological flexibility and other important features in response to environmental pressures. Ecological and genetic characteristics of four species of marine cyanobacteria are listed in the table. Prochlorococcus are the most abundant cyanobacteria on earth. The Prochlorococcus lineage evolved from Synechococcus.

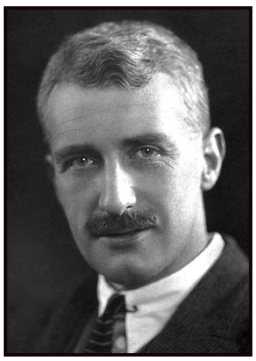
	Synechococcus	Prochlorococcus eNATL	Prochlorococcus eMED4	Prochlorococcus eMIT
Depth at which found	Very deep	Deep	Shallow	Shallow
Region in which found	Global	Global	Poles	Equator
Ability to tolerate low nutrient conditions	Cannot tolerate	Can tolerate	Can tolerate	Can tolerate
Ability to tolerate high light exposure	Cannot tolerate	Cannot tolerate	Can tolerate	Can tolerate
Ability to tolerate high temperatures	Cannot tolerate	Cannot tolerate	Cannot tolerate	Can tolerate
Genome size (mB)	2.4	1.87	1.66	1.71
Number of genes in genome	2700	2100	1900	1700

	True	False
A species requires more genes to specialise to a new habitat.		
Prochlorococcus species can tolerate low nutrient conditions because they have more genes with which they can utilise their environment.		
Intense equatorial sunshine drove the evolution of light tolerance.		
Measuring genome size can be used to estimate the number of genes Prochloroccous has.		

REPRODUCTION & EVOLUTION

ORGANISM SCALING

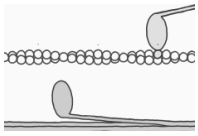
Archibald Hill (1886-1971) invented the field of biophysics, which can use simple geometric equations to predict how the anatomy of large and small animals differs.
(1) Organisms exchange substances across a surface area. These substances are used to supply a volume of tissue.
(2) The maximum force a muscle can generate is proportional to the number of muscle fibres contracting in parallel.
(3) The maximum force a column can withstand is proportional to its cross-sectional area.



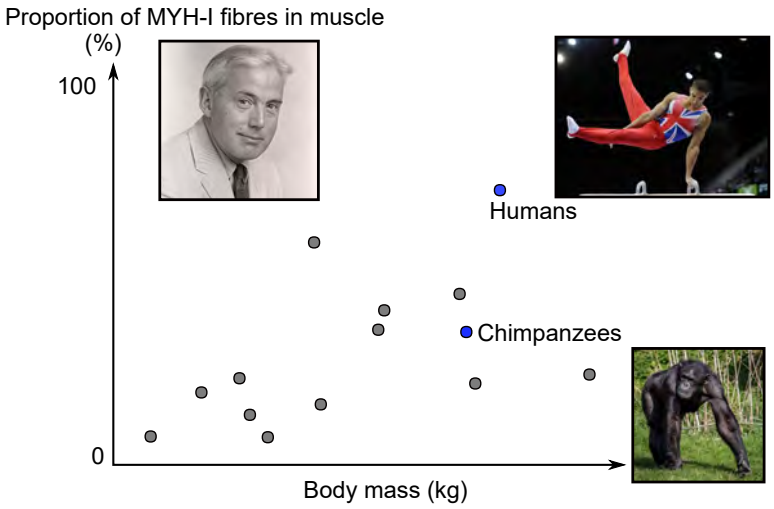
	True	False
Increasing an organism's mass 8 times approximately halves its surface area to volume ratio.		
Diffusion rates are more likely to be inadequately low for large animals than small animals.		
Larger animals can carry heavier objects, compared to their body weight, than small animals.		
A cat's (Felis silvestris catus) bones are disproportionately thick, as a ratio of their body size, when viewed alongside an elephant's (Elephantidae) skeleton.		

MUSCLE ANATOMY

Hugh Huxley (1924-2013) proposed the sliding filament theory of muscle contraction. Myosin can bind actin filaments, then change conformation, tugging on actin. Skeletal muscle myosin can only generate tension on actin by this change of conformation, and releases actin immediately once it is complete. During each cycle of binding, myosin hydrolyses one ATP molecule.



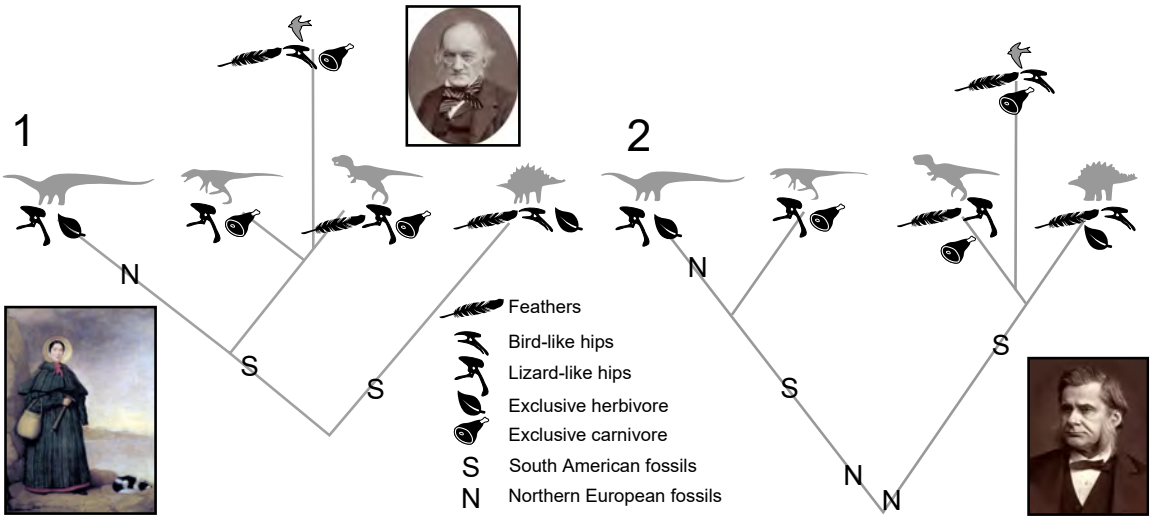
Myosin is found as two alternative forms; MYH-I or MYH-II. Individual muscle fibres either contain MYH-I, or MYH-II, but individual muscles contained a mix of fibre-types. The mix of fibre-types in different mammal species (dots) was measured. MYH-II cycles more quickly than MYH-I.



	True	False
Human muscles contract more quickly than chimp (Pan) muscles when opposed by the same load.		
A muscle fibre generates more force when it is shortening rapidly, compared to when its shortening is resisted by a load.		
Chimps generate a greater proportion of the ATP in their muscles aerobically, compared to humans.		
The most recent common ancestor of humans and chimps is likely to have had muscles more similar to humans' than chimps'.		
A tensed muscle that is not shortening, does not consume ATP.		

DINOSAURS

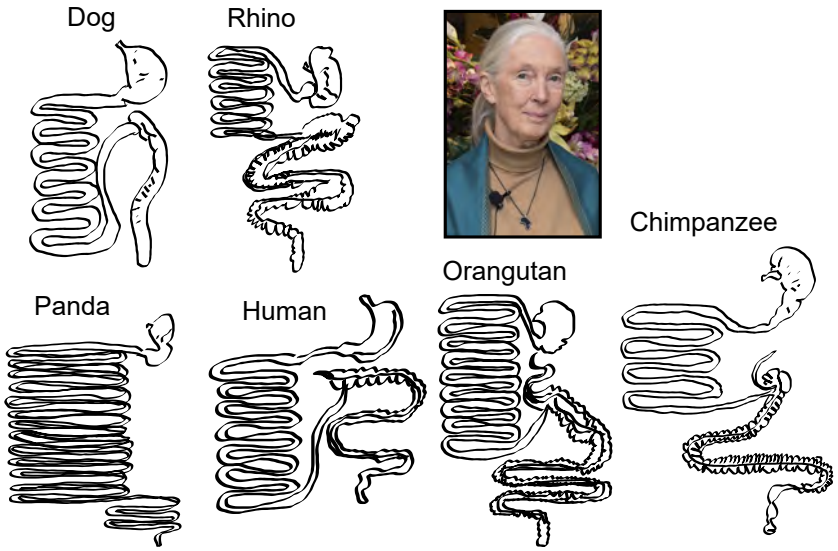
Mary Anning (1799-1847) developed the concept of prehistoric life, by collecting fossils. Richard Owen (1804-1892) coined the term dinosaurs, whilst Thomas Huxley (1825-1895) used fossils to show birds (Aves) evolved from, and are, dinosaurs (Dinosauria). Until last year, scientists believed the dinosaur phylogeny was as shown in (1). In 2017, British scientists analysed many more fossils and produced a new tree (2) based on hundreds of characteristics, including those shown. For birds, the characters are representative of ancestral birds.



	Phylogeny (1)	Phylogeny (2)
Some sauropods (Sauropoda; the group farthest left in each tree) were feathered.		
Bird-like hips evolved multiple times (convergence)		
Exclusive carnivory evolved multiple times.		
The earliest dinosaurs evolved in the Southern hemisphere.		

DIGESTIVE SYSTEMS

Dame Jane Goodall (1934-present) discovered that great apes (Hominidae) use tools, to access more nutritious food, and hunt for meat. Bears (Ursidae) exhibit similar behaviour, but giant pandas (Ailuropoda melanoleuca) only eat bamboo. These different animals have gut anatomies which reflect their diets, as shown. Sketches have been enlarged to similar sizes to allow comparison. Dogs (Canis lupus) represent a typical carnivore, Rhinos (Rhinocerotidae) a typical herbivore.



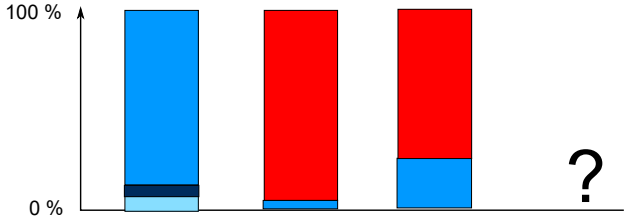
	True	False
Humans invest more energy in digestion to acquire nutrients than chimpanzees (Pan) do.		
Chimpanzees eat more meat and fruits than orangutans (Pongo).		
Giant panda digestive systems extract most of the nutrients present in Bamboo.		
Food passes more rapidly through orangutans than through humans.		

PREHISTORIC BRITONS

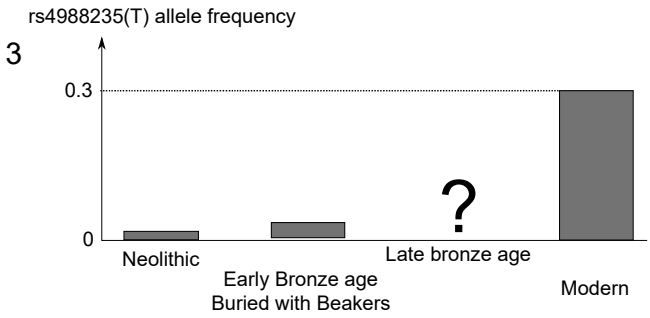
Stonehenge was built in the late Neolithic (Stone age; ~ 3000 BC) on what was Europe's most important trade route, between Cornwall and the Eastern Mediterranean. In the Early Bronze age (~ 2500 BC), the Beaker phenomenon swept across Europe, and many peoples began producing characteristic pottery (1). To discover whether British people bought and made Beaker pots, or Britain was invaded by a people that did, remains from different sites were genome sequenced. The average proportion of alleles originating from different populations (colours) in the genomes of Neolithic, Beaker and Late Bronze Age individuals was compared (2). Rs4988235(T) is an allele of the gene for the enzyme lactase which causes it to be produced into adulthood. Its frequency in British people through time was measured (3). Lactose is a sugar in milk.

1

2 Average proportion of allels from different populations



3

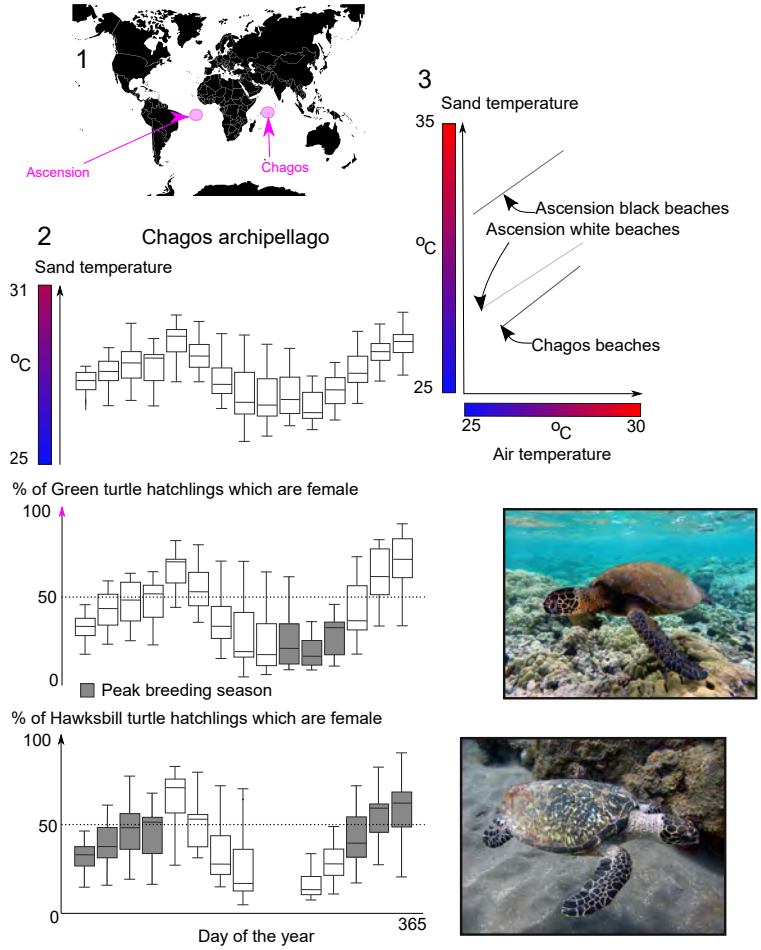


	True	False
A large proportion of Beaker people in Britain were native British people.		
Beaker people in Britain mostly replaced non-Beaker people.		
From this data, it can be concluded that modern Britons are very genetically distinct from bronze age Britons.		

	0.1	0.2	0.3	0.4	0.5
Choose the nearest proportion to the correct answer.					

TURTLES

British Territories in the Atlantic, Indian, Mediterranean and Pacific Oceans are vast new marine reserves which Green turtles (Chelonia mydas) and Hawksbill turtles (Eretmochelys imbricata) inhabit (1). Sex determination in turtles depends on the temperature of the nest, as shown for Chagos Archipelago hatchlings (2). Sand temperature in turn depends on the nest site (3). The majority of breeding occurs in peak breeding season, but a scarcity of males reduces breeding rates.



	True	False
Ascension produces an excess of female turtles.		
The Chagos Archipelago produces a roughly balanced sex ratio of Hawksbill hatchlings.		
Chagos island turtle breeding will be less disrupted by global warming, than Ascension island turtle breeding.		
Conservationists should protect heavily shaded nest beaches as a priority.		

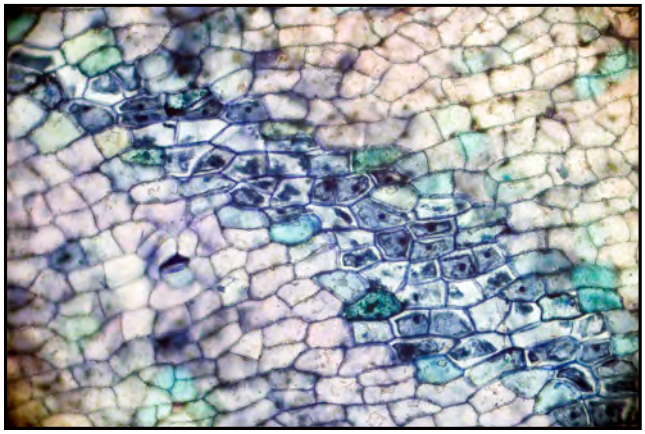
TESTES HISTOLOGY

Robert Hooke (1635-1703) popularised microscopy in his famous book Micrographia, and invented the term 'cells'. Analysing the size and shape of cells indicates their identity, whilst the appearance of their nucleus can indicate how transcriptionally active a cell is, or whether it is dividing. Specific junctions between cells allow internal substances to be transferred between them, or external substances to be trapped behind them. Testes have a distinct appearance under electron microscopes, as shown. Germ cells (which could pass their genetic material to the next generation) may undergo meiosis, and gradually adopt a morphology specialised for motility: these mature sperm are released into the centre of fluid filled tubes, in a process that happens in continuous waves.

	True	False
Cell i helps prevent autoimmunity against testes-specific antigens.		
Cell ii is a diploid (has two copies of each chromosome) germ-line cell.		
Cell iii facilitates transport of sex hormones (testosterone).		
Cell iv is using unique histones (DNA-binding proteins) to super-compact DNA.		

FLOWER SCENTS

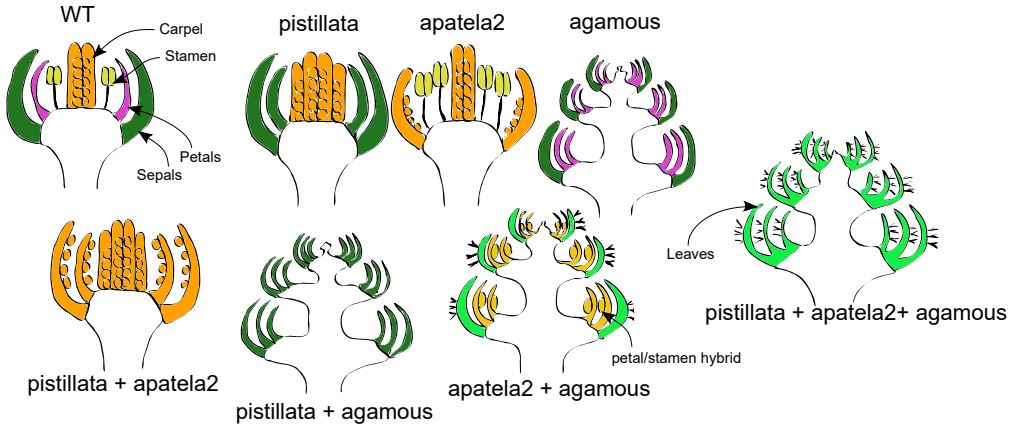
Flowers produce volatile fragrances from their petals to attract pollinators, but only once they have become fertile. Some volatile molecules diffuse through petal-cell (pictured) membranes into the air.
The ABC superfamily of transmembrane transporters use ATP to pump substances out of cells. These include multi-drug resistance pumps that export many foreign chemicals from bacterial, plant and cancer cells. To investigate whether ABC transporters pump some volatile fragrances into the air, scientists generated several testable hypotheses.



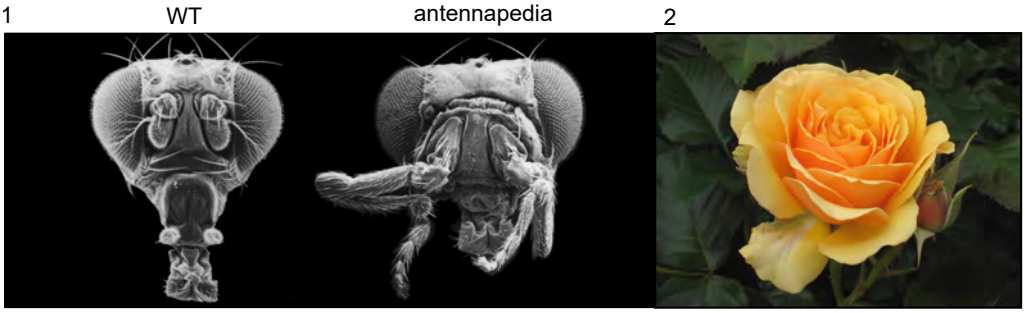
	True	False
An ABC transporter which is most highly expressed in budding flowers, compared to open flowers, is the one involved in fragrance emission.		
Plant strains which express ABC transporters at high levels in their flowers are more fragrant, compared to strains which express ABC transporters at low levels in their flowers.		
There is a higher concentration of volatile fragrances inside petal cells when ABC transporters are blocked.		
Altering ABC transporter function has a greater effect on the emission of small volatile molecules, than large volatile molecules.		

ABC MODEL OF FLOWERING

Arabidopsis flowers are formed incorrectly when the pistillata, apatela2 or agamous genes are knocked-out, as shown. Genes which determine the identity of parts of an organism are called homeotic selectors (or HOX genes in animals). HOX genes expressed more posteriorly (towards the anus) tend to repress those expressed more anteriorly (towards the head).



(1) shows a WT fruit fly (Drosophila melanogaster) head, and one which has the antennapedia mutation. (2) shows a typical decorative rose with an agamous phenotype.



	True	False
Homeotic selector genes tend to have small and simple promoters compared to other genes.		
PISTILLATA expression is necessary for cells to determine they should become part of a flower.		
Expression of AGAMOUS causes floral meristems to stop growing after four whorls.		
The antennapedia mutation is a loss of function, or knock-out, mutation.		
All these genes are first expressed once a cell is specialising/differentiating into its final role.		

COURTING FLIES

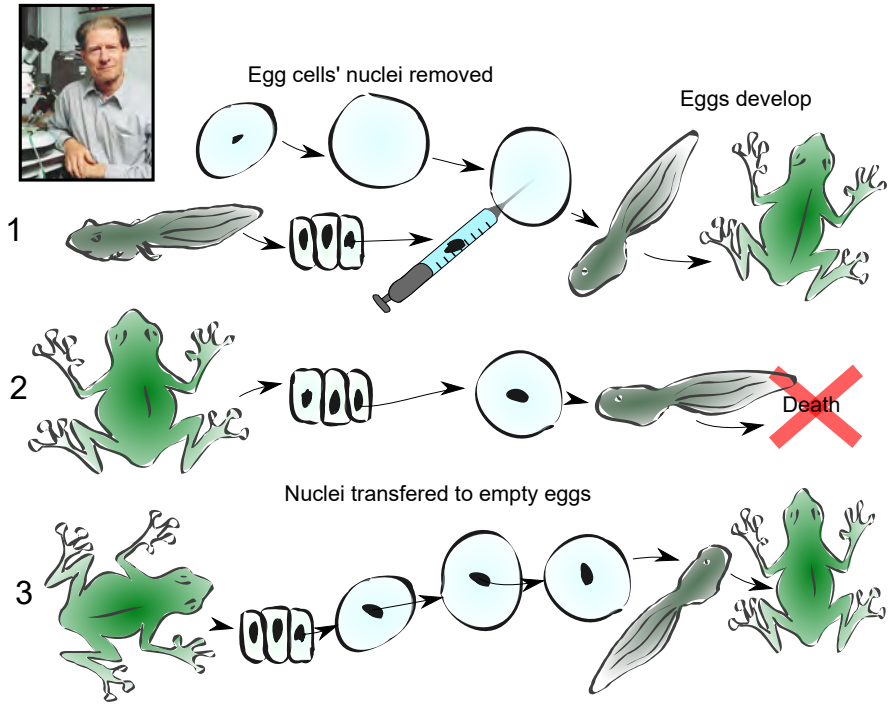
Sexual orientation in Drosophila matings (male with female, versus male with male, versus female with female) can be controlled by the gene fruitless. Fruitless mRNA is cut (spliced) in multiple ways to give two forms, FRUITLESS-A and FRUITLESS-B.
The sexual development and sexual orientation of WT and fruitless knockout flies, and flies which express either FRUITLESS-A or FRUITLESS-B, were studied.

Genotype of fly	Male		Female	
	Appearance of fly	Fly mates with	Appearance of fly	Fly mates with
WT	Male	Females	Female	Males
fruitless knockout	Male	Males and females	Female	Males
FRUITLESS-A only	Male	Females	Female	Females
FRUITLESS-B only	Male	Males	Female	Male

	True	False
Fruitless controls the development of appearance in flies.		
FRUITLESS-A causes flies to court females.		
FRUITLESS-B has a role in determining the sexual orientation of female flies.		
FRUITLESS-A and FRUITLESS-B perform the same role in male and female flies.		

MASTER DEVELOPMENTAL REGULATORS

Sir John Gurdon (1933-present) took differentiated cells from tadpoles (1) or frogs (2, 3), and transferred their nuclei to enucleated eggs. These eggs were allowed to develop (1, 2), or the nuclei were passaged through more enucleated eggs (3). He was able to artificially clone animals (Xenopus laevis) for the first time.



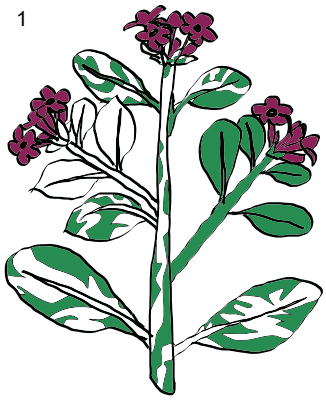
	True	False
Gurdon proved adult cells contain all the DNA required by the fetus.		
Cytoplasmic factors are sufficient to regulate cell type.		
The most powerful (irreversible) regulators of cell type are turned on early in development.		
Factors which determine cell type can take a long time to act on some genes.		

VARIEGATED PLANTS

Four o'clock plants (Mirabilis jalapa) can have a mix of white and green patches on their leaves, so they appear variegated - a picture showing the different colours of branches possible, but not necessarily the usual pattern of these branches, is shown (1). Variegated plants were grown, and flowers on green, white or variegated branches were fertilised by pollen from green, white or variegated branches. The progeny had the following phenotypes.

Phenotype of branch bearing seed	Phenotype of branch bearing pollen	Phenotype of offspring plant
White	White	White
White	Green	White
White	Variegated	White
Green	White	Green
Green	Green	Green
Green	Variegated	Green
Variegated	White	White, green, or variegated
Variegated	Green	White, green, or variegated
Variegated	Variegated	White, green, or variegated

1



	True	False
Chloroplasts can be transmitted through pollen during Four o'clock plant reproduction.		
During cell division as a plant grows, each daughter cell has the same composition of alleles.		
Egg cells in a variegated flower can contain different chloroplasts with distinct genomes.		
Older branches of a variegated four o'clock plant are more likely to be all white, or all green, than younger branches.		

IVF

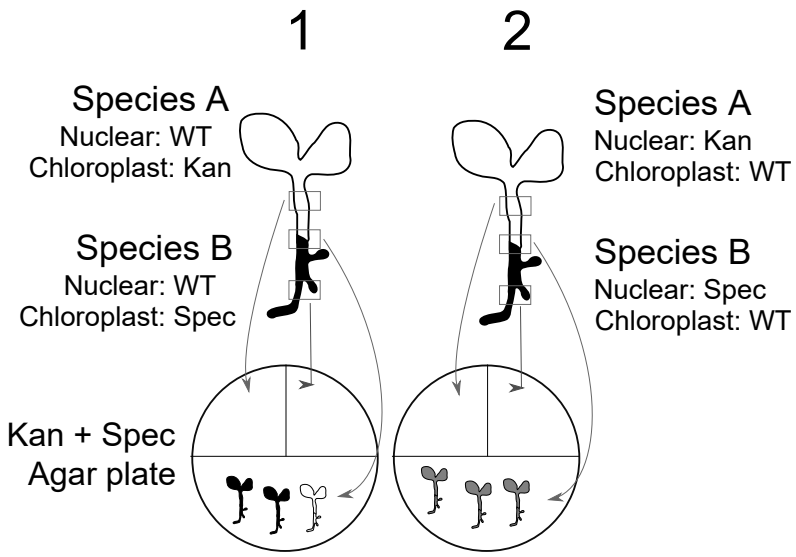
Sir Robert Edwards (1925-2013) invented in vitro fertilisation (IVF) and Sir Douglas Turnbull developed '3 parent IVF': the nuclear DNA of a mother and father are transferred into an enucleated oocyte from a second female. The ethicist Baroness Mary Warnock (1924-present) has enabled the UK to pioneer the safest and most advanced reproductive medicines, to combat genetic diseases such as Leigh syndrome.
Leigh syndrome is caused by mutations to the mitochondrial gene COX2. Mitochondrial DNA (mtDNA) in the muscles typically has the following distributions.

Sample	% of mtDNA which is WT	% of mtDNA which is COX2 mutant
Healthy mother of healthy child	100	0
Healthy mother of Leigh's child	30-50	50-70
Healthy child	100	0
Leigh's child	<20	>80

	True	False
30% of fully functional mitochondria is sufficient to prevent Leigh's disease.		
The father of a Leigh's child should be screened for COX2 mutant mtDNA.		
If only a small amount of cytoplasm is accidently transferred with the nuclear DNA, the three-parent IVF child is safe from Leigh syndrome.		
Rapidly dividing tissues are typically more affected by mtDNA mutations than slowly dividing tissues.		
Sampling a cell from an early IVF embryo could determine whether the foetus will develop Leigh syndrome when implanted.		

GRAFTING

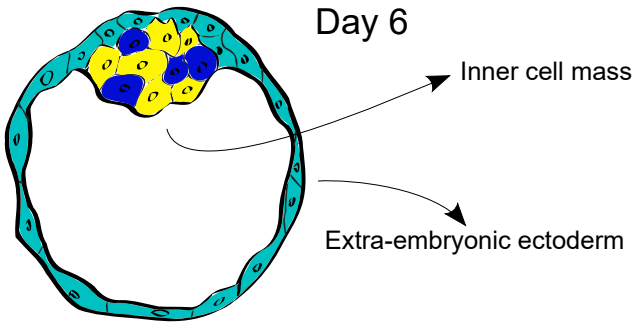
In nature, different plant species can graft together. An experiment was done where shoots from species A were grafted onto roots of species B. Plant chloroplast and nuclear genomes were independently transformed with different antibiotic resistance genes (Kan and Spec). Single cells from the shoot, root, and graft junction were excised, then grown on agar with antibiotics. Surviving cells are grown into adult plants. Plants phenotype is denoted by its colour.

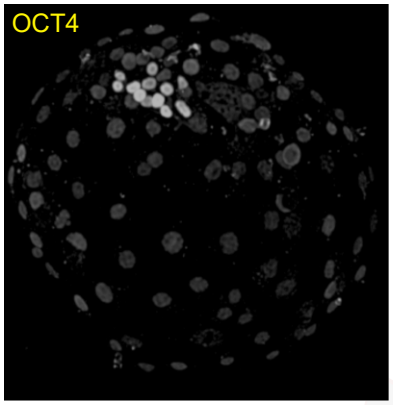


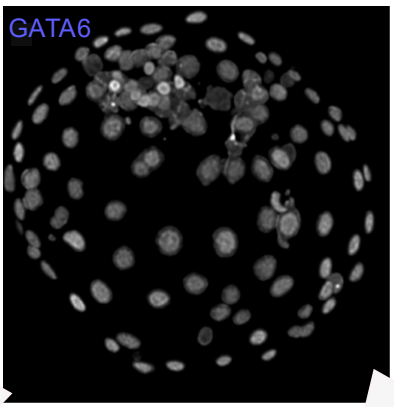
	True	False
Chloroplasts can travel the complete length of the plant.		
Genomes can be transferred between species.		
Plants which grow on the agar plates from (1) can cross with their parents.		
Plants which grow on the agar plates from (2) can cross with their parents.		

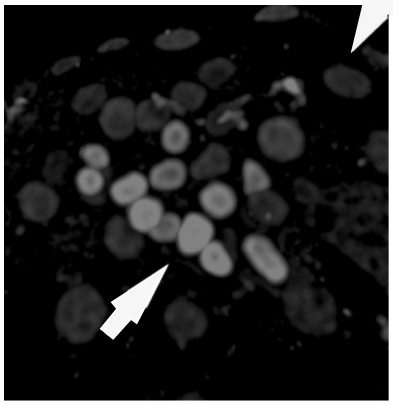
HUMAN EMBRYOLOGY

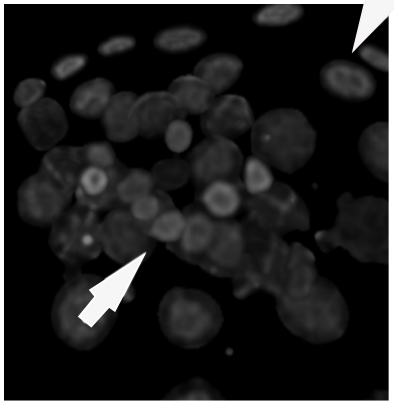
Sir Martin Evans (1941-present) was the first person to culture Embryonic Stem Cells (ESCs)(from a mouse). It is now known that the following transcription factors:
- OCT4 determines ESCs to become epiblast,
- GATA6 determines ESCs to become extra-embryonic endoderm,
-CDX2 determines ESCs to become epiblast.
In all previously known animal studies, OCT4 and GATA6 are found only in the inner cell mass, and block the transcription of one-another, until cells adopt one fate. Additionally, no known animal cells express all three markers at the same time. However, closely related species can have quite different embryos. Hence, in 2016 English scientists grew human embryos in Vitro for a record breaking 14 days, and stained them for these transcription factors. Arrows mark the same point on each image.



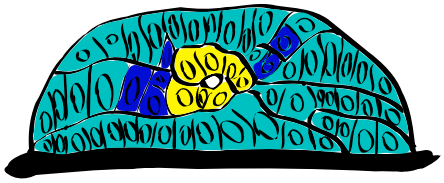




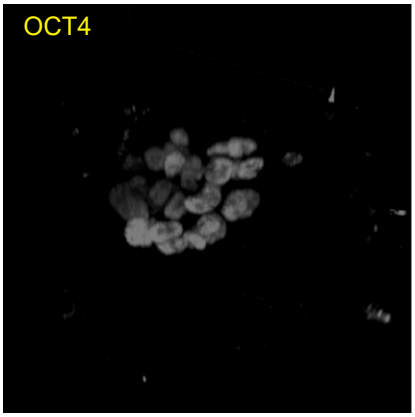


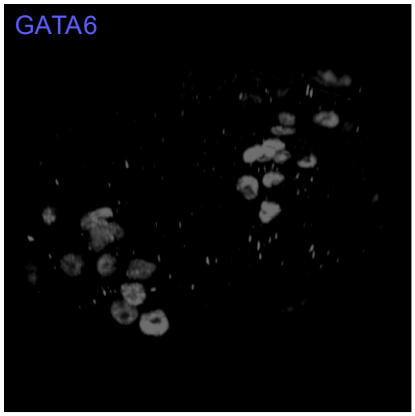


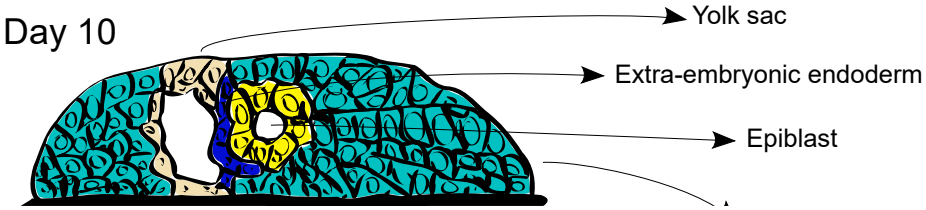
Day 8



Implants onto artificial uterus







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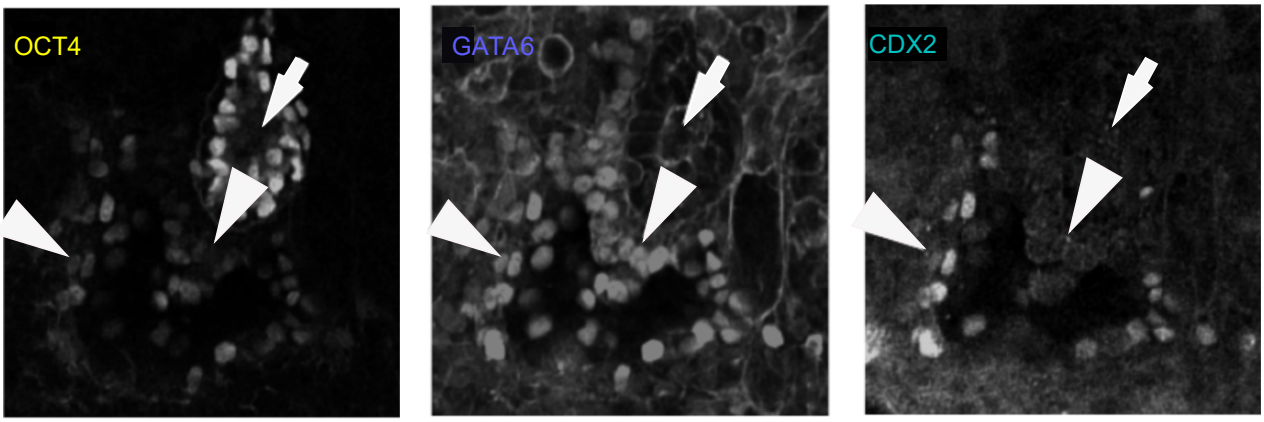
Extra-embryonic ectoderm



	True	False
OCT4 and GATA6 repress one-another to differentiate the inner cell mass in humans.		
OCT4 is not found outside the inner cell mass in humans.		
Human yolk sac cells are typical of previously known animal yolk sac cells.		
Cells expressing OCT4 may adhere more strongly to one another, than to other cell types.		
It can be concluded from these images that a population of GATA6 expressing cells switch their fate after day 8.		

DOMESTICATION

Plants have a plastic developmental body plan, built up of simple units. Brassica oleracea is the progenitor for many domesticated Brassica crops. During domestication of each crop different units were selected.

Brassica oleracea

Brussel sprouts

Cauliflower

Kale

Kohlrabi

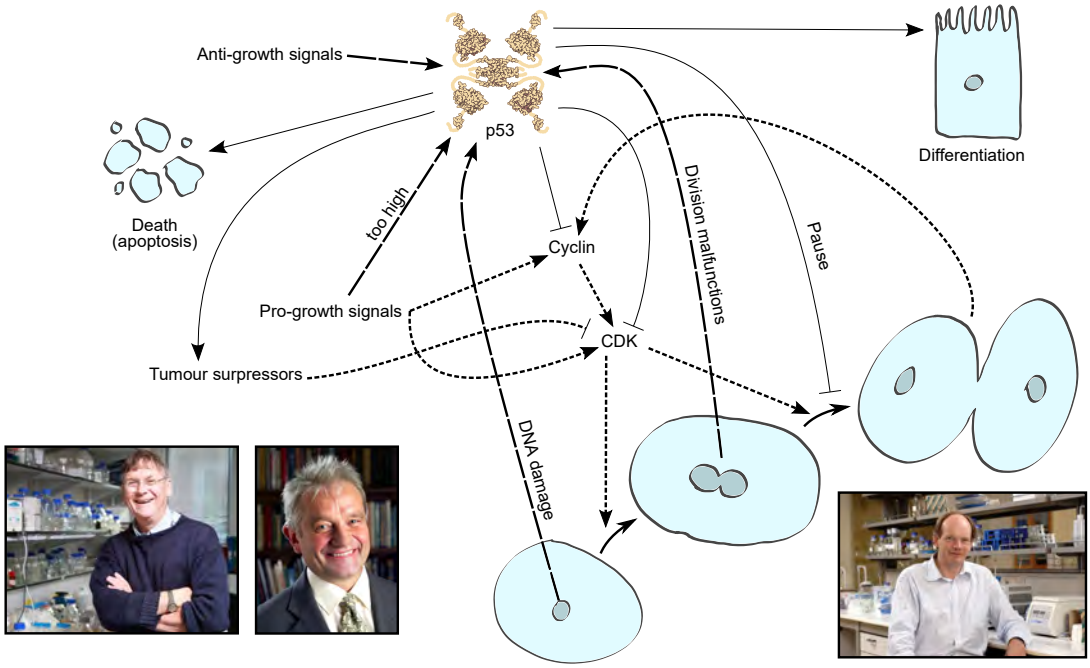
Broccoli

	Shoot apical meristem	Root apical meristem	Leaf	Axillary meristem	Internode
Brussel sprouts					
Cauliflower					
Kale					
Kohlrabi					
Broccoli					

DISEASE & DECAY

THE CELL CYCLE

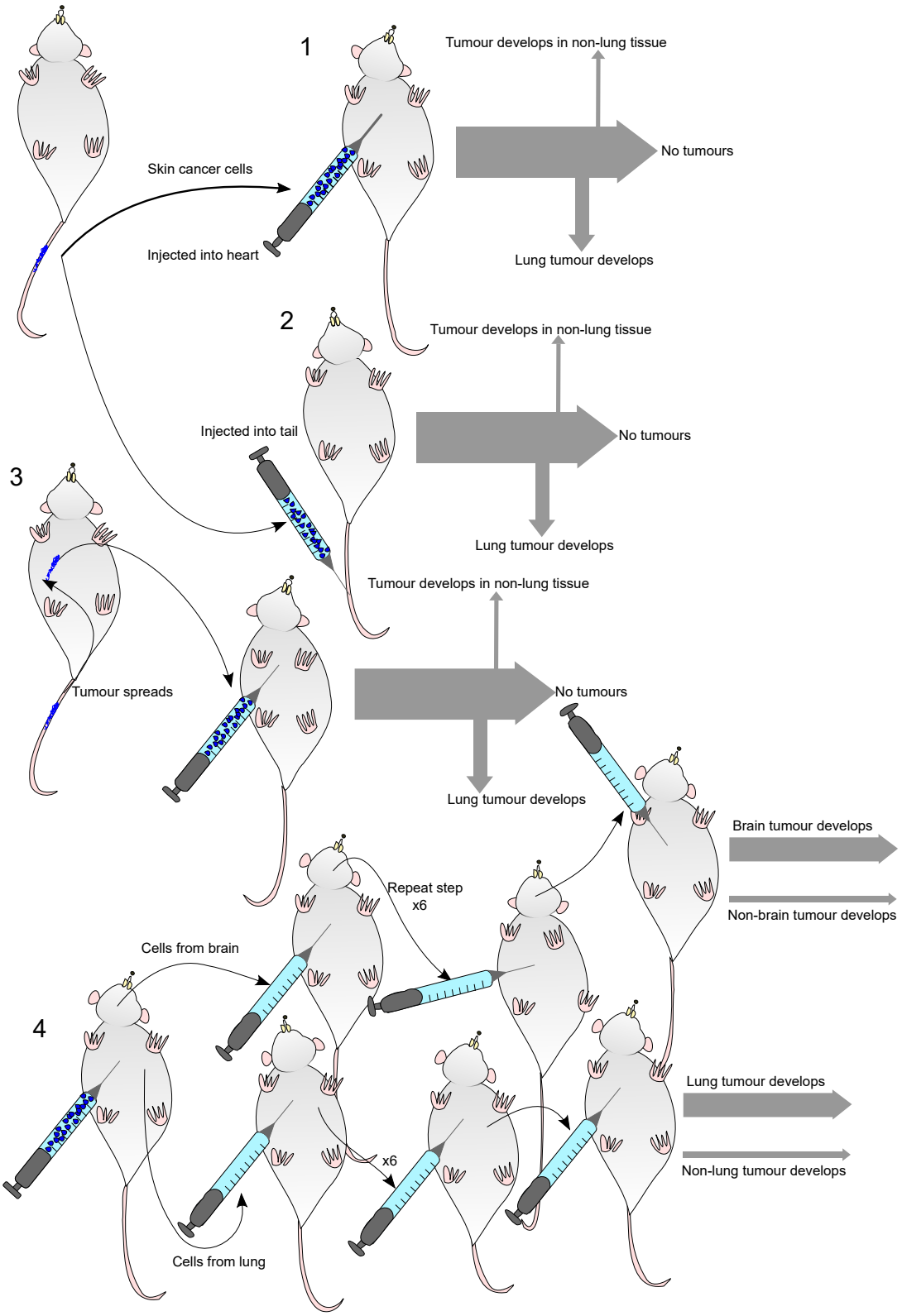
The major ways by which the cell-cycle is regulated in all eukaryotes were discovered by British scientists. In humans, Cyclins (discovered by Sir Tim Hunt; 1943-present) are transcribed at specific cell-cycle stages, and bind cyclin-dependent kinases (CDK; discovered by Sir Paul Nurse; 1949-present), to coordinate division. Protein-53 (p53; discovered by Sir David Lane; 1952-present) is activated by a huge array of post-translational modifications, which allows it to exert diverse effects. p53 can exert these effects even when its activity is reduced by half, but each p53 monomer is only active when bound to three other functional p53 monomers in a homotetramer. p53 is mutated in the majority of cancers ever sequenced.



	True	False
Tumours which have lost p53 activity have higher mutation rates than tumours which have p53 activity.		
Single celled organisms, such as yeast (Saccharomyces), possess equally powerful regulators like p53.		
Treatments which deliver more p53 to cells, would reduce the division of healthy cells.		
Both alleles of p53 are usually mutated in cancer.		
P53 knockout mice (Mus musculus) show an overgrowth of bone-marrow cells.		

METASTASIS

Different types of primary tumours give rise to secondary tumours at different rates, and in characteristic places. (The primary organ is where the primary tumour occurs, the secondary organ is where the secondary tumour develops). To understand why, healthy mice (Mus musculus) were injected with cells from skin cancers which spontaneously developed in different mice: Arrow thickness = relative proportion of mice exhibiting the symptom.
(1) Cells from the primary tumour were injected into the heart.
(2) Cells from the primary tumour were injected into the tail vein.
(3) Cells from a secondary tumour were injected into the heart.
In (1, 2 & 3) cancer cells were recovered from the lymph of 100% of the injected mice within hours.
In (4), cells from primary tumours were injected into the heart, and cells recovered from homogenised brain or lung were serially passed through fresh mice.

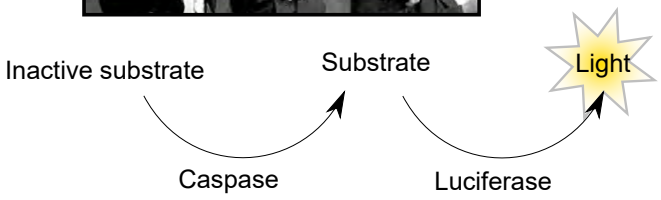


	True	False
The pattern of secondary tumours can be accurately predicted simply by how close different organs are to the primary tumour.		
Crossing the blood vessel wall, in the secondary organ, is the limiting step in the formation of secondary tumours from circulating cancer cells.		
Cells of a new secondary tumour evolve over time to thrive in the secondary organ.		
Cancer evolves as it spreads to seed new secondary tumours more efficiently.		

APOPTOSIS

Sir Alastair Currie (1921-1994), Sir John Sulston (1942-present) and colleagues discovered how cells can commit controlled suicide (apoptosis).
Apoptosis is executed by Caspase enzymes. Cyclohexamide (CH), which inhibits ribosomes, was used to induce apoptosis in cells treated with the hormone bone morphogenetic protein-9 (BMP9). To measure the number of apoptotic cells after treatment, inactive luciferase substrate, and the light-emitting enzyme luciferase, were added.

1



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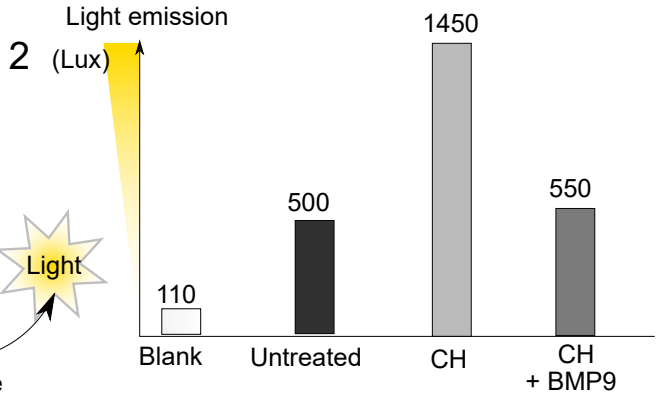
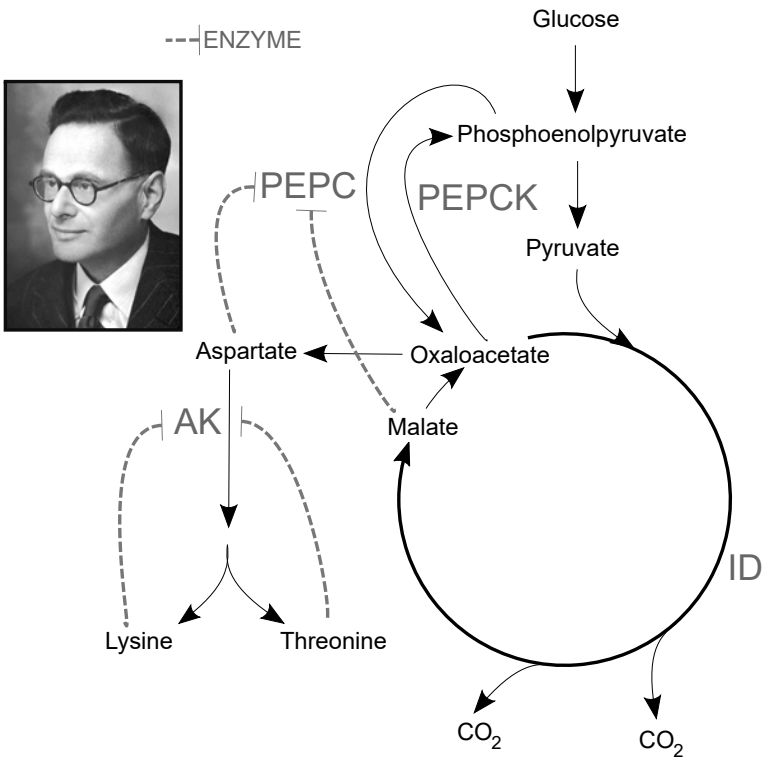


	-80 %	-70 %	- 60 %	- 50 %	- 40 %
Choose the nearest change to the correct answer.					

	True	False
BMP9 treatment causes an increase in apoptosis.		
A large excess of both inactive substrate and luciferase is required to give a linear luminescence signal in response to caspase activity.		
Caspase gene expression is increased during apoptosis.		

KREBS CYCLE

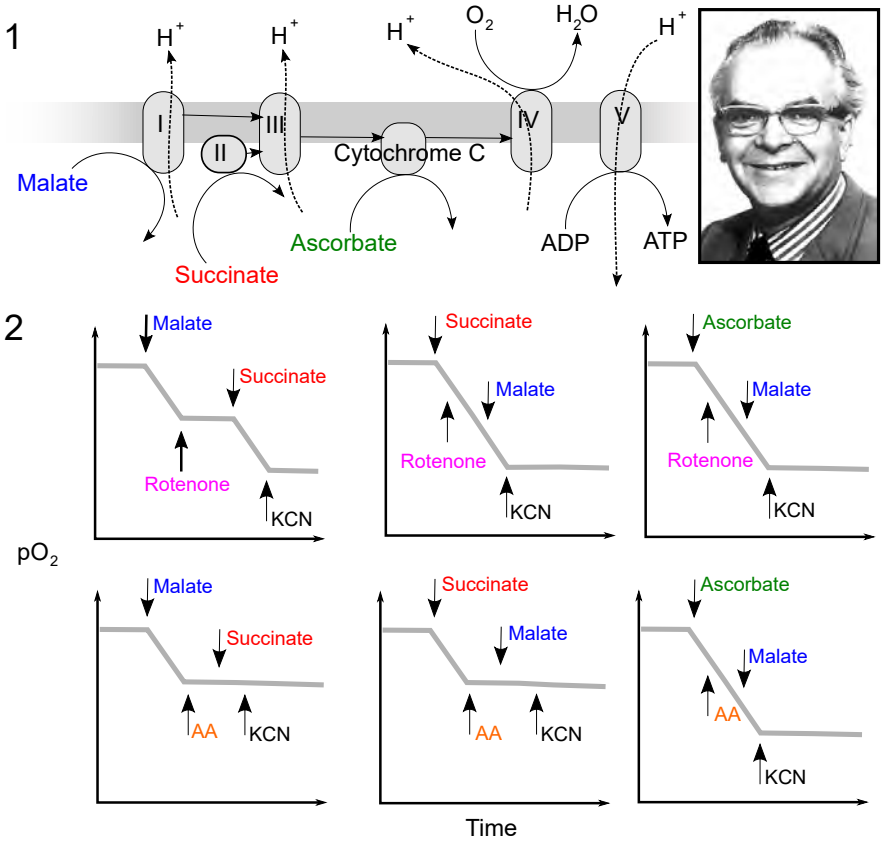
Sir Hans Krebs (1900-1981) uncovered the major biochemical pathway of mitochondria.
The Krebs cycle was artificially modified in a free prokaryote to maximise lysine production.



	True	False
Blocking the final step of threonine synthesis leads to an unregulated increase in lysine synthesis.		
Increasing ID activity increases lysine synthesis.		
Making PEPC insensitive to malate/aspartate increases lysine synthesis.		
Increasing PEPCK activity increases lysine synthesis.		

ELECTRON TRANSPORT CHAIN

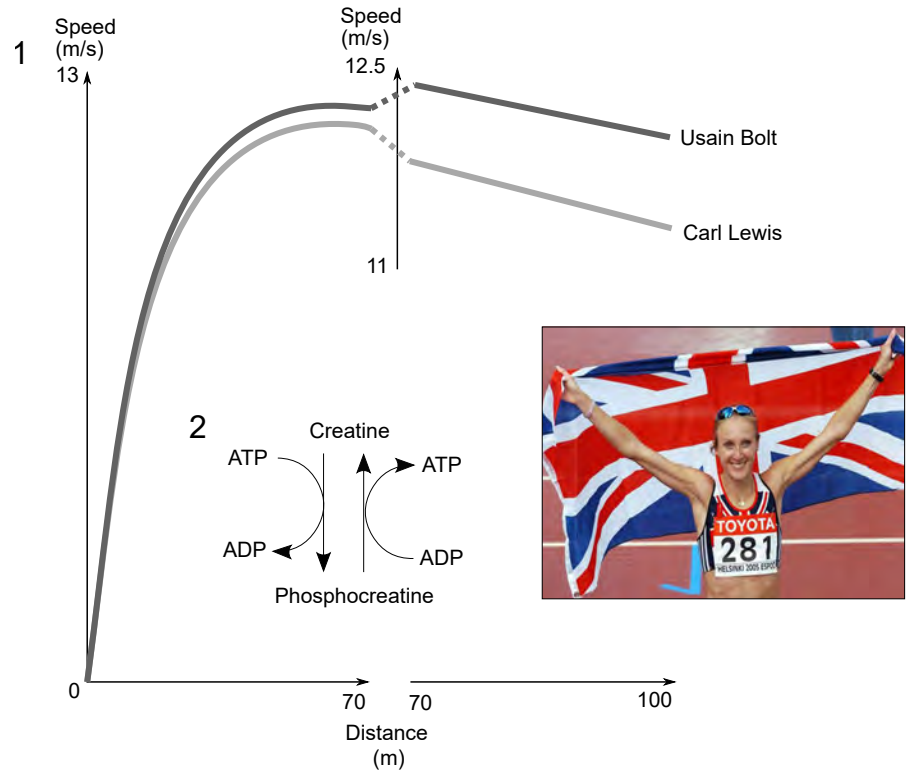
Peter Mitchell (1920-1992) discovered how mitochondria produce ATP.
Electrons are harvested from succinate, malate and ascorbate (vitamin C), and drawn onto oxygen. Complexes I-IV sequentially harness their energy to pump protons across mitochondrial inner membranes (1).
The oxygen saturation of a suspension of mitochondria, treated with substrates and the poisons potassium cyanide (KCN), rotenone or antimycin A (AA) at the indicated points, was measured over time (2).



	True	False
Rotenone inhibits complex I.		
Antimycin A inhibits cytochrome C.		
Cyanide poisoning can be treated with malate.		
Oxygen consumption is increased by poisons which introduce pores to mitochondrial membranes.		

ELITE RUNNERS

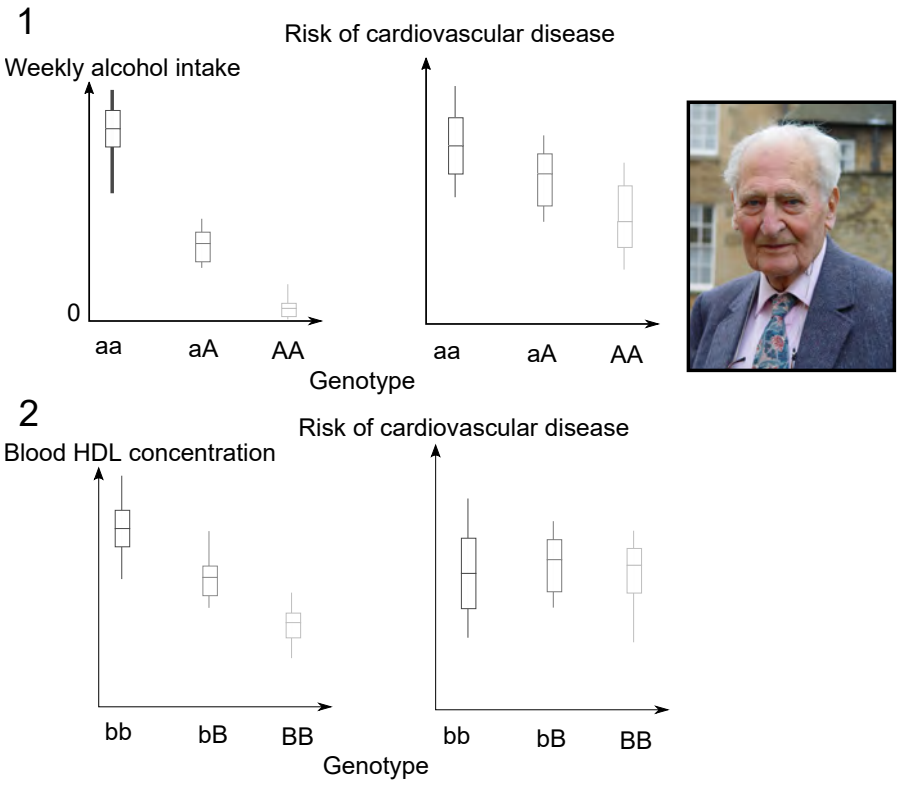
In the last few games, team GB has used sport science to finish second in Olympic and Paralympic medal tables.
The running velocity of different gold-medal 100m sprinters is presented (1).
Phosphocreatine, which is present in the cytoplasm of muscle, buffers ATP levels in a one-step reaction (2).
Glycolysis generates a few ATP by converting glucose to pyruvate. Mitochondria generate dozens of ATP by converting pyruvate to CO_2.



	True	False
Faster sprinters metabolise more muscle glycogen to CO_2 than slower sprinters.		
The kinetics of their glycolytic enzymes are an essential determinant of which medals these sprinters win.		
Creatine, as a dietary supplement, would enhance the performance of Usain Bolt (Jamaica's 100 and 200 m winner) more than Paula Radcliffe (Britain's record breaking marathon runner).		
Glycolysis becomes the main energy source of these sprinters after ~ 70 meters.		

MENDELIAN RANDOMISATION

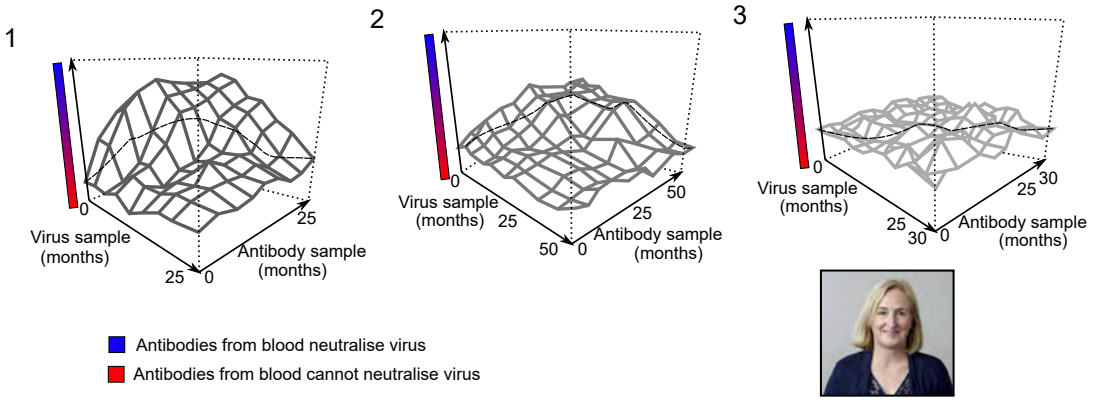
Sir Richard Doll (1912-2005) invented statistical methods to prove smoking causes human disease. Mendelian randomisation was invented to investigate more subtle behaviours, such as the health impacts of alcohol (1) and high density lipoproteins (HDLs; 'good' cholesterol) (2). An underlying genotype, inferred to cause a behaviour, is identified, and its correlation with disease is assessed. White British people were recruited for this study.



	True	False
Compared to not drinking any alcohol, consuming small amounts of alcohol is beneficial to health.		
Drugs which raise HDL are expected to reduce cardiovascular disease.		
If people with the genotype aa, who happen to consume no alcohol for religious reasons, have a high risk of cardiovascular disease, it should be concluded alcohol contributes to disease directly.		
If the allele a is found to be more common in Scotland, and A in Wales, the conclusions of a UK wide study will be strengthened.		

REDQUEEN HIV

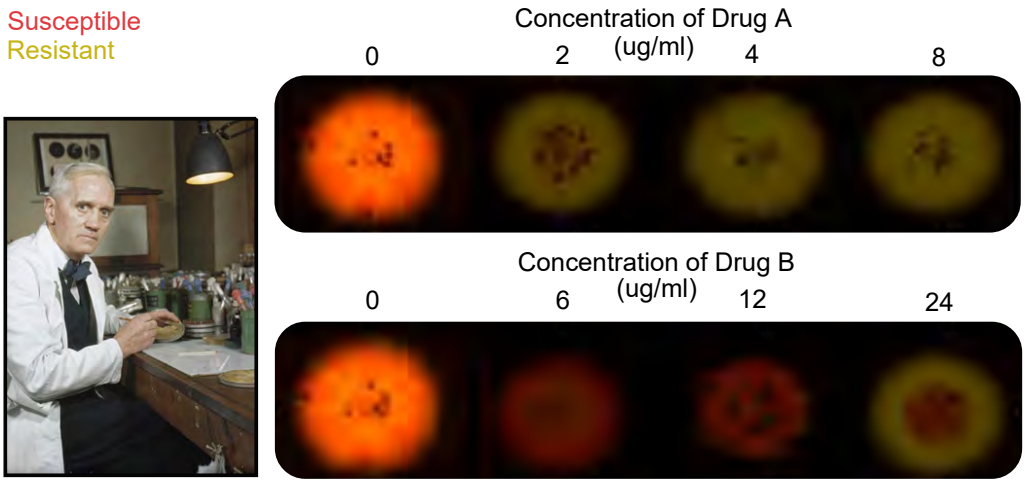
Dame Amanda Fisher discovered many properties of the HIV.
HIV has two states. It can remain dormant within cells or can be active, replicating and producing viral proteins. In 2016, the National Health Service announced a new treatment, which awakens dormant HIV and kills active HIV. Many recipients are preliminarily cured.
Three patients (1, 2, & 3) contracted HIV at time 0, and remained untreated. Each month, blood samples were taken from each patient. Antibodies and virus were separately extracted from the samples. Antibodies from each timepoint were mixed with viruses from each timepoint, and the infectiousness of the antibody-treated virus was measured.



	True	False
In the first month of infection, patients suppress circulating HIV.		
Patients' antibodies will be more effective against awakened dormant virus, than currently active virus.		
Patient 2 developed AIDS last.		
The virus evolved most rapidly in patient 3.		
The immune system is better at targeting cells infected with inactive virus than active virus.		

ANTIBIOTIC RESISTANCE

Sir Alexander Fleming (1881-1955) discovered antibiotics, but humanity's biggest killers are now mostly resistant to them.
In one pathogen, antibiotics are degraded either by intracellular enzymes, or by enzymes released into the surrounding environment. A strain susceptible to antibiotics was labelled red, and a resistant strain was labelled yellow. Equal amounts of susceptible and resistant bacteria were mixed and seeded as a dense lawn on plates. These were treated with drug A or B at different concentrations, and grown for a period of time. The colour of the remaining cells was photographed.



	True	False
This species of bacteria expresses the target of Drug B.		
When there is no drug, the plates will become increasingly yellow, and less red, with time.		
Resistance to Drug A involves an extracellular enzyme.		
Plasmids carrying genes for antibiotic resistance are more likely to spread when resistance uses extracellular enzymes, than when it uses intracellular enzymes.		

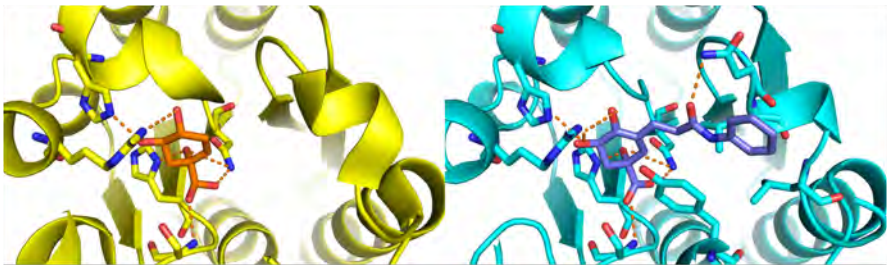
PRIONS

John Griffith (1928-1972) explained the biology of prion diseases. Prions are proteins which have folded incorrectly into a more stable form. When a prion comes into contact with its correctly folded counterpart, it catalyses this protein to also re-fold into a prion. Prion build-ups, which resist proteolysis, damage the brain, and in the 1990s millions of cattle (Bos taurus) in the UK had to be destroyed to prevent prions from spreading.

	True	False
At the start of disease, prions accumulate exponentially.		
Animal prion diseases may spread to humans.		
Cattle with some genetic variants may be protected from prion diseases.		
Banning animal protein supplements in livestock diets is an effective way to reduce prion diseases.		

TUBERCULOSIS DRUGS

The UK runs the biggest collaborations to screen for new antibiotics for tuberculosis. Molecules X and Y were found, which binds to the active site of a Mycobacterium tuberculosis enzyme. Dashed lines indicate hydrogen bonds.
Molecule Z was also found to inhibit the enzyme, by binding a site other than the active site.

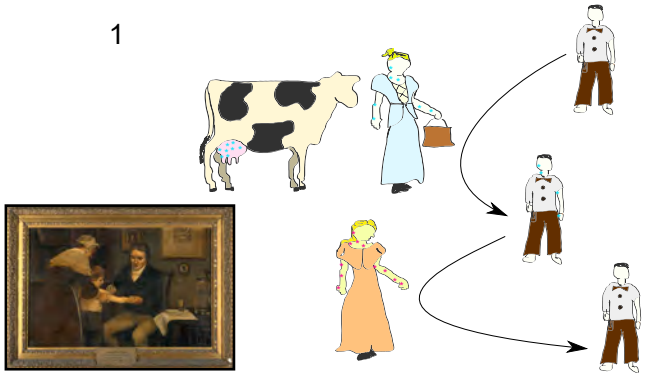


X Y

	True	False
Molecule X binds to the enzyme's active site reversibly.		
Molecule Y could have been found in a screen for molecules which increase the temperature at which the enzyme denatures.		
Molecule X binds to the active site more tightly than molecule Y.		
Molecule Z is a better drug candidate if the substrate concentration is usually very high.		

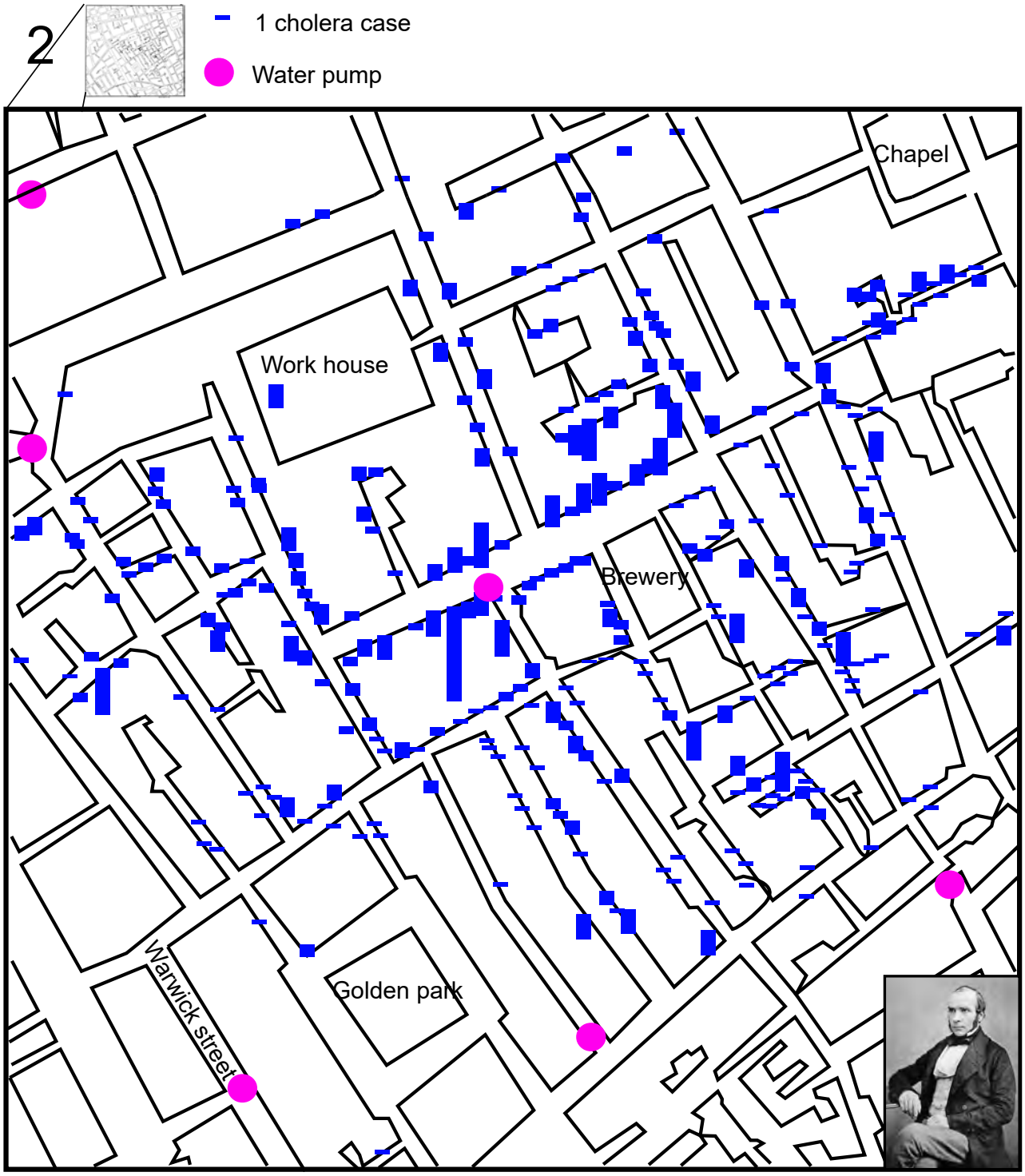
VACCINATION AND EPIDEMIOLOGY

Edward Jenner (1749-1823), the inventor of immunology, pioneered modern vaccination. Jenner noticed milkmaids exposed to cowpox did not catch smallpox. Jenner injected pus from a cowpox infection (top), into a boy, who became mildly ill. Jenner later injected the boy with pus from a smallpox victim (bottom), and the boy did not become ill (1). Smallpox was usually spread through the respiratory tract, was highly contagious, and quite deadly, but, due to vaccination, is now the only human pathogen to have been driven extinct.



John Snow (1813-1858) invented epidemiology. Snow mapped the occurrence of cases in Victorian London during the first Cholera pandemic, and saved many lives (2). In 1961, the current seventh global Cholera pandemic began in Indonesia.

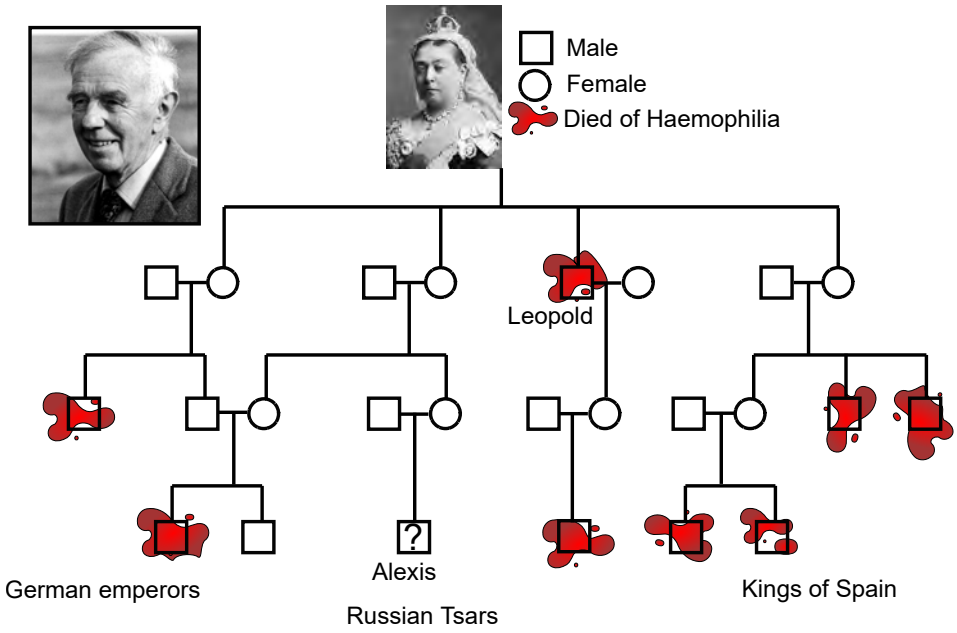
2



	True	False
Smallpox and Cowpox share some amino-acid sequences on their surface.		
People often contracted smallpox more than once.		
Snow ended the Cholera outbreak by removing the handle from the Warwick Street water pump.		
Smallpox remains viable outside of the host for longer than Cholera.		
Smallpox lingers in isolated communities longer than Cholera.		

HAEMOPHILIA

Robert Macfarlane (1907-1987) explained the biochemistry of blood clotting, and discovered the cause of haemophilia B, which causes fatal bleeding.
Queen Victoria's son, Prince Leopold, was the first European noble to develop haemophilia B, but it quickly devastated European royal lines. An incomplete family tree is shown.



	0 %	12 %	25 %	50%	100 %
Choose the nearest probability to the correct answer.					

	True	False
In this family, haemophilia B could have originated from a new (de novo) mutation during meiosis in Queen Victoria's oocytes.		
Clotting factor activity is reduced by more than half in these haemophiliacs.		