UNIVERSITY OF CAMBRIDGE

# Natural Sciences Admissions Assessment

## Specimen Paper Section 1: Explained Answers

*New Format for 2020*

# MATHEMATICS

**1**

The answer is option **A**.

We can write:

area of shape $=$ area of square $-$ area of semi-circle.

If we let the length of one side of the square be $2x$, so that the radius of the semi-circle is $x$, then this becomes:

$$100 = 4x^2 - \frac{1}{2}\pi x^2 = x^2\left(4 - \frac{\pi}{2}\right)$$

Rearranging:

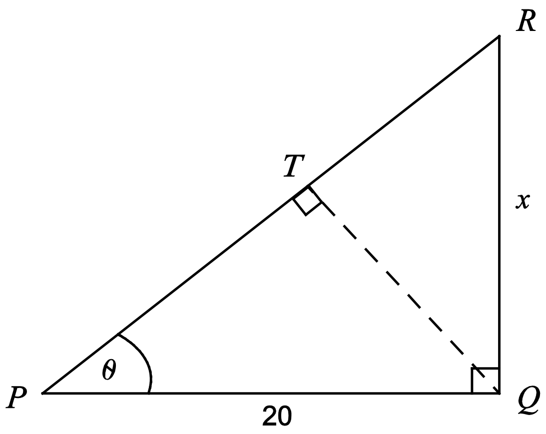
$$x = \sqrt{\frac{200}{8-\pi}} = 10\sqrt{\frac{2}{8-\pi}}$$

So the length of one side of the square is $2x = 20\sqrt{\frac{2}{8-\pi}}$

**2**

The answer is option **E**.

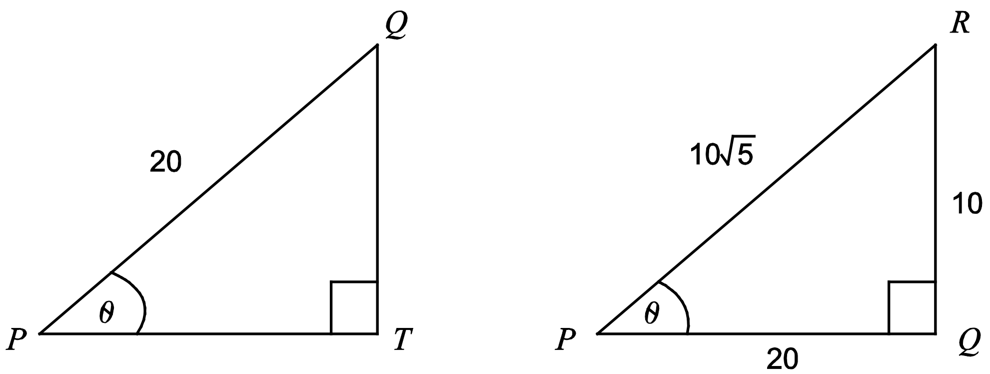
Let $RQ = x$




We know $RQ : PQ$ is $1:2$ so we can deduce $x = 10$

By Pythagoras' Theorem, we have $PR = 10\sqrt{5}$

We notice triangles $PQT$ and $PRQ$ are similar:

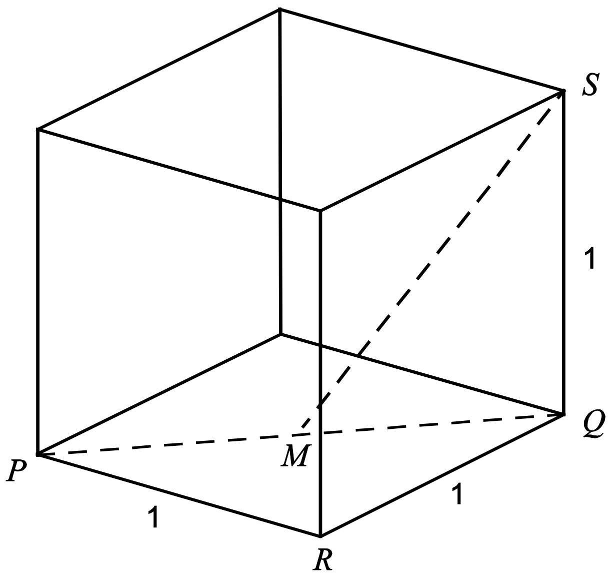



So we can write: $\frac{QT}{10} = \frac{20}{10\sqrt{5}}$

Giving: $QT = \frac{20}{\sqrt{5}} = 4\sqrt{5}$

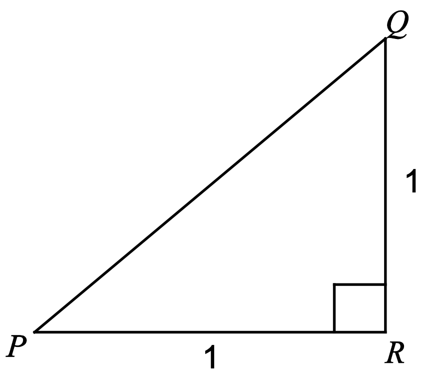
**3**

The answer is option **A**.




[diagram not to scale]

In triangle $PQR$, the angle at $R$ is a right angle so we can use Pythagoras' Theorem to find $PQ$:

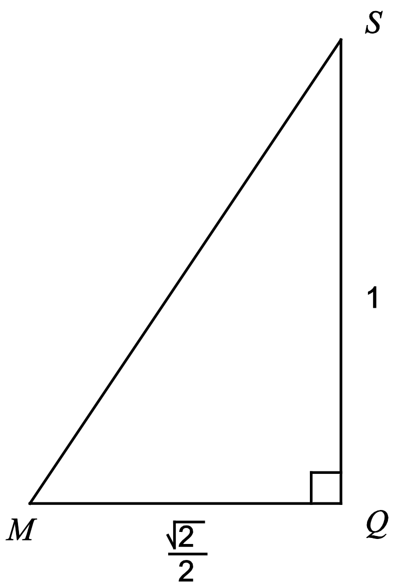



$PQ^2 = 1^2 + 1^2 = 2$

Giving $PQ = \sqrt{2}$

$QM$ is half of $PQ$ so $QM = \dfrac{\sqrt{2}}{2}$

Now looking at triangle $MQS$:




The angle at $Q$ is a right angle so we can use Pythagoras' Theorem:

$$MS^2 = \left(\frac{\sqrt{2}}{2}\right)^2 + 1^2 = \frac{2}{4} + 1 = \frac{3}{2}$$

Giving $MS = \sqrt{\frac{3}{2}}$

**4**

The answer is option **D**.

When the minute hand is pointing to the 9 [indicating 45 minutes past the hour], the hour hand will have moved three-quarters of the angle between the 9 and the 10 on the clock dial. The angle between the 9 and the 10 is 30 degrees so the hour hand will have moved three-quarters of 30 degrees, or 22.5 degrees. The angle between the hands is, therefore, 22.5°.

**5**

The answer is option **B**.

To answer this we shall use:

area of triangle $= \frac{1}{2} \times$ base $\times$ height

This gives:

$$\text{area } = \frac{1}{2}\left(4+\sqrt{2}\right)\left(2-\sqrt{2}\right) = \frac{1}{2}\left(8-4\sqrt{2}+2\sqrt{2}-\sqrt{2}\sqrt{2}\right) = \frac{1}{2}\left(6-2\sqrt{2}\right) = 3-\sqrt{2}$$

**6**

The answer is option **D**.

As the cylinder has the same internal diameter as the sphere, it has the same radius, $r$. As the length of the cylinder is the same as the diameter of the sphere, it has length $2r$. So we can write:

Volume of the sphere $= \frac{4}{3}\pi r^3$

Volume of cylinder $=$ base area $\times$ height $= \pi r^2 \times 2r = 2\pi r^3$

This then allows us to calculate the fraction of the space in the cylinder taken up by the sphere:

$$\frac{\frac{4}{3}\pi r^3}{2\pi r^3} = \frac{2}{3}$$

**7**

The answer is option **A**.

For $0 < x < 1$, we have:

$0 < x^2 < 1$

$0 < \sqrt{x} < 1$

and also:

$1 < \frac{1}{x}$

$\frac{1}{\sqrt{x}} < \frac{1}{x}$

$\frac{1}{1+x} < \frac{1}{x}$

so $\frac{1}{x}$ has the largest value in $0 < x < 1$

**8**

The answer is option **C**.

Using the fact that triangle $ABC$ is similar to triangle $ADE$ [they have the same angles], we can write:

$$\frac{AB}{AD} = \frac{BC}{DE}$$

This gives:

$$\frac{4}{x} = \frac{x}{x+3}$$

From which we get:

$$4(x+3) = x^2$$

Rearranging:

$$x^2 - 4x - 12 = 0$$

Factorising:

$$(x-6)(x+2) = 0$$

Giving $x = 6$ [as we cannot have a negative value for $x$ as it represents a length].

And so $DE = x + 3 = 6 + 3 = 9$

**9**

The answer is option **C**.

$P \propto \frac{1}{Q^2}$ so $P = \frac{k}{Q^2}$ for some $k$

We can use multiplying factors to work out how each symbol changes; for instance, as $Q$ increases by 40% its new value is $1.4Q$

For this question, we have:

$$Q_{new} = 1.4Q$$

Giving:

$$P_{new} = \frac{k}{(1.4Q)^2} = \frac{k}{1.96Q^2} = \frac{1}{1.96}P$$

We then notice:

$$\frac{1}{1.96} \approx \frac{1}{2} \text{ and } \frac{1}{1.96} > \frac{1}{2}$$

so $P_{new}$ is a little over 50% of $P$ and so we can deduce that $P$ has decreased by a little under 50%.

**10**

The answer is option **D**.

We are given: $x \propto z^2$ and $y \propto \frac{1}{z^3}$ which allows us to write: $x = kz^2$ and $y = \frac{c}{z^3}$

We want to eliminate $z$ so we need both expressions to have the same power of $z$ in them:

$$x^3 = k^3 z^6 \text{ and } y^2 = \frac{c^2}{z^6}$$

Eliminating $z$ and ignoring the constants gives:

$$x^3 \propto \frac{1}{y^2}$$

**11**

The answer is option **C**.

To make the question easier to answer, we can let $QX = 2$

We then find, using the given ratios, that $PX = 12$ and $XR = 3$ and so $PR = 15$

As $M$ is the midpoint of $PR$ then $PM = 7.5$ and so $MX = 4.5$

We can then calculate the ratio asked for:

$$\frac{QX}{MX} = \frac{2}{4.5} = \frac{4}{9}$$

**12**

The answer is option **D**.

$x^2 \geq 8 - 2x$

Rearranging:

$x^2 + 2x - 8 \geq 0$

Factorising:

$(x+4)(x-2) \geq 0$

Giving:

$x \geq 2$ or $x \leq -4$

**13**

The answer is option **A**.

We are told:

surface area of cylinder $=$ volume of cylinder

We can write this as follows:

$$2\pi r^2 + 2\pi rh = \pi r^2 h$$

Rearranging:

$$2r = rh - 2h$$

$$2r = h(r-2)$$

Giving:

$$\frac{2r}{r-2} = h$$

**14**

The answer is option **D**.

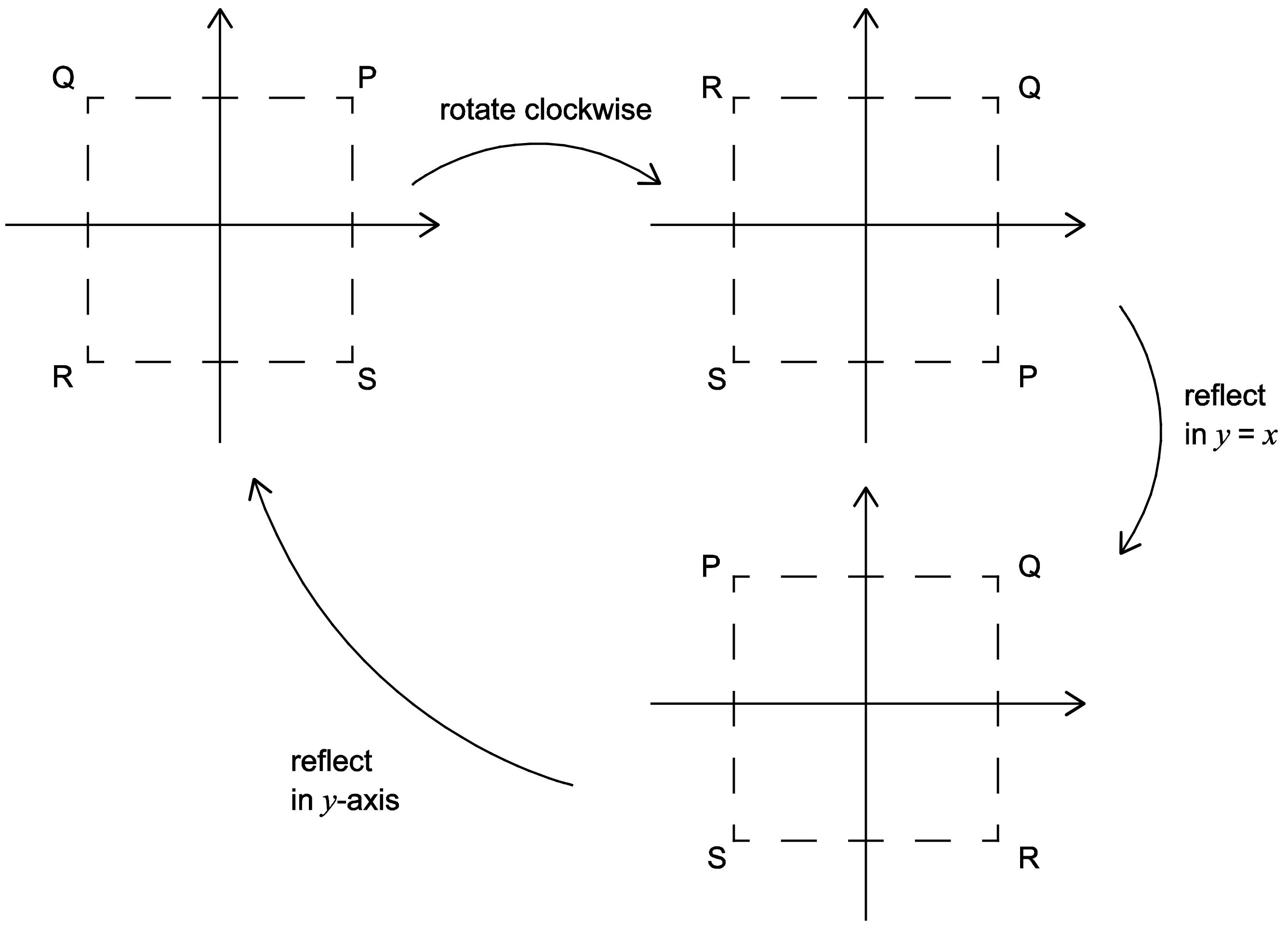
We require: $6 < 2\sqrt{n} < 8$

Which gives, on squaring: $36 < 4n < 64$ or $9 < n < 16$

This is satisfied when $n = 10,11,12,13,14,15$, i.e. there are 6 integers.

**15**

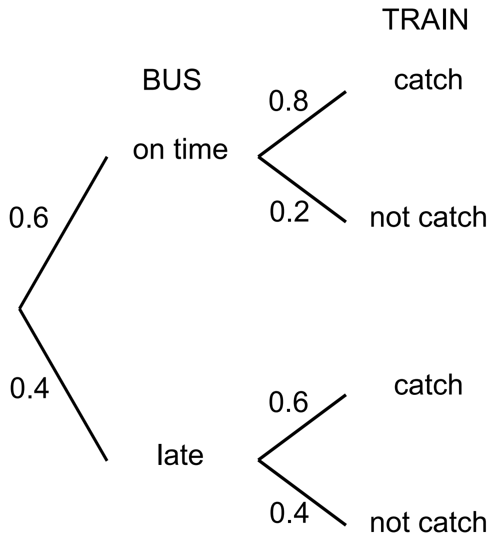
The answer is option **B**.



**16**

The answer is option **E**.

A tree diagram for this question is:




As Sylvie catches the train we have two possible situations: either the bus was on time, or the bus was late.

Probability that Sylvie catches the train

= probability bus on time and catches train + probability bus late and catches train

$= (0.6 \times 0.8) + (0.4 \times 0.6) = 0.48 + 0.24 = 0.72$

Probability that the bus was on time and Sylvie catches the train $= (0.6 \times 0.8) = 0.48$

So the required probability is: $\frac{0.48}{0.72} = \frac{48}{72} = \frac{2}{3}$

**17**

The answer is option **C**.

We can let the length of a side of the large square be 3 to help us find the area scale factor.

First we use Pythagoras' theorem to find the length of one side of the first inscribed square:

Length of side of inscribed square $= \sqrt{1^2 + 2^2} = \sqrt{5}$

This allows us to work out the area scale factor using:

Area of main square $=$ 9

Area of inscribed square $=$ 5

Area scale factor $= \dfrac{5}{9}$

Therefore the area of the fourth square [the third inscribed square] as a fraction of the area of the first square must be:

$$\left(\frac{5}{9}\right)^3 = \frac{125}{729}$$

**18**

The answer is option **C**.

We can use multiplying factors to work out how each symbol changes; for instance, as $x$ increases by 50% its new value is $1.5x$

After the percentage changes the expression becomes:

$$\frac{(1.5x + 1.5y)^2\, 0.8z}{2P}Q$$

This simplifies:

$$\frac{1.5^2\,(x+y)^2\, 0.8z}{2P}Q = \frac{1.5^2 \times 0.8}{2} \times \frac{(x+y)^2 z}{P}Q = 0.9\,\frac{(x+y)^2 z}{P}Q$$

giving a 10% decrease in the value of $M$.

**19**

The answer is option **B**.

Prob of scoring $12 =$ (Prob of scoring 6 on fair dice) $\times$ (Prob of scoring 6 on biased dice)

As the question tells us that the Prob of scoring $12 = \frac{1}{18}$

We can write: $\frac{1}{6} \times$ (Prob of scoring 6 on biased dice) $= \frac{1}{18}$

So: (Prob of scoring 6 on biased dice) $= \frac{1}{3}$

As the probability of scoring a 1 or 2 or 3 or 4 or 5 is the same on the biased dice, we can deduce that:

(Prob of scoring 1 on the biased dice) $= \frac{1}{5} \times \frac{2}{3} = \frac{2}{15}$

And so this gives:

Prob of scoring 2 $=$ (Prob of scoring 1 on fair dice) $\times$ (Prob of scoring 1 on biased dice)

or

Prob of scoring 2 $= \frac{1}{6} \times \frac{2}{15} = \frac{1}{45}$

**20**

The answer is option **H**.

A regular pentagon has 5 sides, so each exterior angle is: $\frac{360}{5} = 72°$

At each vertex of the pentagon the course increases its bearing by 72°.

By the third leg there have been 2 turns so we need to subtract $2 \times 72 = 144°$ from the bearing to get the first leg bearing: $110 - 144 = -34°$

So first leg bearing is 34° beyond North in an anti-clockwise direction.

The bearing of the first leg is $360 - 34 = 326°$

# PHYSICS

**21**

The answer is option **C**.

The forces on the parachutist are 600 N downwards and 900 N upwards.

These cause a resultant force on the parachutist of 900 N − 600 N = 300 N upwards.

acceleration = resultant force / mass = 300 / 60 = 5.0 $\text{m s}^{-2}$ upwards.

**22**

The answer is option **C**.

From the graph, period $T = 2.0\,\text{s}$

$f = \frac{1}{T} = \frac{1}{2.0} = 0.50\,\text{Hz}$

$v = f\lambda = 0.50 \times 1.5 = 0.75\,\text{cm s}^{-1}$

**23**

The answer is option **B**.

momentum $p = mv$ and kinetic energy $\text{KE} = \frac{1}{2}mv^2$

rearranging:

$v = \frac{p}{m}$ and so $KE = \frac{1}{2}\frac{p^2}{m}$

therefore:

$m = \frac{p^2}{2KE} = \frac{900}{300} = 3.0\,\text{kg}$

[Finally, it is good practice to verify this answer by substituting it back into the kinetic energy equation:

kinetic energy $= \frac{1}{2}mv^2 = \frac{1}{2} \times 3 \times 10^2 = 150\,\text{J}$, which is correct.]

**24**

The answer is option **E**.

Looking at each option in turn:

**A** $V = IR$ so volts are amp $\times$ ohm not amp per ohm.

**B** The volt is defined as a joule per coulomb.

Therefore (coulomb per joule) $=$ 1 / volt. This is not equal to the volt.

**C** The joule per second is the watt.

This is not equal to the volt.

**D** Since the volt is defined as a joule per coulomb it is worth expressing the newton as a joule per metre.

Therefore newton per coulomb $=$ (joule per metre) per coulomb $=$ (joule per coulomb) per metre $=$ volt per metre. This is not equal to the volt.

**E** $P = IV$, therefore $V = \frac{P}{I}$ so volts are watt per amp.

**25**

The answer is option **D**.

The background count per minute is taken from the part of the graph where the curve reaches a constant value, after 6 hours.

The graph will never reach zero counts per minute because the background count per minute from the environment will always be present.

Since the graph levels off at 50 counts per minute, this is the approximate background radiation count rate for this experiment.

**26**

The answer is option **B**.

Since air resistance is negligible, all of the initial GPE is transferred to KE so $mgh = \frac{1}{2}mv^2$

Rearranging the equation, we obtain: $h = \frac{v^2}{2g} = 400/20 = 20\,\text{m}$

(Notice that *m* cancels so the result is independent of the mass of the falling body.)

**27**

The answer is option **E**.

As the cyclist loses 100 m of height, he loses gravitational potential energy

$= mgh$
$= 100 \times 10 \times 100$
$= 100\,000$ J

The cyclist is descending the slope at a constant speed, which means that all of this potential energy becomes heat as work is done on the cyclist by the resistive forces.

Therefore, work done by resistive forces $= 100\,000$ J

distance travelled along the slope whilst descending 100 m height $= 100 \times 10 = 1000$ m

Therefore, resistive force $=$ work done / distance $= 100\,000 / 1000 = 100$ N

Alternatively, since the cyclist is moving at a constant velocity he must be in equilibrium. Therefore the drag force must be equal and opposite to the component of weight acting down the slope ($mg\sin\theta$). In this case, $\sin\theta = 10/100 = 0.1$ so the drag force is $0.1mg = 0.1 \times 100 \times 10 = 100$ N.

**28**

The answer is option **D**.

Work done by the motor in lifting the load through 5.0 m $= mgh = 3.0 \times 10 \times 5.0 = 150$ J

Therefore, output power of motor $=$ work done / time taken $= 150/1.5 = 100$ W

Motor is 100% efficient so the electrical input power to the motor is also 100 W

Therefore, average current in motor $=$ power / voltage $= 100/25 = 4.0$ A

Alternatively, since the process is 100% efficient, the power output of the motor ($P = IV$) will equal the power used to lift the mass ($P = mgh/t$).

Equating and rearranging we have: $IV = mgh/t$ so $I = mgh/Vt = (3 \times 10 \times 5)/(25 \times 1.5) = 4.0$ A

**29**

The answer is option **A**.

Let the mass of the ball in kg be *m*. (Its value is not needed to do the question.)

kinetic energy at the point of release $= \frac{1}{2}mv^2 = \frac{1}{2} \times m \times 12^2 = \frac{1}{2} \times 144 \times m = 72m$ joules

At the highest point, all of this kinetic energy has turned into gravitational potential energy

Therefore, at the highest point, gravitational potential energy $= 72m$ joules

This is also equal to *mgh*, where *h* is the height reached.

Therefore, $10mh = 72m$. Notice that *m* cancels out here (as expected), leaving $10h = 72$

Therefore, height reached $h = 72/10 = 7.2$ metres

Alternatively, since all of the initial KE $\left(\frac{1}{2}mv^2\right)$ is transferred to GPE (*mgh*) at the top of the motion:

$mgh = \frac{1}{2}mv^2$, so $h = v^2/2g = 12^2/20 = 7.2\,\text{m}$

**30**

The answer is option **C**.

kinetic energy of lorry $= \frac{1}{2}mv^2$

As the lorry is moving along a horizontal road, the resistive forces need to absorb this energy and no more. Work done by resistive forces in stopping the lorry is therefore $\frac{1}{2}mv^2$

distance travelled by lorry while stopping $=$ work done / stopping force $= \left(\frac{1}{2}mv^2\right)/F = \frac{mv^2}{2F}$

**31**

The answer is option **B**.

An alpha particle consists of two protons and two neutrons so alpha emission results in the reduction of atomic number (bottom) by 2 and the reduction of nucleon number (top) by 4.

A beta-minus particle is an electron emitted when a neutron in the nucleus changes into a proton. This increases atomic number (bottom) by 1 but has no effect on nucleon number (since both protons and neutrons are nucleons).

The decay from $X$ to $Y$ involves the atomic number going down by 2 (from $R$ to $R - 2$). This means that this stage must be alpha decay, and therefore that the mass number must drop by 4. The mass number of $Y$ must therefore be $N - 4$, and this is the value of $P$.

The decay from $Y$ to $Z$ involves the mass number remaining the same ($P$ in both cases). This means that this stage must be beta decay, and therefore that the atomic number of $Z$ must be one higher than that of $Y$. As the atomic number of $Y$ is $R - 2$, the atomic number of $Z$ must be $(R - 2) + 1 = R - 1$, and this is the value of $Q$.

**32**

The answer is option **B**.

This question is simply a straightforward application of speed = distance / time, and the frequency of the pulse is irrelevant.

distance travelled by pulse from transmitter to foetus and back again to receiver $= 2 \times 10$
$= 20\,\text{cm}$
$= 0.20\,\text{m}$

Therefore, time taken = distance / speed = 0.20 / 500 = 0.0004 s = 0.40 ms

**33**

The answer is option **B**.

Both graphs P and Q show an object accelerating with constant acceleration. The value of that acceleration is the gradient of the velocity-time graph.

Graph P: Gradient = 10 / 24, which is not $2.4\,\text{m}\,\text{s}^{-2}$. (You don't need to evaluate 10 / 24 to see that.)

Graph Q: Gradient = (58 – 10) / 20 = 48 / 20 = $2.4\,\text{m}\,\text{s}^{-2}$. So graph Q is correct.

Graphs R and S are both distance-time graphs which are straight lines, signifying constant speed. Constant speed means zero acceleration, and so neither of these graphs shows an acceleration of $2.4\,\text{m}\,\text{s}^{-2}$.

The correct answer is therefore that graph Q only shows an acceleration of $2.4\,\text{m}\,\text{s}^{-2}$.

**34**

The answer is option **D**.

This question is all about the significance of the gradient of a straight–line graph. The gradient of the graph shown is $20/100 = 0.20$ in the units of the *y*-axis divided by the units of the *x*-axis.

**A** As $F = ma$, and therefore $a = F/m$, a graph of acceleration against force will give a straight line with a gradient of $1/m$. If $m = 5\,\text{kg}$ then $1/m = 1/5 = 0.2\,\text{kg}^{-1}$. Graphical representation correct.

**B** As $V = IR$, and therefore $I = V/R$, a graph of current against voltage will give a straight line with a gradient of $1/R$. If $R = 5\,\Omega$ then $1/R = 1/5 = 0.2\,\Omega^{-1}$. Graphical representation correct.

**C** As KE $= \frac{1}{2}mv^2$, a graph of KE against speed squared will give a straight line with a gradient of $\frac{1}{2}m$. If $m = 0.4\,\text{kg}$ then $\frac{1}{2}m = 0.2\,\text{kg}$. Graphical representation correct.

**D** As $v = f\lambda$, and therefore $\lambda = v/f$, a graph would need to be plotted of wavelength against 1/frequency to get a straight line. A graph of wavelength against frequency will not give a straight line. Graphical representation therefore **not** correct.

**E** As $W = Fd$, a graph of work done against distance moved will give a straight line with a gradient of $F$. If $F = 0.2\,\text{N}$ then the graphical representation is correct.

**35**

The answer is option **C**.

For the charge of the ion to be 2+, it must have two more protons than electrons. The number of protons is given as $x - 3$.

The number of electrons is therefore $(x - 3) - 2 = x - 5$

**36**

The answer is option **D**.

Total resistance of circuit $=$ sum of separate resistances $= R_1 + R_2$

Current in circuit is therefore $I = \dfrac{V}{R_{\text{total}}}$

$$= \frac{V}{(R_1 + R_2)}$$

This current is the same in both resistors.

Voltage across $R_1$ is therefore $V = IR_1$

$$= \frac{V}{(R_1 + R_2)} \times R_1$$

$$= \frac{VR_1}{(R_1 + R_2)}$$

Therefore power dissipated in $R_1$ is $P = VI$

$$= \frac{VR_1}{(R_1 + R_2)} \times \frac{V}{(R_1 + R_2)}$$

$$= \frac{V^2 R_1}{(R_1 + R_2)^2}$$

Alternatively, a solution can be reached more quickly by considering dimensions: the power dissipated by a resistor is given by (voltage across resistor)$^2$ / (resistance). The only option with a voltage-squared divided by a resistance is **D**.

**37**

The answer is option **D**.

The distance travelled is the area under the graph, but you also need to match the units. The speeds on the graph are in $m\,s^{-1}$ but the times are in minutes. For the area under the graph to represent distance in metres, the times therefore need to be converted to seconds. This can be done all in one go by multiplying by 60 at the end.

Now consider the areas under each section of the graph.

0–1 minutes: Area $= (16 + 20)/2 \times 1 = 18\ (m\,s^{-1})\,min$

1–4 minutes: Area $= 20 \times 3 = 60\ (m\,s^{-1})\,min$

4–5 minutes: Area $= (20 + 10)/2 \times 1 = 15\ (m\,s^{-1})\,min$

5–6 minutes: Area $\approx (10 + 2)/2 \times 1 = 6\ (m\,s^{-1})\,min$

6–7 minutes: Area $\approx (2 + 0)/2 \times 1 = 1\ (m\,s^{-1})\,min$

(Note there are various ways of approximating the areas under the last two curved sections of the graph. For instance, another way could be to consider 5–6 minutes as being a trapezium from 10 down to $5\,m\,s^{-1}$, effectively importing the last section into the preceding one, and then ignoring the 6–7 minute section. Each method of approximation will produce a slightly different estimate; one such method is shown. All estimates will, however, be within a reasonable range of the key).

Adding these together, total area $\approx 18 + 60 + 15 + 6 + 1 = 100\ (m\,s^{-1})\,min$

At this point it is now convenient to deal with the necessary unit conversion by multiplying by 60, to give a total area $\approx 100 \times 60 = 6000\,m = 6.00\,km$.

(Note the technique of waiting until the end to multiply by 60 both saves time and avoids dealing with large numbers along the way. It is perfectly legitimate to multiply each time by 60 before working out each individual area, but this will make the numbers more awkward to work with and will result in the question taking a lot longer to do.)

**38**

The answer is option **B**.

Consider each statement in turn:

P We have no information about the wavelength of the sound waves produced, and nor do we know how far the waves travel in a given time. It is therefore not possible to deduce the speed from the information given. Statement P cannot be deduced.

Q The maximum distance of oscillation from compression to rarefaction is 5.0 mm, but the amplitude of the wave is from the equilibrium position to the maxima. The amplitude is therefore half of this (2.5 mm) and statement Q is incorrect.

R We cannot deduce the wavelength from the information given, and hence cannot deduce statement R.

S The period of the pulses produced is 0.2 ms = 0.0002 s. This means the frequency of the wave is 1 / period = 1 / 0.0002 = 5000 Hz. Statement S therefore can be correctly deduced from the information given.

The correct answer is that statement S only can be correctly deduced.

**39**

The answer is option **D**.

The truck has a mass, $m$ and $g$ is the gravitational field strength, $v$ is the final velocity of the truck and $h$ is the vertical difference in height between the two positions P and Q. The truck is moving forward at the initial position P with velocity $u$.

gravitational potential energy, GPE = $mgh$

kinetic energy, KE = $\frac{1}{2}mv^2$

The GPE lost is equal to the KE gained, so if $u$ is the initial velocity:

$$mgh = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mu^2$$

$$mgh - \tfrac{1}{2}mu^2 = \tfrac{1}{2}mv^2$$

The value of mass, $m$, cancels, leaving $h$ as the unknown quantity.

$$gh - \tfrac{1}{2}u^2 = \tfrac{1}{2}v^2$$

The value $h$ in this equation is the change in height from P to Q, the difference between distance $x$ and distance $y$, which is distance $z$.

**40**

The answer is option **E**.

There are originally 1000 carbon-14 atoms in the sample living material.

The number of atoms in the sample is 100.

The half-life is 6000 years, so the number of atoms after 6000 years is 500. After a further 6000 years it is 250, and after a further 6000 years it is 125 atoms.

After 3 half-lives amounting to 18 000 years, the number of atoms will be 125.

This is the nearest estimate to 100 atoms and the nearest estimate to 20 000 years.

# CHEMISTRY

**41**

The answer is option **E**.

The pH scale is a measure of the acidity or alkalinity of an aqueous solution.

All indicators in the mixture experience a pH of 5.0.

Methyl orange (colour change at 4.0) will be yellow at pH 5.0.

Bromothymol blue (colour changes at 6.5) will be yellow at pH of 5.0.

Phenolphthalein (colour changes at 9.0) will be colourless at pH of 5.0.

In order: yellow + yellow + colourless = yellow.

**42**

The answer is option **A**.

Aqueous sodium chloride contains two cations ($Na^+$ and $H^+$) and two anions ($Cl^-$ and $OH^-$).

The positive electrode (anode) attracts anions and the negative electrode (cathode) attracts cations.

When two ions are attracted to an electrode, only one can be discharged as atoms. This is called preferential discharge.

In this case:

chlorine is discharged in preference to oxygen at the positive electrode (anode);

hydrogen is discharged in preference to sodium at the negative electrode (cathode).

**43**

The answer is option **A**.

Assessment of each option:

**A:** The high melting and boiling points, together with non-conductivity in the solid and molten states, indicates a giant covalent structure.

**B:** The high melting and boiling points indicate a giant structure. No conductivity when solid but having conductivity when molten is typical of a giant ionic structure.

**C:** Despite the relatively low melting and boiling points, the fact that it conducts electricity when solid and molten means that it is a giant metallic structure.

**D:** With low melting and boiling points, no electrical conductivity and being a liquid at room temperature and pressure, the substance is typical of a simple molecular structure.

**E:** Despite the very low melting point, the good conductivity when solid and molten indicates a metallic structure. In fact, **E** is mercury.

**44**

The answer is option **A**.

The reaction is stated to go to completion.

At the start of the reaction there is a concentration of A of $1.2\,mol\,dm^{-3}$. The equation gives the ratio of A **:** Z as 2 **:** 1. This means that for every unit of A that is reacted, only 0.5 as much Z is produced.

In a complete reaction, all of A will be used up and the final concentration of Z will be $0.6\,mol\,dm^{-3}$, so graph 1 must be correct.

As the chemical A is reacted, Z is produced. Graph 2 shows that an equilibrium state has been reached with the concentration of A being twice that of Z; this is incorrect.

Graph 3 shows that an equilibrium state has been reached with equal concentrations of A and Z; this is incorrect.

**45**

The answer is option **B**.

One method for solving the problem would be as follows:

The oxide ion has a charge of $-2$, $O^{2-}$.

A compound formed from $Fe^{3+}$ and $O^{2-}$ ions must have the formula $Fe_2O_3$.

A compound formed from $Fe^{2+}$ and $O^{2-}$ ions must have the formula FeO.

A 1 **:** 1 mixture of these compounds would give a compound of formula $Fe_3O_4$ ($Fe_2O_3$ + FeO).

So the molar ratio $Fe^{3+}$ **:** $Fe^{2+}$ must be 2 **:** 1, making $Fe^{2+}$ $\frac{1}{3}$ of the iron ion total.

**46**

The answer is option **E**.

Mass number = number of protons + number of neutrons = 40

Atomic number = number of protons = 20

Number of protons = 20, so number of electrons = 20 to balance charge.

Number of neutrons = 40 − 20 = 20

Using the above information and applying it to each statement:

1: Incorrect. The relative mass of the nucleus is 40.

2: Incorrect. A total of 20 electrons would give an electronic configuration of 2,8,8,2. The incomplete outer shell containing two electrons indicates that is in Group 2. Group 2 elements are not noble gases, they are alkaline earth metals.

3: Incorrect. Group 2 elements form 2+ ions by loss of the outer two electrons.

4: Correct.

5: Incorrect. Group 2 elements are metals.

**47**

The answer is option **D**.

Bond breaking is an endothermic process, whilst bond making is an exothermic process.

The reaction is exothermic overall, which means that more energy is released when bonds are made than is needed for bonds to be broken.

The bonds to be broken are on the left of the equation $\left(1 \times N \equiv N \text{ and } 3 \times H{-}H\right)$ and those made are on the right of the equation $\left(2 \times 3 \times N{-}H\right)$. This means that the 6 N—H bond energies must be greater than the $N_2$ and $3 \times H_2$ bond energies in total.

Looking at the number of bonds from the mole ratios in the equation (1 **:** 3 **:** 2), the inequality $6z > x + 3y$ is satisfied.

**48**

The answer is option **C**.

Equations 2 and 3 are correct.

*(Construction of half-equations is another valid solution method with the same conclusion.)*

Oxidising agents accept electrons. Reducing agents lose (or donate) electrons.

Looking at each equation for the first reactant in the equation in turn:

1: Mg is transformed into $Mg^{2+}$. Electrons are being lost and so Mg is a reducing agent.

2: The oxidation state of chromium in the first compound is +6 and it is transformed into $Cr^{3+}$. Electrons are being accepted and so $Cr_2O_7^{2-}$ is an oxidising agent.

3: $Cu^{2+}$ is transformed into $Cu^{+}$. Electrons are being accepted and so $Cu^{2+}$ is a oxidising agent.

4: The oxidation state of sulfur in the first compound is +4 and it is transformed into a compound where it is +6. Electrons are being lost and so the first compound is a reducing agent.

**49**

The answer is option **D**.

1 mole of $H_2O$ has a mass of $(2 \times 1) + 16 = 18\,\text{g}$

The volume of 1 mole of a gas at room temperature and pressure is $24\,\text{dm}^3$

6.00 g of $H_2O$ is $\frac{6}{18} = \frac{1}{3}$ mol, and therefore occupies a volume of $\frac{24}{3} = 8\,\text{dm}^3$

$8\,\text{dm}^3 = 8000\,\text{cm}^3$

**50**

The answer is option **E**.

There are several methods that will give the correct answer, of which one is shown below:

| | I | O |
|---|---|---|
| number of moles: | $\frac{63.5}{127} = 0.5$ | $\frac{20.0}{16} = 1.25$ |
| ratio ($\div 0.5$) | 1 | 2.5 |
| smallest whole number ratio ($\times 2$) | 2 | 5 |

Therefore the empirical formula is $I_2O_5$.

**51**

The answer is option **C**.

Electron configurations of atoms can be used to identify the position of an element in the Periodic Table. The number of electrons in the outer shell determines the group. The number of shells determines in which period the element is.

**A:** 2,4 Group 14, where non-metals are at the top of the group and metals are at the bottom

**B:** 2,6 Group 16, a non-metal

**C:** 2,7 Group 17, a non-metal

**D:** 2,8,1 Group 1, a metal

**E:** 2,8,6 Group 16, a non-metal

**F:** 2,8,7 Group 17, a non-metal

Only **D** can be eliminated. Non-metals react to gain electrons and acquire the configurations of noble gases.

The fewer the electrons to gain, the more reactive the element. This narrows the choice down to **C** and **F**, as both atoms only need to gain one electron.

**C** is the smaller atom (two shells) so there is more attraction between the nucleus and the electron to be gained, compared with **F**. **C** will therefore be more reactive. The element is fluorine.

**52**

The answer is option **C**.

This question is about identifying which possible isotopes can give rise to $CH_2BrCl$ with $M_r = 128$, and the proportion of these isotopes that exist, to identify which isotope combinations give $M_r = 128$ and those that do not.

The combined total mass of bromine and chlorine (removing $CH_2$) must total $128 - 14 = 114$

The only combination of isotopes with this total mass is $^{79}Br$ combined with $^{35}Cl$. As these are the isotopes with lowest mass for each element, any other possibilities would result in a higher $M_r$ for the compound.

The fraction occurring is directly related to probability. We want the probability that $Br = {}^{79}Br$ AND $Cl = {}^{35}Cl$, in $CH_2BrCl$ and these events are independent of each other.

$^{35}Cl$ is three times as common as $^{37}Cl$, and the question states that there are only two isotopes to be considered (3 **:** 1), so the relative frequency of $^{35}Cl$ is $\frac{3}{4}$, and for $^{37}Cl$ it is $\frac{1}{4}$. We can treat these as probabilities.

For bromine, the relative frequency of $^{79}Br$ is $\frac{1}{2}$, and it is the same for $^{81}Br$.

Hence $P(^{79}Br \text{ AND } ^{35}Cl) = P(Br = {}^{79}Br) \times P(Cl = {}^{35}Cl) = \frac{1}{2} \times \frac{3}{4} = \frac{3}{8}$

**53**

The answer is option **A**.

When using a fractionating column, the flask is at the bottom and is heated. The temperature is highest at the bottom of the column and lowest at the top.

The hexane has the lowest boiling point and so will evaporate first in the flask and will rise to the top of the column first (68 °C). The liquid mixture in the flask must be boiling so the temperature must be at least 68 °C, but less than 98 °C, so that only the hexane is vapourised.

**54**

The answer is option **D**.

In this question, stage 1 can be ignored.

In stage 2, the stoichiometry of the equation shows that 1 mole of C will produce 2 moles of CO.

12 g of C ($A_r$ 12) is 1 mole

$M_r$ of CO is $12 + 16 = 28$, so 2 moles of CO is $28 \times 2 = 56$ g

In stage 3, the stoichiometry of the equation shows that 3 moles of CO will produce 3 moles of $CO_2$, i.e. a 1 **:** 1 molar ratio.

56 g (2 moles) of CO will make 2 moles $CO_2$

$M_r$ of $CO_2$ is $12 + (16 \times 2) = 44$, so 2 moles of $CO_2$ is $44 \times 2 = 88$ g

**55**

The answer is option **E**.

**A:** False. There is a different number of molecules on the two sides of the equation so altering the pressure will shift the equilibrium position.

**B:** False. The reaction is exothermic and so increasing the temperature will move the equilibrium position to the left.

**C:** False. Chemical equilibrium is dynamic so reactants are constantly changing to products and products are constantly changing back to reactants.

**D:** False. A catalyst increases the rate at which equilibrium is reached but does not shift the position of equilibrium.

**E:** Correct. Until equilibrium is reached, the forward reaction will be faster than the backward reaction.

**56**

The answer is option **E**.

The chemical equation for the reaction is: $NaOH + HCl \rightarrow NaCl + H_2O$

Molar ratio is 1 NaOH **:** 1 HCl

Number of moles of HCl $= \dfrac{\text{vol. in cm}^3}{1000} \times \text{conc.} = \dfrac{50.0}{1000} \times 0.5 = 0.025$

Therefore, the number of moles of NaOH is also 0.025

$A_r$ of NaOH is $23 + 1 + 16 = 40$, so 1 mole of NaOH has a mass of 40 g

In the question, the number of moles of NaOH present $= 0.025 \times 40 = 1.0$ g

Percentage purity $= \dfrac{1.0}{1.20} \times 100 = 83.3\%$

**57**

The answer is option **C**.

Various approaches can be used to calculate the correct answer, of which one is shown below.

Number of moles $H_2SO_4$ used $= \dfrac{12.5}{1000} \times 2.0 = 0.025$

Molar ratio in the reaction is 2 XOH **:** 1 $H_2SO_4$

So, the number of moles of XOH present $= 0.025 \times 2 = 0.05$

Number of moles $= \dfrac{\text{mass in g}}{M_r}$, so $0.05 = \dfrac{2.8}{M_r}$

Rearranging, $M_r = \dfrac{2.8}{0.05} = \dfrac{28}{0.05} = 56$

$M_r$ of XOH $= A_r(\text{X}) + 16 + 1 = 56$

$A_r(\text{X}) = 39$

**58**

The answer is option **D**.

The number of moles of each element on each side of the equation is:

| | H | N | O |
|---|---|---|---|
| left-hand side | $r$ | $r$ | $3r$ |
| right-hand side | $2s$ | $2 + t$ | $6 + s + 2t$ |

These numbers must balance for each element:

For H, $r = 2s$

For N, $r = 2 + t$

For O, $3r = 6 + s + 2t$

Substituting $r = 2s$ into $3r = 6 + s + 2t$, we get $3 \times (2 + t) = 6 + s + 2t$

Rearranging: $6 + 3t = 6 + s + 2t$, therefore $t = s$

Moles of H and N are equal ($r$), so $2s = 2 + t$

Substituting $t = s$ into this, we get $2s = 2 + s$ and therefore $s = 2$

It follows that $t = 2$ and $r = 4$

**59**

The answer is option **D**.

The volume of $CO_2$ gas produced ($105\,cm^3$) is three times that of the alkane vapour ($35\,cm^3$) at the same temperature and pressure.

Using the reacting volumes of gases ratio, the mole ratio of alkane : $CO_2$ is 1 : 3

As this is complete combustion, all of the carbon atoms in the alkane will form $CO_2$, so it can be deduced that there are 3 carbon atoms in the alkane molecule.

The general formula of alkanes is $C_nH_{2n+2}$, so the alkane formula is $C_3H_8$.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

**60**

The answer is option **B**.

The reaction is faster than the original as it is hotter and the acid is more concentrated. The number of moles of acid reacting is the same as the volume is half of the original but the concentration double. Given that the acid is the limiting reagent with the calcium carbonate in excess, the volume of carbon dioxide formed will be the same as the original.

# BIOLOGY

**61**

The answer is option **D**.

Statement 1 is incorrect as gamete formation occurs due to meiosis. Both statement 2 and statement 3 are also incorrect. However, they are common misconceptions held by students. Growth of an organism such as a human occurs by mitosis as the number of cells increases. The size of a cell does not increase due to mitosis. Mitosis results in the production of new cells which can be used to replace damaged cells in tissues such as muscles and organs such as skin. However, mitosis cannot repair cells, so statement 3 is incorrect.

Therefore the only correct statement is statement 4 – replacement of skin cells.

**62**

The answer is option **D**.

As oxygen is being supplied and used, aerobic respiration is occurring in these muscle cells. However, as the oxygen demand between 0 and 11 minutes is greater than the supply, as shown by the higher position of the oxygen demand line on the graph, the muscle cells are also carrying out anaerobic respiration.

**63**

The answer is option **F**.

Competition for limiting resources can occur both within a species (intraspecific – statement 1) and between species (interspecific – statement 2). Likewise, natural selection can lead to evolution due to individuals with advantageous adaptations being more likely to survive and pass on their alleles, thus passing on the advantageous adaptations to their offspring (statement 3). For a species that competes less well, natural selection may lead to extinction (statement 4). Therefore all four statements are correct.

**64**

The answer is option **E**.

The main factors affecting the rate of photosynthesis are light intensity, temperature and carbon dioxide concentration. Any change in the level of a factor will affect the rate of reaction and the process will be limited by the factor which is in the shortest supply.

In the case of temperature, the rate of reaction will increase until the optimum temperature for the enzymes controlling the reaction is reached, as long as the other factors are present in sufficient amounts. Therefore statement 1 is correct. After this point the enzymes start to become denatured and no longer work, so statement 2 is correct. An increase in temperature produces an increase in kinetic energy and, up to a temperature of 22 °C the rate of photosynthesis also increases. However temperature does not increase the rate across the whole of the range studied as after the optimum temperature has been reached, the rate of photosynthesis decreases. Therefore statement 3 is incorrect.

**65**

The answer is option **G**.

Statement 1 is incorrect as at position 21 there are three chromosomes rather than two. As such, this is an example of a chromosome mutation and leads to Down's syndrome. Statement 2 is correct as the 23$^{rd}$ pair of chromosomes are the sex chromosomes and as they are XY this means the cell has been donated by a male. White blood cells are diploid body cells and so they contain two copies of each chromosome with two sex chromosomes as shown in the karyogram, so statement 3 is also correct.

**66**

The answer is option **G**.

Bone marrow stem cells will divide by mitosis, rather than meiosis, to produce genetically identical offspring, so statement 1 is incorrect. Human stem cells, including bone marrow stem cells, are diploid and so contain 46 chromosomes (statement 2 is correct). Stem cells of the bone marrow are able to differentiate into white blood cells so statement 3 is also correct.

**67**

The answer is option **B**.

Although carbon dioxide is converted into sugars this takes place in the photosynthetic parts of plants which are not normally the roots so statement **A** is incorrect. Photosynthesis takes place in leaves.

Although carbon dioxide is taken up and converted into sugars in the leaves, the sugars produced are transported to the roots by translocation and not transpiration. So statement **C** is incorrect.

Carbon dioxide does enter the leaves but it is not transported to the roots to be converted into sugars so statements **D** and **E** are incorrect.

During photosynthesis carbon dioxide is taken up and used to make sugars. These sugars can then be transported around the plant, including to the roots, by translocation. So statement **B** is correct.

**68**

The answer is option **F**.

The two females with attached ear lobes are homozygous recessive. The female in the first generation must be heterozygous, as she has the dominant phenotype, but must have inherited the recessive allele from her mother (who is homozygous recessive). The male parent, the male in the first generation, and the people in the second generation who have unattached ear lobes could be either heterozygous or homozygous dominant. So the maximum possible number of heterozygous individuals is 7.

**69**

The answer is option **A**.

A change from $0.12\,\text{mol}\,\text{dm}^{-3}$ to $0.084\,\text{mol}\,\text{dm}^{-3}$ gives an increase in percentage haemolysis (read graph from right to left) from 2% up to 72%, which is an increase of 70%. The increase is due to the uptake of water through osmosis into the cells, which occurs as a result of the reduction in the concentration of the $NaCl$ solution.

**70**

The answer is option **D**.

The diagram contains clues to allow the various blood vessels to be identified. Blood vessel 1 has a narrow wall and large lumen, whilst blood vessel 2 has a wide wall and narrow lumen. Veins, such as the vena cava, have a structure as shown by blood vessel 1. Arteries, such as the aorta, have the same structure as shown by blood vessel 2. Any vessel leading directly to vessel 1 is a vein, whilst any vessel leading directly from vessel 2 is an artery.

Urea is produced in the liver and removed by the kidney. Therefore the highest concentration of urea will be found in the tube leading away from the kidney to the bladder, which is tube 5. The name of tube 5 is the ureter, but it is often confused with the urethra which carries urine from the bladder to the outside world.

The blood flowing away from the kidney should have the least urea, since the kidney removes urea from the blood that enters via the renal artery. The renal vein is identified as vessel 3, since it is joined to vessel 1, the vena cava. The vena cava will contain some urea, since as blood passes around the circulatory system, only some of it will enter the kidneys through the renal artery. The rest (containing urea) will travel through other arteries and eventually end up in the vena cava.

**71**

The answer is option **B**.

Statement 1 is correct. Body temperature is controlled by homeostasis using negative feedback. The fall in body temperature could have been brought about by increased sweat production, leading to the cooling of the skin by increased evaporation.

Statement 2 is incorrect. Whilst the thermoregulatory centre in the brain is responsible for regulating body temperature, a fall in body temperature as shown between X and Y on the graph will only occur if the hairs on the skin lie flat. When the body temperature is too low, the hairs on the skin are raised in order to trap an insulating layer of air, in order to reduce heat loss.

Statement 3 is incorrect. Whilst the thermoregulatory centre in the brain is responsible for regulating body temperature, a fall in body temperature as shown between X and Y on the graph will only occur if more blood flows to the surface of the skin, so that heat from the blood can be lost to the environment.

**72**

The answer is option **D**.

In order to interpret this data correctly you need to ensure that you understand what is represented by the graph.

The *x*-axis shows the years studied from 1959 to 2008.

The left-hand vertical axis represents the number of wolves, with a range from 0 to just over 50.

The right-hand vertical axis represents the number of moose, with a range from 0 to just under 2500.

Trend 1 is quickly determined to be incorrect, since from 1959 to 1965, overall both the wolf and moose populations are increasing. Additionally, with no knowledge of what has happened before 1959 it cannot be said that there has been an increase in the wolf population as there was an earlier increase in moose population.

Trend 2 is correct. You need to remember that the two vertical scales are different. Reading from the graph, the maximum wolf population is 50, whilst the minimum moose population is about 400.

Trend 3 is incorrect. Whilst the point plotted for wolves is higher than that for moose in 1965, you need to remember that the two vertical scales are different. There are about 30 wolves but there are about 750 moose.

Trend 4 is correct. When wolf populations are low on the graph, such as from 1968 to 1973 and from 1982 to 1995, there is a corresponding increase in the size of the moose population.

**73**

The answer is option **G**.

The ratio of X **:** A in columns 1 and 2 is 0.5 **:** 1 which makes the flies male, irrespective of the presence or absence of the Y chromosome. The ratio of X **:** A in columns 3, 4 and 5 is 1 **:** 1 which makes the flies female, irrespective of the presence or absence of the Y chromosome.

**74**

The answer is option **H**.

Process 1 is photosynthesis and therefore should not feature in any answers. For carbon to be incorporated into animals and decomposers, digestion of carbon-rich compounds must initially occur (processes 2 and 3). Respiration can release carbon into the air as $CO_2$ which is illustrated by process 4.

**75**

The answer is option **A**.

The genetic code is a triplet code (three bases code for one amino acid). A section of DNA with 420 base pairs can code for 140 amino acids (420 divided by 3).

The DNA contains four bases (adenine, guanine, cytosine and thymine). Adenine binds with thymine and guanine with cytosine. If the DNA contains 42% adenine it will also contain 42% thymine. 42% × 2 is 84%.

This means that 16% are guanine and cytosine together. 16% divided by 2 is 8%.

This DNA therefore contains 42% of adenine, 42% of thymine, 8% of cytosine and another 8% of guanine.

**76**

The answer is option **B**.

In order to genetically modify bacteria to produce human insulin you need to cut out the DNA coding for human insulin from a normal, healthy human's DNA. A special enzyme is used to cut the DNA. Therefore statement 1 is correct.

This DNA is then inserted into the DNA of a bacterium. Bacteria do not have a nucleus, so statement 2 is incorrect.

The modified bacteria have to be cultured. This means that they are grown in a fermenter so that large numbers of bacteria are produced. Therefore statement 3 is correct.

The bacteria are used to produce human insulin, which is extracted from them and purified. This insulin is then used to treat diabetics. Therefore, statement 4 is incorrect, since bacteria are not injected into humans with diabetes.

**77**

The answer is option **F**.

Mutations are random changes in the DNA sequence of an organism. If this occurs within the sequence of a gene that codes for a protein then it can change the bases in the triplet sequence of that gene and may alter the amino acids that they code for (statement 1). If the mutation occurs within an enzyme that is part of an essential cell process, like respiration, then the cell may no longer be able to function correctly and may die (statement 3).

Some mutations do produce positive changes in cells that could be beneficial to the organism. If they take place in a cheek cell instead of a gamete however, they will not be passed on to any offspring of the organism so statement 2 is incorrect.

**78**

The answer is option **E**.

Using the information in the question, as the condition is caused by at least one allele it must be a dominant allele (statement 1). Therefore a person with the condition can be heterozygous or homozygous. For U to show the condition she must have received the allele for this condition from one of her parents and this would be T as he shows the condition (statement 2). In this case U would be heterozygous. Although U's mother does not show the condition a mutation could occur in the egg that is fertilised by T's sperm (statement 3). In this case U would be homozygous for the condition.

**79**

The answer is option **G**.

Starch is found in plant cells, not animal cells such as a liver cell, so statement 1 is incorrect. Within the liver cell's DNA there would be one pair of sex chromosomes. If the cell was from a male these would be XY and in a female these would be XX. In either case there is at least one X chromosome, so statement 2 is correct. An adult liver cell is a diploid body cell so it will contain the same genes as all other diploid body cells, including the gene for amylase, so statement 3 is correct.

**80**

The answer is option **A**.

The question tells us that a cell is surrounded by a dilute glucose solution which has a lower concentration of glucose than the glucose in the cytoplasm of the cell. It also tells us that both water molecules and glucose molecules enter the cell.

There is net movement of water molecules into a cell by osmosis. So we know that the concentration of water molecules outside the cell must be higher than the concentration of water molecules in the cell. Osmosis is a type of passive movement and so will be unaffected by the chemical which inhibits respiration as it does not require energy from the cell to take place. So water molecules will move into the cell.

There is net movement of glucose into the cell against a concentration gradient as the concentration of glucose molecules is lower outside the cell than inside. Glucose molecules must therefore enter by active transport.

Active transport uses energy supplied by respiration. If respiration is inhibited then active transport will no longer take place and glucose molecules will not be able to move into the cell.