5A Photosynthesis

5A Checkpoint

5A.1 The importance of ATP

1 (a) It means that the reaction can be reversed so ADP and P_i can be joined together to re-form ATP.

(b) ATPase

2 Energy released when ATP is broken down to ADP is in a form available to all cell enzymes.

ADP and inorganic phosphate can be reformed into ATP by ATPase using energy from universal reactions, such as redox reactions, within the cell. Any other valid points.

3 *Might be*: The most important reaction because almost all life on Earth depends on it; it is the only large-scale way in which new organic molecules are synthesised in living organisms and the only way in which a new supply of ATP can be built up. Any other valid point.

Might not be: Without respiration, cells die so photosynthesis cannot take place. Without synthesis of proteins, there is no ATPase, so no ATP cycle. It is almost impossible to rank reactions in terms of importance. Any other valid point.

5A.2 Chloroplasts and chlorophyll

1 (a) Because not all the cells carry out photosynthesis – any parts of the plant that are not directly exposed to light will not contain chlorophyll.

(b) Folded membranes give large surface area.

Enzymes on membranes and in stroma to carry out reactions.

Presence of several photosynthetic pigments to absorb different wavelengths of light.

Any other valid point.

2 None of the pigments absorb well in the green/yellow areas of the spectrum. As this light is not absorbed, it is reflected, which is why plants appear green.

3 R_f for pigment X = 21/74 = 0.28 so pigment X is xanthophyll 1.

5A.3 The biochemistry of photosynthesis

1

Cyclic photophosphorylation	**Non-cyclic photophosphorylation**
Only involves PSI	Involves PSI and PSII
Electrons come from and return to chlorophyll in PSI	Electrons lost on excitation from the chlorophyll molecules in PSII are replaced by electrons from the oxidation of water
No reduced NAD produced as electrons return to chlorophyll	NAD reduced to reduced NAD during the process
Only ATP formed	ATP, reduced NAD and oxygen formed

2 The reactions take place in the absence of light – they are not catalysed or triggered by light. As long as the enzymes of the cycle have a supply of reduced NAD and ATP they will continue with or without light.

The Calvin cycle continues in the absence of light, but it is dependent on the products of the light reactions for its raw materials. Without light there is no long-term supply of reduced NAD or ATP and so the Calvin cycle cannot continue without the light-dependent reactions – it is indirectly dependent on light.

3 Because GALP is the key molecule produced in photosynthesis on which the synthesis of all the other main molecules needed by the plant depends. Not only glucose, but also polysaccharides, such as starch and cellulose, amino acids and fatty acids for lipids.

4 In a biochemical process that depends on or is affected by a number of factors, the process will be limited by the factor that is nearest to its minimum value.

The amount of light available affects the amount of chlorophyll that can be excited and therefore the amount of reduced NAD and ADP produced in the light-dependent stage. If there is a low level of light, insufficient reduced NAD and ATP will be produced to allow the reactions of the light-independent stage to progress at their maximum rate, so light is the limiting factor.

Low levels of carbon dioxide available for fixing in the Calvin cycle mean that the reactions cannot proceed at the maximum rate. When this is the case, carbon dioxide is the limiting factor. In the natural situation of plants, it is most often carbon dioxide that is the limiting factor.

All of the Calvin cycle reactions and many of the light-dependent reactions of photosynthesis are controlled by enzymes and are therefore sensitive to temperature. This means that even when the light and carbon dioxide levels are suitable for a very high rate of photosynthesis, if the temperature is low the plant will be unable to take advantage of the conditions.

By monitoring and controlling these three factors – raising or lowering levels artificially as needed – growers can maximise the growth of their plants.

5A Exam practice

1 C

2 D

3 B

4 (a) Photolysis (of water)

(b) Sufficient light intensity

(c) Electrons combine with H^+ and NADP to produce reduced NADP.

Electrons absorb energy from photons (to become excited).

Electrons carry the energy into the electron transport chain.

Electrons pass from carrier to carrier in electron transport chain releasing energy in small amounts.

(d) Transfer energy from the light-dependent stage to the light-independent stage.

The energy is used to make bonds.

Converting, GP to GALP / GALP to RuBP.

Transfer hydrogen atoms from the light-dependent stage to the light-independent stage.

Hydrogen atoms used to reduce GP to GALP.

(e) Used to make hexose sugars.

Used to remake RuBP.

5 (a) Thylakoids / thylakoid membranes

(b) (i) D

(ii) C

(c) Absorption of light excites an electron (in chlorophyll).

The electron is taken up by an electron acceptor.

And passes down the electron transport chain to PS.

(d) Carbohydrate production will stop.

No ATP will be made.

The Calvin cycle / light-independent stage, will stop.

The plant will not have energy to convert PG to GALP / GALP to RuBP.

6 (a) X = chlorophyll, Y = NADP

(b) It transports hydrogen atoms to the light-independent stage.

These hydrogen atoms reduce GP to GALP.

(c) (i) Initially not enough, electron acceptors / NADP, available.

More electrons are excited than can be accepted by the electron acceptors.

(ii) After one second electron acceptors pass electrons to light-independent stage.

Electron acceptors / NADP recycled to light-dependent stage to pick up more electrons.

(d) No GP made.

Cannot convert GP to PGAL.

No reduced NADP is used.

Less / no NADP recycled to accept electrons.

7 (a) B

(b) In the photosystems, on the thylakoid membrane.

(c) (i) Red

(ii) A black filter lets very little or no light through. Therefore, there is no light reaching the plant and it has no energy so it cannot photosynthesise.

(iii) A green filter lets only green light through. Chlorophyll reflects green light. It is not absorbed very well so there is little energy for photosynthesis.

(iv) There was some other source of light that allowed a little photosynthesis to occur. The bubbles observed were not oxygen.

(v) Take repeat readings and calculate a mean. Ensure that the intensity of the light passing through each filter was the same.

8 (a) Stroma

(b) (i) ATP and reduced NADP

(ii) Carbon dioxide

(c) B

(d) Quantity of RuBP rises.

Because there is less carbon dioxide to be fixed and converted to GP.

Quantity of GP falls.

Because less RuBP is being converted to GP.

5B Ecology

5B Checkpoint

5B.1 What is ecology?

1 The habitat is the 'address' of the organism – it describes where it lives. Suitable examples of habitats should be included – for example, tropical rainforest, under a log, etc. (there are many).

The niche describes the role of an animal within a habitat – so several organisms may inhabit the same habitat but occupy different niches within it. For example, food niches in woodland – top predator = fox; primary consumer = rabbit; tree-dwelling herbivore = squirrel, etc.

2 Full details should be given of whichever biomes are chosen. A clear understanding of the link between adaptations and the conditions of the habitat should be shown.

Answer to (c) should show understanding of the effect of temperature on growth rates through enzyme activity and rates of photosynthesis either for biomass or for food supply. Should show awareness of the importance of water availability to the ability of organisms to grow and thrive, and how it affects their form and function.

5B.2 How ecosystems evolve

1 The process by which communities of animals and plants colonise an area and then, over time, are replaced by other communities. The changes continue until a steady state is achieved, where the number and type of species remain roughly the same until conditions change again.

2 A community reached at the end of a series of stages of development that continues to consist of the same plant and animal species. Different habitats have different climax communities.

3 Primary succession occurs from bare rock or sand dune, secondary succession happens on land that was colonised by living things, but was cleared.

5B.3 The effect of abiotic factors on populations

1 (a) The non-living elements of the environment in which a population of organisms is living. Examples could include any of those listed in the book or any other relevant points, such as pH of the soil.

(b) Abiotic factors determine the fertility of the soil: the temperature, water availability, etc. This, in turn, decides which plants will be able to grow and thrive in an area which, in turn, affects the other organisms that will be able to survive. In terms of the basic colonisers of an area, abiotic factors are crucial.

2 Any suitable example, such as: in a windy environment water will evaporate from the ground more rapidly so will be less available for living organisms; high light levels, but low oxygen levels mean many organisms cannot grow well and reproduce; etc.

3 Any suitable examples demonstrating an understanding of how the animal/plant, etc. is adapted to the particular abiotic factor selected.

5B.4 The effect of biotic factors on populations

1 Any three suitable examples, including one bird, one fish and one mammal, with clear explanation of how territories are marked and defended, for example, scent-marking, physical display/dance, fighting.

2 With little biodiversity, if one organism is affected by disease it will have a major impact on the small number of other organisms in the ecosystem – they will not get eaten or their prey numbers will fall substantially. With little biodiversity there will be few other available food resources. Also, disease is more likely to spread between individuals where there are few buffer species.

In a more diverse community, changes due to disease are likely to have less of an effect as there is much more variety of food choice and more buffering organisms to prevent spread of disease.

3 Some regions appear to show 'classic' predator/prey relationships, with numbers of prey rising followed by predator numbers rising as there is more food, then prey numbers falling as they are predated more followed by predator numbers falling as there is less food available; at that point, prey numbers rise again, for example around 1862–1880 and 1907–1935.

At other times, the cycle is lost – for example, in 1852 the two cycles seemed to be completely in opposition, with the peak of prey coinciding with the minimum of predators, whilst around 1905 both predator and prey numbers peaked at the same time. This is because the predator/prey relationship is not simple. Food supply for the prey animals varies as do other predator numbers and disease. The same is true for the predators – they are affected by disease and hunting levels, and they have more than one prey species, for example. Predators may have been adversely affected by disease or hunting or the loss of another prey species at the time around 1852 when they appeared not to take advantage of high prey numbers. There may have been an excess of plant food – perhaps a very good growing season – or alternative prey animals in good supply – in 1905 when both species peaked at the same time.

5B.5 Ecosystem interactions and the importance of the niche

1 Intraspecific – between members of the same species, for example, for territory, mates, food.

Interspecific – between members of different species, for example, for space, food.

Intraspecific competition tends to affect the abundance of a particular species of organism – low resources, much competition, less reproduction and more mortality – numbers decrease. Plenty of resources, little competition, lots of breeding, low mortality – numbers increase.

Interspecific competition tends to affect the distribution of species in a habitat and also the abundance of species – the biodiversity. If one species competes very successfully against others, it will tend to drive them to extinction in the area.

2 (a) In all four population phases, the impact of fertiliser is low/has no major effect.

The impact of excluding predators is highest in the decline population, where hare density more than doubled.

The impact of food is also highest in the decline phase, where hare density tripled.

By far the highest impact is of adding food and excluding predators, in the decline phase, where the two conditions led to an increase in hare density by a factor of approx. 14.

(b) If food is added, hares breed more successfully, but more will also be taken by predators, which will also breed successfully. So the impact of the food on the hare population is not fully illustrated in the population numbers. (Or any other sensible explanation.)

(c) Where the hare population has increased as a result of the experimental manipulation, other factors begin to limit it – for example, the natural food supply begins to be exhausted, disease/parasites begin to impact on the more crowded population, or any other sensible suggestion. This causes the hare numbers to fall. The fact that the population which showed the least growth, where predators were excluded, also shows only a very small dip, supports this idea, as in those enclosures the population did not reach levels which had a major impact on the natural resources and so population size could be maintained. The enclosures where fertiliser was applied to the grass did not see any sustained population growth and so did not experience a dip resulting from over-density. (Or any other valid suggestion.)

3 Both abiotic and biotic factors can be density-independent or density-dependent – for example, if there are relatively few plants in an area, light intensity is density-independent – the amount of light that falls is affected by cloud cover, day or night, seasons, etc., but not living organisms. In a woodland the amount of light that reaches plants on the ground is very much dependent on other living organisms as well as all of the abiotic factors.

Density-independent factors tend to limit the distribution of species – for example, abiotic factors, such as rainfall or temperature, will affect the overall conditions and therefore which species can survive in a particular area. Can also affect abundance – for example, if light levels, temperature and rainfall are suitable for a species, then the numbers of individuals will affect how much light, water, etc. is available to individuals; so becomes density-dependent also.

Density-dependent factors are based on the numbers of organisms present so will tend to affect the abundance of an organism rather than whether or not it can survive in a particular habitat, unless a particular disease is so damaging that it wipes out a species, for example, Tasmanian devils and facial cancer.

5B.6 Investigating abundance and distribution of organisms

1 Because plants do not move around, but many animals do. Animals might move into or out of quadrats before counting is complete.

2 Frame quadrats – easy to use, portable, useful for measuring abundance in terms of individual counts or percentage cover.

Point quadrats – again portable and easy to use, pinpoint individual organisms, can be used to calculate percentage cover.

Permanent quadrats – in place all the time. Can be much bigger than frame and point quadrats. Allows data collection from same places over time, which makes for very reliable data – but disadvantage is that the points are fixed so less randomness after initial positioning.

5B.7 Statistics and ecology

1 (a) There is no relationship between the populations of the two bog plants *D. flexuosa* and *Agrostis* sp.

(b) Spearman's rank correlation coefficient – because the data collected is ordinal (can be ranked) so the Spearman's rank correlation coefficient can be used to show if there is a correlation between the two ranked variables – if there is correlation, the SRCC (r_s) does not equal 0.

(c) For Spearman's rank correlation coefficient degrees of freedom to use = number of data sets minus 2. In this case that means 26 − 2 = 24. There are 24 degrees of freedom.

2 (a) The Student's *t*-test is a statistical test used to determine if the mean of a variable in one group differs significantly from the mean of the same variable in a different group.

(b) Because the data measured did not look at the same mean variable in two different populations of plants.

(c) Data that could be collected from the site and analysed using the Student's *t*-test might be the mean diameter of both types of plant from the same area of the bog.

3 (a) That there is no significant association between the distribution of ghaf and mesquite trees (in other words, distribution is random).

(b)

	Ghaf			
Mesquite		**Present**	**Absent**	**Total**
	Present	29.33 (110 × 40/150)	80.67 (110 × 110/150)	110
	Absent	10.67 (40 × 40/150)	29.33 (40 × 110/150)	40
	Total	40	110	**150**

	Ghaf			
Mesquite			**Present**	**Absent**
	Present	***O***	25	85
		E	29.33	80.67
		$(O - E)^2$	18.74	23.81
		$\frac{(O - E)^2}{E}$	0.64	0.23
	Absent	***O***	15	25
		E	10.67	29.33
		$(O - E)^2$	23.81	23.81
		$\frac{(O - E)^2}{E}$	1.76	0.64

Chi squared = 0.64 + 0.23 + 1.76 + 0.64 = 3.27

2 species involved so 2 – 1 = 1 degree of freedom

The chi squared figure of 3.27 is just below the threshold for statistical significance. Suggests no association between the species – but would need more study to come to a clear conclusion.

5B Exam practice

1 (a) (i) A
(ii) B
(iii) B
(iv) A

(b) Only the most hardy species live in extreme conditions.
Hardy species are not good competitors.
They modify the environment allowing less hardy species to grow.
These less hardy species are better competitors.
They out-compete the original species which die out.

2 (a) Place a one metre square quadrat at each site.
Carefully observe all the species found in each quadrat.

(b) Site 1 has two species compared to four species at site 9 / site 1 has fewer species than site 9.
None of the species found at site 1 are found at site 9 / there are no species found at both sites.

(c) (i) C
(ii) B

(d) (i) Spartina is adapted to high salt concentrations.
The soil in the hole has too much salt for other species.
No competition from other species allows Spartina to grow.
(ii) Silt / mud will be deposited.
The hole will become less deep.
Less waterlogging will occur.
The salt concentration will decrease.
Less tolerant / other plants will be able to grow.

3 (a) A self-sustaining community of organisms, with a constant biodiversity.
A combination of organisms with maximum productivity for the conditions.

(b) (i) Grass species could survive the grazing and grow well to out-compete other species.
Other species / shrubs, could not survive the grazing.
Once grazing stops, other species / shrubs can grow.
These other species / shrubs are better competitors and replace the grass.
(ii) They will continue to develop to a full climax community.

(c) Exposure to wind / cold weather stops shrubs growing.
There were no shrub seeds / young plants present on the islands.

4 (a) Succession

(b) As the size of the plants increases, the number of bird species increases.
As the community of plants gets more complex, the number of bird species increases.
Larger plants provide a wider variety of habitats for the birds.
Larger trees provide a wider variety of habitats for insects and other food for the birds.
A wider variety of plants provides more habits for insect / birds.

(c) With pine trees, the variety of plants decreases.

There are fewer habitats for insect / birds.

With mixed woodland the variety of plants and therefore habitats rises again.

5 (a) D

(b) B

(c) (i) Members of different species compete for resources that are in short supply.

(ii) A predator–prey relationship:

Where members of one species (predator) hunts and feeds on members of another species (prey).

A parasite–host relationship:

One species (the parasite) lives in or on another species (the host) deriving benefit.

5C Environment and climate change

5C Checkpoint

5C.1 Transfers between trophic levels

1 Trophic levels are terms used to describe the position of an organism in a food chain or web and describe its feeding relationship with other organisms. They are extremely useful because they indicate the type of food the organism eats and how prevalent it is likely to be in an ecosystem – tertiary consumers are much less common than producers, for example.

2 **Advantages**

Pyramid of numbers	Pyramid of biomass	Pyramid of energy
Easy to observe and count.	Shows combined biomass of organisms at different trophic levels in a food chain.	Gives most accurate model of what is happening in an ecosystem.
Gives rough idea of feeding relationships.		
		Shows the change in amount of energy stored in living organisms along a food chain.
	Biomass can be measured wet or dry.	
	Gives a very good working model of relationships.	

Disadvantages

Rarely an accurate reflection of reality because of different sizes of organisms.	Only samples of organisms used to avoid destroying habitat.	Extremely difficult to measure stored energy.
		Often involves outdated models of energy.
	Wet mass less accurate than dry mass, but much easier to measure and does not involve killing organisms to measure.	
	Snapshot – does not give relationships over time.	

Any other sensible points made by students are acceptable.

5C.2 Net primary productivity

1 (a) Algae and coral reefs. (25 000 g m^{-2} $year^{-1}$ production per 1% of the Earth's surface.)

(b) Open ocean. (2.3 g m^{-2} $year^{-1}$ production per 1% of the Earth's surface.)

(c) Although they have a low productivity there is an enormous amount of open ocean so it has a big overall impact on total productivity.

2 (a) Producers to primary consumers: 16.6%

Primary to secondary consumers: 4.2%

Secondary to tertiary consumers: 6.1%

(b) (16.6 + 4.2 + 6.1)/3 = 26.9/3 = 9.0%

3 (a) Any suitable reason(s), such as would be too complicated to follow as a food web, can ignore the minor species within a trophic level, much easier to compare with studies of other ecosystems.

(b) Any reasonable assumptions, including using average body mass to calculate energy within biomass of a particular species, estimates of population size, possibly ignoring species which are very small and/or few in number, making estimates of energy transfer into a species over a whole year.

5C.3 The carbon cycle in nature

1 The answers should include some or all of the following; other points may be valid.

The link should be made between releasing carbon from sinks more rapidly than normal and more rapidly than photosynthesis, etc., can remove it.

2 Atmosphere: increasing industrialisation, electricity generation, cars and other road vehicles, aeroplanes – all producing carbon dioxide; emissions affect amount of carbon dioxide in the atmosphere.

Soil organic matter: temperature, (rate of activity of breakdown), death rate of organisms, any sensible alternative.

Ocean: temperature, any sensible alternative.

Marine sediments: erosion, acidity of water, acid rain, etc., any sensible alternative.

Terrestrial plants: season of the year in temperate areas has a big effect on global photosynthesis levels, deforestation, crop growth and harvesting.

5C.4 Greenhouse gases and climate change

1 The greenhouse effect describes the process by which infrared radiation from the Sun, that has been absorbed and radiated by the surface of the Earth, is absorbed and reradiated back to the surface of the Earth by gases such as carbon dioxide and methane (the greenhouse gases) in the atmosphere. This maintains the temperature at the surface of the Earth at a level suitable for life. So the greenhouse effect is vital to life and is a very positive process.

It is used inaccurately and negatively to describe the enhanced greenhouse effect that appears to be resulting from an increase in the concentration of greenhouse gases in the atmosphere causing a rise in temperatures at the surface of the Earth.

2 (a) Climate is the average weather in a relatively large area, e.g. a country, over a long period of time, e.g. 30 years. Weather is the conditions in the atmosphere at one particular time – for example, whether it is sunny or windy or rainy when you go outside.

(b) Weather is local and variable whereas global climate change is measured over a very large area over a very long time. So a single extreme weather event is simply an example of natural variations in weather patterns, not a long-term trend. However, if the numbers of extreme weather events increase significantly over a long period of time, this CAN be evidence of global climate change.

3 That people stop eating beef and using dairy products. Because millions of people around the world rely on meat and milk from ruminants as a major part of their diet and big farming interests have a lot of economic power/influence and would object. Any other valid point.

5C.5 Looking at the evidence

1 20.81%; allow 19–21%

2 Carried out over long period of time, very large number of readings, same or similar measuring equipment used throughout, area of low air pollution etc. Any other relevant points.

3 Gives a much longer time perspective (readings going back over a thousand years), shows natural falls and rises in carbon dioxide concentration and events of last couple of hundred years. Reliability 0.2 ppm. Correlation with other evidence. Any other valid points.

4 The data show that atmospheric carbon dioxide levels have increased. They do not show the source of the carbon dioxide.

5 (a) Student should question validity of data, statistical methods used, inclusion of tree ring data in original.

(b) 2008 version contains a large amount of extra data from hundreds of studies, two different statistical methods used, figures calculated both with and without tree ring data. Any other valid point.

5C.6 The global warming debate: Correlation or causation?

1 Close correlation in pattern between temperature and carbon dioxide levels. Which comes first – change in carbon dioxide or change in temperature? – not always easy to see. Very reliable data based on isotopic decay of gases from ice cores.

2 Over the period 1990 to 2010:

Increase in carbon dioxide is from 24 to 33 million tons = 38% increase. Accept answers close to this figure showing working.

For all sources increase from 34 to 45 million tons = 32% increase. Accept answers close to this figure showing working.

Carbon dioxide from fossil fuels increased more than other sources. Based on this graph the figures are necessarily approximate but the pattern is clear.

3 (a) Evidence of careful research and ability to weigh up the strengths and weaknesses in terms of clarity of ideas, reliability of data, etc.

(b) Look for closeness of data, which comes first in rise on graph, temperature or possible cause, etc. Comments should be made on validity and reliability of data. Any other valid points.

5C.7 Models of climate change and their limitations

1 Any valid points, e.g. impossible to predict new technologies which may emerge to help us reduce carbon emissions, do not know increase in production by developing economies, do not know how effective drive to reduce carbon footprint will be, etc.

2 (a) (i) 19×10^{22} J / 60 = 0.317×10^{22} J per year

(ii) 5.5/11.5 × 100 = 47.8% reduction

(iii) 40 million km^2 down to ~34 million km^2, i.e. 15% decrease

(b) 125 mm

(c) Increasing carbon dioxide levels thought to cause rise in global temperatures due to enhanced greenhouse effect. Increasing temperatures causing melting of snow cover on mountains, due to rising temperatures there is less snow falling and there is melting of snow at poles – this in turn causes rise in average sea levels.

5C.8 The biological impact of climate change

1 Particularly affects diseases with insect vectors. Linked to climate change – rising carbon dioxide and rising temperatures, means insect vectors can survive in areas where they couldn't previously live and therefore carry diseases such as malaria and bluetongue to areas where they have previously not been an issue.

2 There are many different examples – students are likely to choose examples from their own country.

Changes in temperature: Rise in temperature – e.g. affects enzymes, time of reproduction etc., many different examples e.g. can change the sex of reptiles as they develop in the egg.

Fall in temperature: changes the plants which grow which affects the animals which feed on them, affects reproduction timing.

Rainfall patterns – excessive causes flooding, destroys habitats.

Lack of rainfall: drought, fish die out, plants die, etc.

Seasonal timings – disconnect between animals and the food they need e.g. in reproduction – e.g. birds can't find the food they need for young.

3 Look for clarity of thought and understanding of the possible sequences of events.

5C.9 Climate change and evolution

1 (a) In order to plant the apple orchards, huge areas of natural bushes would have been ploughed up. This would have destroyed many hawthorns, the natural habitat of the flies, which in turn would have led to some females being left with no alternative but to lay their eggs on the apple trees. Then some of these flies would have had alleles which helped them recognise the scent of the apples, or digest apples effectively, or lay eggs at times that fit the pattern of apple tree flowering and fruiting rather than hawthorns. These flies would be most likely to survive and pass on their alleles, thus changing the allele frequency in the population and moving towards speciation.

(b) The trees of the two species flower at different times and the flies have adapted and slowly evolved to live on different plants and reproduce at different times. Anthropogenic climate change means the plants which can survive in a habitat are changing, and plants are flowering at different times. So insects and other animals will need to adapt and evolve in the same way to cope with those differences.

2

Global warming and climate change	Impact on allele frequencies and speciation
Temperature changes	Populations with greater genetic variation adapt better to changes There will be a move to the alleles that produce adaptations which help in temperature adaptation with temperature extreme
New islands/land masses	Speciation increases as animals and plants become isolated
More extreme conditions	Animals and plants with very specific needs die out
More droughts/extremes of temperature/longer winters	Selection pressure on plants to produce seeds with better survival times etc.
Any other sensible points	

5C.10 What can be done?

1 Accept any valid points. Important to show awareness of the fact that no single body can legislate for the whole world, difficult to say that developing countries cannot strive to have the same standard of living as that enjoyed by more developed countries even though that involves massive increase in carbon dioxide emissions, politicians don't want to be unpopular at a national level and measures to reduce use of electricity/petrol, etc., are inevitably unpopular as they impact on individual choice or economics.

2 (a) Biofuels:

Advantages: carbon neutral/uses natural; process of photosynthesis to remove carbon dioxide/could use waste plant material.

Disadvantages: uses land which could be used to grow food for people; uses land where people can live/results in deforestation to provide land to grow crops for biofuels.

Any other sensible points.

(b) Reforestation:

Advantages: take carbon dioxide out of the atmosphere by photosynthesis/produces sustainable resource/new carbon sinks.

Disadvantages: uses land which could be used to grow food for people/provide homes.

Any other sensible points.

3 Answer should cover the ways in which the evidence differs, that there is no complete answer, and that organisations may have vested interests.

Other points may be valid.

5C Exam practice

1 (a) D

(b) (i) Loss = 2250 − 240 = 2010

% loss = 100 × 2010/2250 = 89.334%

(ii) Prey not eaten.

Parts of prey not digestible.

(c) Blue and red light are absorbed by chlorophyll.

Green light is reflected.

The energy in green light cannot be converted to chemical energy in biomass.

2 (a) C

(b) (i) A

(ii) Reflected by the leaf.

Passes straight through the leaf.

Used in leaf in other ways.

(iii) Not all the secondary consumers are eaten.

Not all parts of the secondary consumers eaten are digestible.

The secondary consumers lose energy through excretion and respiration.

3 (a) (i) The leaves and branches make up the same biomass in both primary and secondary rainforest.

There is a lower biomass of leaf litter in secondary rainforest.

300 million tonnes per hectare compared to 400 million tomes per hectare / 75%.

There is a much lower biomass of roots in secondary rain forest.

75 million tonnes per hectare compared to 200 million tonnes per hectare / 37.5%.

(ii) After 25 years the land has not fully recovered.

(Tree roots have not grown as much and so) the soil may not be stable / trees may be unable to grow to full size / water uptake is reduced.

(The biomass of leaf litter has also not recovered to its full extent so) there is less recycling of carbon / other nutrients.

(b) Biodiversity reduced.

Disturbance / noise / presence of humans may scare wildlife away.

Habitats are lost / destroyed.

Populations of animals are reduced and may not survive.

Reduced genetic diversity in smaller populations.

4 (a) C

(b) B

(c) (i) Energy used in respiration.

Energy loss in excretion.

(ii) The seeds are dormant.

Very little energy being used in respiration.

No excretion losses.

5 (a) D

(b) D

(c) Rising sea levels:

Land is flooded with saltwater which destroys habitats reducing biodiversity.

Increasing temperatures alter enzyme activity:

Organisms may need to migrate or evolve in order to survive.

(d) Reforestation:

The growing trees will absorb carbon dioxide and reduce the greenhouse effect.

Legislation to reduce use of fossil fuels:

Less carbon dioxide will be emitted so reducing the enhanced greenhouse effect.

6A Microbiology

6A Checkpoint

6A.1 Bacteria and viruses

1 Extremely small so can easily get into the body.

Simple structure of protein coat and genetic material means the virus can withstand harsh conditions and retain infectivity.

Has virus attachment points (YAPs) to enable the virus to attach to specific types of cells.

Some have specific mechanisms for injecting their DNA into cells.

Viral genetic material is adapted to take over host cell mechanisms. For example, viral DNA acts directly as a template for both new viral DNA and for the mRNAs needed to induce synthesis of viral proteins. Viral RNA directs the synthesis of reverse transcriptase which proceeds to make DNA corresponding to the viral genome which is then used as a template for new viral proteins and ultimately a new viral RNA genome.

Other points may be valid.

2 The answers should include some or all of the following. Other points may be valid.

(a) Like living organisms, they reproduce, contain genetic material, undergo evolution, are obligate intracellular parasites (can only exist and reproduce as parasites in the cells of other living organisms).

(b) Unlike living organisms, they don't feed, respire, excrete, move, or show any sensitivity. The only characteristic of living things shown is reproduction.

3

Structure	Bacteria	Viruses
Genetic material	A nucleoid – a single, circular strand of DNA	DNA or RNA, may be single or double stranded
Plasmids	yes	no
Outer layers	Cell wall containing peptidoglycans, cell membrane, may have slime capsule	Protein coat or capsid consisting of identical capsomeres, may have lipid envelope
Ribosomes	70S	none
Antigens on surface	yes	yes

6A.2 How viruses reproduce

1 Lytic: viral genetic material is replicated independently of the host DNA straight after entering the host; mature viruses are made by host cell, which eventually bursts, releasing large numbers of new virus particles to invade other cells; virus is virulent (disease causing) straight from infection.

Lysogenic: viruses non-virulent when they first get into the host cell; viruses insert their DNA into the host DNA so it is replicated every time the host cell divides; no

mRNA produced from the viral DNA because one of the viral genes causes the production of a repressor protein, which makes it impossible to translate the rest of the viral genetic material; virus spends time dormant while simply part of the reproducing host cells; viruses in lysogenic state can become lytic.

2 (a) Retroviruses have RNA as genetic material instead of DNA.

(b) They have more complex lifecycles as the RNA first has to be translated into DNA by reverse transcriptase in the cytoplasm of the host cell. This DNA passes into the nucleus to be inserted into the host DNA. Viral DNA is then transcribed to make viral mRNA and viral genome RNA. The viral mRNA acts as a template for new viral proteins and other chemicals to make new viruses.

6A.3 The growth of bacterial colonies

1 (a) Rapid, reliable – can occur every 20 minutes in ideal conditions.

(b) Brings about genetic variation which can enable bacteria to survive unfavourable conditions.

2 $\log_2(2^x) = \log_2(16777216)$

$x = 24$

It will take 24 × 30 minutes = 12 hours for the population of the bacteria to reach 16 777 216.

If you need to show the population at each stage in time, then:

16 777 216/2 = 8 388 608/2 = 4 194 304/2 = 2 097 152/2 = 1 048 576/2 = 524 288/2 = 262 144/2 = 131 072/2 = 65 536/2 = 32 768/2 = 16 384/2 = 8192/2 = 4096/2 = 2048/2 = 1024/2 = 512/2 = 256/2 = 128/2 = 64/2 = 32/2 = 16/2 = 8/2 = 4/2 = 2/2 = 1

3 (a) Bacterial growth is very fast so numbers get very big, for example, in 12 hours from 1 to 16 777 216, and it becomes impossible to show what is happening on a graph. Log numbers are used as the difference in numbers from the initial organism to the millions or even billions of descendants is too great to represent using standard numbers. In a logarithmic scale, the numbers on the scale are actually logarithms; usually powers of 10.

(b) Graph using data – students show translation to logs and then plot of the graph with clearly labelled axes.

(c) Annotated sketch graph similar to **fig B**.

6A.4 Microbial techniques

1 (a) Add measured amount of sterile nutrient medium to a sterile flask and seal with sterile cotton wool → take sample from starter culture using sterile pipette or loop sterilised in Bunsen flame and cooled → remove cotton wool and add sample to broth as quickly as possible → close with fresh sterile cotton wool → label clearly → incubate at suitable temperature (below 25 °C in schools).

(b) Sterilise inoculating loop in hot Bunsen flame → cool in air → dip sterilised loop in starter culture → lift lid of agar plate and streak with starter culture, taking care not to damage surface → close lid and seal with pieces of tape → label clearly and turn upside down to avoid condensation → incubate at suitable temperature (below 25 °C in schools).

2 Wash hands before handling cultures – to avoid culturing any potentially pathogenic bacteria on your hands.

Wash hands after handling cultures – to avoid transferring any potentially pathogenic microorganisms from the culture to your own mouth, etc.

Sterilise all equipment to avoid contamination from pathogens in the lab.

Incubate at 25 °C or below to minimise chance of human pathogens growing (they grow best at around 37 °C).

Sterilise all cultures after working with them and dispose of them to avoid environmental contamination.

Any other sensible points.

3 To grow a pure culture of microorganisms, manipulate the medium in or on which they are grown. Nutritional requirements of different microorganisms vary greatly so by manipulating the culture medium you can favour the growth of some organisms and inhibit the growth of others. You may: control the range of nutrients available; introduce selective growth inhibitors, antibiotics or antifungal chemicals; use indicator media that cause certain types of bacteria to change colour. All of these media enable you to isolate and grow specific organisms for pure cultures.

NOT oxygen levels as question asks for media.

6A.5 Measuring the growth of bacterial cultures

1 One curve is the turbidity of the culture and the other is the viable cell count using an alternative method. This is used to produce a calibration curve that enables you to measure the turbidity of any other culture of the same organism and work out bacterial numbers.

2 1:10, 1:100, 1:1000, 1:10 000, 1:100 000

3 Tube 4: $28.0 \times 10\,000 = 280\,000$ or 2.8×10^5

Tube 5: $3.0 \times 100\,000 = 300\,000$ or 3.0×10^5

4 Mean cell count in original sample $= (2.63 \times 10^5 + 2.8 \times 10^5 + 3.0 \times 10^5)/3$

$= 8.43 \times 10^5/3$

$= 2.81 \times 10^5$ per cm^3

6A.6 Invading the body

1 The answers should include some or all of the following. Other points may be valid. Suitable table along with comments such as:

Vectors: tough skin, blood clotting fomites: natural skin flora and sebum

Direct contact: skin, natural flora, sebum, saliva

Inhalation: mucus, lysozymes, phagocytes ingestion: saliva, mucus, stomach acid

Inoculation: clotting

2 Lysozymes are enzymes that can destroy bacterial cell walls. Lysozymes are present in the mucus that lines the respiratory system, the gut, the urinary and reproductive tracts. They act to destroy bacteria, and are particularly effective against Gram-positive bacteria. They are also present in tears and destroy bacteria that enter and might infect the eyes.

3 Physical barriers:

Skin is a tough waterproof outer layer impregnated with keratin that prevents pathogens from gaining entry to the moist, blood-rich tissues where they could invade cells and easily grow to cause disease.

Mucus forms a sticky layer which acts as a physical barrier to the entry of pathogens. It traps pathogens and prevents them reaching the moist tissues below in the respiratory tract and gut, for example.

Chemical barriers:

Sebum is a layer of oil on top of the skin that contains chemicals which inhibit the growth of pathogenic bacteria but which support the growth of the natural healthy skin bacteria.

Acid in the stomach has a low pH and acts as a barrier to most pathogens which are destroyed if they are ingested.

4 Endotoxins are part of the structure of the bacterial cell walls so they cause a response in the area of the body around the bacteria – hence it is often local to the site of infection. Exotoxins are usually soluble proteins produced and released by bacteria into the body fluids and bloodstream, so they are carried around the body and often have effects far away from the original site of infection.

6A.7 Case studies of disease: tuberculosis

1 It is transmitted from one person to another by droplet infection.

It can affect a wide variety of tissues, but particularly infects the lungs which means it is easily coughed out and spread.

It has evolved a protective wax outer covering. This allows bacteria with the random mutation which provides the thickest outer coat to remain dormant or grow very slowly for years until the host is in a low physical condition resulting in reduced immune response, at which point the bacteria can take hold and become active. Those bacteria best fitted for survival in these conditions are the ones which will be passed on.

Attacks the immune system of the host and so reduces the defences against it.

It has evolved resistance to many of the most commonly used antibiotics, which means it is more successful at surviving and spreading easily.

2 Primary infection: often symptomless but causes an inflammatory response from the immune system. The immune response forms a mass of tissue called a tubercule with dead bacteria and macrophages trapped in the centre where conditions are completely anaerobic. After about eight weeks the immune system controls the mycobacteria, the inflammation dies down and the lung tissue heals.

Active tuberculosis: the bacteria multiply rapidly and destroy the lung tissue. Symptoms include fever, night sweats, loss of appetite, loss of weight, feeling tired and listless. As the infection invades the lungs, it causes a cough. As the cough gets worse, the tissue of the lungs becomes damaged and blood may be coughed up in the sputum. The structure of the lungs is steadily destroyed, with the alveoli breaking down to produce large, inefficient air spaces. The T cells of the immune system are affected so antibody production is reduced. Eventually TB causes death, either because the individual cannot get enough oxygen from the air through their damaged lungs, their organs fail through lack of nutrition, or through opportunistic infections such as pneumonia.

3 The answers should include some or all of the following. Other points may be valid.

Poverty: malnutrition therefore suppressed immune systems making infection easier.

Crowded living and working conditions: ease of infection.

High rates of illness from malaria, waterborne diseases, etc., so immune system is under pressure.

High rates of HIV/AIDS so the immune system is inactivated, making opportunistic infection easier.

Poor infrastructure and limited medical resources, so lack of vaccination programmes, lack of accurate diagnosis and lack of drugs to treat symptoms effectively for the time required.

Cattle infected with bovine TB and milk not pasteurised.

6A.8 Case studies of disease: HIV/AIDS

1 Initially after infection people may have fevers, headaches, tiredness, and swollen glands but may have no symptoms. About 3–12 weeks after infection, HIV antibodies appear in the blood so person is HIV positive. Once the infection is established, all symptoms disappear and this stage may last many years (in fit young people with access to effective anti-AIDS drugs), or months to years (people with little food or medicine).

During this stage, the virus replicates, infecting the CD4 T helper cells but is kept in check by the T killer cells. This is the stage when other people may become infected through high-risk behaviour. Eventually secondary infections develop as the immune system begins to be overwhelmed and symptomatic disease returns. The viral load becomes so large that the immune system can no longer cope. The normal T helper cell count falls from 500 per mm^3 of blood to about 200 per mm^3, and symptoms develop including weight loss, fatigue, diarrhoea, night sweats and low-grade infections such as thrush. This rapidly progresses to the final stage.

As the T helper cell numbers fall, severe symptoms begin to appear such as major weight loss, dementia as brain cells become infected, cancers (e.g. Kaposi's sarcoma) and serious infections such as TB and cryptococcal meningitis. These serious diseases, along with opportunistic infection such as pneumonia, lead to death.

2 The answers should include some or all of the following. Other points may be valid.

TB: Bacterial; infects a wide range of cells, including lungs, lymph and bone, as well as macrophages of the immune system; often remains dormant for months to years within the lungs but can cause immediate infection; causes a particular set of symptoms and can kill because of damage to lungs or malnutrition, but also leaves body open to opportunistic infections as damages the immune system; can be treated effectively and cured by antibiotics; can be prevented by vaccination.

HIV/AIDS: Viral; infects the T helper cells of the immune system; after initial infection period remains dormant within the immune system for months to many years; causes a particular set of symptoms but the main impact is on the immune system; leaves host vulnerable to a wide range of opportunistic infections which usually result in death; the course of disease can be slowed but not prevented by medication; no cure; no effective vaccine.

3 Main mechanisms: the thick coat of *M. tuberculosis* enables them to survive inside macrophages for many years in a dormant or slow-growing state. This is the result of evolution, as those with the thickest coats survive and will be able to infect other hosts and so are the most successful pathogens. Multidrug-resistant strains are also the result of evolution.

HIV: rapid mutations (and therefore evolution) mean changes in antigens which makes it very difficult for the immune system to attack the virus. The targeting cells of the immune system reduce the effectiveness of the host in fighting the virus. Rapidly evolving antigens makes vaccine production very difficult.

Some people have genes which make them resistant to HIV. In countries where the disease is rife those genes will become dominant in a population as individuals with them survive to reproduce.

6A Exam practice

1 (a) B

(b) (i) D

(ii) A sample of bacterial culture is placed on the slide / apparatus.

Use a light microscope to view apparatus.

Count cells in each square.

Count cells touching top and right lines not cells touching bottom and left.

(c) (i) To show which cells are alive.

Dead cells are stained.

(ii) 16

(iii) To calculate a mean value.

To ensure the results are repeatable.

2 (a) Through unprotected sexual intercourse.

Through using infected/contaminated blood products.

Through sharing needles during e.g. drug abuse.

(b) (i) In all areas, the percentage of people with new infections has risen from 1980 to 2000.

In Eastern Europe and sub-Saharan Africa, it has continued to rise until 2010.

The greatest rise is in sub-Saharan Africa.

From 0.0% in 1980 to 15.2% in 2010.

In Western Europe the percentage of new infections fell between 2000 and 2010.

(ii) Western Europe is more developed.

Better primary health care.

Better education to teach people about HIV/AIDS.

Drugs more available to treat infections and reduce transmission.

(c) HIV is a virus.

Viruses do not respond to antibiotics.

HIV cannot be treated with antibiotics.

Secondary infections may be bacterial or fungal, which can be treated with antibiotics.

3 (a) The original suspensions of the bacteria should have contained the same number of cells per mm^3.

If one was denser than the other then the number of colonies counted would have been higher, giving a false impression of the effect of pH on cell viability.

Full aseptic technique should be used to avoid infection.

Infection with another microorganism may have altered the growth of the bacterium investigated, reducing the number of colonies counted or the unwanted cells may have grown into colonies and been mistaken for the bacterium investigated so increasing the number of colonies counted.

(b) (i) D

(ii) *E. coli* does not grow well in acid conditions / low pH.

As pH increases growth of *E.coli* increases until it becomes alkaline pH 8.

pH 6 reduces growth *of E.coli* more than alkaline pH 8.

As pH rises, growth of *L. bulgaricus* is reduced.

Neither bacterium grows in alkaline pH 9.

(iii) Bacteria require enzymes for growth.

Enzymes are deactivated / denatured at extremes of pH.

Different species may have enzymes adapted to different pH conditions.

4 (a) (i) As pH falls, the number of cells increases.

At higher pH between pH 6.5–5.0 growth is most rapid.

Growth stops when pH falls to approx. 4.25.

(ii) $n = (8 - 7) / 0.301 = 3.322$

(b) (i) Any three from:

Between 1985 and 1995 the numbers of cases are fairly similar.

Between 100 and 200 cases a year.

Staphylococcus shows a slow decline in cases between 1985 and 1998.

Salmonella remained fairly constant before 1985 and again between 1989 and 1995.

Salmonella had rapid increases between 1988 and 1989 and again after 1995.

(ii) Endotoxins are part of the cell wall but exotoxins are molecules produced and released by the pathogen.

Endotoxins are lipopolysaccharides and exotoxins are usually proteins.

5 (a) A

(b) C

(c) (i) Transmitted in airborne droplets.

The pathogen enters the lungs as we inhale.

It attacks cells to form tubercules.

(d) (i) Decreased.

From about 900 to 300 cases a year / to one-third.

(ii) Immigration from areas where it is still common.

Overcrowded housing where many immigrants are living in very close proximity.

6B Immunity

6B Checkpoint

6B.1 Non-specific responses to infection

1 Lysozymes are enzymes which can destroy bacterial cell walls. Lysozymes are present in the mucus that lines the respiratory system, the gut, and the urinary and reproductive tracts, and they act to destroy bacteria – they are particularly effective against Gram-positive bacteria. Lysozymes are also present in tears and they destroy bacteria which might enter and infect the eyes.

2 Mast cells and damaged white blood cells release chemicals known as histamines which cause the blood vessels in the area, particularly the arterioles, to dilate causing local heat and redness.

Heat reduces the efficiency of reproduction of pathogens.

Histamines also make the walls of the capillaries leaky so fluid, including plasma, white blood cells and antibodies, is forced out of the capillaries causing swelling (oedema) and often pain.

White blood cells engulf pathogens by phagocytosis, antibodies inactivate pathogens, pain makes you take care of injured site.

3 Because they simply react to non-self – the response is not specific to a particular pathogen.

4 (a) A raised temperature can help the body combat infection by lowering the reproduction rate of the pathogens, and the immune system works better at higher temperatures and so will be more successful at combating the infection.

(b) If body temperature rises above 40 °C the denaturation of some enzymes may occur causing permanent tissue damage. If the temperature is not lowered fairly quickly, death may result.

6B.2 The specific response to infection

1 Please refer to **fig E** on page 128 of the Student Book.

2 The immune system responds to foreign antigens on the surface of pathogens. The cells of the body have antigens which the immune system recognises as ‘self’ and so does not attack them.

3 An antibody is a special glycoprotein known as an immunoglobulin, released into the circulation by B cells. The antibody binds to a specific antigen on the pathogen that has triggered the immune system, so it is destroyed in one of several ways. The plasma cells that make antibodies only last a few days, but can produce up to 2000 antibody molecules per second while they are alive. Antibodies remain in the blood for varying lengths of time and the memory cells may stay in the blood for years or even life. Antibodies work in several ways to greatly reduce the ability of most pathogens to bind to their host cells:

- When antibodies bind to the antigens on pathogens, the microorganisms agglutinate or clump together, preventing them spreading through the body and making it easier for them to be engulfed by phagocytes.
- The antibody acts as an opsonin, a chemical which makes an antigen or pathogen more easily recognisable by phagocytes.
- Antibodies neutralise the effects of bacterial toxins by binding to them.

4 B cells have receptor proteins which recognise the antigens on the surface of invading pathogens. They give rise to clones of cells which produce antibodies to a specific pathogen.

T cells come in two types. T helper cells produce chemicals which stimulate the production of antibodies. T killer cells produce chemicals which destroy pathogens.

5 The primary immune response involves the production of antibodies by the plasma cells produced from the B effector cells, stimulated by the T helper cells, and it is extremely effective. It takes days or even weeks for the primary immune response to become fully active against a particular pathogen. Disease symptoms develop so we are ill when pathogens are reproducing freely inside our bodies before the immune system can deal with it. The secondary immune response is much faster. When the B-cell antigen-presenting cell divides, it also produces B memory cells that are very long-lived. They enable the body to respond very rapidly to a second invasion by the same antigen. When you have had a disease once, you usually do not catch it again because when you do encounter it, the B memory cells help you produce the antibodies against it so rapidly that it is destroyed before the symptoms of the disease develop.

6B.3 Developing immunity

1 NAI: Infected by pathogen which may reproduce and cause symptoms of disease. Immune system is activated, immune cascade initiated, B cells, antibodies and T cells produced which destroy pathogen. Immunological memory ensures that if pathogen is met again, the immune system is activated before disease results.

NPI: Antibodies against various diseases passed from mother to baby through placenta or in breast milk.

API: Antibodies produced in one individual or animal are given to another individual if they have come into contact with a particularly dangerous pathogen, for example, tetanus.

AAI: Expose immune system to attenuated pathogen (dead, inactivated toxin, attenuated live organism, protein coat fragment or DNA fragment). Stimulates immune response and immunological memory ensures that if live pathogen is encountered, B cells, T cells and antibodies would deal with it before it can cause symptoms of disease. For example, vaccination against polio, whooping cough, etc.

2 Herd immunity occurs when enough of a population is vaccinated against a disease for it to be eradicated, eliminated or simply controlled. When this proportion is reached it makes it very difficult for the disease to spread because so few people are vulnerable to it. Herd immunity is important because it can effectively stop the spread of a disease through a community. As many people as possible must be vaccinated to protect both individuals against the disease, and people who cannot be or have not been vaccinated including very young babies, very old people, people with compromised immune systems and people who are very ill with other diseases. The percentage of the population that needs to be vaccinated to give herd immunity varies from one disease to another, depending on factors such as how the disease is spread and how infectious it is.

3 (a) Not immune to that disease, therefore if they meet the pathogen, in home country or abroad, likely to become ill and may be permanently damaged or die.

(b) If child not vaccinated may carry infection or become ill and put other unvaccinated children, for example, those allergic to eggs or with compromised immune systems – at risk of disease.

Any other valid points.

6B.4 Antibiotics: treating bacterial disease

1 53% deaths from infection in 1900, 3% deaths in 2010.

So percentage reduction is 50/53 × 100 = 94.3%

Alternative method 100 − (3/53 × 100) = 94.3%

2 (a) Any two suggestions from: interrupt metabolic pathways, inhibit protein synthesis, prevent cross-linking in cell walls, damage the cell membrane, stop bacterial DNA from coiling so that it does not fit in the bacterium – any other suitable suggestions.

(b) Bactericidal – kill bacteria. Bacteriostatic – stop bacteria from growing/reproducing.

3 **Fleming:** In 1928, Alexander Fleming was growing *Staphylococci* bacteria to study. He was rather careless, often leaving the lids off his cultures and after one holiday, he noticed lots of his culture plates had mould growing on them. He observed a clear ring in the jelly around some of the spots of mould and realised something had killed the bacteria. Fleming called the substance that killed bacteria 'penicillin' after the *Penicillium* mould that produced it. He tried unsuccessfully for several years to extract an active juice from the mould that could be used to kill bacteria in medicine before giving up and moving on to other work.

Chain and Florey: Ernst Chain and Howard Florey set about trying to extract penicillin. They worked with other people, including **Norman Heatley**, and they succeeded in extracting enough to try it out on infected mice. Next, they gave penicillin to a man dying of a blood infection and he made an amazing recovery until the penicillin ran out. Even though their patient died, Florey and Chain showed penicillin could cure bacterial infections in people. Then they succeeded in completely curing a 15-year old boy of a post-operative infection.

Penicillin had the potential to save thousands of lives in the 1939–45 war in Europe but scientists couldn't make enough. Eventually, Howard Florey used contacts in the US and, working with Pfizer, Florey and Chain made penicillin on an industrial scale, producing enough to supply the demands of the Second World War. It is still used today.

Ronald Hare trained a as doctor and became involved in medical research. It was Hare as Professor Fleming's assistant who made an extraordinary discovery. Although Alexander Fleming discovered penicillin in 1928, he didn't know why it worked. It was Hare who was able to point out that the penicillin had worked only because of an unusual change of temperature at that time of year. Referring to the London Meteorological Records for that fortnight in July 1929, Ronald Hare discovered that there had been a nine-day period of unusual cooler temperatures. This favoured the growth of the *Penicillium* mould. *Penicillium* grows at 25 °C, staphylococcus at 35 °C.

Cecil George Paine qualified at St Mary's in 1928 and was a student of bacteriology under Alexander Fleming. He moved to Sheffield as a junior pathologist in 1929. Paine had known about the penicillin work at St Mary's and obtained some cultures of penicillin from Fleming and kept these growing in meat broth in his laboratory. In 1930, Paine successfully treated babies at the Sheffield Royal Infirmary with penicillin for eye infections and a coal miner whose corneal laceration was infected with the then dreaded pneumococcus.

In 1943, **Mary Hunt** found a golden mould growing on an American Cantaloupe (*Penicillium chrysogenum*). A number of experiments took place and researchers discovered that if Mary's mould was exposed to X-rays, a mutant *Penicillium* strain was produced that dramatically increased the quantity of antibiotic compound. These successes had a significant impact which meant that by 1945 more than 1 million people had been treated with the drug as opposed to less than 1000 in early 1943.

6B.5 Antibiotic resistance

1 Mutation causes a key change, such as changes to a process that affects the way the antibiotic works or the structure of the wall.

Antibiotic is a selection factor by killing all bacteria that are sensitive to it.

Therefore, rapid evolution of the resistant type is the most common form.

Include reference to bacterial transformation, etc.

2 (a) Keep antibiotic prescription to a minimum, ensure that patients complete the course, be especially careful with the use of broad-spectrum antibiotics in the case of *C. difficile*, etc. – any points relating to current guidelines, which will change from country to country and from year to year.

(b) Minimise exposure of bacteria to antibiotics – reduce likelihood of resistant mutation being selected for. Make sure whole course used so that bacteria with only slightly increased resistance are definitely killed/inactivated. Use appropriate antibiotic to ensure bacteria are killed, etc.

3 (a) Broad spectrum antibiotics wipe out large numbers of the normal gut flora so *C. difficile* can get established, produce toxins and cause disease symptoms.

(b) Narrow spectrum antibiotics targeted at the organisms that are causing a specific infection are less likely to have an impact on gut flora and so minimise opportunities for *C. difficile* to become established.

(c) The number of new antibiotics available is falling steadily. This means that as HAIs develop, there is a reducing pool of antibiotics available to which the bacteria are not already resistant. This means that HAIs may rapidly become untreatable.

4 Understanding the causes and methods of spread of HAIs means doctors, nurses and other healthcare professionals can implement codes of practice that will reduce the spread of these conditions. Examples of good practice include:

- Doctors, nurses and other healthcare professionals washing their hands or using alcohol-based gels between patients: this gets rid of bacteria on the skin and so reduces the chances of passing them on. Spores of *C. difficile* are not destroyed by the alcohol gels so these are of limited use in outbreaks of *C. difficile* infection.
- Clothing, etc., which might carry bacteria from patient to patient to be avoided, for example, long ties, wrist watches and long-sleeved shirts – the cuffs can carry bacteria.
- Health professionals wear sterilised scrubs all of the time to avoid bringing in pathogens from the outside (no evidence it makes any difference).
- Monitoring patients for infection when admitting, and treating and nursing in isolation: avoids spread of pathogens.
- Encourage visitors to wash hands/use alcohol gels to minimise risk of bringing infection into hospital or taking one out.
- Thorough cleaning of hospital wards, toilets, bed pans, etc., is another way of preventing and controlling the spread of disease by removing bacteria, faecal traces, etc.
- Using chlorine-based disinfectant to be sure *C. difficile* is destroyed.

Any other valid points.

6B Exam practice

1 (a) C

(b) D

(c) (i) DNA

(ii) D

(iii) 14001 / 10000 = 1.4

(d) On the first infection the host immune system makes antibodies and memory cells against the virus antigens.

If the same antigens are detected a secondary response is rapid and prevents symptoms developing.

A mutation will alter the shape of the antigen.

The host memory cells will no longer recognise the antigen.

(e) Ciliated cells move mucus up the respiratory tract.

Infected cells die and the mucus stops moving.

Bacteria are caught in the mucus.

Bacteria experience ideal conditions and reproduce quickly.

2 (a) (i) C is bactericidal, the number of bacteria falls to zero.

(ii) B is bacteriostatic, the number of bacteria stays constant.

(b) The bacterium is resistant to antibiotic A.

A is a bacteriostatic antibiotic which disrupts cell metabolism.

A mutation in the DNA of the bacterium prevents the action of the antibiotic.

(c) Produce a number of nutrient agar plates.

Spread a lawn of bacteria over each plate.

Place discs soaked in different antibiotics on each plate.

Incubate at 20 °C for two days.

Use sterile technique throughout.

3 (a) Pathogens evolve new ways to infect hosts.

Hosts evolve new ways to protect themselves from the pathogens.

(b) Bacterial DNA mutates.

Provides slight resistance to antibiotic.

Overuse of antibiotic / not finishing antibiotic course, selects the resistant bacteria.

Surviving bacteria reproduce and resistance increases over several generations.

(c) Reduced prescription of antibiotics.

Hand washing / disinfection.

General cleaning in hospitals – particularly door handles, surfaces and other things that many people touch.

4 (a)

Immunity	**Active**	**Passive**
Natural	Q	P
Artificial	R	S

(b) D

(c) (i) It is a complex process.
B cells, T cells and antigens must be present.
(ii) B cells are needed as these produce the plasma cells that make antibodies.
T cells are needed as these stimulate the B cells.
(iii) Glucose, as a source of energy.
Amino acids, to use in protein synthesis.

5 (a) B

(b) Coughing up blood, general weakness.

(c) (i) Fewer / less than half as many, T helper cells and macrophages.
Slightly fewer T killer cells.
(ii) T killer cells attack host cells infected by viruses.
Release enzymes that make pores form in the membrane of the infected cells.
Tuberculosis is not caused by a virus so no T killer cells are needed.
(iii) Fewer T helper cells to activate the B cells.
Fewer macrophages to become antigen presenting cells.
B cells not activated so, no / fewer, antibodies to attack the bacteria.

(d) The inhibitors, stop TNF activity / reduce immunity to tuberculosis.
Bacteria become more active / symptoms of tuberculosis develop.

6 (a) The immune system is activated.
To make its own antibodies.

(b) Memory cells are made.
These remain in the blood for many years.

6C Decomposition and forensics

6C Checkpoint

6C.1 Microorganisms and decomposition

1 Plants constantly remove carbon dioxide from the air, and water and mineral ions from the soil, for photosynthesis and the synthesis of other materials. Plants are constantly eaten by animals. If there was no recycling of the nutrients, the resources of the Earth would have all been used up a long time ago.

2. Decomposers break down carbohydrates, lipids and parts of protein molecules in cellular respiration to form carbon dioxide and water.

Carbon dioxide used in photosynthesis to synthesise new material or excreted into atmosphere.

Photosynthetic bacteria remove carbon dioxide from the atmosphere and turn it into sugars.

3. Diagram showing microorganisms involved at the following stages: dead organic matter → carbon compounds in decomposers, carbon compounds in decomposers → CO_2 in air or water.

6C.2 Forensic science and the time of death

1 (a) The heat of the body is produced as a result of the metabolic reactions taking place, particularly respiration in active tissues such as the muscles and the brain. After death these reactions slow down and stop, so no more heat energy is produced. At the same time heat energy is lost by radiation and conduction from the skin and latent heat of evaporation so the body cools down.

(b) The metabolic reactions do not all stop immediately after death – many cells continue to respire, contract, and so on, until all the available oxygen and ATP is used up. So, heat continues to be generated in the first hours after death, although at a slower rate, so body temperature drops but relatively slowly.

(c) The temperature gradient between the body and the environment will affect rate of cooling, for example if someone dies inside a warm house the body will cool down more slowly than if it is on a cold windy hillside, so the external temperature and weather conditions have to be taken into consideration.

A naked body will cool much faster by convection than a clothed body, and a body wrapped in blankets or a duvet will cool down even more slowly due to insulation.

A wet body will cool faster than a dry body as a result of heat lost as the water evaporates, and death in a warm bath or beside some form of heating will also change the rate of cooling.

Even the body position affects the rate of cooling- a stretched out body has a much bigger exposed surface area to volume ratio than a curled up one and so will cool down faster.

All of these different factors have to be taken into consideration when using temperature as a guide to the time of death.

2 Limited value because, although there is a generalised pattern of rigor, there are large variations from one individual to another depending on factors such as:

- amount of ATP stored in the muscles at the time of death which depends on genetic tendency and levels of fitness
- level of activity before death – how much ATP has been used, temperature of the individual at the point of death, temperature of the surroundings
- speed at which rigor passes also depends on a variety of factors such as external temperature, activity of enzymes.

Other examples may be valid.

6C.3 The process of decay

1 The first stage is caused by the colonisers – anaerobic bacteria. Enzymes from lysosomes break down cells releasing cell contents on which anaerobic bacteria grow. As more cells are broken down, the bacteria spread. →

The bacteria are followed by a number of species of flies, e.g. blowflies, which lay eggs. The larvae (maggots) feed on the tissues, breaking them down further.

As the body liquefies, adult flies can feed on it too. →

Beetles arrive whose larvae feed on maggots. Parasitic wasps lay their eggs in the larvae. →

As the body is eaten away, it dries out and different species such as the cheese flies and coffin flies move in. →

When the remains of the body are too dry to support fly larvae any more, beetle species with strong chewing mouthparts move in, e.g. carcass beetles, ham beetles and hide beetles. →

At the end, mites and moth larvae feed on the hair until only dry bones are left.

2 The obvious choice of factors are temperature and level of exposure of body (buried or not, inside or outside), but any other valid factor could be chosen e.g. clothed/unclothed.

Clear scientific explanations should be given of the effect on decomposition. For example, temperature affects the rate of chemical/enzymic reactions – higher temperature increases rate and lower temperature slows them down. Or, the level of exposure will affect the availability of the body to insect decomposers, etc.

3 Succession follows a regular pattern so, by examining the stage of succession in a body, along with data on the conditions where the body has been found, forensic scientists can build up a fairly precise picture of how long the body has been dead.

4 (a) Exposed body: peaks and troughs roughly follow ambient temperature but body temperature gets higher than the air. This is because of the metabolic heat released by the bacteria and other organisms living on the body. When the temperature is higher, reaction rates increase and so more heat is released and the body temperature increases further.

Underground: the temperature shows less variation as the body is insulated from changes in air temperature. Fluctuations in temperature are due to variations in the activity of the decomposing organisms.

(b) Advantages: far fewer ethical issues, easy availability of animal carcasses, fewer problems with obtaining burial sites. Any other valid points.

Disadvantages: animals are not people, so there may be differences in colonising organisms, differences in skin thickness, fat layers etc. So data obtained will be only an approximation of human situation. Any other relevant points.

6C.4 Polymerase chain reaction (PCR)

1 Polymerase chain reaction uses the normal replication of DNA, using the enzyme DNA polymerase. By mixing all the ingredients together at the beginning and then changing the temperature of the mixture in the PCR machine, a tiny amount of DNA can be amplified to produce millions of identical molecules very quickly and efficiently.

The reactants – the DNA sample which is to be amplified, DNA polymerase, primers (small sequences of DNA which must join to the beginning of the separated DNA strands before copying can begin) and a good supply of the four nucleotide bases – are mixed together in a PCR vial and placed in a PCR machine.

The reaction mixture is first heated to 90–95 °C for about 30 seconds, which causes the DNA strands to separate as the hydrogen bonds holding them together break down.

The mixture is then cooled down to 55–60 °C when the primers bind (or anneal) to the single DNA strands.

Finally, the mixture is heated up again to 75 °C for at least a minute. This is the optimum temperature for the DNA polymerase enzyme which builds up complementary strands of DNA identical to the original molecule.

These three basic steps are repeated around 30 times to give around 1 billion copies of the original DNA.

2 To separate the DNA strands requires temperatures of around 90 °C, which denatures the DNA polymerase of most organisms. Any replication process requires repeated changes of temperature and high temperatures so could not be automated as the enzymes were denatured in each heating cycle. The enzymes of bacteria found in hot springs are not denatured by heat as the bacteria live at high temperatures. By using DNA polymerase from hot spring bacteria, the process of DNA polymerisation could be automated and repeated many times because the enzymes remained active throughout the constant temperature changes and high temperature. This made it possible to amplify small DNA samples.

3 PCR enables scientists to amplify tiny specimens of DNA to produce enough to carry out DNA profiling. This is very important in forensic investigations as often only minuscule traces of DNA are left at crime scenes or left in cold investigations. By using PCR the DNA can be amplified to give enough to develop a profile that can be used to prove an individual guilty or innocent.

6C.5 DNA profiling

1 DNA profiling is the production of an analysis of the DNA of an individual based on mini- or micro-satellite groupings from a limited number of introns, which can be compared with similar profiles from other individuals.

2 To produce a DNA profile, the strands of DNA from a sample are chopped up into fragments using restriction endonucleases which cut the DNA at particular points in the intron sequences. Different restriction enzymes cut DNA molecules into fragments at specific base sequences known as recognition sites, which are found at either side of mini- and micro-satellite units, leaving repeated sequences intact.

The different length fragments are separated by gel electrophoresis, by their mass and overall charge. The DNA fragments are placed in wells in an agarose gel medium in a buffering solution (to maintain a constant pH). The gel contains a dye which binds to the DNA fragments in the gel. The dye will fluoresce when placed under UV light, which makes the DNA bands visible when the electrophoresis is complete. The most commonly used dye is EtBr (ethidium bromide).

A different dye is also added to the DNA samples to show the position of the samples as they move through the gel.

An electric current is passed through the apparatus and the DNA fragments move through the medium at different rates depending on their mass and charge. They all move towards the positive anode, because of the negative charge on the phosphate groups. Known DNA fragments are usually placed in a control well.

Once the electrophoresis is complete the plate is placed under UV light – the DNA fragments fluoresce and show up clearly so they can be identified. This is the original method of DNA fingerprinting, which needs a relatively large sample of DNA. It shows up large DNA fragments containing a minimum of 50 base pairs – in other words, mini-satellites. The resultant DNA profile (fingerprint) looks very like a supermarket bar code. However, smaller regions of DNA (micro-satellites) and specific genes can now be identified using extensions of this technique.

3 (a) Traces of biological material are used as sources of DNA which is amplified using PCR and then used to produce a profile. Because the chances of two individuals having the same DNA profile are incredibly low, if the DNA profile of a suspect matches DNA from the crime scene this is taken as strong evidence of their involvement in some way.

(b) Only identical twins have identical DNA profiles, but family members show many more similarities than non-related people. So if the DNA at a crime is checked, if DNA from another family member is on the database, siblings and/or parents and children could come up as identical depending on the number of introns used in the profile. The more intron regions that are used in a profile, the less likely it is that family members will appear as the same person. If there is confusion, more introns are analysed and differences will appear. However, close family matches can be helpful as they can lead police to the right suspect, even if their DNA is not on the database, through family links.

4 There are a number of small areas of DNA – genes or clusters of genes – which are common to many different species of animals or plants. The DNA sequence is slightly different in each species – the more closely related a species is, the more similar the DNA sequence. Profiling short genetic sequences from a part of the genome common to particular groups of organisms e.g. in animals a region of the mitochondrial cytochrome oxidase 1 gene (CO1), containing 648 bases, allows us to identify them quickly and accurately. In plants, two gene regions in chloroplasts that have been approved for use to produce a standard barcode for plants, to be used in the same way as the animal barcodes. It is important that every specimen used to produce the definitive barcodes is preserved for reference. DNA profiling like this can be used both to identify species and to show the links between them – the more different the sequence the more distant the relationship between the organisms.

6C Exam practice

1 (a) C

(b) B

(c) (i) Increase the amount of DNA.

Creating identical copies.

(ii) $1 \times 2^{15} = 32\ 768$

(iii) Not enough nucleotides added at start.

Primers do not anneal properly.

Strands do not separate fully.

2 (a) (i) C

(ii) B

(b) S3

All the bars for S3 match the bars from the window.

No other suspect matches all the bars.

(c) Identical twins will have same DNA.

Closely related people have similar DNA.

A large number / at least 11, micro-satellite sites should be compared.

(d) Classification based on visible differences may not be accurate.

Relationships between closely related species can be checked by comparing the DNA.

More closely related species have more similar DNA.

3 (a) C

(b) (i) A suspension of the fragments is placed into a well on the gel plate. A potential gradient is applied along the gel plate. The DNA fragments move towards the positive electrode. The smaller normal allele will travel faster and will move further than the larger sickle cell allele.

(ii) To remove, proteins bound to the DNA / histones.

So that the proteins do not interfere with the movement of the DNA fragments.

(c) (i) A length of single stranded DNA with a specific nucleotide sequence.

The probe will attach to the complementary sequence in a gene.

The probe has a label attached so that it can be detected.

(ii) After the DNA fragments are separated, they must be identified.

A probe is necessary because the DNA is not visible.

The gene probe will have a specific nucleotide sequence that is complementary to a specific sequence on the allele for muscular dystrophy.

A solution of probes will be added to the profile.

The probes will identify the presence of the mutant gene.

4 (a) At 95 °C the double helix is split by breaking the hydrogen bonds holding the two strands together.

55 °C allows the primers to bind to the single stranded DNA.

72 °C is the optimum temperature for the activity of the taq polymerase which creates the new DNA molecules.

(b) After splitting, the DNA is single stranded. DNA polymerase cannot bind to single stranded DNA. So the primers are short sequences of complementary DNA that bind to produce double stranded DNA to act as a binding site for the DNA polymerase.

(c) Place the wells at the cathode.

DNA is negatively charged and will move towards the anode.

OR

Run the plate for longer than two minutes.

This will cause greater separation of the fragments.

OR

Add a dye / probe.

Allows the DNA banding pattern to be seen.

5 (a) Conditions the body is left in.

Surface area to volume ratio of the body.

Body mass

(b) Blow fly live on dead/decomposing organic matter.

They arrive on dead body and lay eggs.

The life cycle of the blow fly can be used to determine how long the body has been dead.

Putting larvae on the body will make the police think that the body has been dead longer.

(c) The presence of blow fly is just one way to age the body.

Other evidence such as, body temperature / other insects / level of decay, is also used.

7A Cellular respiration

7A Checkpoint

7A.1 Respiration in cells

1 It supplies energy in the form of ATP for all cellular reactions, and substrates for other metabolic pathways including amino acids and fatty acids.

2 Strengths: succinct summary, sums up the necessary reactants, the desired product and the waste products, shows the proportions of the reaction chemicals, etc.

Limitations: shows it as a single reaction, whereas it is actually a complex series of reactions; not balanced as ATP suddenly appears on right-hand side of the reaction; does not show where in the process ATP is made; no indication of enzymes involved; no indication that alternative substrates can be used; no mention of hydrogen acceptors, coenzymes, etc.; any other valid points.

3 (a) Respirometers look at carbon dioxide output and use that to calculate oxygen uptake during respiration. Respirometers look at the whole organism – this gives an overall picture, but no detail of what is happening in individual cells, whether carbon dioxide comes from aerobic or anaerobic respiration. Any other valid point.

(b) Respirometer on the right – more sophisticated, capillary tubing so changes seen more easily, scale so movements of fluid can be measured accurately and there is consistency between readings, use of KOH in both tubes, three-way tap giving more control. Any other sensible points.

4 Evidence to associate the substrate molecules or enzymes needed for particular stage of respiration with the membranes or contents of a particular area of a mitochondrion. Blocking/poisoning one mechanism and observing a build-up of product in a particular area of the mitochondrion, etc., electron micrograph evidence of structures shown to be associated with stages of process. Any other valid points.

7A.2 Glycolysis and anaerobic respiration

1 Diagram similar to **fig A** on page 167 with annotations, such as the following:

- Glucose, 6C sugar, is starting point.
- ATP used to phosphorylate glucose – 2 phosphate groups added to give phosphorylated 6C sugar, one reaction controlled by phosphofructokinase, rate-controlling reaction for the whole process of cellular respiration.
- Phosphorylated 6C sugar splits to form 2 molecules of 3C glycerate-3-phosphate (GP).
- Each molecule of GP converted to pyruvic acid in a series of steps – for each molecule of GP, 2 hydrogen atoms removed to reduce NAD, which is passed along electron transfer/transport system to produce 3 molecules of ATP, so 6 ATPs formed in total per glucose molecule.
- The initial phosphorylation reactions are reversed before the final intermediate is converted to pyruvate and the phosphate group released is used to produce ATP from ADP.
- 2 molecules of pyruvate enter mitochondrion and go into Krebs cycle for every glucose molecule that enters glycolysis.
- If insufficient oxygen, pyruvate converted to lactate or ethanol.

2 During the process, 2 hydrogen atoms are removed from the 3C sugars and taken up by NAD to form reduced NAD, which then enters the electron carrier system producing energy that is used to phosphorylate 3 molecules of ADP. ATP made directly when the 3C sugar converted to pyruvate. Replaces the ATP used up in priming the 6C sugar, and the remainder is available as useful energy for cell metabolism, assuming the substrate moves on and aerobic respiration takes place.

3 Calculations: glycolysis −150 kJ

Aerobic respiration −2880 kJ

150/2880 × 100 = 5.2%

Mean efficiency of anaerobic respiration in the muscles compared to aerobic respiration = 5.2%.

4 During exercise muscles respire anaerobically, producing lactate, which builds up in muscles and is carried away in the blood. When exercise stops, as well as the normal demands of the body, lactate must be oxidised to pyruvate and glucose in the liver, ATP and phosphocreatine levels need to be restored, myoglobin needs to be reoxygenated, metabolic reactions go faster due to the raised temperature, using more ATP. Therefore, the oxygen demands of the body remain high for some time after the completion of the exercise. The rate of breathing continues to be raised to supply the needs of the body, and the heart rate remains high to pump extra oxygenated blood around the body and remove the excess carbon dioxide.

7A.3 The Krebs cycle

1 Glycolysis: does not need oxygen for ATP to result, linear, relatively simple, takes place in cytoplasm, etc.

Krebs: cycle needs oxygen for ATP to result, cyclical, complex, takes place in mitochondria, etc.

2 Energy cannot be produced. The Krebs cycle produces ATP. The energy stored in the bonds of ATP can be used to drive the reactions of metabolism in the cell. The Krebs cycle alone does not produce ATP – glycolysis also provides ATP for the cell, the Krebs cycle directly produces very little ATP for the cell – it produces reduced carrier molecules which then enter the electron transport chain, which in turn drives the production of ATP.

3 The answer should contain some or all of the following along with any other points from research:

Krebs used enzyme inhibitors to block particular enzymes or stages in the pathway, resulting in a build-up of the reactants of that reaction and a lack of products compared with an analysis of the normal process. This enabled Krebs and his team to work out exactly which chemicals are involved in a particular step of the process. Diagram of lollipop apparatus might be included. Used a multidisciplinary team – unusual at the time.

7A.4 The electron transport chain

1 Answer should include some or all of the following. Other points may be valid.

Diagram should show all the main stages of aerobic respiration: glycolysis, link reaction, Krebs cycle and electron transport chain, making clear where and how many ATP molecules are used and formed, where reduced NAD and reduced FAD are formed and oxidised, and where oxygen is used and carbon dioxide formed. An indication of how many ATP molecules formed for each molecule of glucose respired could be included. Clarity of information and of layout of diagram are important for full marks.

2 Oxidation of glucose is a multi-step process during which the glucose molecule is split into 3C units, built back into 6C molecules and then dismantled again. As hydrogen is removed it is used to reduce carrier molecules, which feed into the electron transport. As the components of the chain are reduced and then oxidised again sufficient energy is released to drive the production of ATP. By the end of the process glucose has been completely oxidised to carbon dioxide and water.

3 (a) Krebs cycle is longer with a more complex series of reactions; glycolysis has to expend ATP to move reduced NAD into the mitochondria to reach the electron transport chain; 1 hydrogen removed from each 3C sugar in glycolysis while 5 hydrogen atoms are passed into the electron transport chain from each 3C pyruvate molecule that enters Krebs cycle; aerobic respiration involves complete oxidation of glucose while anaerobic only partial breakdown. Any other valid points.

(b) ATP yields may not always be in whole numbers – current best estimates are that the oxidation of 2 molecules of reduced NAD supplies enough energy to make 5 molecules of ATP and oxidation of 2 molecules of reduced FAD produces about 3 molecules of ATP, giving an overall yield for aerobic respiration of around 31 molecules of ATP. But proton gradients in the mitochondria can be used to drive the active transport of several different molecules and ions through the inner membrane into the matrix, and NADH can be used as a reducing agent for many different reactions. So, depending on conditions in cell, the functional yield of ATP ranges from under 30 to 38 molecules.

4 Peter Mitchell proposed that protons are actively transported into the space between the inner and outer mitochondrial membranes, using the energy provided as the electrons pass along the transport chain. The inner mitochondrial membrane is impermeable to protons. This means that as a result of the active transport of the protons there are different hydrogen ion concentrations on the two sides of the inner membrane. The membrane space has a higher concentration of hydrogen ions than the matrix, so there is a concentration gradient across the membrane.

As a result of the different hydrogen ion concentrations there is also a pH gradient. And because positive hydrogen ions are concentrated in the membrane space there is an electrochemical gradient too. All of these factors mean that there is a tendency for the hydrogen ions to move back into the matrix. However, the membrane is generally impermeable to hydrogen ions. The only way that they can move back into the matrix is through special pores. These pores are found on the stalked particles, and the movement of the hydrogen ions along their electrical, concentration and pH gradients is linked to an ATPase enzyme. The energy from the gradients is used to drive the synthesis of ATP.

It is important because it provides a mechanism for the observed events, a mechanism which holds true and works in a wide variety of cells, and it shows exactly how the removal of hydrogen atoms from glucose molecules can result in the production of ATP.

7A.5 Respiratory substrates and respiratory quotient

1 Respiratory substrate: the type of compound which is broken down and which enters the respiratory pathway, e.g., carbohydrate, lipid.

Respiratory quotient: a method of calculating the respiratory substrate being used by comparing the amount of carbon dioxide produced in respiration with the amount of oxygen taken in.

$$\text{respiratory quotient (RQ)} = \frac{\text{carbon dioxide produced}}{\text{oxygen used}}$$

2 Different respiratory substrates enter into different stages of the respiratory pathways giving different numbers of opportunities for ATP to be produced, e.g., carbohydrates enter glycolysis at the beginning, glycerol from lipid hydrolysis enters glycolysis with 3-carbon phosphorylated sugars, amino acids at pyruvate and acetyl coA, and fatty acids when acetyl coA enters the Krebs cycle.

Fatty acids in particular can be very large molecules so many 2-carbon units enter into the Krebs cycle which means they can produce a lot of ATP.

3 Organism A is using glucose or glycogen as respiratory substrate.

Organism B is using lipids as respiratory substrate.

Organism C is using a mixture of carbohydrates and lipids as respiratory substrate (NOT using proteins as substrate).

Organism D is respiring anaerobically.

7A Exam practice

1 (a) A

(b) D

(c) (i) It is a series of reactions.
The product of one step becomes the substrate of the next step.
(ii) In the mitochondria.
In the (mitochondrial) matrix.

(d) B, C, D, F

2 (a) C

(b) Cytoplasm

(c) (i) C
(ii) A
(iii) C

(d) If no oxygen is available aerobic respiration is unable to make ATP.
Converting pyruvate to lactate uses hydrogen from reduced NAD.
This releases the NAD and enables stage 3 to continue.
Stage 3 is where some ATP is made.

3 (a) (i) D
(ii) D
(iii) B and C
(iv) A and F

(b) If no oxygen is available it is used to reduce ethanal to ethanol.
If oxygen is available it enters the mitochondrion.
It passes the hydrogen to an electron transfer chain.

4 (a) (i) Mitochondrial matrix and crista.
(ii) C

(b) (i) Respiration stopped.
Because it ran out of substrate / glucose / ADP / phosphate ions.
(ii) Antimycin A prevents electrons moving along the electron transport chain.
Oxygen is only used at the end of the electron transport chain.
(iii) ATP production will stop.
No hydrogen ions are pumped into the intermembrane space / no chemiosmosis takes place.
ATPase has no energy to phosphorylate ADP to form ATP.

7B Muscles, movement and the heart

7B Checkpoint

7B.1 Tissues of the skeletal system

1 Synovial fluid is produced by synovial membranes in joints with biggest range of movement. It acts as a lubricant between the cartilage covering the ends of the bones. Prevents wear and tear of the cartilage.

2

Skeletal tissue	Properties
Bone	Made up of bone cells embedded in a matrix of collagen and calcium salts. Strong, particularly strong under compression, hard and relatively light.
Cartilage	Made up of chondrocytes within an organic matrix containing varying amounts of collagen fibrils. Hard, flexible, elastic, able to withstand compression so a good shock absorber.
Ligaments	Made of yellow elastic tissue with varying amounts of collagen and white fibrous tissue. Strong and elastic, with the elasticity varying depending on the proportions of collagen and white fibrous tissue.
Tendons	Made up almost entirely of white fibrous tissue (bundles of collagen fibres). Strong but relatively inelastic.

3 Bones: form the framework and support; hard, strong tissue; act as levers.

Joints: where two bones meet; allow movement.

Ligaments: form capsules around the joints; hold bones in place so they can do useful work without becoming separated; also need to be elastic to allow the bones of the joint to move when necessary; yellow elastic tissue gives strength with elasticity; tightness of capsules varies with movement needed in joint.

Muscles: provide the power to move the joints; tissue can contract and relax; are attached to bones by tendons which don't stretch, so the contraction of the muscle is converted into movement; occur in antagonistic pairs as they can only pull, so one muscle moves a bone in one direction and when it relaxes, another muscle pulls the bone back to its original place.

Any other valid descriptions, diagrams etc.

7B.2 What is muscle?

1

Striated muscle	Smooth muscle	Cardiac muscle
attached to the skeleton	not attached to skeleton	not attached to skeleton
involved in locomotion	involved in moving food through gut, controlling diameter of blood vessels etc.	pumps blood out of heart around lungs and body
controlled by voluntary nervous system	controlled by involuntary nervous system	contracts spontaneously, some voluntary and involuntary control
striated appearance under microscope	no striations seen under microscope	striations with cross connections seen under microscope
contracts rapidly	contracts slowly	average around 70 contractions a minute
fatigues rapidly	fatigues slowly	does not fatigue

2 Whole muscle is made up of many muscle fibres. Different fibres might have different thresholds for response, or different levels of response, so when the whole muscle is stimulated the contraction might be more or less than expected.

7B.3 Different types of muscle fibre

1 (a) Aerobic respiration takes place in the mitochondria supplying the active muscle cells with ATP as an energy supply. Myoglobin is a protein similar to haemoglobin, with one chain rather than four, which binds oxygen and has a much higher affinity for oxygen than haemoglobin. Myoglobin readily accepts oxygen from the blood and acts as an oxygen store in the muscles.

(b) Fast twitch fibres have few mitochondria and little myoglobin: they produce a quick burst of aerobic energy then anaerobic respiration continues: they fatigue quickly. Slow twitch fibres have many mitochondria and plenty of myoglobin; tend to have a rich blood supply bringing oxygen which is taken up and stored by the myoglobin; allow plenty of aerobic respiration over time.

2 Leg muscles contain lots of slow twitch fibres, with a good blood supply and lots of myoglobin. Therefore, these muscles are a dark colour, contain lots of mitochondria and so provide sustained activity for walking around but less speed and power in initial contraction. Breast meat contains more fast twitch fibres, with relatively little myoglobin and few blood vessels. Therefore, they are a pale colour, good for short explosive bursts of activity such as a short flight.

3 The answer should include some or all of the following. Other points may be valid.

Fast twitch muscles	Slow twitch muscles
pale pink/white (little myoglobin)	deep red (lots of myoglobin)
few capillaries	lots of capillaries
little myoglobin	lots of myoglobin to store oxygen
large glycogen stores	not much stored glycogen
lots of sarcoplasmic reticulum	little sarcoplasmic reticulum
fatigue easily	doesn't fatigue easily
relatively few mitochondria	many mitochondria

7B.4 How muscles contract

1 Diagrams as in **fig B**, fully labelled to show the H zone, I bands, A band, Z lines, actin and myosin filaments.

2 Calcium ions released in response to nervous stimulation of the muscle set up contraction of the sarcomeres. Calcium ions bind to troponin changing the shape of the molecule. This changes the shape of the troponin molecules, so they pull on the tropomyosin molecules to which they are attached. This moves the tropomyosin away from the myosin binding sites on the actin molecules, exposing them, so that they can bind with the myosin heads which sets up the contraction. Calcium ions also needed for the action of the ATPase enzyme in the myosin heads, which enables the heads to return to their resting position.

3 (a) ATP binds to the myoglobin head, and the release of energy when it is hydrolysed allows the head to return to the resting position. The bonding of the ADP and inorganic phosphate results in changes in the shape of the myosin head so it can bind to the actin binding site. The release of the ADP and inorganic phosphate results in another shape change which results in the release of the myosin head from the actin binding site. ATP is also needed as the energy supply for the calcium pump which returns calcium ions to the sarcoplasmic reticulum, ending the contraction.

(b) The answer should include some or all of the following.

After death, once there is no more ATP, the myosin heads cannot return to the resting position but remain locked upright, so the muscle becomes stiff and rigid.

Other points may be valid.

7B.5 Cardiac muscle and control of the heartbeat

1 (a) The intrinsic rhythm of the heart is maintained by a wave of electrical excitation similar to a nerve impulse which spreads through special tissue in the heart muscle. It starts in the sinoatrial node (SAN) which acts as a natural pacemaker and sets up a wave of electrical excitation (depolarisation) which causes the atria to start contracting, initiating the heartbeat. The excitation spreads to another area of similar tissue called the atrioventricular node (AVN).

This introduces a slight delay before the wave of depolarisation passes into the bundle of His, a group of conducting fibres in the septum of the heart, ensuring the atria have stopped contracting before the ventricles start. The bundle of His splits into two branches and carries the wave of excitation on

into conducting fibres that penetrate down through the septum and spread around the ventricles, known as the Purkyne tissue.

As the depolarisation travels through the tissue it sets off the contraction of the ventricles, starting at the bottom and so squeezing blood out of the heart.

(b) Many other factors including hormones and nervous stimulation have an effect on the heart rate and it usually beats faster than the intrinsic rate to supply all the oxygen etc needed by the tissues of the body

2 Natural pacemaker should send impulses regularly through the conductive tissue of the heart to the ventricles to trigger them to contract and pump blood out of the heart to lungs and round the body. When the sinoatrial node (SAN) fails, the artificial pacemaker delivers an electric shock to the ventricles triggering contraction in the ventricles, which replicates the intrinsic rhythmicity of heart.

3 If the heart rhythm is out of sequence this is likely to be due to disturbance in the electrical signals. These can be picked up with an ECG which can identify potentially dangerous electrical patterns such as atrial fibrillation, ventricular fibrillation and people can learn to identify the patterns.

7B.6 Principles of homeostasis

1 Homeostasis is the maintenance of the internal conditions of the body within a narrow range in a dynamic equilibrium, through the responses of the body to internal and external stimuli.

It is important because all of the biochemical reactions that take place to maintain an organism have very specific requirements of temperature, pH, oxygen levels and required reactants. They are affected by toxins. The proteins that act as enzymes catalysing many of the cellular reactions are denatured or inactivated if the temperature or pH varies beyond a narrow range, for example. So homeostasis, the process that maintains this ideal range, is vital for life.

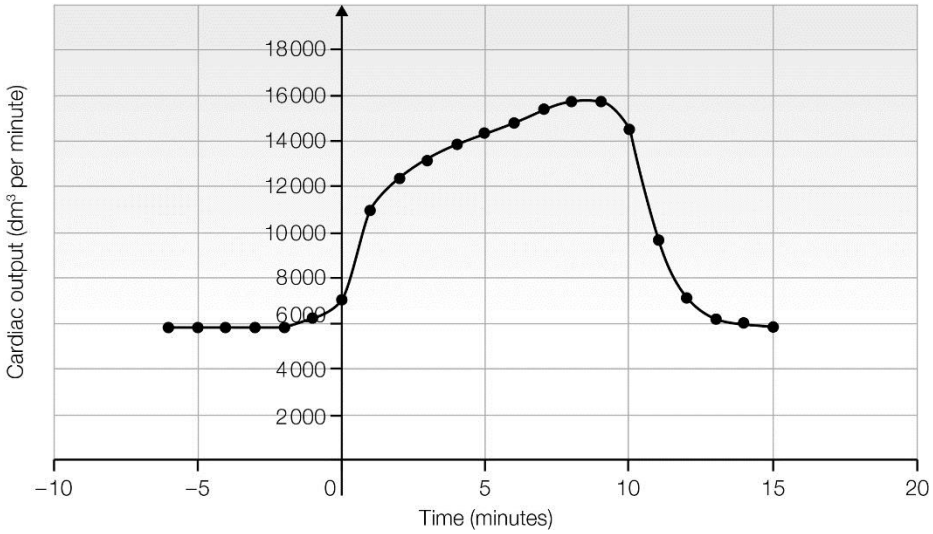
2 Conditions inside the body are not steady. They are constantly changing with everything an organism does. Homeostasis aims to ensure that conditions vary within narrow ranges and is monitored by receptors in feedback systems that make sure conditions are constantly restored to the optimum. So a dynamic equilibrium is a much more accurate representation of what is happening than a steady internal state.

3 Negative feedback systems work to maintain conditions, such as concentration or pH, within a narrow range. A change is monitored and changes put in place to restore conditions to their starting point. So negative feedback systems are ideal for maintaining homeostasis. Positive feedback systems enhance change, making the change bigger and bigger in one direction only, so they have limited use in homeostasis.

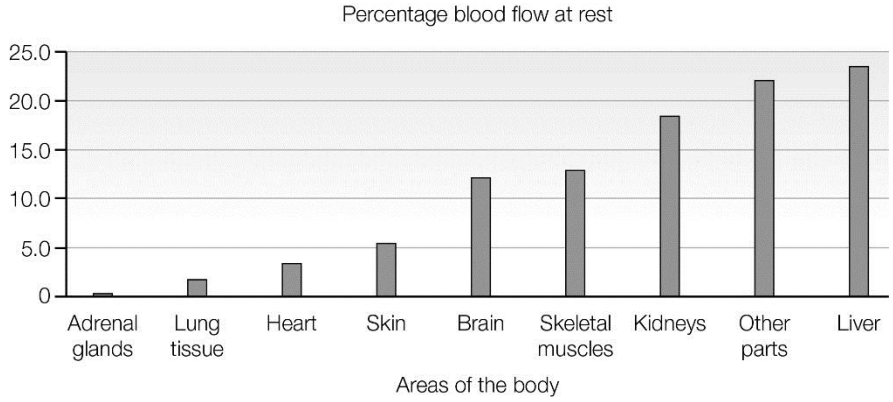
7B.7 Controlling the heart and breathing rates

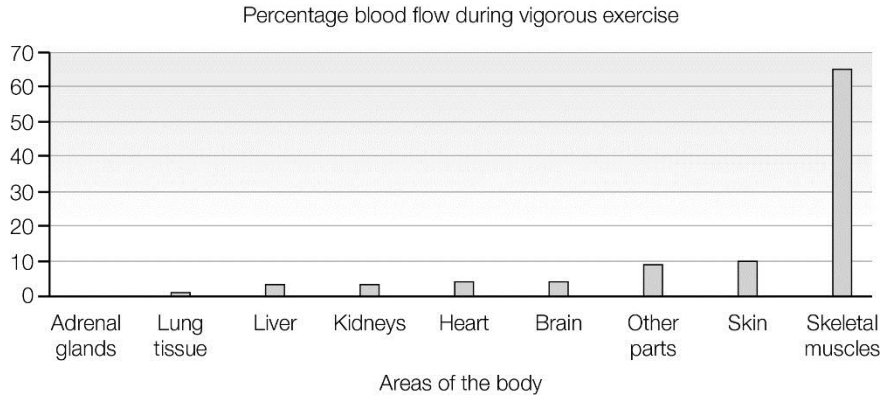
1 Normal blood pressure → exercise raises blood pressure → baroreceptors in carotid arteries detect rise in blood pressure → baroreceptors send nerve impulses to cardiovascular centre in brain → cardiovascular centre sends nerve impulses to heart and blood vessels → heart rate slows and blood vessels dilate → blood pressure falls back to normal.

2 Cardiac output graph:



3 (a) Exercise graphs:





(b) When the body is at rest or carrying on normal activities, the skeletal muscles need a given amount of blood to supply the oxygen needed to work against gravity and move around. However, far more of the blood needs to go to the liver, which deals with the products of digestion, detoxifying urea, etc., and the kidneys, which are filtering the blood and removing excess water, salt, all urea, etc. Relatively small blood flow to the skin to maintain temperature,

brain has large blood flow for size as it has coordination of the body and thinking at all times.

During exercise, the needs of the body change completely and the blood supply is shifted. The flow to the gut, liver and kidneys is very reduced as these activities are less immediately important. Blood supply to the muscles is almost doubled to provide the food and oxygen for vigorous contraction. Blood flow to the heart increases enormously to pump the blood to the muscles, etc., faster, in order to supply the food and oxygen needed, and blood flow through lungs doubles to get more oxygen into the body. Blood flow to the skin also increases greatly to keep the body cool, while the brain gets a little more blood to deal with potential dangers, increased alertness, etc.

4 Nervous control: involuntary – sympathetic speeds up heart rate, parasympathetic slows it down. Nerves come from cardiovascular centre. Impulses from these nerves affect the SAN and so change the rhythm of the heart in line with the demands of the body.

Cardiovascular centre in brain affected by input from stretch receptors in heart which are affected by volume of blood returning to heart as exercise starts or stops, and by input from baroreceptors which measure blood pressure in the arteries in the neck, which is particularly important as exercise ends. Carbon dioxide sensors, etc. also impact on heart rate through the cardiovascular centre.

Voluntary – nerves from conscious parts of the brain can also be used to stimulate or inhibit the SAN.

Hormonal: adrenaline stimulates the SAN, speeding up the excitation rate of the heart so that it beats faster and more strongly to prepare for flight or fight.

Any other valid points.

7B.8 The response of the breathing system to exercise

1 Spirometers can be used to measure the breathing rate at rest and whilst exercising, etc.

Also, the simple process of counting breaths with a stop watch can give a rough idea.

2 Diagram should include chemoreceptors in the brain, chemoreceptors in the carotid bodies, chemoreceptors in the aortic bodies, stretch receptors in the intercostal muscles and diaphragm, stretch receptors in the bronchi lungs. All mentioned directly or by association.

3 Carbon dioxide levels in the blood increase with exercise as more cellular respiration takes place (and pH levels which fall as carbon dioxide concentration goes up) and fall as hard breathing continues after exercise. Levels are detected by chemoreceptors in the hindbrain, the carotid bodies in the carotid arteries of the neck and the aortic bodies in the aorta. They respond to changes in levels by changing the rate of impulses sent to the respiratory centre in the brain which, in turn, send impulses to the intercostal muscles and the diaphragm to change the rate and depth of breathing.

Brain cortex: recognises movement has begun and stimulates the respiratory centre to cause an increase in breathing rate.

Stretch receptors in muscles register movement, and in the lungs measure the degree of stretching, and respond with impulses to the respiratory centre to affect breathing rate.

Voluntary nerves can be used to increase or decrease rate or depth of breathing within boundaries, beyond which the normal breathing reflex kicks in.

Any other valid suggestions.

7B Exam practice

1 (a) B

(b) Medulla / cardiovascular centre

(c) Anticipation causes release of adrenalin.
This speeds up the heart rate by direct action on the SAN.
Increased respiration releases more carbon dioxide.
This reduces the pH of the blood.
Detected by chemoreceptors which send signals to the cardiovascular centre.
More impulses sent to SAN to increase heart rate.

2 (a) (i) D
(ii) C

(b) The autonomic nervous system controls involuntary actions.
The sympathetic system stimulates heart activity / speeds heart rate up.
By releasing noradrenalin.
The parasympathetic system slows heart rate down.
By releasing acetylcholine.
Both act on the sinoatrial node.

(c) Any three from:
- Cardiac muscle does not tire.
- Cardiac muscle has cross-bridges between the fibres, striated muscle does not.
- Cardiac muscle is myogenic, striated muscle is not.
- Cardiac muscle has cells but striated muscle is not cellular.
- Cardiac muscle has intercalated discs / special junctions between the cells.

3 (a) (i) A
(ii) D

(b) Impulses arriving at the neuromuscular junction cause an action potential in the sarcolemma.
This releases calcium ions from the sarcoplasmic reticulum.
Calcium ions bind to the troponin causing it to change shape.
This moves the tropomyosin exposing binding sites on the actin.
Allows the myosin heads to bind to the actin / allows cross-bridges to form.
When mysosin binds it causes the actin and myosin filaments to slide past one another.
The sarcomere and the whole fibre get shorter.

(c) (i) To release the myosin head and make it swing back to the starting position.
To pump calcium ions into the sarcoplasmic reticulum.
(ii) When ATP runs out calcium leaks from the sarcoplasmic reticulum.
It binds to the troponin allowing contraction.
No ATP is available to release the myosin heads from the actin.

4 (a) The SAN initiates an impulse.
This spreads over the walls of the atria causing contraction.
The impulse is delayed at the AVN.
It passes down the bundle of His / Purkyne fibres.
It then spreads up the walls of the ventricles causing contraction.

(b) (i) Any two from:
- the resting heart rate decreases from 72 to 50 bpm
- the stroke volume at rest increases from 70 to 80 cm^3
- the stroke volume during exercise increases.

(ii) The larger stroke volume at rest allows sufficient blood to be pumped in fewer beats.

(iii) Cardiac output at rest = 50 × 80 = 4000cm^3 min^{-1}.

(iv) Cardiac output during exercise = 125 × 170 = 21 250 cm^3

% increase = 100 × (21 250 − 4000)/4000

431%

5 (a) (i) Skeletal muscles

(ii) 100 × (12 450 − 740)/740 = 1582%

(b) The skeletal muscles need more oxygen.

The heart works harder to pump more blood around the body.

(c) The blood flow to the kidneys and liver is reduced.

These organs do not need to be active during vigorous exercise.

Blood flow to the skin also falls at first as blood is directed away from the skin.

As the body creates heat blood flow returns to the skin to release excess heat.

6 (a)

Component of joint	**Function**
bone	support body weight
ligament	*holds bones together*
tendon	*attaches muscle to bone*
cartilage	protects ends of bone
synovial fluid	lubrication

(b) As the muscle contracts it pulls on the tendon.

If the tendon stretches, the bone will not move.

(c) The muscles work against each other.

A muscle can contract (get shorter) but it cannot elongate on its own.

The contraction of one muscle elongates its antagonistic (opposing) muscle.

7 (a) Tidal volume is the volume of air breathed in or out in one normal breath (usually at rest).

Vital capacity is the maximum volume of air that can be inhaled or exhaled in one breath.

(b) Any two from:
- nose must be blocked / pegged to prevent air being gained or lost
- student must be healthy with no asthma or breathing problems
- the mouth piece should be sterilised / replaced
- the spirometer should contain medical grade oxygen
- the spirometer must have no leaks.

(c) (i) A label marked anywhere on the upward slope of a peak.

(ii) (1.5 + 1.3. + 1.2)/3 = 1.33 dm^3

(iii) (5.80 − 5.50)/(55 − 7) = 0.00625 dm^3 s^{-1}

7C Control of the internal environment

7C Checkpoint

7C.1 Homeostasis and hormones

1 (a) In animals, hormones are organic chemicals (usually either proteins or peptides or steroids), produced in endocrine glands and released into the blood to be carried to parts of the body where they bring about changes, which may be widespread or highly targeted.

(b) Produces hormones

Has no duct – releases hormones directly into the blood

2 Protein and peptide hormones are not lipid soluble so they cannot enter a cell directly. The molecule binds to a receptor in the cell membrane, triggering a series of membrane-bound reactions that result in the formation of a second chemical messenger inside the cell. The second messenger, for example cyclic AMP, then activates a number of different enzymes within the cell, altering the metabolism. The second messenger can activate a number of different responses in the cell, which include increased cellular respiration, increased contraction of muscle cells and relaxation of smooth muscle in blood vessels.

3 Steroid hormones enter the cell itself as they can pass through the membrane. Inside the cell they bind to a specific receptor molecule and it is this hormone–receptor complex that passes through the pores of the nuclear membrane into the nucleus. It is the hormone–receptor complex, not the hormone alone, that acts as a transcription factor, regulating gene expression.

7C.2 Osmoregulation in mammals: the kidney

1 Osmoregulation is the maintenance of a relatively constant osmotic potential in the tissues of a living organism by controlling the water and salt concentrations.

It is important because, if the concentration of water and solutes inside and outside of a cell is not balanced, water may enter the cells by osmosis, causing the cells to swell and burst, or leave the cells by osmosis so that the cytoplasm becomes shrunken, concentrated and unable to function.

2 The liver has many homeostatic functions. One is to convert the ammonia produced by the breakdown of excess amino acids into less toxic urea. This urea is then excreted in the urine by the kidneys, which are the key organs of osmoregulation.

3 Main points of answer should include:

- High blood pressure develops in the glomerular capillaries because the diameter of the blood vessel coming into the glomerulus is greater than that of blood vessel leaving.
- High pressure squeezes the blood out through the capillary wall through pores that allow almost all of the plasma contents through apart from the blood cells and the largest plasma proteins.
- Podocyte cells of the Bowman's capsule act as an additional filter.
- Filtrate in capsule contains glucose, salt, urea and many other substances in the same concentrations as they are in the blood plasma.
- Process of selective reabsorption begins – returns over 80% of the glomerular filtrate to the blood in the first or proximal tubule, including all the glucose, amino

acids, vitamins and all but some very small hormones along with about 85% of the sodium chloride and water.

- Sodium ions are actively transported out of the proximal tubule, and the chloride ions and water follow passively down concentration gradients.
- Once the substances are in intracellular spaces, they pass by diffusion into the extensive capillary network surrounding the tubules.
- The fluid that enters the loop of Henle is isotonic with the tissue fluid that surrounds the tubule and the blood.
- The descending limb of the loop of Henle is freely permeable to water, but is not permeable to sodium and chloride ions.
- As the fluid travels down the descending limb deeper into the medulla, the external concentration of sodium and chloride ions in the tissue fluid of the medulla and the blood in the capillary network increases as a result of the events in the ascending limb of the loop of Henle.
- As a result, water moves out of the descending limb into the tissue fluid by osmosis down a concentration gradient and on into the blood of the capillary network, again down a concentration gradient.
- The fluid at the hairpin bend at the bottom of the loop of Henle is very concentrated and hypertonic to the arterial blood.
- The fluid then moves up the ascending limb where the first section is very permeable to sodium and chloride ions, but not permeable to water.
- Sodium and chloride ions move out of the very concentrated fluid in the loop of Henle down concentration gradients into the tissue fluid of the medulla.
- The second, thicker section of the ascending limb of the loop of Henle is also impermeable to water, but sodium and chloride ions are actively pumped out of the tubule into the tissue fluid of the medulla and the blood of the capillary network. This gives the tissues of the medulla the very high sodium and chloride ion concentration that causes the water to pass out of the descending limb by osmosis.
- As the ascending limb of the loop of Henle is impermeable to water, water cannot follow the chloride and sodium ions out down the concentration gradient so the fluid becomes less concentrated.
- When the fluid leaves the loop of Henle it enters the distal tubule. This is permeable to water but the permeability depends on levels of antidiuretic hormone (ADH).
- If levels of salt in the body are low, sodium may be actively pumped out of the distal tubule with chloride ions following.
- Water leaves by osmosis if the walls of the tubule are permeable but stays in the tubule if they are not.
- The fluid passes into the collecting duct and water moves out down a concentration gradient as it passes through the medulla, with its high levels of sodium and chloride ions, so the urine becomes steadily more concentrated.
- Water may move out of the collecting duct by osmosis all the way along, so very hypertonic urine can be made to conserve water for the cells of the body.
- The amount of water that moves out of the collecting duct back into the body depends on the permeability of the collecting duct to water and this is strongly affected by ADH.
- The urine produced is collected first in the pelvis of the kidney and then passes along the ureters to the bladder.
- Urine is stored in the bladder until it is sufficiently stretched when it passes out of the body along a tube called the urethra.

4 Adaptations that help mammals survive in a very hot dry environment such as a desert include:

- They have a relatively large proportion of juxtamedullary nephrons. These help ensure that large amounts of water can be reabsorbed as they are the nephrons with the longest loop of Henle.
- The loops of Henle are adapted to produce a very high concentration of ions in the tissue fluid of the medulla.
- This high concentration of sodium and chloride ions in the tissue fluid of the medulla makes it possible to produce very highly concentrated urine and so reduces the need to drink.
- Kangaroo rats (an extreme example, they never drink) have very high numbers of infoldings in the cell membranes of the epithelial cells lining the tubules. This gives a greatly increased surface area for diffusion of inorganic ions and water. This in turn helps develop the steep concentration gradients needed to make very concentrated urine and reduces the need to drink.
- The epithelial cells of the nephrons of kangaroo rats contain high numbers of mitochondria. These mitochondria have densely arranged cristae for maximum cellular respiration. These specialised mitochondria provide the large quantity of ATP needed for the active pumping of inorganic ions into or out of the tubules. This active pumping is needed to produce the concentration gradients needed to produce very concentrated urine, again reducing the need to drink.

7C.3 Control of the kidney and homeostasis

1 (a) Blood becomes more dilute → detected by osmoreceptors in hypothalamus → no impulses from hypothalamus to posterior pituitary → ADH release by pituitary gland is inhibited → walls of distal tubule and collecting duct remain impermeable to water → little or no reabsorption takes place → large volumes of dilute urine are produced → blood water potential returns to normal.

(b) Blood becomes more concentrated → detected by osmoreceptors in hypothalamus → impulses sent to posterior pituitary → stored ADH is released by pituitary gland → permeability of walls of distal tubule and collecting duct to water increases → water leaves tubules by osmosis into tissues of renal medulla and on into capillaries → lots of reabsorption takes place → small volumes of concentrated urine are produced → blood water potential returns to normal.

2 ADH cannot cross the membrane of the tubule cells. It binds to specific receptors, triggering reactions that result in the formation of cAMP as the second messenger. This triggers the vesicles containing water channels in the cells lining the tubules to move to, and fuse with, the cell membranes. The water channels are inserted into the membrane, making it permeable to water so water can move through the channels out of the tubules and into the surrounding blood capillaries by osmosis.

3 An increasing plasma concentration is detected by osmoreceptors in the hypothalamus. They send nerve impulses to the posterior pituitary, which in turn releases stored ADH into the blood. The ADH is picked up by receptors in the cells of the kidney tubules. ADH increases the permeability of the distal tubule and the collecting duct to water. As a result, water leaves the tubules by osmosis into the surrounding capillary network. This means more water is returned from the filtrate to the blood plasma, and a small volume of concentrated urine is produced.

If the blood plasma becomes more dilute, the change is detected by the same osmoreceptors of the hypothalamus. When the concentration of the blood plasma falls, it inhibits the release of ADH by the pituitary gland. The walls of the distal tubule and the collecting duct remain impermeable to water and so little or no reabsorption

takes place. Large amounts of very dilute urine are produced and the concentration of the blood is maintained.

The release of ADH is also stimulated or inhibited by changes in the blood pressure. These changes are detected by the baroreceptors in the aortic and carotid arteries. A rise in blood pressure is often a sign of an increase in blood volume. It will suppress the release of ADH and so increase the volume of water lost in the urine. This, in turn, reduces the blood volume and so the blood pressure falls. A fall in blood pressure, which may indicate a loss of blood volume, causes an increase in the release of ADH from the pituitary and the conservation of water by the kidneys. Water is returned to the blood and a small amount of concentrated urine is produced.

7C.4 Thermoregulation and exercise

1 Because the chemical reactions that occur in cells only take place within a relatively narrow range of temperatures before the enzymes that control the reactions are denatured.

2

(a) External temperature drops	(b) External temperature rises
Sensors in hypothalamus pick up fall in blood temperature	Sensors in hypothalamus pick up rise in blood temperature
Heat gain centre in hypothalamus is stimulated	Heat loss centre in hypothalamus is stimulated
Impulses through autonomic nervous system	Impulses through autonomic nervous system
Vasoconstriction occurs	Vasodilation occurs
Sphincter muscles around arterioles leading to superficial capillaries contract	Sphincter muscles around arterioles leading to superficial capillaries are not stimulated to contract and therefore relax
This constricts the passage into these capillaries and more blood flows through deeper shunt vessels	More blood can flow into these capillaries, dilating them with the pressure; less blood flows through deeper shunt vessels
Less blood flows close to the body surface	More blood flows close to the body surface
As most blood is diverted further from the body surface, the temperature gradient between the body surface and the environment is less steep, so heat loss by conduction and radiation is reduced	As more blood flows close to the body surface, the temperature gradient between the body surface and the environment becomes steeper, so heat loss by conduction and radiation is increased
Hair erector muscles contract – hairs stand up to trap insulating layer of air	Hair erector muscles relax – hairs lie flat against the skin
Muscles shiver to warm blood	Muscles of ribcage and diaphragm may cause panting
Adrenal glands increase adrenaline secretion	Sweat glands produce more sweat so cooling by evaporation takes place from skin surface

Body temperature rises	Body temperature falls
Sensors detect this, and heat conservation and generation measures are reduced	Sensors detect this and heat loss measures are reduced

3 (a) Large surface area-to-volume ratio so large surface area for the transfer of energy to the surroundings, cooling the body; if little hair, no insulating layer to reduce energy transfer.

(b) Small dens lined by insulating material help to minimise transfer to the environment by insulating the surroundings; fluffy offspring have a layer of insulating air trapped against the skin to reduce energy transfers to the environment.

Any other sensible points.

7C Exam practice

1 (a) A

(b) C

(c) (i) Testosterone / oestrogen / progesterone

(ii) Steroid hormones are soluble in lipids.

Protein / polypeptide hormones are not lipid soluble.

(iii) The hormone enters the nucleus and switches a gene on.

The gene may then be transcribed to make many mRNA molecules.

Each mRNA molecule can be translated many times to make many protein molecules.

(iv) Passing through the cell membrane and entering the nucleus takes longer than binding to a cell surface receptor.

Proteins made are long lasting molecules.

2 (a) C

(b) The loop of Henle performs as a countercurrent multiplier.

It increases the concentration of salts in the medulla.

So that water can be reabsorbed from the collecting duct.

(c) ADH is released into the blood from posterior pituitary gland.

When water potential of blood is too low.

Binds to cell surface receptors on cells of collecting duct.

Activates release of secondary messengers inside the cells.

Causes vesicles containing water channels to join cell membrane.

Making wall of collecting duct more permeable.

So more water can be reabsorbed.

3 (a) As sweat evaporates it helps cool the body.

Using latent heat of vaporisation.

(b) (i) Temperature dropped, very slightly / by 0.1 °C in first 5 minutes.

Temperature dropped, slightly / by 0.4 °C, during 10 minutes in bath.

Temperature took 10 minutes to return to original / 37 °C after got out of bath.

(ii) The temperature of the bath was lower than body temperature.

Heat was lost by conduction / radiation / convection.

(iii) Vasoconstriction occurred / the vessels leading to the surface of the skin constricted.

Reducing blood blow to the skin surface.

Less heat transferred away from skin.

4 (a) (i) A

(ii) C

(b) (i) $100 \times (300 - 60) / 300 = 80\%$

(ii) There are no differences between high and low levels of ADH in regions A–D.

In regions E–G the concentration of solutes is lower when there is a low level of ADH.

The effect of ADH level increases towards the end of the nephron.

In region E the concentration drops from 300 to 80 au when ADH is low / in F it drops from 400 to 60 au / in G it drops from 1200 to 60 au.

(iii) Higher level of ADH increases the permeability of the walls in E, F and G.

More water is reabsorbed from the fluid in the nephron.

5 (a) Homeostasis is the maintenance of a constant internal environment. The environment is not kept perfectly constant but will oscillate around a mean.

(b) Internal parameters must be kept constant or fairly constant. If an external change such as a drop in external temperature caused the internal temperature to change then it must be brought back to the set point. A system must be put in place to reverse the change – so that if the core temperature drops it is raised back to the correct set point.

(c) (i) Blood flow was diverted away from the skin.

To supply more oxygen to the muscles.

Less heat was carried to the skin.

(ii) Exercise produces heat.

When the body gets too hot the excess heat must be lost.

Blood was diverted back to the skin to lose excess heat.

8A The nervous system and neurones

8A Checkpoint

8A.1 The structure of neurones

1 Nerve fibre is the axon or dendron of an individual nerve cell (neurone). Each individual nerve fibre will either carry impulses to (sensory) or from (motor) the brain but not both.

Nerve is a bundle of nerve fibres – may be all sensory, all motor or a combination, so a nerve may carry both motor and sensory impulses.

2 Nerve cell in CNS with dendrites to synapse with and receive input from other nerve cells, fibre long to reach tissues, myelinated to increase speed of transmission, synapses on effector to pass on impulse – any other valid points.

3 In invertebrates speed of transmission of a nerve impulse is directly related to diameter of nerve fibre and there is a limit to how big a nerve fibre can grow. Most vertebrate neurones are associated with Schwann cells and the Schwann cell membrane wraps itself repeatedly around the nerve fibre forming a fatty layer known as the myelin sheath. There are gaps between the Schwann cells known as the nodes of Ranvier. The impulse jumps from node to node so transmission is much faster. Therefore, vertebrate nerves that need to carry impulses fast are myelinated, with relatively small diameters – and those that are not myelinated do not need to carry impulses very fast so they can have small diameters.

4 Squid giant axons are large so they carry impulses relatively quickly to give an escape mechanism. This means that they are easy to find and access, and easy to insert micropipettes into. Squids are invertebrates so fewer ethical issues with using them in experimentation of this type.

8A.2 How the nervous system works

1 The membrane of an axon is partially permeable. At rest, the axon membrane is relatively impermeable to sodium ions, but quite freely permeable to potassium ions. It also contains a very active sodium/potassium pump which uses ATP to move sodium ions out of the axon and potassium ions in. The effect of this is to lower the concentration of sodium ions inside the axon – they are pumped out and cannot diffuse back in again. At the same time, potassium ions are moved in – but they then diffuse out again along a concentration gradient through open potassium ion channels. Eventually, the movement of positively charged potassium ions out of the cell along the concentration gradient is opposed by the electrochemical gradient. As a result, the inside of the cell is left slightly negative relative to the outside – it is polarised. This gives a potential difference across the membrane of around −70 mV, which is known as the resting potential.

2 (a) When a neurone is stimulated, the axon membrane shows a sudden and dramatic increase in its permeability to sodium ions. Specific sodium channels, or sodium gates, open up, allowing sodium ions to diffuse rapidly down their concentration and electrochemical gradients. As a result, the potential difference across the membrane is briefly reversed, with the cell becoming positive on the inside with respect to the outside. This depolarisation lasts about 1 millisecond. The potential difference across the membrane at this point is about +40 mV. This is known as the action potential.

At the end of this brief depolarisation, the sodium channels close again and the excess sodium ions are rapidly pumped out by the sodium pump. This active transport system uses up ATP. Also, the permeability of the membrane to potassium ions is temporarily increased as voltage-dependent potassium ion channels open as a result of the depolarisation. As a result, potassium ions diffuse out of the axon down their concentration gradient and electrochemical gradient, attracted by the negative charge on the outside of the membrane. As the positive sodium and potassium ions leave the cell, the inside becomes negative relative to the outside once again. It takes a few milliseconds before the resting potential is restored and the axon is ready to carry another impulse.

(b) The events of the action potential can be recorded clearly using an internal/external electrode combination. A very fine glass microelectrode is inserted into an axon. Another electrode records the electrical potential from the outside. The results are shown on an oscilloscope. The oscilloscope trace is often referred to as the 'spike' because of its shape.

3 The graph shows the effect of the metabolic poison dinitrophenol (DNP) on the movement of sodium out of a cuttlefish axon. It is known that DNP prevents the production of ATP and the graph shows it also prevents the axon from functioning properly. When an axon is treated with DNP, no more ATP can be made. The sodium pump stops working as ATP is used up and the resting potential is lost at the same rate as the concentration of ATP decreases. This suggests that the ATP is being used to power the sodium pump – when it runs out, the pump no longer works. As the DNP is washed away, the metabolism returns to normal and ATP production begins again. The resting potential is restored, suggesting that the sodium pump has started up again with the return of ATP.

8A.3 The neurones in action

1 Involved in making the neurotransmitter substances in the presynaptic knobs.

Involved in the production of vesicles.

Involved in the breakdown of neurotransmitters on the post-synaptic membrane so stimulation of the PSP ends.

Involved in the production of ATP to power the various ion pumps and the synthesis and breakdown of neurotransmitters.

Any other valid points.

2 (a) Arrival of an impulse at the synaptic knob increases the permeability of the presynaptic membrane to calcium ions as calcium ion channels open up → calcium ions move into synaptic knob down concentration gradient → cause the synaptic vesicles containing acetylcholine to move to the presynaptic membrane → vesicles fuse with the presynaptic membrane → release acetylcholine into the synaptic cleft → acetylcholine diffuses across the gap → attached to specific protein receptor sites on the sodium channels of the post-synaptic membrane → sodium ion channels in the membrane open → sodium ions move into the nerve fibre, causing a change in the potential difference across the membrane → EPSP/IPSP set up → acetylcholine destroyed by acetylcholinesterase embedded in post-synaptic membrane → components diffuse back across cleft into presynaptic knob → re-synthesised into acetylcholine in vesicles.

(b) Arrival of an impulse at the synaptic knob increases the permeability of the presynaptic membrane to calcium ions as calcium ion channels open up → calcium ions move into synaptic knob down concentration gradient → cause the synaptic vesicles containing noradrenaline to move to the presynaptic

membrane → vesicles fuse with the presynaptic membrane → release noradrenaline into the synaptic cleft → noradrenaline diffuses across the gap → attached to specific protein receptor sites on the sodium channels of the post-synaptic membrane → sodium ion channels in the membrane open → sodium ions move into the nerve fibre, causing a change in the potential difference across the membrane → EPSP/IPSP set up → noradrenaline leaves receptors and moves back into synaptic cleft → diffuses back into the presynaptic knob where it is repackaged in vesicles again.

3 (a) EPSP – the potential difference across the post-synaptic membrane caused by an influx of sodium ions into the nerve fibre. This is the result of the arrival of a molecule of neurotransmitter on the receptors of the post-synaptic membrane that makes the inside more positive than the normal resting potential. If there are enough EPSPs, the positive charge in the post-synaptic cell exceeds the threshold level and an action potential is set up, which then travels on along the post-synaptic neurone.

IPSP – the potential difference across the post-synaptic membrane caused by an influx of negative ions as the result of the arrival of a molecule of neurotransmitter on the receptors of the post-synaptic membrane, which makes the inside more negative than the normal resting potential. This makes it less likely that an action potential will be triggered in the post-synaptic cell.

(b) Each individual impulse is an all-or-nothing event. EPSPs and IPSPs allow summation of effect and greatly increased sensitivity and flexibility in the response of the nervous system.

8A.4 The effect of drugs on the nervous system

1 The answer should include some or all of the following.

Electron micrographs: show the presence of vesicles in the synaptic knob of the presynaptic neurone before an action potential; after repeated action potentials these vesicles are no longer visible, implying that they have released their contents as a result of stimulation. Also shows large numbers of mitochondria which supply the energy for the synthesis of the neurotransmitters, etc.

Botulinus toxin: blocks the release of acetylcholine; shows that acetylcholine from the presynaptic membrane is needed for the transmission of an action potential across a synapse.

Strychnine: prevents action of enzyme acetylcholinesterase, showing that acetylcholine causes the setting up of action potentials in post-synaptic neurones, because preventing the breakdown of acetylcholine causes the neurones to respond continuously.

Other points may be valid.

2

Main effects of drugs on nervous system
Increase the amount of neurotransmitter synthesised.
Block the synthesis of neurotransmitter.
Increase the release of neurotransmitter from the vesicles at the presynaptic membrane.
Cause neurotransmitter to leak from vesicles and be destroyed by enzymes.
Bind to post-synaptic receptors and activate them or increase the effect of the normal neurotransmitter, for example, nicotine.

Prevent the release of neurotransmitter from vesicles.
Prevent the degradation of neurotransmitter by enzymes or prevent reuptake into presynaptic knob.
Block the receptors and prevent neurotransmitter binding, for example, lidocaine.
Block voltage-gated sodium channels preventing action potentials, for example, cobra venom.

3 (a) Patient discomfort down from 9 to 2 so a 7-point reduction: 7/9 × 100 = 78%.
Ease for doctors 3 down to 1 so a 2-point reduction: 2/3 × 100 = 67%.

(b) 1.5 mins with lidocaine and 4.5 mins without.

(c) 10% failed with lidocaine, 85% failed without.

(d) Lidocaine molecules block the voltage-gated sodium channels in post-synaptic membranes, preventing the production of an action potential in sensory nerves and so preventing you from feeling pain. If patients cannot feel pain, they will be much more relaxed and stay still. Doctor will be less worried about hurting patient – combination means procedure becomes much easier for both.

8A.5 Sensory systems and the detection of light

1 (a) Receptor cells have a resting potential which is dependent on the maintenance of a negative interior by membrane sodium pumps. When a receptor cell receives a stimulus, sodium ions move rapidly across the cell membrane along concentration and electrochemical gradients and this generator current sets up a generator potential. A small stimulus results in a small generator potential and a large stimulus results in a large generator potential – generator potentials do not obey the all-or-nothing law. If the generator potential produced is large enough to reach the threshold of the receptor neurone, an action potential will result in that neurone. If it is not, there will be no action potential – the action potential does obey the all-or-nothing law. Stimulus → local change in permeability → generator current → generator potential → action potential is common in one form or another to most sensory receptors.

(b) In convergence, several receptor cells will often synapse with a single receptor neurone. This means that even if the generator potential from an individual receptor cell is insufficient to set up an impulse, the potentials from several may add together or summate and trigger an action potential. This increases the sensitivity of a sensory system to low level stimuli. This is an important feature of the retina cells, the light-sensitive cells of the eye.

2 (a) Rhodopsin

Rhodopsin is formed from two components, opsin and retinal. Opsin is a combination of lipid and protein (a lipoprotein) and retinal is a light-absorbing derivative of vitamin A. Retinal exists in two different isomers, cis-retinal and trans-retinal. In the dark, it is all in the cis-form. When a photon of light (the smallest unit of light energy) hits a molecule of rhodopsin, it converts the *cis*-retinal into trans-retinal. This changes the shape of the retinal and puts a strain on the bonding between the opsin and retinal. As a result, the rhodopsin breaks up into opsin and retinal. This breaking up of the molecule is referred to as bleaching.

(b) The bleaching of the rhodopsin changes the permeability of the cell membrane of the rod to sodium ions (Na^+). The membranes of most neurones are relatively impermeable to sodium ions, but rod cell membranes are normally very permeable to Na^+. Sodium ions move into the rod cell through sodium (cation) channels and the sodium pump moves them out again.

When rhodopsin is bleached by light trans-retinal is formed. This triggers a cascade reaction which results in the closing of the sodium channels. The rod cell membrane becomes much less permeable to sodium ions and so there are fewer sodium ions in the rod cell. However, the sodium pump continues to work at the same rate, pumping Na^+ out of the cell, so the interior becomes more negative than usual. This hyperpolarisation is what is known as the generator potential in the rod. The size of the generator potential depends on the amount of light hitting the rod and so the amount of rhodopsin-bleaching that takes place. If it is large enough to reach the threshold, or if several rods are stimulated at once, neurotransmitter substances are released into the synapse with the bipolar cell. An action potential is then set up in the bipolar cell which passes across the synapse to cause an action potential in the sensory neurone. All the sensory neurones leave the eye at the same point to form the optic nerve leading to the brain. In the visual areas of the brain this visual information is converted into an awareness of the image.

3 Each cone has an individual neurone going into the optic nerve – so each cone that is stimulated sends an impulse to the brain, giving great visual acuity, but only in bright light.

Several rods feed into one neurone going into the optic nerve. So this neurone only fires when several rods are stimulated. This gives a less clear image, but greater sensitivity to low light levels.

4 (a) Several rods synapse with a single bipolar cell, so there is summation of the generator potentials which means low light levels that would not result in an action potential in the bipolar cell from a single rod can give an action potential from the summation of generator potentials from several rods. Each cone synapses with a single bipolar cell so it is less likely to trigger an action potential in dim light.

In addition, iodopsin, the light-sensitive pigment in cones, needs to be hit with more light energy to be bleached than rhodopsin in the rods – so again, the rods will respond to dimmer light.

(b) Convergence – several rods synapse on a single bipolar cell – means that subtle changes in light level as something moves are detected by rods although not necessarily clearly. Cones need much bigger light differences and no convergence so less likely to pick up movement – also peripherally there are no cones.

(c) Cones respond only to bright light and each individual cone synapses onto a single bipolar cell. As a result, any image is clear and crisp.

8A.6 Synapses and habituation

1 Invertebrates with fast impulses in unmyelinated nerves have relatively large diameter nerve fibres which make the fibres relatively easy to identify and stimulate artificially. Also, as invertebrates, fewer ethical issues arise from their use as experimental animals.

2 The blink reflex is protective and so when there is a sudden movement towards your eye this is detected, calcium ions are released into the presynaptic knob, vesicles containing neurotransmitter move to and fuse with the presynaptic membrane,

releasing neurotransmitter into the synaptic cleft which in turn triggers an action potential in the post-synaptic neurone and you blink.

With repeated stimulations the calcium channels in the presynaptic membrane become less responsive. With fewer calcium channels open, fewer calcium ions cross into the presynaptic knob. Consequently, fewer vesicles move to the presynaptic membrane, fuse and discharge their neurotransmitter. When there is less neurotransmitter available to bind to the post-synaptic membrane, the post-synaptic excitatory potential is not high enough to trigger an action potential so there is no response.

3 Habituation is part of the development and learning process in almost all animals, including human beings. It is very important in the development of young animals, as they need to learn not to react to the neutral elements in the world around them. For example, sea slugs which grow up in the sea habituate to the movements of the sea and do not respond, but an animal which grows up in a still tank of water will react and withdraw its siphon when the water moves.

Habituation may be a relatively short-term adaptation to a particular stimulus such as a loud sound in a particular environment, or it may become long-term so that a response is lost permanently. Memory is a crucial element of learning and scientists think that habituation is involved in the brain development which occurs as memories are formed, when permanent changes take place in the synapses.

8A Exam practice

1 (a) A

(b) (i) B

(ii) C

(c) Both axons conduct more rapidly as diameter increases.

If diameter is below 1 µm, the non-myelinated axon is faster.

Above 1 µm diameter the myelinated axon is faster.

(d) The movement of ions across the membrane is relatively slow.

Myelin insulates the membrane preventing movement of ions.

The ionic exchange of an action potential can only occur at the nodes of Ranvier.

So the action potential appears to jump from one node to the next using local currents.

(e) (i) 0.025 / 0.0034 = 7.35 m/s

(ii) 1.7 µm

2 (a) A

(b) Action potential causes calcium ions to enter neurone.

Calcium ions make vesicles move towards pre-synaptic membrane.

Vesicles fuse with pre-synaptic membrane releasing transmitter.

(c) (i) 1 ms

(ii) 3 ms

(iii) 1 / 0.0045 = 222.22

(d) Cl^- entering the neurone and K^+ leaving the neurone will cause charge inside neurone to become more negative (hyperpolarised).

An action potential needs inside to become more positive so it is more difficult to achieve.

3 (a) Diagram correctly drawn with labels of presynaptic neurone, post synaptic neurone, cleft, vesicles.

(b) (i) Absorbed through epithelium of lungs / alveoli.

Transported in blood.

Diffuses through tissues.

(ii) Nicotine mimics effect of acetylcholine.

Binds to acetylcholine receptors.

Triggers post-synaptic action potentials.

(c) The venom binds to acetylcholine receptors.

Does not cause post-synaptic potential but prevents acetylcholine binding.

4 (a) (i) Aerobic respiration to supply ATP.

To manufacture vesicles / neurotransmitter OR to move the vesicles.

(ii) A lot of energy is needed.

(iii) To contain the neurotransmitter.

To transport the neurotransmitter to the pre-synaptic membrane.

(b) B

(c) Habituation

Constant sound causes calcium channels to be less responsive.

Fewer calcium ions enter pre-synaptic knob.

Fewer vesicles are moved to the pre-synaptic membrane.
Sound of that frequency is not responded to.

5 (a) Label to parallel bars in upper half of cell.

(b) In bright light the rhodopsin is bleached and the rods do not function.
In dim light the rhodopsin is reformed as retinal rejoins the opsin.
This rhodopsin can now detect the dim light.

8B Coordination in animals and plants

8B Checkpoint

8B.1 The central nervous system

1 Cerebral hemispheres associated with higher brain functions – seeing, thinking, learning and emotions, for example. Folding of the cerebral hemispheres increases the surface area of these regions of the brain. It is thought that greater folding, and thus greater surface area, is associated with greater intelligence, more complex emotions and ability to learn, etc. Humans have greater abilities than other primates – and more folding. It is not just surface area that counts – the volume of tissue is important too, which is a function not just of folding, but of thickness. So dolphins have a big surface area, but less volume because the tissue layer is thinner. They are very intelligent, but it is thought that their development does not rival humans.

2 The answer should include some or all of the following. Other points may be valid.

Brain area	Function
Cerebral hemispheres	Vision, sight, thinking, learning, emotions
Frontal lobe	Emotional responses, planning, reasoning, decision-making. Primary motor cortex controls many movements
Temporal lobe	Sound recognition, hearing, speech, many memory functions
Occipital lobe	Vision, shape recognition, colour vision, sense of perspective
Cerebellum	Coordinates smooth movements, maintains posture and balance
Hypothalamus	Coordinates autonomic nervous system, including thermoregulation, and controls many basic drives, for example, thirst, hunger, aggression, reproductive behaviour
Medulla oblongata	Controls reflex centres for heart rate, breathing rate, blood pressure, coughing, sneezing, swallowing, saliva production, peristalsis

3 The frontal lobe of the cerebrum contains the primary motor cortex of the brain, which is involved in the control of many of the body movements. The control comes via motor neurones that pass through the hindbrain and the spinal cord, carrying impulses to the muscles. If this area is damaged a person is likely to lose conscious control over their movements.

The cerebellum coordinates smooth movements. It uses information from the muscles and the ears to control balance and maintain posture. If the cerebellum is damaged you are likely to lose your balance, and your walking and movements will become more jerky and less coordinated.

4 (a) The brain is a combination of grey matter, made up of neurone cell bodies, and white matter, consisting of nerve fibres. There are areas of the human

brain with very specific functions concerned with the major senses and control of basic bodily functions. There are also many regions of the brain where we do not yet clearly understand the precise functions and interrelationships with other areas of the brain. Scientists have estimated that there are around a hundred thousand million neurones working together in the human brain and that each neurone synapses with up to 10 000 other neurones. The brain contains centres or nuclei made up of cell bodies that make intercommunication between millions of cells possible. The great nerve tracts from the spinal cord cross over as they enter and leave the brain, so that the left-hand side of the brain receives information from and controls the right-hand side of the body and vice versa.

The spinal cord is a tube made up of a core of grey matter surrounded by white matter which runs out from the base of the brain (the medulla oblongata) through the vertebrae. It is approximately 43–45 cm long. Impulses from sensory receptors travel along sensory nerve fibres into the spinal cord, through the dorsal roots, and then travel in sensory fibres up the cord to the brain. Instructions from the brain travel as impulses down motor fibres in the spinal cord and out in motor neurones through the ventral roots to the effector organs. The spinal cord acts as a coordination centre for reflex reactions that take place without conscious thought.

(b) Stimulus received by sensory receptors in skin of foot → action potential travels along sensory neurone into spinal cord → synapse with relay neurone in grey matter → synapse with motor neurone in grey matter → action potential in motor neurone leaves spinal cord → reaches motor end plate in muscle → stimulates contraction of muscle that withdraws foot from stone.

8B.2 The peripheral nervous system

1 Many continuous and/or basic functions of the body, such as control of the heart and breathing rates, the control of gut function, etc., can take place without conscious thought, leaving the conscious areas of the brain free to make decisions, judgements, etc. Voluntary nervous system gives conscious control and can often override the autonomic system if necessary.

2 (a) Parasympathetic nervous system is part of the autonomic nervous system. The neurones have long preganglionic fibres and short post-ganglionic fibres, and the ganglions are close to the effector organs. The neurotransmitter is usually acetylcholine. The parasympathetic nervous system slows things down as a general rule.

Sympathetic nervous system is part of the autonomic nervous system. The neurones have short preganglionic fibres and long post-ganglionic fibres, and the ganglions are close to the CNS. The neurotransmitter is usually noradrenaline. The sympathetic nervous system speeds up responses as a general rule.

(b) In some of their responses they can be seen as having the opposite effects – sympathetic ‘fight-or-flight’, parasympathetic ‘rest and digest’. However, this is an oversimplification – for some functions there is no antagonistic action – for example, sympathetic stimulates secretion of adrenaline and noradrenaline, parasympathetic has no effect; parasympathetic stimulates secretion of bile, sympathetic has no effect, etc. Also they usually work cooperatively, with interplay between the two systems to maintain body functions at an ideal level.

3

Chemical coordination (hormones)	Electrical coordination (nervous system)
- Based on chemicals (hormones) produced in specific glands - Produced in specific glands - Travel around the body in blood - Depends on specific receptors on target cell membranes - Often important in slow, sustained responses over months and years, although can be involved in rapid responses e.g. adrenaline, insulin - Any other sensible points	- Based on electrical impulses but also needs chemical involvement across synapses - Travel along specific nerve pathways - Depends on sensory receptors and specific effectors - Usually involved in rapid responses - Any other sensible points

8B.3 Investigating the human brain

1 Brain very complex, encased in the skull, ethics of investigating human brains experimentally – imaging enables us to see inside the skull and observe the brain – even in real time activity.

2 X-rays: pass through body, absorbed differentially by different tissues, make an image on photographic film. Good for taking images of hard tissue, e.g. bones, but much less useful for producing images of soft tissues such as the brain. Particularly good for imaging water in the body. The signals are analysed by computer and used to produce an image. Images show much finer detail than CT scans.

Computerised tomography (CT scan): thousands of tiny beams of X-rays passed through an area of the body, e.g. head. Beams attenuated by the density of the tissue.

The X-rays which make it through are detected and measured. A computer collates the data to produce a cross-sectional image of a thin slice through the body. Special dyes can make areas X-ray opaque so they show up more clearly in the scan. Can identify major structures in the brain and detect problems such as brain tumours, bleeding in the brain or swellings of the arteries in the brain (aneurisms). Cannot be used to show how areas of the brain are used or change during different activities. Can be linked to observed changes in behaviour to indicate the importance of certain areas of the brain in particular functions.

Magnetic resonance imaging (MRI scan): Uses magnetic fields and radio waves to image the soft tissues (mainly due to amount of water in tissue), so no potentially damaging.

2D scans are usually produced – a computer can create a 3D image from these. Can distinguish regions of the brain. Widely used to diagnose brain injuries, strokes, tumours and infections of the brain or the spine. Can also indicate links between the structures in the brain and patterns of behaviour.

Functional magnetic resonance imaging (tMRI): monitors uptake of oxygen in different brain areas, so indicates active areas of the brain. Can be observed in real time, so makes it possible to watch brain response while people carry out tasks. Gives an extremely spatially accurate image of the brain. Has to be carried out with patient's head remaining completely still, which limits tasks that can be done. Used

mainly to investigate normal brain structure and function. May soon be used to diagnose diseases such as the early signs of stroke damage and the onset of Alzheimers.

Positive emission tomography (PET) scans: involves injecting a patient with a radioactive tracer (radiotracer) which is similar to glucose and is carried to all the cells. The scanner detects the radiation given off by the radiotracer and computer analysis shows where the tracer has accumulated and where it has not. Gives detailed, 3-dimensional images of the brain, can reveal abnormal areas in the body, show how well different areas are working and PET scans can be combined with CT scans and MRI scans to produce very detailed images to help with diagnosis. They can be used to plan surgery by giving surgeons a 3D image of the areas of the brain that are affected.

8B.4 The chemical balance of the brain

1 Neurotransmitter synthesis and storage: if a drug blocks this process, synaptic transmission would lessen and then stop as supplies of neurotransmitter reduced. This would mean nerves using that neurotransmitter would no longer be able to pass impulses between them, causing loss of motor or sensory skills and processes in the brain.

Neurotransmitter release: a drug stopping neurotransmitter release would stop synaptic transmission as the impulse in the presynaptic fibre would not be transmitted to the post-synaptic membrane causing loss of motor or sensory skills and processes in the brain.

Neurotransmitter-receptor binding: a drug blocking this would stop the development of the post-synaptic potentials which in turn would prevent the development of an action potential in the post-synaptic fibre. Alternatively, the drug may maintain binding so that the stimulus to the post-synaptic fibre was continuous, causing confusion and fatigue further in the system.

Neurotransmitter reuptake: a drug blocking this would slowly reduce the intensity of the response as less neurotransmitter would be re-synthesised and be ready for release. This would speed up fatigue etc.

Neurotransmitter breakdown: a drug blocking this would mean that stimulation would continue as the concentration of neurotransmitter in the synaptic gap would build up steadily so there would be constant stimulation of the post-synaptic membrane and fatigue.

2 Dopamine synapses: produce the neurotransmitter dopamine, the axons from them spread through the frontal cortex, the brain stem and the spinal cord, so they are closely involved in the control and coordination of movement.

Serotonin synapses: produce serotonin in a group of cells in the brain stem with axons that spread throughout the brain into the cortex, the cerebellum and the spinal cord. They have a widespread influence on cells throughout the brain so low levels mean overall brain activity is suppressed. Particularly related to depression.

3

L-dopa	Ecstasy
- Precursor of dopamine so crosses the blood–brain barrier	- Crosses blood–brain barrier
- Enables brain cells to maximise dopamine production	- Affects serotonin synapses in brain; blocks the serotonin reuptake system so synapses flooded with serotonin and may cause release of all the serotonin from presynaptic knob, flooding brain with serotonin

- Relieves stiffness and slowness of movement	- Acts as stimulant to brain and psychotropic
- Therapeutic	- Improves mood, sense of wellbeing, energy, etc.
	- Physiological effects include increased heart rate, change in thermoregulation, loss of thirst sensation, prevention of urine production by kidney

8B.5 Chemical control systems in plants

1 Light: needed for photosynthesis, important that shoots and leaves move towards it. Roots need to be in the soil so response away from light helps make sure they grow in the right direction. Respond to direction, intensity and length of exposure.

Gravity: growth movements of plant parts towards or away from the pull of gravity. Roots grow towards gravity, shoots away. This helps to orientate the young plant as the seed germinates below ground – shoots grow up, roots down, whichever way up the seed is planted.

Chemicals: plant roots will grow towards some chemicals and away from others.

Water: roots grow towards water – moves them into right direction in the soil.

Temperature – some plants or parts of plants respond to changes in temperature. In some cases, there is a positive movement towards lower temperature – for example, many roots – and sometimes parts of the plant respond to protect the cells and tissues – for example, rhododendron leaves curl in the cold. Important in order to help roots grow in the right direction and also to protect plant tissues from cold.

Touch – thigmotropism, plants grow around things in response to touch – for example, runner beans curving up canes, etc.

2 Plants respond to stimuli by growth. They need to respond to light levels, direction, etc. throughout life so it is important that they can continue to grow. Animals respond largely by muscle contractions, etc., in response to nerves so they can continue to respond when growth has stopped.

8B.6 Phytochrome and flowering

1 (a) A blue–green plant pigment that is sensitive to different wavelengths of red light and that is involved in the control of flowering. Phytochromes exist in two interconvertible forms: P_r or P_{660} absorbs red light; P_{fr} or P_{730} absorbs far red light. When one form of the pigment absorbs light, it is converted reversibly into the other form.

(b) The balance between the two forms of phytochrome is affected by varying periods of light and dark, and the phytochrome balance in turn affects the plant metabolism, including flowering patterns. Sunlight contains more red light than far red light, so in daylight most of the phytochrome is in the far red form, P_{fr}. If the night period is long enough, it is all converted back into the red form, P_r.

In some cases, phytochromes have a stimulating effect on plants, in others an inhibitory effect. The current hypothesis is that, in short-day plants, the biologically active molecule P_{fr} inhibits flowering and a lack of P_{fr} allows flowering to occur. During long periods of darkness, the levels of P_{fr} fall as it is almost all converted to P_r. This allows flowering to take place.

In long-day plants it appears that high levels of P_{fr} stimulate flowering. The nights are short so relatively little P_{fr} is converted back to P_r. As a result, relatively high P_{fr} levels are maintained all the time, stimulating flowering.

2 Suggests chemical message produced in leaf exposed to periods of light and dark which travels to the flowering apical meristem.

If it is a chemical message, takes time to be synthesised and to travel through plant from leaf to buds – so if leaf removed immediately no time for message to be made and moved.

Suggests chemical message moves from one plant to another to stimulate flowering in both.

Chemical from leaf exposed to light and dark moves out into tissues of host plant – again suggests chemical message.

3 Can be done in various ways – look for evidence that students have followed the main points of the process and demonstrate that they understand the interaction of phytochromes and the theoretical compound florigen (using FTmRNA).

8B.7 Phytochrome and transcription

1 Different students will approach this differently – look for the key elements of the theory and an understanding of how the different elements interact.

2

Part of plant affected	**Effect of red light (light, build-up of P_{fr})**	**Effect of far red light (dark, build-up of P_r)**
Seed	Stimulates germination	Inhibits germination
Stem	Elongation inhibited by red light	Elongation stimulated by far red light
		Exposure to far red light gives the same effect as etiolation
Leaf	Expansion is stimulated by red light	Expansion is inhibited by far red light
	Chlorophyll formation stimulated	Chlorophyll formation inhibited
Lateral roots	Growth of lateral roots is inhibited	Growth of lateral roots is stimulated
Flowering	In SDPs red light inhibits flowering	In SDPs far red light promotes flowering
	In LDPs red light stimulates flowering	In LDPs far red light inhibits flowering

8B Exam practice

1 (a) (i) D

(ii) B

(iii)

Area of Brain	Function
cerebrum	conscious thoughts and movements
medulla oblongata	*control heart rate*
hypothalamus	*thermoregulation*
cerebellum	fine control of movement

(b) B = medulla oblongata

C = cerebellum

(c) To increase surface area.

So it can contain more cells.

2 (a) A

(b)

Effect	Auxins	Gibberellins
Promote cell elongation	✓	✓
Promote root formation in cuttings and calluses	✓	×
Promote fruit growth	×	✓
Inhibit lateral bud development	✓	×
Promote the breaking of dormancy in seed	×	✓

3 (a) C

(b) (i) C

(ii) Phytochrome P_{fr} is the active form.

It inhibits flowering.

At night P_{fr} is converted to P_r slowly.

It takes more than 7 hours to convert enough P_{fr} to allow flowering.

(c) (i) The part of the leaf covered for ten hours converted its P_{fr} to P_r.

Inhibition of flowering was removed.

The activated chemical (FTmRNA) circulated around the plant.

(ii) E is a control.

It shows that only part of the plant needs to be covered / it shows that it is not total light absorbed that causes flowering.

(d) Allows plants to flower at certain time of year.
They can flower when conditions in habitat are most suitable.
Avoid competition from other plants.

4 (a) (i) D

(ii)

stimulus	receptor	coordination	effector	response
high light intensity	cells in retina	centres in mid brain and oculomotor nerve	circular muscles in iris	reduce size of pupil

(iii) In bright light the visual pigments are bleached.
Unable to respond to light.
Reducing size of pupil prevents complete bleaching so vision is retained.

(b) The autonomic nervous system is divided into two parts, the sympathetic and the parasympathetic systems.
The sympathetic system and the parasympathetic have nerves which connect to the pacemaker of the heart.
Impulses sent down the sympathetic nerve will speed up the heart rate.
There are also sympathetic nerves to the adrenal glands which release adrenalin and speed the heart up.
Impulses down the parasympathetic nerves will slow down the heart rate.

5 (a) $100 \times (70 - 4)/4 = 1650\%$

(b) The shoots treated with gibberellins already had auxin present as the apical buds were not removed.
This means that he was investigating the effect of combining auxin and gibberellins.
Also, the shoots treated with auxin already had auxin present so she was investigating the effect of increasing the auxin concentration.
He did not investigate the effect of gibberellin on its own nor did she compare auxin to no auxin.

(c) Growing plants with the apical bud intact but no gibberellins or auxin applied.

(d) To show the results are repeatable / reliable.
To enable a mean to be calculated.
To enable any anomalous results to be identified.

8C Gene technology

8C Checkpoint

8C.1 Producing recombinant DNA

1 Either synthesis of an artificial copy of desired gene or restriction endonucleases chop up healthy DNA to isolate desired gene leaving sticky ends → integrate new gene into vector, for example, DNA ligases attach the new DNA segment into the DNA of the plasmid or virus to be used as a vector → the vector is used to introduce the new DNA to the host cell → once vector in host, nucleus forms recombinant DNA.

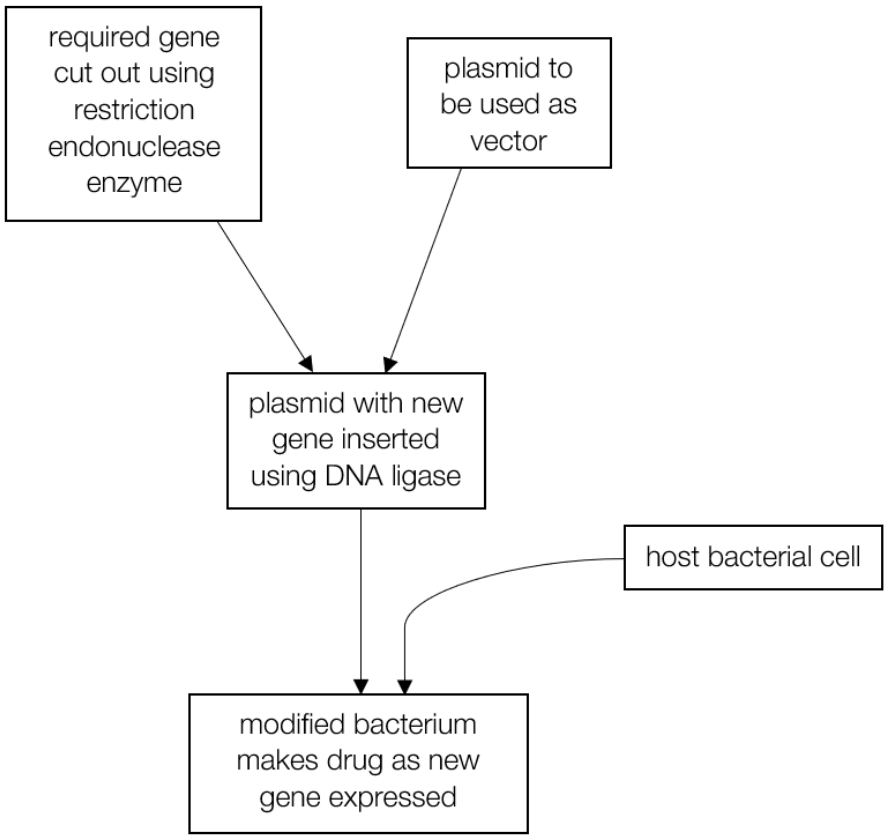
2 Usually attempts are made to genetically modify a lot of organisms, but relatively few attempts are successful. With bacteria, replica plating allows the identification of those organisms that have been successfully genetically modified so that they can be isolated and grown into pure cultures of GM organisms. Often a gene giving a colour change with a particular medium, or an inability to survive in a medium with particular amino acids or other nutrients missing, is engineered into the organism with the desirable gene. This gives a way of identifying successfully modified organisms. A mixture of bacteria is grown on complete medium and a replica plate of colonies in the same positions is grown on an amino acid-deficient medium. The colonies that are missing in the replica plate are those that have been successfully engineered. Those colonies are then removed from the master plate and grown on as pure cultures of the GM organisms.

3 They are all effective at getting new DNA into a host cell, but they have different advantages and disadvantages.

- Plasmids (bacterial DNA) are particularly useful in bacteria as they pass into the host cell and can combine with or work independently of the main host DNA. They are not helpful in engineering animals as plasmids are not part of animal genetics.
- Harmless viruses infect cells and insert their genetic material into the host cell DNA. This makes them useful for inserting desirable genes into human cells where the viral DNA with the new gene combines with the host DNA. However, this method is limited as viruses must be harmless and must be effective at inserting their DNA in a range of hosts.
- With gene guns the required DNA is shot into the cell at high speed, carried on minuscule gold or tungsten pellets. Some cells survive and accept the DNA as part of their genetic material. Used relatively successfully on plant cells.
- Liposomes are lipid spheres which fuse with cell membranes and allow new DNA into the cell – hopefully some of this makes it to the nucleus to fuse with the host DNA. There are hopes that this technique will work for human cells as it is relatively non-invasive.

8C.2 Drugs from genetically modified organisms

1 The diagram given here is a minimum. Give credit for any correct extra details



2.

Drugs from GM plant	Drugs from GM microorganism
- Required gene cut from human or other organism and inserted into TI plasmid of *Agrobacterium tumefaciens*	- Required gene cut from human or other organism and inserted into plasmid
- Plant cells infected by modified *A. tumefaciens* which transfers desired gene to the plant genome	- Plasmid transferred into host bacterial cells where it becomes part of bacterial DNA, marker gene usually added
- Plant cells then cloned on suitable hormone- containing medium to produced mass of undifferentiated modified plant cells	- Bacteria identified by marker cultured in fermenters to make new protein drugs
- Plant cells then transferred to suitable medium to produce huge numbers of GM plantlets that will mature to produce the desired drug in their leaves/fruit etc.	- Downstream processing required to separate the microorganisms and the desired end product

3 The answer should include some or all of the following.

Possible examples include: blood-clotting factors Factor VII and IX from goat / sheep / rabbit milk; alpha-1-antitrypsin from sheep milk; ATryn (for treating hereditary antithrombin deficiency) from goat milk.

Evaluation will depend on drug chosen, but should include an assessment of cost of producing the drug, effect on animals used, success of procedure used to create

transgenic animals, benefits to people who are treated with the drug compared with previous treatment.

Other points may be valid.

8C.3 Microarrays and bioinformatics

1 Collect mRNA samples – reference and patient → reverse transcriptase enzymes convert both mRNA samples to cDNA → cDNA samples given fluorescent labels (green known, red unknown) → samples mixed and applied to microarray slide → cDNA binds to matching probes (hybridisation) → microarray scanned to measure fluorescence → data analysed to identify specific gene.

2 Bioinformatics is the development of the software and computing tools needed to organize and analyse raw biological data, including the development of algorithms, mathematical models and statistical tests. It is important because the volume of data now generated in many areas of biology – for example using microarrays and other forms of DNA analysis – is so enormous, and bioinformatics allows us to process and use the information generated.

8C.4 Benefits and risks of GMOs

1 Many people think that the use of GM bacteria in the production of drugs such as insulin is a very good thing that does not damage the bacteria, but that brings a lot of benefit to many people and makes a number of drugs more accessible to people.

Some people think that changing the genetic material of any organisms is interfering with nature / the will of their God and feel it is unethical and wrong, even if it does save many lives and improve the quality of life of many people.

Any other sensible and well-expressed positions.

2 Look for evidence of research from a reputable site and an evaluation of the available evidence.

3 The changed balance of fatty acids in soya beans benefits the producers because there is a higher percentage of oleic acid. This does not oxidise easily so the soya beans and their products last longer before going off. This benefits the producers.

Oleic acid is a monounsaturated fatty acid and there is some evidence that it is better for the health than linoleic acid. So, using products made with the modified soya beans means consumers have potential health benefits as well as possible price reductions because the beans have a longer shelf life.

4 Any three sensible points, for example:

GM crops can be engineered to give much higher yields so much more food can be grown using the same amount of land.

GM crops can be engineered to contain specific levels of nutrients and so aspects of malnutrition, for example, lack of protein or vitamins, could be overcome by a GM version of a normal staple crop.

Crops can be engineered to withstand extremes of weather, such as flooding or drought, enabling food to be grown successfully in spite of possible climate changes and extreme weather events.

Crops can be engineered to produce their own pesticides/fertiliser and so reduce production costs and pollution, keeping soil and environment healthier.

8C Exam practice

1 (a) D

(b) B

(c) A = reverse transcriptase, B = DNA polymerase

(d) Cut plasmid with restriction enzyme creating sticky ends.

Add sticky ends to cDNA.

Ligase enzyme then joins cDNA to plasmid.

2 (a) It involves genetic modification of yeast.

(b) (i) Reverse transcriptase used to make cDNA from mRNA.

DNA polymerase used to convert single stranded DNA to double stranded.

Ribosomal enzymes used to make prochymosin in yeast cells.

Enzymes used to convert prochymosin to chymosin.

(ii) The cDNA incorporates a fluorescence gene.

When successfully modified yeast grow they will fluoresce in ultraviolet light.

3 (a) Larger crop / less loss of cotton to insect.

Better quality crop / less damage to cotton by insects.

Less use of chemicals so other insects in habitat not harmed (and health and safety of farmers is protected).

(b) Both plant breeding and genetic modification produce new combinations of characteristics in the cotton plants.

Both produce new combinations of genetic information.

In traditional plant breeding new alleles of existing genes are introduced from other plants of the same species.

In genetic modification new genes are introduced from another species.

(c) Arguments **for** GM:

- can grow crops that have better nutritional value
- can grow crops faster / bigger yield
- can make use of land that is not productive
- can help to reduce famine / starvation.

Arguments **against**:

- modified genome could escape to the wild and cause disruption of habitat
- food may cause disease / cancer
- we do not know what the long terms effect of genetic engineering may be
- who owns the new genome? – will unethical companies force people to pay for products.

4 (a) (i)

Name of enzyme	**Process**
ligase	*Join sections of DNA together*
DNA polymerase	Produce new DNA molecules / replicate DNA
Restriction endonuclease	*Cut DNA at specific sequence*
Reverse transcriptase	Make single stranded DNA from mRNA

(ii) C

(b) (i) D

(ii) B

(c) (i) Plasmid
(ii) Bacterium Agrobacterium tumefaciens.
(iii) Liposomes.
(iv) Virus

(d) T R S V W U