EXAMPLE GRAMMAR SCHOOL

ESAT Mock: Worked Solutions

Biology

Paper SMP-2026-09 · Version 1.0

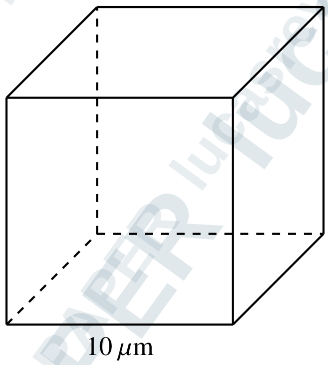
Staff copy

This document contains the answers. Keep it away from candidates until the paper has been sat. Marking guidance is in the separate mark scheme.

Question 1

B2.1 · Cells · ★★☆☆☆ · 40 s

The diagram shows a cubic cell, with the length of one side marked. What is its surface area to volume ratio in its simplest integer form?



A. 6 : 1
B. 1 : 10
C. 3 : 5
D. 5 : 3
E. 3 : 50

Answer C. Key idea

Surface area grows with the square of a length while volume grows with the cube, so the ratio of the two is not a fixed property of a shape: it depends on size. For a cube of side L the surface area is $6L^2$ and the volume is L^3, so the ratio is $6L^2 : L^3$, which simplifies to $6 : L$. The larger the cell, the smaller its surface area to volume ratio, which is why a large cell cannot supply its interior by diffusion across its surface alone.

Worked solution

1. Calculate Surface Area

$\mathrm{SA} = 6 \times L^2 = 6 \times (10)^2 = 6 \times 100 = 600\,\mu\mathrm{m}^2$

2. Calculate Volume

$V = L^3 = (10)^3 = 1000\,\mu\mathrm{m}^3$

3. Simplify ratio

Ratio = 600 : 1000 Divide both sides by their greatest common divisor (200): 3 : 5

Matches Option **C**.

Why the other options are wrong

- **A** (6 : 1): Squared the side instead of cubing it when finding the volume, so V = 100 rather than 1000. That gives 600 : 100, which simplifies to 6 : 1. *(Calculation Error)*
- **B** (1 : 10): Counted the area of one face only, taking SA = 10 x 10 = 100 instead of 6 x 100 = 600. That gives 100 : 1000, which simplifies to 1 : 10. *(Conceptual Error)*
- **D** (5 : 3): Reversed the ratio to Volume : Surface Area, giving 1000 : 600, which simplifies to 5 : 3. *(Reading Error)*
- **E** (3 : 50): Forgot to square the side in the surface area, taking SA = 6 x 10 = 60 instead of 6 x 100 = 600. That gives 60 : 1000, which simplifies to 3 : 50. *(Calculation Error)*

Common mistake. Reversing the ratio to Volume:Surface Area.

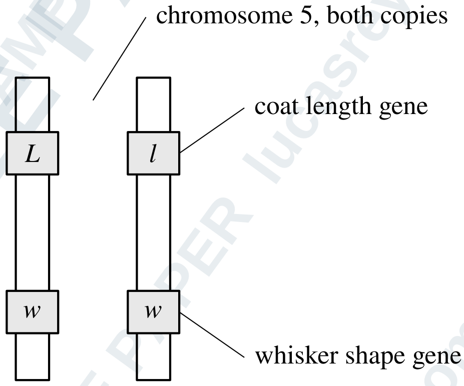
Takeaway. The Cheat Code: for a cube of side L the ratio is always 6 : L before simplifying. Compute the two quantities separately, then cancel: never quote the ratio the other way round, because surface area comes first in the name.

Time-saving tip. Speed Heuristic: Look at the relative magnitudes and units in the multiple-choice options to eliminate extreme or impossible values immediately.

Question 2

B4.2 · Genetics · ★★☆☆☆ · 85 s

In domestic cats, one gene on chromosome 5 controls coat length, with the short-fur allele L completely dominant over the long-fur allele l. A second gene on the same chromosome controls whisker shape, with the straight allele W completely dominant over the curled allele w. The diagram shows the alleles carried on one cat's two copies of chromosome 5. Which statement describes this cat correctly?



A. It is homozygous for coat length and heterozygous for whisker shape, so it has short fur and straight whiskers.
B. It is homozygous for coat length and homozygous for whisker shape, so it has short fur and curled whiskers.
C. It is heterozygous for coat length and heterozygous for whisker shape, so it has short fur and straight whiskers.
D. It is heterozygous for coat length and homozygous for whisker shape, so it has short fur and curled whiskers.
E. It is heterozygous for coat length and homozygous for whisker shape, so it has long fur and curled whiskers.
F. It is homozygous for coat length and homozygous for whisker shape, so it has long fur and curled whiskers.

Answer D. Key idea

Homozygous and heterozygous describe one pair of alleles, not an organism as a whole, so the same cat can be homozygous at one gene and heterozygous at another. Whether the two alleles at that gene are identical is the only thing that decides the term. Which characteristic then shows is a separate question, settled by dominance: a completely dominant allele shows whenever it is present, so the recessive characteristic appears only where both alleles at that gene are the recessive one.

Worked solution

1. Compare the two alleles at each gene

Take the genes one at a time, reading across the pair of chromosomes.

At the coat-length gene the cat carries L on one copy and l on the other. Two different versions of one gene means heterozygous.

At the whisker gene it carries w on one copy and w on the other. Two identical versions means homozygous, and here homozygous for the recessive allele.

2. Apply dominance to get the characteristics

L is completely dominant, so it shows whenever it is present: the Ll cat has short fur. The whisker pair is ww, with no W anywhere on either chromosome, so there is nothing to mask the recessive allele and the whiskers are curled.

The cat is therefore heterozygous for coat length, homozygous for whisker shape, short-furred and curl-whiskered.

Sanity check: the two options offering straight whiskers both need a W that the diagram does not show, and the two options offering long fur both need the L on the left-hand copy to be masked by l, which contradicts L being completely dominant. Only one statement survives both tests.

Matches Option **D**.

Why the other options are wrong

- **A** (It is homozygous for coat length and heterozygous for whisker shape, so it has short fur and straight whiskers.): Swaps the two words, calling the mixed pair Ll homozygous and the identical pair ww heterozygous. Following that through, the supposedly heterozygous whisker pair is then given the dominant characteristic, so the whiskers come out straight. *(Terms Swapped)*
- **B** (It is homozygous for coat length and homozygous for whisker shape, so it has short fur and curled whiskers.): Reads both characteristics correctly, short fur because L is completely dominant in the Ll pair and curled whiskers because the ww pair contains no W to mask the recessive allele, but calls both genes homozygous on the grounds that each gene is present on both copies of chromosome 5. Homozygous asks whether the two alleles at one gene are the same letter, and at the coat-length gene they are L and l, so that pair is heterozygous. This differs from the reading that makes the same mistake with the terms and then also lets the recessive l show and reports long fur: here dominance is applied correctly and only the terminology is wrong, which is why it needs the definition to eliminate. *(Homozygous read as carrying two copies of the gene)*
- **C** (It is heterozygous for coat length and heterozygous for whisker shape, so it has short fur and straight whiskers.): Assumes an individual must be heterozygous at every gene because its two chromosome copies came from different parents. Both pairs are then called heterozygous, and a heterozygote shows the dominant characteristic, giving straight whiskers as well as short fur. *(Conceptual Error)*
- **E** (It is heterozygous for coat length and homozygous for whisker shape, so it has long fur and curled whiskers.): Reads both terms correctly but lets the lower-case l show in the Ll pair. That treats the long-fur allele as the one expressed in a heterozygote, which reverses the dominance stated, and gives long fur. *(Dominance Reversed)*

- **F** (It is homozygous for coat length and homozygous for whisker shape, so it has long fur and curled whiskers.): Takes homozygous to mean nothing more than carrying two alleles of one gene, which is true of every pair, so both genes are called homozygous. The recessive letter is then read off at each, giving long fur and curled whiskers. *(Conceptual Error)*

Common mistake. Calling the whole cat heterozygous because its two chromosomes came from different parents. The terms apply gene by gene, and at the whisker gene the two copies happen to carry the same allele.

Takeaway. **The Cheat Code:** Read each gene's pair on its own. Two letters the same is homozygous, two letters different is heterozygous. Then, with complete dominance, the small letter shows only where there is no capital in that pair.

Time-saving tip. Speed Heuristic: Go to the whisker gene first. Both copies carry w, so curled whiskers are certain and the two options promising straight whiskers go at once. Only the coat-length pair on the three survivors then has to be read.

Question 3

B4.1 · Know and understand the nucleus as a site of genetic material in eukaryotic cells · ★★☆☆☆ · 45 s

Gene expression is controlled from the nucleus by

A. selecting which genes are transcribed to mRNA.
B. deleting unused genes permanently.
C. moving genes to the ribosomes.
D. choosing which proteins are eaten.
E. dissolving the nuclear membrane.

> ### Answer A. Key idea
> The nucleus controls gene expression by selecting which of its genes are transcribed into mRNA at any given time. The DNA stays inside the nucleus; only the mRNA copy leaves, so control is exercised over transcription rather than over the genes themselves.

Worked solution

The nucleus: stores chromosomes (DNA+protein), transcribes selected genes to mRNA, controls the cell's activities. Prokaryotes keep DNA free in the cytoplasm.

Applied: gene expression is controlled from the nucleus by. . . → selecting which genes are transcribed to mRNA.

Matches Option **A**.

Why the other options are wrong

- **B** (deleting unused genes permanently.): Cells regulate TRANSCRIPTION, not genome content. *(Conceptual Error)*
- **C** (moving genes to the ribosomes.): mRNA travels; genes stay. *(Conceptual Error)*
- **D** (choosing which proteins are eaten.): Nutrition is irrelevant to gene expression control. *(Conceptual Error)*
- **E** (dissolving the nuclear membrane.): That happens only in division. *(Conceptual Error)*

Common mistake. Nutrition is irrelevant to gene expression control.

Takeaway. Treat the nucleus as both library and head office: it stores the chromosomes intact and decides which genes get transcribed. Regulation changes which mRNA is made, never which genes the cell possesses.

Time-saving tip. nucleus = library + head office, apply and verify.

Question 4

B3.4 · Sex determination · ★★☆☆☆ · 45 s

A sperm carrying a Y chromosome fertilises an X egg. The child will be

- **A.** female (XX).
- **B.** female (X).
- **C.** male (YY).
- **D.** male (XX).
- **E.** male (XXY).
- **F.** male (XY).
- **G.** female (XY).
- **H.** cannot be determined.

Answer F. Key idea

Every egg carries an X, so the sperm's sex chromosome decides the outcome: an X sperm gives a female (XX), a Y sperm gives a male (XY). Here a Y sperm fertilises the X egg, so the zygote is XY and the child is male.

Worked solution

Females are XX (all eggs carry X). Males are XY (sperm split 50/50 X:Y). Punnett square of XX $\times$ XY: 2 XX, 2 XY $\rightarrow$ 1:1 sex ratio, decided at fertilisation.

Applied: a sperm carrying a Y chromosome fertilises an X egg. The child will be... $\rightarrow$ male (XY).

Matches Option **F**.

Why the other options are wrong

- **A** (female (XX).): Two X's make female; this zygote has X and Y. *(Conceptual Error)*
- **B** (female (X).): Records only the mother's contribution, the single X of the egg, and calls the zygote female because no Y has been written down. The sperm's Y enters the zygote as well, giving XY. *(Conceptual Error)*
- **C** (male (YY).): Assumes the male pair matches, by analogy with the female XX: the sperm brought a Y, so the pair is written YY. The egg still contributes its X, so the zygote is XY. *(Conceptual Error)*
- **D** (male (XX).): XX is female genotype. *(Conceptual Error)*
- **E** (male (XXY).): Forgets that meiosis halves the chromosome number and treats the mother as passing both her X chromosomes: XX from the egg plus Y from the sperm gives XXY, called male because a Y is present. An egg carries one X, not two, so the zygote is XY. *(Conceptual Error)*
- **G** (female (XY).): XY determines male. *(Conceptual Error)*
- **H** (cannot be determined.): The chromosomes given settle it. *(Conceptual Error)*

Common mistake. Defaulting to 'female' because the egg contributes an X: the egg always carries X, so it is the sperm's chromosome (here Y) that decides the sex.

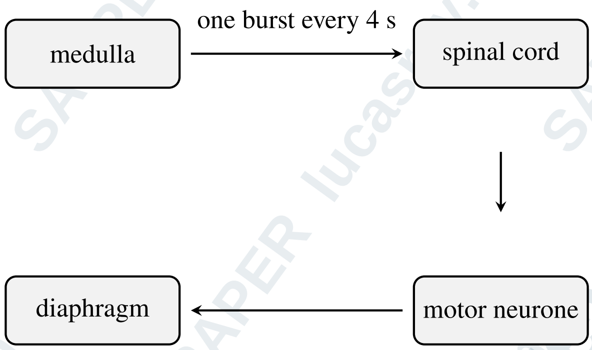
Takeaway. **The Cheat Code:** Mum can only give an X, so Dad's sperm flips the coin: an X sperm makes XX (female) and a Y sperm makes XY (male), which is why the ratio is 1:1.

Time-saving tip. Mum only has X; Dad's sperm flips the coin, apply and verify.

Question 5

B9.2 · Human physiology · ★★☆☆☆ · 90 s

The diagram shows the pathway and the timing of the bursts of impulses that drive each inspiration in a resting adult. Every burst contains 30 impulses, and each whole burst produces one contraction of the diaphragm, drawing 450 cm^3 of air into the lungs. Breathing stays quiet and regular. Calculate the volume of air drawn into the lungs each minute.



A. 6750 dm^3 min^{-1}
B. 13.5 dm^3 min^{-1}
C. 27.0 dm^3 min^{-1}
D. 0.45 dm^3 min^{-1}
E. 1.8 dm^3 min^{-1}
F. 202.5 dm^3 min^{-1}
G. 67.5 dm^3 min^{-1}
H. 6.75 dm^3 min^{-1}

Answer H. Key idea

A motor neurone carries impulses out from the central nervous system to an effector, and the whole burst that arrives drives one contraction of that effector, however many impulses the burst contains. The volume of air moved per minute is then the volume drawn in by one contraction multiplied by the number of contractions in a minute, with both quantities put into the units the answer is wanted in.

Worked solution

1. Turn the burst interval into a breathing rate

One whole burst produces one contraction of the diaphragm, so one burst is one inspiration whatever the number of impulses inside it. A burst every 4 seconds gives

$$\frac{60}{4} = 15 \text{ inspirations per minute.}$$

The 30 impulses describe the traffic along the motor neurone that drives a single contraction; they are not a count of breaths.

2. Put the volume into the units of the answer

$$450\ \text{cm}^3 = \frac{450}{1000} = 0.45\ \text{dm}^3 \text{ drawn in per inspiration.}$$

3. Combine volume per breath with breaths per minute

$0.45 \times 15 = 6.75\ \text{dm}^3\ \text{min}^{-1}$.

Sanity check: a resting adult moves roughly half a cubic decimetre of air about fifteen times a minute, so an answer near 7 $dm^3\ min^{-1}$ is the size expected. An answer of 6750 $dm^3\ min^{-1}$ would be over six cubic metres of air every minute.

Matches Option **H**.

Why the other options are wrong

- **A** (6750 $dm^3\ min^{-1}$): Multiplies 450 by 15 and labels the result in cubic decimetres: $450 \times 15 = 6750$. The tidal volume is measured in cm^3 and $1000\ cm^3 = 1\ dm^3$, so it must be divided by 1000 before the multiplication. *(Volume conversion omitted)*
- **B** (13.5 $dm^3\ min^{-1}$): Takes the 30 impulses in a burst as thirty inspirations: $0.45 \times 30 = 13.5$. Every impulse in one burst serves the same single contraction, so the burst counts once, not thirty times. *(Impulses counted as breaths)*
- **C** (27.0 $dm^3\ min^{-1}$): Assumes one inspiration each second, giving sixty per minute: $0.45 \times 60 = 27.0$. The recording places one burst every 4 seconds, so the sixty seconds must be divided by four first. *(Interval dropped from the conversion)*
- **D** (0.45 $dm^3\ min^{-1}$): Converts the tidal volume and stops there: $450 \div 1000 = 0.45$. That is the volume drawn in by one contraction, and it still has to be multiplied by the 15 inspirations a minute contains. *(Volume per breath reported as volume per minute)*
- **E** (1.8 $dm^3\ min^{-1}$): Reads 'a burst every 4 seconds' as four inspirations per minute: $0.45 \times 4 = 1.8$. An interval has to be inverted before it becomes a rate, and $60 \div 4$ gives 15 inspirations per minute. *(Interval used directly as a rate)*
- **F** (202.5 $dm^3\ min^{-1}$): Gets the burst rate right but gives every impulse its own contraction: $30 \times 15 = 450$ contractions per minute, then $0.45 \times 450 = 202.5$. The stem states that one whole burst, all 30 impulses of it, produces a single contraction. *(Each impulse counted as a contraction)*
- **G** (67.5 $dm^3\ min^{-1}$): Divides by 100 instead of 1000: $450 \div 100 = 4.5$, then $4.5 \times 15 = 67.5$. There are 1000 cm^3 in 1 dm^3, so each inspiration is 0.45 dm^3. *(Wrong factor in the volume conversion)*

Common mistake. Using the number of impulses in a burst as the breathing rate. The impulses are the signal that produces one contraction; how often breathing happens is set by how often a burst arrives, which here is once every 4 seconds.

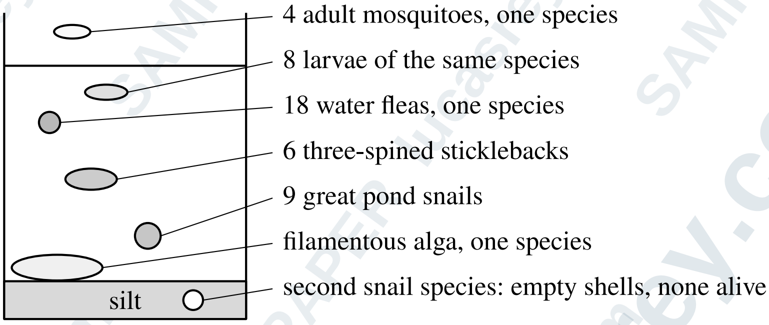
Takeaway. The Cheat Code: Turn an interval into a per-minute rate before anything else, and convert the volume into the units the options use at the same time. Any per-minute total is then volume per event multiplied by events per minute.

Time-saving tip. Speed Heuristic: $60 \div 4 = 15$, then split the multiplication: $0.45 \times 10 = 4.5$ and $0.45 \times 5 = 2.25$, which add to 6.75. The count of 30 impulses never enters the arithmetic.

Question 6

B10.1 · Ecology · ★★☆☆☆ · 90 s

A drainage ditch is surveyed as part of a study of freshwater ecology. The diagram shows the ditch in cross-section, and what the survey recorded in it. The surveyors also record the temperature of the water, the depth of the silt and the concentration of dissolved oxygen. Assume the survey found every species that is present as a living organism, and that the ditch is isolated from other water bodies. How many populations make up the community in this ditch?



- **A.** 5
- **B.** 4
- **C.** 6
- **D.** 7
- **E.** 45

Answer A. Key idea

The levels of organisation in an ecosystem are nested: an individual is one organism, a population is all the individuals of one species living in the same place, a community is all the populations living there together, and the ecosystem is that community together with the non-living surroundings it interacts with. Counting populations therefore means counting living species rather than individuals, and a larva and an adult of one species belong to a single population, while a species left only as dead remains has no living members and so no population in that place.

Worked solution

1. Separate the living organisms from everything else recorded

A community is made up of living organisms only, so the temperature of the water, the depth of the silt and the concentration of dissolved oxygen are set aside straight away. They are the non-living part of the ecosystem, not members of the community.

2. Group the living individuals into species

Water fleas, great pond snails, three-spined sticklebacks, mosquitoes and the filamentous alga make five species. The alga is counted: a population is a population whether the organism photosynthesises or not, and the producers belong to the community as much as the consumers do. The 8 larvae and the 4 adult mosquitoes are one species at two stages of a single life cycle, so they are 12 individuals forming one population, not two populations.

3. Rule out the species with no living members

The second snail species appears only as empty shells in the silt. A population is the living individuals of a species in a place, so with none alive in the ditch that species contributes no population to this community. The community is therefore made up of 5 populations.

Sanity check: every number in the survey, 18, 9, 6, 8 and 4, counts individuals, and individuals sit one level below populations, so the answer must be far smaller than their total of 45.

Matches Option **A**.

Why the other options are wrong

- **B** (4): Took a community to mean the animals in it and left the filamentous alga out, counting only water fleas, snails, sticklebacks and mosquitoes for 4. A community is every population in the habitat, and the producers are part of it just as the consumers are. *(Producers excluded)*
- **C** (6): Added the second snail species on the strength of its empty shells, giving $5 + 1 = 6$. Shells are dead remains, and with no living individual of that species in the ditch there is no population of it to count. *(Dead remains counted)*
- **D** (7): Counted the empty shells as a population and also split the mosquitoes into a larval population and an adult population, giving $5 + 1 + 1 = 7$. The shells are not alive, and the larvae and adults of one species make one population. *(Dead remains counted and life stages split)*
- **E** (45): Added the individuals recorded, $18 + 9 + 6 + 8 + 4 = 45$, and gave that as the answer. Individuals are the level below populations: those 45 organisms are grouped into populations, and the question asks how many of those groups there are. *(Individuals counted instead of populations)*

Common mistake. Splitting one species across its life stages. The 8 mosquito larvae and the 4 adult mosquitoes look like two different kinds of animal and get counted as two populations, but they are the same species living in the same ditch, so they are 12 individuals of one population.

Takeaway. **The Cheat Code:** Go down the list once and ask two questions of every entry: is it alive, and is it a species already counted? Anything non-living belongs to the ecosystem rather than the community, and any second life stage, second sex or second colour form of a species already on the list adds nothing to the total.

Time-saving tip. Speed Heuristic: Count species names, not entries. Strike out the three physical measurements, merge the larvae with the adults, and delete the shells, and the survey collapses to five living species before a single number is used.

Question 7

B3.1 · Cell division · ★☆☆☆☆ · 20 s

A single cell undergoes 4 consecutive rounds of mitosis. Assuming all daughter cells survive and divide, how many cells will be present at the end?

A. 8
B. 488
C. 16
D. 831
E. 547

Answer C. Key idea

Apply fundamental principles of Cell division. Isolate the unknown variable systematically and check dimensional and physical consistency.

Worked solution

1. Understand mitosis cell division

Each round of mitosis doubles the number of cells. The formula for the number of cells after n divisions is 2^n.

2. Calculate

$2^4 = 16$

Matches Option **C**.

Why the other options are wrong

- **A** (8): Multiplied by 2 instead of calculating 2^n. *(Mathematical Error)*
- **B** (488): Arises from a common inversion, algebraic sign error, or omitting an intermediate conversion factor. *(Calculation / Conceptual Error)*
- **D** (831): Arises from a common inversion, algebraic sign error, or omitting an intermediate conversion factor. *(Calculation / Conceptual Error)*
- **E** (547): Arises from a common inversion, algebraic sign error, or omitting an intermediate conversion factor. *(Calculation / Conceptual Error)*

Common mistake. Multiplying the number of divisions by 2 instead of taking 2 to the power of n.

Takeaway. The Cheat Code: Always inspect units and algebraic structure before calculating. Simplifying fractions and factoring terms early reduces computation time by more than 50%.

Time-saving tip. Speed Heuristic: Look at the relative magnitudes and units in the multiple-choice options to eliminate extreme or impossible values immediately.

Question 8

B1.3 · Know and understand the levels of organisation within organisms as · ★★☆☆☆ · 45 s

Which list goes from simplest to most complex?

A. muscle cell → muscle tissue → heart → circulatory system.
B. circulatory system → heart → muscle tissue → muscle cell.
C. muscle tissue → muscle cell → circulatory system → heart.
D. muscle cell → heart → muscle tissue → circulatory system.
E. heart → muscle cell → muscle tissue → circulatory system.
F. muscle cell → muscle tissue → circulatory system → heart.

Answer A. Key idea

muscle cell → muscle tissue → heart → circulatory system

Worked solution

The hierarchy: CELL (basic unit) → TISSUE (similar cells, one job) → ORGAN (different tissues, one structure) → ORGAN SYSTEM (organs cooperating) → ORGANISM.

Applied: which list goes from simplest to most complex. . . → muscle cell → muscle tissue → heart → circulatory system.

Matches Option **A**.

Why the other options are wrong

- **B** (circulatory system → heart → muscle tissue → muscle cell.): Reversed. *(Conceptual Error)*
- **C** (muscle tissue → muscle cell → circulatory system → heart.): Tissues precede systems, not organs. *(Conceptual Error)*
- **D** (muscle cell → heart → muscle tissue → circulatory system.): Tissues build organs, not the reverse. *(Conceptual Error)*

- **E** (heart → muscle cell → muscle tissue → circulatory system.): Swaps both pairs: it places muscle tissue before the muscle cell (cells build tissues) and the circulatory system before the heart (organs build organ systems). *(Conceptual Error)*
- **F** (muscle cell → muscle tissue → circulatory system → heart.): Gets the bottom of the hierarchy right, cell then tissue, then swaps the top two by placing the heart last as the largest single structure named. The circulatory system contains the heart together with the blood vessels, so the organ sits below the organ system: cell, tissue, organ, organ system. *(Organ ranked above the system containing it)*

Common mistake. Cells are the building blocks, they come first.

Takeaway. cells→tissues→organs→systems→organism

Time-saving tip. cells→tissues→organs→systems→organism, apply and verify.

Question 9

B3.3 · Cell division and reproduction · ★★☆☆☆ · 85 s

A gardener takes a single healthy potato plant and grows 200 new plants from its tubers, planting no seed. She then crosses two different potato varieties and raises 200 seedlings from the seed produced. Assuming no mutations occur, which statement about the two groups of 200 plants is correct?

A. The tuber-grown plants are all genetically identical; the seedlings are not.
B. The seedlings are all genetically identical; the tuber-grown plants are not.
C. All 400 plants are genetically identical to one another.
D. Neither group contains any two plants that are genetically identical.
E. Each seedling is genetically identical to one tuber-grown plant, though neither group is uniform.

Answer A. Key idea

The number of parents decides whether offspring are copies. Asexual reproduction involves one parent and no fusion of gametes, so when no mutations occur the offspring carry exactly that parent's genes and are therefore genetically identical to the parent and to each other. Sexual reproduction involves two parents, and each offspring receives its own combination of genes drawn from both, so the offspring differ from their parents and from one another. Growing plants from the tubers of one plant is the first case; raising plants from seed made by crossing two varieties is the second.

Worked solution

1. Classify each of the gardener's two methods

Tubers are part of the parent plant itself. Growing 200 plants from the tubers of one potato plant involves that single plant and no other, and no gametes fuse, so this is asexual reproduction with one parent.

The seed was produced by crossing two different varieties. Two parents contributed and each seed carries a combination of genes drawn from both, so this is sexual reproduction with two parents.

2. Apply the genetic consequence to each group

Asexual reproduction copies one parent's genes, and the stem rules out mutations, so nothing at all introduces a difference. All 200 tuber-grown plants therefore carry the same genes as the original plant and so as each other: that group is uniform.

Sexual reproduction combines two different sets of genes, and every seed receives its own combination. The two varieties crossed were different varieties, so there is real variation to draw on, and the 200 seedlings differ from one another.

Putting the two together: the tuber-grown group is genetically identical throughout and the seedlings are not.

Sanity check: the phrase assuming no mutations occur is what makes the first group exactly uniform, since mutation is the only thing that could disturb a copy. It does nothing to the second group, because the seedlings' variation comes from combining two parents rather than from mutation.

Matches Option **A**.

Why the other options are wrong

- **B** (The seedlings are all genetically identical; the tuber-grown plants are not.): This swaps the two methods over. It follows from thinking that a seed, which is shed by one plant, must be a copy of it, while tubers dug up and replanted in separate places must give rise to different plants. The direction is backwards: the seed here carries genes from two varieties, and the tubers carry the genes of one plant only. *(Asexual and sexual routes reversed)*
- **C** (All 400 plants are genetically identical to one another.): This takes assuming no mutations occur to mean that nothing can differ anywhere, so all 400 plants are counted as copies. Removing mutation does fix the tuber-grown group as identical, but the seedlings' variation was never caused by mutation. It comes from combining the genes of two different varieties, which the assumption does not touch. *(No-mutation assumption over-extended)*
- **D** (Neither group contains any two plants that are genetically identical.): This applies the rule for sexual reproduction to both batches, assuming that reproduction always produces offspring that differ. It overlooks the defining feature of the one-parent route: with no gametes fusing and no mutations, there is nothing to make one tuber-grown plant differ from the next, so that group contains 200 plants that are identical. *(Variation assumed to be universal)*
- **E** (Each seedling is genetically identical to one tuber-grown plant, though neither group is uniform.): This assumes the two batches were drawn from one shared stock, so that the seedlings mirror the tuber plants one for one. Nothing in the scenario links them that way. The tuber plants copy a single original plant, while each seedling is a fresh combination from two different varieties, so pairing them off across the groups has no basis, and it also denies that the tuber group is uniform. *(Invents a pairing between the two groups)*

Common mistake. Reading assuming no mutations occur as a promise that nothing anywhere can differ, and concluding that all 400 plants must match. That assumption only removes the one source of difference that could disturb copies made from a single parent. Variation among the seedlings has an entirely different origin: two parents, each contributing a different set of genes.

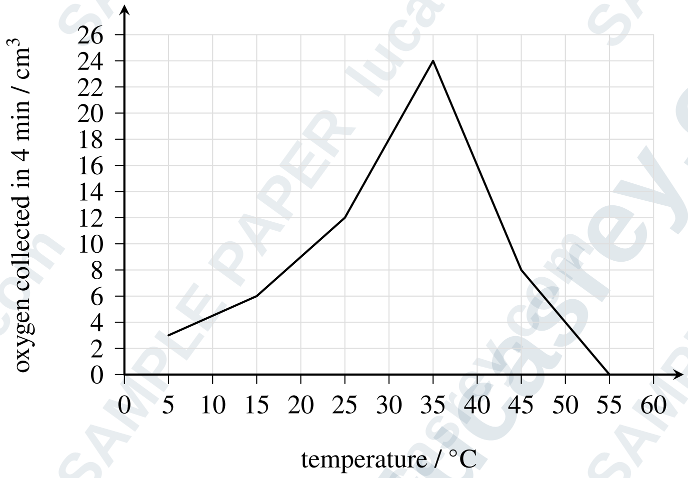
Takeaway. **The Cheat Code:** Count the parents before anything else. One parent with no mutations means the offspring are copies of it and of each other; two parents means every offspring is a fresh combination and no two need match. Tubers, runners, bulbs and cuttings are all the one-parent route, even though the plants they give end up growing separately.

Time-saving tip. Speed Heuristic: Label the two batches one parent and two parents before you read a single option, then look for the option that pairs identical with the one-parent batch. Four of the five can be dismissed without thinking about potatoes at all.

Question 10

B8.3 · Enzymes and digestion · ★★★☆☆ · 90 s

A student investigates catalase, the enzyme in potato tissue that breaks hydrogen peroxide down into water and oxygen. Identical potato discs are dropped into hydrogen peroxide held in a water bath, and the volume of oxygen collected during the first four minutes is recorded at six temperatures. The graph shows the results. Below its optimum temperature this enzyme obeys a temperature coefficient $Q_{10} = 2.0$, meaning that the rate is multiplied by 2.0 for every 10°C rise. Assume hydrogen peroxide is in excess throughout and that all the gas is collected at room temperature and pressure. Using the 15°C reading, calculate the rate of oxygen production at 45°C that this relationship predicts.



- **A.** 9 $cm^3\ min^{-1}$
- **B.** 24 $cm^3\ min^{-1}$
- **C.** 3 $cm^3\ min^{-1}$
- **D.** 48 $cm^3\ min^{-1}$
- **E.** 6 $cm^3\ min^{-1}$
- **F.** 2 $cm^3\ min^{-1}$
- **G.** 8 $cm^3\ min^{-1}$
- **H.** 12 $cm^3\ min^{-1}$

Answer H. Key idea

Below the temperature at which it denatures, an enzyme works faster as the temperature rises, because substrate and enzyme molecules collide more often and with more energy. A temperature coefficient of 2.0 states that this speeding up is a doubling for every 10°C, so a rise made up of n ten-degree steps multiplies the rate by 2.0^n, not by $2.0n$. Above the optimum the relationship fails, because the active site is losing its shape and the measured rate falls. Any prediction of this kind must start from a rate, so a volume collected over a fixed interval has to be divided by that interval first.

Worked solution

1. Turn the graph reading into a rate

At 15°C the apparatus collects 6 cm^3 of oxygen in four minutes. A rate is a volume per unit time, so this reading must be divided by the collection time before it can be scaled:

$$\text{rate at 15°C} = \frac{6}{4} = 1.5\ cm^3\ min^{-1}$$

2. Find the multiplying factor for the temperature rise

From 15°C to 45°C is a rise of 30°C, which is three separate 10°C steps. Each step multiplies the rate by 2.0, so the steps compound:

factor = $2.0^3 = 8$

3. Apply the factor

predicted rate = $1.5 \times 8 = 12$ cm^3 min^{-1}

Sanity check: the plotted points below the optimum do double every ten degrees, running 3 → 6 → 12 → 24 cm^3 per four minutes at 5, 15, 25 and 35°C. One further step gives 48 cm^3 per four minutes at 45°C, and dividing by four again returns 12 cm^3 min^{-1}. The graph shows only 8 cm^3 per four minutes actually collected at 45°C, because above the optimum the enzyme is denaturing and the relationship no longer holds; the question asks for the predicted value, not the measured one.

Matches Option **H**.

Why the other options are wrong

- **A** (9 cm^3 min^{-1}): The number of steps is used as a multiplier rather than a power: $2.0 \times 3 = 6$, then $1.5 \times 6 = 9$ cm^3 min^{-1}. Repeated doubling compounds, so the correct factor is $2.0^3 = 8$. *(Multiplying by the coefficient instead of raising it to a power)*
- **B** (24 cm^3 min^{-1}): Counts the four temperatures 15, 25, 35 and 45°C as four steps rather than the three gaps between them: $2.0^4 = 16$, then $1.5 \times 16 = 24$. A rise of 30°C contains three steps of 10°C, so the factor is $2.0^3 = 8$. *(Ten-degree steps counted one too many)*
- **C** (3 cm^3 min^{-1}): The coefficient is applied once, whatever the size of the rise: $1.5 \times 2.0 = 3$ cm^3 min^{-1}. This treats Q_{10} as a single doubling rather than a doubling per 10°C, and it ignores two of the three steps between 15°C and 45°C. *(Coefficient applied once for the whole rise)*
- **D** (48 cm^3 min^{-1}): The four-minute volume is used as though it were already a rate: $6 \times 8 = 48$. That is the volume the apparatus would collect in four minutes at 45°C, so it is a factor of four too large for an answer in cm^3 min^{-1}. *(Collection time never divided out)*
- **E** (6 cm^3 min^{-1}): Counts only the two readings lying between the start and the target, at 25 and 35°C, as the steps: $2.0^2 = 4$, then $1.5 \times 4 = 6$. The rise from 15°C to 45°C is three ten-degree steps, not two. *(Ten-degree steps counted one too few)*
- **F** (2 cm^3 min^{-1}): This is the measured point read straight off the graph at 45°C: 8 cm^3 in four minutes, so $8 \div 4 = 2$ cm^3 min^{-1}. It is what the enzyme really does, but the enzyme is denaturing there, so it is not what the Q_{10} relationship predicts. *(Reading the observed value instead of extrapolating)*
- **G** (8 cm^3 min^{-1}): Reads the plotted point at 45°C, 8 cm^3 collected in four minutes, and quotes the 8 as though it were already a rate; the multiplying factor $2.0^3 = 8$ lands on the same number and makes it look confirmed. Dividing by the four minutes gives 2 cm^3 min^{-1}, and that point is the denatured measurement rather than the prediction asked for. *(Graph value quoted without dividing by the collection time)*

Common mistake. Multiplying the coefficient by the number of steps instead of raising it to that power: taking $2.0 \times 3 = 6$ and reporting $1.5 \times 6 = 9$ cm^3 min^{-1}. Three successive doublings give $2 \times 2 \times 2 = 8$, not 6.

Takeaway. The Cheat Code: A Q_{10} is a multiplier per 10°C, so count the whole ten-degree steps the temperature moves and make that count the power, never the multiplier. Then check what the axis of the graph actually measures: a volume collected over a fixed interval is not yet a rate, and one division separates the two.

Time-saving tip. Speed Heuristic: Do the division by four last. $6 \times 8 = 48$, then $48 \div 4 = 12$, and both steps are mental arithmetic. The intermediate 48 is itself printed as an option, so seeing your working land on a listed value is the signal that you have not yet divided by the collection time.

END OF SOLUTIONS

Questions 11 to 27 are in the full paper

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