

## Instructions for teachers for Engineering and Physical Sciences

There are ten sessions of multiple-choice questions here, on the following topics:

1. S.I. units, dimensional analysis, measurement theory (**pages 2-6**)
2. Electrostatics and magnetism (**pages 7-11**)
3. Electromagnetic induction and energy (**pages 12-16**)
4. Thermal energy and ideal gases (**pages 17-21**)
5. Static pressure and fluid dynamics (**pages 22-26**)
6. Scalars, vectors, couples and equilibrium (**pages 27-31**)
7. Material science, work and friction (**pages 32-36**)
8. Projectile motion, Newton's laws and momentum (**pages 37-41**)
9. Waves (**pages 42-46**)
10. Circular motion and SHM (**pages 47-51**)

To run a session, you need to print **two documents per pair of students**:

- *student questions*,
- *student feedback*.

Students having to share the questions and feedback sheets is an important part of the set-up, as it should help to encourage discussion.

The questions have been written or selected/modified from resources such as examination papers, to be deliberately challenging and tricky at times, since if the questions are too easy, it often leads to little discussion. Reassure students, where applicable, that questions like this won't be used in their summative assessments. Please emphasise to students that this activity is not about knowing the answers, but an opportunity to discuss and explore ideas.

Avoid the temptation to correct students whilst they are discussing. Instead, it is a good idea to allow time following the activity to discuss the most challenging questions as a group.

Always feel free to reach out at:

[m.heron@surrey.ac.uk](mailto:m.heron@surrey.ac.uk), our project lead, or another member of the research team: <https://www.surrey.ac.uk/research-projects/educational-dialogue-improving-foundation-year-student-outcomes#team>.

Whilst efforts have been made to correct errors and resolve ambiguities, some likely persist – let your discussions explore and uncover them!

# **1. S.I. units, dimensional analysis, measurement theory**

## **Feedback Sheet**

**If you picked 'A':**

**Question 1.** [Incorrect] The kelvin is the base unit for temperature.

**Question 2.** [Correct] Selecting a suitable equation helps here:  $V = IR$  and  $V = E/Q$ .  $R = E/IQ = [J]/[A\ C] = [kg\ m^2\ s^{-2}]/[A\ A\ s] = kg\ m^2\ s^{-3}\ A^{-2}$ . This made use of  $V = IR$  (Ohm's law),  $V = E/Q$  (definition of voltage) and a suitable equation for energy, e.g., work done = force x displacement.

**Question 3.** [Incorrect] Mega is the prefix for  $10^6$  (a million). Write each mega, giga, micro, and femto in brackets and multiply it all together.

**Question 4.** [Incorrect] Temperature is a physical quantity, we can measure it. Units, on the other hand, are arbitrary and do change the measurements.

**Question 5.** [Incorrect] The permittivity of free space is a physical quantity which describes how easy it is for an electric field to establish in free space.

**Question 6.** [Correct] Pressure is force per unit area, so  $F/A = ma/A = kg\ ms^{-2} / m^2 \rightarrow [M][L^{-1}][s^{-2}]$ .

**Question 7.** [Incorrect] Accuracy is often thought to be most important because we think of accuracy as 'the right answer'. However, sometimes we are more concerned about the predictability of a measurement, in which case precision is more of a concern. If possible, we would want both high accuracy and high precision, but this is not always possible for a given experiment, budget, or set of control variables.

**Question 8.** [Incorrect] It is good if other researchers using the same equipment/procedures are able to confirm your results. This would be an example of reproducibility, a good quality for an experiment since you do not expect to get different answers just because someone else is doing the experiment!

**Question 9.** [Incorrect] Since the measurements will always be  $1^\circ C$  higher than they should be, this will represent a systematic error (which can be subtracted from our measurements to report the true value).

**Question 10.** [Correct]  $\pm 1\ cm$ . A common theme in experiments is that the user must make decisions which affect the reporting of results. Here is one such example. The smallest increment on a 1 cm ruler (without any sub-divisions) is 1 cm, so this would be its resolution. You measure to the nearest 1 cm and report that. However, of course, you might as an experimenter be confident in rounding to the nearest half cm, being able to decide if you are closer to the middle of the increments or not. In this case, you can report a resolution of half a division, or 0.5 cm here. This is why it is so important to report your results (for example, in a lab write-up) on the resolutions you have used.

**If you picked 'B':**

**Question 1.** [Incorrect] The mole is the base unit for 'quantity' given by the number  $6.022 \times 10^{23}$ . This is most often used in chemistry, for example, the masses given on the periodic table of elements are in grams per mole.

**Question 2.** [Incorrect] This does not correspond to a physical quantity commonly used. Which equations have you used to help you? Consider using Ohm's law ( $V = IR$ ) and the definition of voltage ( $V = E/Q$ ). You will need an equation for energy too, for example, work done = force  $\times$  displacement to help you.

**Question 3.** [Incorrect] Giga is the prefix for  $10^9$  (a billion). Write each mega, giga, micro, and femto in brackets and multiply it all together.

**Question 4.** [Incorrect] The average kinetic energy of particles is the physical origin of what we call 'temperature' and therefore is a physical quantity.

**Question 5.** [Correct] pi is a calculation of the ratio of the circumference of a circle to its diameter. As such, you cannot measure pi, but rather, you have to always calculate it.

**Question 6.** [Incorrect] This would be force divided by volume – close but not quite right.

**Question 7.** [Incorrect] An accurate location is needed in order to ensure correct navigation.

**Question 8.** [Incorrect] This is a good experimental procedure, however, this would give us insight into the precision of our measurements. If each measurement is close to one another, we have higher levels of precision.

**Question 9.** [Correct] Digital noise – a digital thermometer is used to measure the temperature of a room. Electronic noise changes the reading a little bit even though the room remains at a constant temperature – systematic error. Fluctuations in the recorded temperature due to electronic noise will most likely be random since there are no good models to predict its behaviour and manifests in both over- and under-estimations of the temperature. The best we can do is to take several measurements (say 20 measurements) and record the error against the known temperature of the room. Taking the average will help us quantify this random error in our final results

**Question 10.** [Correct]  $\pm 0.5$  cm. A common theme in experiments is that the user must make decisions which affect the reporting of results. Here is one such example. The smallest increment on a 1 cm ruler (without any sub-divisions) is 1 cm, so this would be its resolution. You measure to the nearest 1 cm and report that. However, of course, you might as an experimenter be confident in rounding to the nearest half cm, being able to decide if you are closer to the middle of the increments or not. In this case, you can report a resolution of half a division, or 0.5 cm here. This is why it is so important to report your results (for example, in a lab write-up) on the resolutions you have used.

**If you picked 'C':**

**Question 1.** [Correct] A decision was taken to select either the coulomb or the ampere as a basic unit for electrical properties. The ampere was selected and therefore the coulomb is an S.I.-derived unit. You can calculate it as,  $Q = I T$ ;  $[C] = [A][s]$  so 1 Coulomb is 1 A s.

**Question 2.** [Incorrect] Selecting a suitable equation helps here:  $V = IR$  and  $V = E/Q$ .  $R = E/IQ = [J]/[A C] = [kg m^2 s^{-2}]/[A A s] = kg m^2 s^{-3} A^{-2}$ . This made use of  $V = IR$  (Ohm's law),  $V = E/Q$  (definition of voltage) and a suitable equation for energy, e.g., work done = force x displacement.

**Question 3.** [Correct] mega ( $10^6$ ) x giga ( $10^9$ ) x micro ( $10^{-6}$ ) x femto ( $10^{-15}$ ) =  $10^{-6}$  = micro.

**Question 4.** [Incorrect] The intermolecular force between particles might be measured in many different ways. For example, are they Van der Waal forces, partial charges or ionic (strong electrostatic) forces? Regardless of how we define them and therefore measure them, they are a physical quantity. We ascribe the unit of 'Newtons' to measure these forces.

**Question 5.** [Incorrect] The Planck constant  $h = 6.63 \times 10^{-34} J s$ , is the amount of energy a photon of a particular wavelength (or frequency) has. It is therefore a physical quantity.

**Question 6.** [Incorrect] This would be an equation for force, not pressure. Remember that pressure is force per unit area.

**Question 7.** [Incorrect] Decisions are made about weather forecasts (e.g., agriculture). When a prediction is made, an accurate measurement of temperature to make predictions is critical.

**Question 8.** [Correct] A scientific consensus must be reached through measurements of the same physical constant through different theoretical and experimental procedures. 'True' values are ultimately determined by consensus, we typically need different experiments which measure the same quantity. If they all agree, we are more confident that we know the 'true' value, for a physical quantity. Obviously, researchers do not have access to all the equipment/time/money/expertise to conduct all these different experiments. So, we publish our work in (for example) journals, and other researchers can use the results to support their investigations.

**Question 9.** [Incorrect] When the measurements are conducted under warmer conditions, the (metal) ruler would have expanded more than in cooler conditions. Our measurements will therefore under-estimate length in warm conditions. If we measure the temperature of the room during our measurements, we could account for this by using the linear expansion coefficient of the ruler's material and recording the measurement time. Even though the expansion may not be consistent throughout the day, it is modelled by the linear expansion coefficient, and recording the temperature of the room when the measurement is taken, can be accounted for. Thus, this is a systematic error.

**Question 10.** [Incorrect] It would be unreasonable to assume you can determine by eye being the closest quarter of a division without smaller increments. If you had one increment between 1 cm markings, then you might be able to justify this.

**If you picked 'D':**

**Question 1.** [Incorrect] The candela is the unit of luminous intensity. Interestingly, 1 cd is approximately the luminous intensity of a common wax candle.

**Question 2.** [Incorrect] This does not correspond to a physical quantity commonly used. Which equations have you used to help you? Consider using Ohm's law ( $V = IR$ ) and the definition of voltage ( $V = E/Q$ ). You will need an equation for energy too, for example, work done = force x displacement to help you.

**Question 3.** [Incorrect] Femto is the prefix for  $10^{-15}$  (a millionth of a billionth). Write each mega, giga, micro, and femto in brackets and multiply it all together.

**Question 4.** [Correct] The kelvin is the unit for the physical quantity temperature.

**Question 5.** [Incorrect] The speed of light in a vacuum,  $c = 3 \times 10^8 \text{ ms}^{-1}$ , is a physical quantity. Note, that it has units (dimensions) so cannot be a dimensionless quantity.

**Question 6.** [Incorrect] This would be an equation for energy, not pressure. Remember that pressure is force per unit area. What would you divide energy by to get to force?

**Question 7.** [Correct] A laboratory measuring the concentration of a chemical in a solution for experimental research. Here, the lab is providing concentrations for others to use in experiments. It is more important that repeated measurements or concentrations are close to one another so that experiments are consistent (even if the specific concentration was not accurately measured). At least a systematic error could be identified back to the measurement of these concentrations.

**Question 8.** [Incorrect] Higher resolution tends to be desirable in experiments, however, it comes at a price. The higher resolution equipment tends to be much more expensive (e.g., a ruler is pennies compared to a micrometre which can be hundreds of pounds). Further, higher resolution equipment tends to require far more training and time to use effectively increasing the difficulty in making the measurement.

**Question 9.** [Incorrect] Temperature can fluctuate for several reasons, in this case, when someone opens the door, warm air from inside the temperature-controlled room can escape, cooling the room down a little bit until the room is warmed again by an air conditioning unit. Without any more information, this would be classified as a random error, since you do not know how many times the door opened, the effect on temperature each time it happened, or any other complicated processes (such as convection currents). If you were able to model these effects for each measurement, you would be able to account for their effects and correct your measurements (possibly).

**Question 10.** [Incorrect] This would be the standard resolution of a ruler which has 10 divisions, splitting a 1 cm marking up into 10 lines, each representing a millimetre. You might possibly then suggest you could resolve 0.5 mm (half a division).

## **2. Electrostatics and magnetism**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Correct] A small (unit) change in the distance between the two point charges will cause a larger corresponding change in the electric field strength. Field strength is inversely proportional to the square of the distance between the charges. This nonlinear relation means small changes in distance can cause very large changes in electric field strength.

**Question 2.** [Incorrect] Whilst this number appears in the Coulomb equation, it is a constant for point charges in a vacuum. It is therefore not a measurement of field strength, but a scale factor of the field strength in a given medium.

**Question 3.** [Incorrect] Close, but this isn't generally true; the particle's actual path depends on its initial velocity and other forces acting on it.

**Question 4.** [Incorrect] The gradient of the graph will tell you whether you are looking at a  $1/r^2$  or  $1/r$  relationship. The  $1/r^2$  will drop faster than the  $1/r$ . Then look at the magnitude of the y-axis intercept. It will be larger for Force and Electric Potential Energy because they involve two charges, both with a magnitude of 2 C. Try again, and use the equations given to you to help. No calculation is needed!

**Question 5.** [Correct] This accurately describes the electric potential as the work done per unit charge to bring a charge from infinity to the point in question.

**Question 6.** [Incorrect] If the particle was stationary, there would be no component of magnetic force given  $F_B = qv \times B$ . So, the particle must have a non-zero velocity. The question then, is which direction does it point?

**Question 7.** [Incorrect] The net force comes from the *interaction* between the external magnetic field and the magnetic field generated by moving charges in the wire.

**Question 8.** [Correct] The magnetic field of a single loop is stronger at the centre of the loop compared to the field at a similar distance from a straight wire.

**Question 9.** [Incorrect] A refrigerator door seal uses a permanent magnet, not an electromagnet, to ensure the door closes tightly.

**Question 10.** [Incorrect] If the wire is parallel to the field, the force is zero. The formula  $F = BIL$  assumes the quantities are perpendicular to one another.



**If you picked 'B':**

**Question 1.** [Incorrect] Extreme environments (such as dielectrics) can have large effects on the strength of the electric field when the permittivity of free space ( $\epsilon_0$ ) is scaled by the permittivity of the medium or substance ( $\epsilon_s$ ) giving  $\epsilon = \frac{\epsilon_s}{\epsilon_0}$ . However, these environments are rare, instead, the changing the magnitude of the charges, or the distance (distribution) between them, are more likely to occur.

**Question 2.** [Incorrect] The measure of strength is best described by the electric field strength which depends on both the magnitude of the charge, the distance (squared) away from the charge, as well as the response of the medium (permittivity).

**Question 3.** [Correct] This correctly captures the behaviour of a positive test charge, since a negative charge would feel an oppositely directed force.

**Question 4.** [Incorrect] The gradient of the graph will tell you whether you are looking at a  $1/r^2$  or  $1/r$  relationship. The  $1/r^2$  will drop faster than the  $1/r$ . Then look at the magnitude of the y-axis intercept. It will be larger for Force and Electric Potential Energy because they involve two charges, both with a magnitude of 2 C. Try again, and use the equations given to you to help. No calculation is needed!

**Question 5.** [Incorrect] This is close, but it incorrectly describes the work as being done by the field from the point to infinity. Think about the start (reference point) and end (the distance/radius) of the 'r' in the equation.

**Question 6.** [Incorrect] This would be the direction if no magnetic field was present. The magnetic force direction can be determined by using the left-hand rule, where the thumb is the magnetic force, the index finger is the velocity, and the middle finger is the direction of the magnetic field.

**Question 7.** [Correct] This stresses the importance that it is the result of the interaction of two magnetic fields (one from the permanent magnet and one from a moving charge (the current)). This interaction results in a net force and thus movement of the charged particles – the wire moves as a result.

**Question 8.** [Incorrect] The magnetic field of a single loop is stronger at its centre, not weaker, compared to the field of a straight wire at the same distance. Hint: think about the right-hand rule for solenoids.

**Question 9.** [Incorrect] A traditional compass relies on the Earth's magnetic field and does not use an electromagnet.

**Question 10.** [Correct] The force can be calculated directly using  $F = BIL$ .

**If you picked 'C':**

**Question 1.** [Incorrect] Coulomb's law will scale linearly with the magnitude of each charge. Larger charges will cause larger electric fields between them. However, it is possible the change the electric field strength in a non-linear way, can you determine which quantity this would be?

**Question 2.** [Incorrect] Permeability is related to the ability of magnetic fields to be established, not electric fields. Different materials can respond differently to magnetic and electric fields.

**Question 3.** [Incorrect] The concept of a field itself might be abstract, however, field lines represent 'lines of force' or 'lines of action' and correspond to a physical quantity, e.g., force.

**Question 4.** [Correct] You can determine this from two properties of the graphs. It's gradient (how quickly the line changes) which is much steeper for  $1/r^2$  relationships, and the y-axis intercept, which for two charges of 2 C each, Force and Electric Potential Energy will be larger than the field and potential counterparts (which involve one charge each).

**Question 5.** [Incorrect] The electric potential is related to energy, not force. We would integrate the electrostatic force with respect to displacement. What will the limits of this integration be? We need to choose a reference point that makes sense.

**Question 6.** [Incorrect] The magnetic force direction can be determined by using the left-hand rule where the thumb would be the magnetic force, the index finger the velocity, and the middle finger the direction of the magnetic field.

**Question 7.** [Incorrect] Whilst the current will have an associated electric field, it is made of up of charged particles after all, the electric field does not contribute to the motor effect. The effect is due to the external magnetic field interacting with the magnetic field generated by a current.

**Question 8.** [Incorrect] The magnetic field will be uniform along its axis for a given distance.

**Question 9.** [Correct] Magnetic levitation systems, such as those used in maglev trains, utilise electromagnets to create a magnetic field that levitates and propels the train, allowing for frictionless transportation.

**Question 10.** [Incorrect] The formula should be modified to account for the angle off perpendicular, e.g., by multiplying by  $\sin(60^\circ)$  or  $\cos(30^\circ)$  depending on how you define  $0^\circ$ .

**If you picked 'D':**

**Question 1.** [Incorrect] Within the Coulomb law formulation, we assume that masses are 'point charges' and thus have no internal structure or geometry. As such, changing the shape will not alter the field strength since it does not feature in the equation. When the distances between charges are much larger than the diameter of the charge surfaces, this approximation works well.

**Question 2.** [Correct] A large number means it is easier to set up (respond) to an external electric field passing through the medium. Dielectrics have larger values of  $\epsilon$ . For a vacuum, which is not easy to polarise, the permittivity of free space is very small.

**Question 3.** [Incorrect] There is a relationship between field line density and field strength, specifically, the more line per unit area, the stronger the field strength is in that region, however, this does not tell us about the physical interpretation of field lines as 'lines of force'.

**Question 4.** [Incorrect] The gradient of the graph will tell you whether you are looking at a  $1/r^2$  or  $1/r$  relationship. The  $1/r^2$  will drop faster than the  $1/r$ . Then look at the magnitude of the y-axis intercept. It will be larger for Force and Electric Potential Energy because they involve two charges, both with a magnitude of 2 C. Try again, and use the equations given to you to help. No calculation is needed!

**Question 5.** [Incorrect] The electric potential difference is related to the energy per unit charge, not the total charge that flows between two points. We can determine the energy through work done = force x displacement.

**Question 6.** [Correct] When a charged particle moves through both electric and magnetic fields, it experiences forces from each field. For the net force to be zero, the electric force  $F_E = qE$  and the magnetic force  $F_B = qv \times B$  must cancel each other out. Since the electric field is along the x-axis and the magnetic field is along the z-axis, the particle must have a velocity component along the y-axis. Further, we can determine the particle has a positive charge (given the electric force acts in the direction of the electric field) causing a velocity in the positive y-axis direction. A negatively charged particle would have similar behaviour, but the velocity would be in the negative y-axis direction.

**Question 7.** [Incorrect] The motor effect is strongest when the wire (current) is perpendicular to the magnetic field, not parallel.

**Question 8.** [Incorrect] The magnetic field of a loop is not uniform along its axis; it varies in strength and shape as you move away from the centre.

**Question 9.** [Incorrect] A mechanical wristwatch uses a balance wheel and escapement mechanism, for timekeeping, and does not need an electromagnet (or battery!). Instead, it can use a coiled spring to store energy as elastic potential energy.

**Question 10.** [Incorrect] If the wire forms a loop with the magnetic field enclosed within it, the force calculation involves additional considerations related to the geometry of the loop and the net effect on the wire, so we cannot use  $F = BIL$  in this form.

### **3. Electromagnetic induction**

#### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Incorrect] While a changing magnetic field can induce an e.m.f., this scenario is about a moving rod, so the focus should be on motion-induced e.m.f. rather than a time-varying magnetic field.

**Question 2.** [Correct] It creates a magnetic field opposing the increase in B thus aligning with Lenz's Law's principle of opposing the change in flux. Remember, Lenz's law is underpinned by the conservation of energy.

**Question 3.** [Incorrect] While increasing N will increase the e.m.f., it might also require more material and space, potentially making the coil bulkier and more difficult to rotate efficiently. This is particularly in applications where space or material is limited. There is a more generally efficient way without redesigning the equipment.

**Question 4.** [Correct] In an ideal transformer (no energy loss), the power on the primary side is equal to the power on the secondary side, which means  $P_{\text{primary}} = P_{\text{secondary}}$ . Since power  $P = IV$ , and the transformer steps down the voltage from 240 V to 12 V, the current must increase to keep the power constant. The current in the secondary coil will indeed be higher to compensate for the lower voltage, as power is conserved.

**Question 5.** [Incorrect] This might seem logical at first, but transformers rely on changing magnetic flux, direct current (DC) creates a constant magnetic field, which may at first induce the necessary voltage changes in a transformer as it is switched on at the DC is established but will quickly stop inducing any voltages.

**Question 6.** [Incorrect] There may be disagreements on what renewable means, particularly when it is often used interchangeably with 'clean' or 'green' energy, but a sense of timescale is important. The most obvious timescale is of human nature (e.g., hundreds of years), certainly because the industrial revolution (fossil fuel driven) has occurred on this timescale. As such, nuclear energy is probably hard to justify as being 'renewable', but this does not mean it is not a worthwhile process for long-term energy production. Of course, if you take an absolute approach the renewable energy, then no energy resource will be renewable, given, for example, the sun will eventually stop shining, but this is on an extreme timescale.

**Question 7.** [Incorrect] This is partially correct. Motor X does have a higher power output (at 50 W), but you need to also consider efficiency to determine overall performance. Efficiency affects how effectively the work is being done, not just how quickly.

**Question 8.** [Correct] The efficiency of the motor is calculated as the ratio of the useful output energy (which is the gravitational potential energy gained by the load,  $mg \times h$ ) to the total electrical energy supplied to the motor, which is  $VIt$  (potential difference  $\times$  current  $\times$  time).

**Question 9.** [Incorrect] While the energy transformation from gravitational potential to kinetic energy is correct, assuming the ball returns to its original height ignores real-world energy losses. Even with negligible air resistance, some energy is lost to heat and sound during the bounce, so the ball will not reach the same height.

**Question 10.** [Incorrect] Gravity is far too weak to affect interactions between protons and neutrons. The strong nuclear force dominates at both short and medium distances, while at large distances, the mean field of the neutron's quarks tends to zero, causing the interaction to weaken, not remain strong.

**If you picked 'B':**

**Question 1.** [Incorrect] Moving parallel to the magnetic field lines does not change the magnetic flux through the rod, hence no e.m.f. is induced.

**Question 2.** [Incorrect] This option incorrectly interprets the idea of opposition, misunderstanding that Lenz's Law requires the induced current to generate a field in the opposite direction to the change in flux.

**Question 3.** [Incorrect] Although increasing B would substantially increase the e.m.f., it is often more challenging in practice compared to altering the rotational speed, particularly when using natural or existing magnets. Is it feasible to always increase field strength? A 2 Tesla field is found in large MRI machines, for example.

**Question 4.** [Incorrect] This option reverses the roles of the primary and secondary coils. The transformer is designed to step down the voltage, meaning the primary coil has a higher voltage (240 V), and the secondary coil has a lower voltage (12 V). The turns ratio of the transformer determines the voltage change:  $\frac{V_{\text{primary}}}{V_{\text{secondary}}} = \frac{N_{\text{primary}}}{N_{\text{secondary}}}$ . In this case, with 800 turns in the primary coil and 40 in the secondary, the voltage is stepped down by a factor of 20, leading to 12V at the secondary coil.

**Question 5.** [Correct] The most important factor in transformer design is the use of alternating current (AC). AC creates a constantly changing magnetic flux, which induces voltage in the secondary coil, allowing transformers to step up or step down voltage. DC, on the other hand, would not generate the required changing magnetic flux, making it unsuitable for transformer operation.

**Question 6.** [Incorrect] There may be disagreements on what renewable means, particularly when it is often used interchangeably with 'clean' or 'green' energy, but a sense of timescale is important. The most obvious timescale is of human nature (e.g., hundreds of years), certainly because the industrial revolution (fossil fuel driven) has occurred on this timescale. As such, nuclear energy is probably hard to justify as being 'renewable', but this does not mean it is not a worthwhile process for long-term energy production. Of course, if you take an absolute approach the renewable energy, then no energy resource will be renewable, given, for example, the sun will eventually stop shining, but this is on an extreme timescale.

**Question 7.** [Incorrect] Motor Y actually has a lower power output compared to Motor X, but it is indeed more efficient.

**Question 8.** [Incorrect] You need to think about using input energy, which would be the amount of electricity you used. The product of  $V \times I$  is input power. How do you get from Power to Work done?

**Question 9.** [Correct] This is the most realistic scenario. As the ball falls, its gravitational potential energy is converted into kinetic energy, but during the bounce, some energy is lost (e.g., through heat, sound, and deformation). As a result, the ball does not return to its original height, which aligns with the principle of energy conservation in real-world scenarios.

**Question 10.** [Incorrect] While quarks have electric charges (up quarks are  $+2/3$ , down quarks are  $-1/3$ ), the repulsion and attraction in this context are dominated by the strong nuclear force, not electrostatic interactions. At large distances, the strong force diminishes as the quark fields from the neutron tend toward zero, so the interaction does not remain strong at long distances.

**If you picked 'C':**

**Question 1.** [Correct] Moving perpendicular to the magnetic field lines maximises the change in magnetic flux, hence maximising the induced e.m.f.

**Question 2.** [Incorrect] This option is incorrect because it suggests a response that violates Lenz's Law, which dictates that the system will resist the increase in flux.

**Question 3.** [Incorrect] Increasing  $A$  does indeed increase the e.m.f., the mechanical and design challenges associated with enlarging the coil could make this option less desirable. For example, increasing the area will also increase the moment of inertia, making it more difficult to maintain or increase the angular velocity, or change rotational direction.

**Question 4.** [Incorrect] While energy can be lost in transformers, the high current in the secondary coil, not the primary coil, causes the increase in energy transferred. Eddy currents in the core are indeed a source of energy loss, but this loss occurs due to changing magnetic fields in the core, not the current in the primary coil.

**Question 5.** [Incorrect] While core material efficiency is important, it's not the most critical factor when deciding to use a transformer. Before we worry about efficiency, we first need to make sure we can induce a current through Faraday's law (equation given in Question 2). It relies on a time-varying magnetic flux linkage.

**Question 6.** [Incorrect] There may be disagreements on what renewable means, particularly when it is often used interchangeably with 'clean' or 'green' energy, but a sense of timescale is important. The most obvious timescale is of human nature (e.g., hundreds of years), certainly because the industrial revolution (fossil fuel driven) has occurred on this timescale. As such, nuclear energy is probably hard to justify as being 'renewable', but this does not mean it is not a worthwhile process for long-term energy production. Of course, if you take an absolute approach the renewable energy, then no energy resource will be renewable, given, for example, the sun will eventually stop shining, but this is on an extreme timescale.

**Question 7.** [Correct] Motor X has a higher power output of 50 W compared to Motor Y's 40 W. However, Motor X has an efficiency of 80% while Motor Y's efficiency is 81%. Thus, Motor X is more powerful but less efficient, and Motor Y is more efficient but less powerful.

**Question 8.** [Incorrect] You need to think about using input energy, which would be the amount of electricity you used. The product of  $V \times I$  is input power. How do you get from Power to Work done?

**Question 9.** [Incorrect] The ball cannot gain more energy than it had initially unless an external force is applied to it. The force from the surface in this case does not add energy, but rather some of the initial energy is lost during the bounce.

**Question 10.** [Incorrect] The forces involved here are not primarily electrostatic but due to the strong nuclear force. The interaction weakens at long distances because the mean field from the neutron's quarks tends to zero, not due to the proton's weaker field.

**If you picked 'D':**

**Question 1.** [Incorrect] Rotation in this manner can induce an e.m.f., but unless specific details (like angular velocity) are provided, this situation is less straightforward compared to linear motion perpendicular to the field. This option is more complex and less likely to result in the maximum e.m.f. compared to option 3.

**Question 2.** [Incorrect] Remember, the objective of Lenz's Law is to oppose the change in magnetic flux, not to support or enhance it as it would in this case.

**Question 3.** [Correct] Doubling the angular velocity  $\omega$  is often the most effective and easiest to adjust in practice, as it directly increases the rate of change of magnetic flux, leading to a more significant impact on the induced e.m.f. With minimal additional materials and redesign, higher angular velocities are usually easiest to implement.

**Question 4.** [Incorrect] Not quite, this statement is incorrect because in a step-down transformer, the current in the secondary coil is higher than in the primary coil, as power is conserved. When voltage decreases, current must increase in an ideal transformer. Additionally, this option confuses the cause of energy loss. Energy loss in transformers is not because of the difference in current but due to factors like eddy currents, hysteresis, and Joule heating in the windings. These are the real contributors to energy loss in real-world transformers, not the simple difference between current in the primary and secondary coils

**Question 5.** [Incorrect] Good insulation is essential to prevent overheating, but this isn't the most important design decision when it comes to the fundamental operation of a transformer. Similarly, a laminate core is great for reducing eddy currents, but even more importantly, is ensuring there is a time-varying magnetic flux.

**Question 6.** [Correct] This is a tricky question, and definitions matter. One common definition of 'renewable' is whether or not the energy resource is replenished on a 'human timescale'. A human timescale might be considered approximately 100 years. Nuclear fission relies on uranium-238 which is not replenished on this timescale. Nuclear fusion will rely on Lithium and Tritium which are extracted from the Earth's surface and water respectively, again, not replenished on a human timescale. However, the resources themselves (Uranium-238, Lithium, Tritium) could last thousands of years of energy production.

**Question 7.** [Incorrect] Motor X and Motor Y do not have the same power output (50 W vs. 40 W). Efficiency is calculated by useful work done divided by total energy input.

**Question 8.** [Incorrect] Efficiency should always be the ratio of useful energy output to the total energy input. What would you consider useful here? And what was the input energy?

**Question 9.** [Incorrect] Although the ball may lose some energy during the bounce, this option incorrectly suggests that gravitational potential energy is not fully converted into kinetic energy as the ball falls. In the absence of air resistance, the potential energy is indeed fully converted into kinetic energy before the bounce.

**Question 10.** [Correct] At very short distances, the strong nuclear force between quarks becomes repulsive, as they are pushed too close together. At slightly longer distances, the strong nuclear force is attractive, binding the proton and neutron. As the distance increases, the net field generated by the neutron's quarks tends toward zero (since the neutron is neutral), and the interaction weakens.



## **4. Thermal energy and ideal gases**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Incorrect] While increasing the surface temperature will increase the rate of heat transfer, the temperature difference only changes from  $70-25=45^{\circ}\text{C}$  to  $90-25=65^{\circ}\text{C}$ . This results in a proportionate increase, but doubling  $h$  or  $A$  affects the heat transfer rate more significantly.

**Question 2.** [Incorrect] Convection is driven by temperature differences. A larger temperature difference increases the driving force for heat transfer, increasing the rate of convection.

**Question 3.** [Correct] The rate of radiative energy transfer is most significantly affected by temperature. According to the Stefan-Boltzmann law, the radiative power emitted by a surface is proportional to  $T^4$ . This means that even small temperature increases can lead to a very large increase in radiative energy transfer. Temperature is the most significant factor in increasing radiation and is often controllable through the input of radiation.

**Question 4.** [Incorrect] Increasing the volume flow rate means more liquid passes through the chamber per unit time, which tends to reduce the temperature increase ( $\Delta t$ ). The same amount of heat from the heater is being distributed over a larger mass of liquid, meaning less temperature rise for each unit of liquid. Think about how the same energy is spread out over more fluid, lowering the temperature difference.

**Question 5.** [Incorrect] This equation incorrectly places the masses of the car  $M$  and the brake discs  $m$  in the wrong positions relative to the terms. The correct equation needs to account for the fact that the kinetic energy of the car  $\frac{1}{2}MV^2$  is transferred into the brake discs. The mass of the brake discs  $m$  should be in the denominator, and the mass of the car  $M$  should be in the numerator. Consider how the car's kinetic energy is distributed over the brake discs.

**Question 6.** [Correct] Excellent! Specific heat capacity measures how much energy is needed to change the temperature of a substance without a phase change. Latent heat refers to the energy required for a phase change (such as melting or boiling) at constant temperature. This distinction is crucial in understanding thermal processes during heating and phase changes.

**Question 7.** [Incorrect] This number is much too small for the given mass of  $\text{CO}_2$ . To calculate the number of molecules, first determine the molar mass of  $\text{CO}_2$ , which is  $44 \text{ g/mol}$ . For  $2.2 \text{ kg}$  (or  $2200 \text{ g}$ ), you can calculate the number of moles of  $\text{CO}_2$  using  $n = \frac{\text{mass}}{\text{molar mass}}$ . Then, multiply by Avogadro's constant  $6.02 \times 10^{23}$  to find the number of molecules.

**Question 8.** [Incorrect] This is a valid assumption of the kinetic theory model. Gas particles are assumed to undergo perfectly elastic collisions with each other and with the walls of the container. In an elastic collision, no kinetic energy is lost, meaning the total energy is conserved in these collisions. This ensures that the internal energy of the gas is related to the temperature.

**Question 9.** [Incorrect] The resultant line is pointing towards the left, which is in the direction of the wall. Since the ball moves towards the right, the change in momentum cannot be pointing towards the wall. Consider what the change in vertical components and horizontal components are independently.

**Question 10.** [Correct] Some sanity-checking tells us this is the right answer. First, we would expect the internal energy of a gas to be zero when the temperature is zero (in Kelvin) since it will not be moving (no kinetic energy), and the assumption is that there is no potential energy (from the ideal gas law derivation). Second, the gradient should be linear since from the ideal gas law,  $PV$  is proportional to  $T$ .

**If you picked 'B':**

**Question 1.** [Incorrect] Increasing the air temperature reduces the temperature difference to  $70-60=10^{\circ}\text{C}$ , which would decrease the rate of heat transfer.

**Question 2.** [Incorrect] The rate of convection depends directly on the surface area available for heat transfer. Increasing the surface area of the plate allows more heat to be transferred via convection, increasing the overall rate of heat loss. More surface area provides more opportunity for air to contact the plate and carry away heat.

**Question 3.** [Incorrect] Increasing the emissivity of the plate does indeed increase the rate of radiation transfer, as emissivity is a measure of how effectively a material emits radiation. However, emissivity ranges from 0 to 1, meaning the potential increase is relatively limited compared to the other variables of the Stefan-Boltzmann equation:  $P = \epsilon\sigma AT^4$ .

**Question 4.** [Correct] The rate of radiative energy transfer is most significantly affected by temperature. According to the Stefan-Boltzmann law, the radiative power emitted by a surface is proportional to  $T^4$ . This means that even small temperature increases can lead to a very large increase in radiative energy transfer. Temperature is the most significant factor in increasing radiation and is often controllable through the input of radiation.

**Question 5.** [Incorrect] Although the general structure is closer to the correct answer, the factor of 2 in the numerator is unnecessary. The kinetic energy of the car is  $\frac{1}{2}MV^2$ . The temperature rise is determined by the relationship between the car's kinetic energy and the brake discs' capacity to absorb this energy. Try to think about the role of specific heat capacity and the need to divide the energy by  $mc$ .

**Question 6.** [Incorrect] Specific heat capacity does not apply to temperature changes during a phase change. When a substance is undergoing a phase change (like melting or boiling), its temperature remains constant, and the energy involved is latent heat. Try to focus on the fact that latent heat is the energy required to overcome intermolecular forces during the phase change, not to change temperature.

**Question 7.** [Incorrect] This value is also too small by several orders of magnitude. The correct approach is to first calculate the number of moles of  $\text{CO}_2$  in 2.2 kg by dividing the mass of  $\text{CO}_2$  (2200 g) by the molar mass (44 g/mol). Then, multiply this by Avogadro's constant  $6.02 \times 10^{23}$ .

**Question 8.** [Incorrect] This is also a correct assumption of the kinetic theory model. Gas particles are assumed to have negligible volume compared to the volume of the container, meaning the distance between the particles is much larger than their actual size. This allows the gas to behave ideally, where the interactions between particles are minimal.

**Question 9.** [Correct] Without calculation we might suspect this is the correct answer given that the ball will always be travelling vertically (since this component has not changed), but its horizontal component as gone from left (towards the wall) to right (away from the wall) and so the change (final – initial) will be a longer line ( $2mv$ ) pointing away from the wall.

**Question 10.** [Incorrect] This option suggests the non-zero internal energy at zero Kelvin. we would expect the internal energy of a gas to be zero when the temperature is zero (in Kelvin) since it will not be moving (no kinetic energy), and the assumption is that there is no potential energy (from the ideal gas law derivation). The gradient, however is correct since from the ideal gas law,  $PV$  is proportional to  $T$ .

**If you picked 'C':**

**Question 1.** [Incorrect] Doubling the surface area will directly double the heat transfer rate because  $Q$  is proportional to  $A$ . However, when comparing this with doubling the convective heat transfer coefficient ( $h$ ), both have the same direct effect, but the impact of  $h$  might be more significant depending on the specific design and materials.

**Question 2.** [Correct] Well done! The thermal conductivity of the metal plate affects how heat moves within the plate, but convection is primarily concerned with the heat transfer from the plate to the surrounding fluid. Changing the thermal conductivity of the plate does not directly impact the rate of convection, which is governed by the properties of the fluid and the temperature difference between the plate and its surroundings.

**Question 3.** [Correct] While increasing the surface area will increase the total radiative energy transfer, it does so proportionally. Refer to the Stefan-Boltzmann relationship for a black body radiator:  $P = \epsilon \sigma A T^4$ . Consider which factor changes radiation more dramatically.

**Question 4.** [Incorrect] While increasing the resistance of the heating element might seem like it could lead to more heat generation, the actual energy output from the heater is determined by the power supply. In a steady-state system, the power delivered by the heater remains constant, so increasing the resistance alone without changing other parameters, such as voltage, will not increase the heat delivered to the liquid and thus will not affect  $\Delta t$ .

**Question 5.** [Correct] This is the correct answer. The kinetic energy of the car is  $\frac{1}{2}MV^2$ , which is dissipated as heat in the brake discs. The heat energy  $Q$  transferred into the brake discs is related to the temperature rise  $\Delta T$  by the formula  $Q = mc\Delta T$ , where  $m$  is the total mass of the brake discs, and  $c$  is their specific heat capacity. Therefore, the rise in temperature is given by  $\Delta T = \frac{\frac{1}{2}MV^2}{mc}$ .

**Question 6.** [Incorrect] Specific heat capacity applies to any phase (solid, liquid, or gas) and refers to the energy required to raise the temperature of that phase. Latent heat, on the other hand, applies during the phase transition itself, regardless of whether the substance is changing from solid to liquid or liquid to gas.

**Question 7.** [Incorrect] This is close to the correct value, but it's slightly lower than the actual answer. Recalculate the number of moles and multiplying by Avogadro's constant.

**Question 8.** [Correct] This is not an assumption in the kinetic theory model. While gas particles do travel very quickly, the time they take to move between the walls is not assumed to be negligible in the theory. The model assumes that the speed of the particles is related to the temperature of the gas, and they take a non-negligible time to travel across the container, depending on their velocity. The key assumptions focus more on energy, collisions, and particle size, not the time it takes to traverse the container.

**Question 9.** [Incorrect] This option suggests that the ball observes a momentum change in the vertical direction, pointing downwards. The ball is moving upwards and towards the wall, hits the wall, then continues moving upwards but now away from the wall.

**Question 10.** [Incorrect] The intercept (at 0,0) is correct given we would expect the internal energy of a gas to be zero when the temperature is zero (in Kelvin) since it will not be moving (no kinetic energy), and the assumption is there is no potential energy (from the ideal gas law derivation). However, the gradient of the line is nonlinear, possibly quadratic, which we would not expect from the ideal gas law equation.

**If you picked 'D':**

**Question 1.** [Correct] Doubling the convective heat transfer coefficient ( $h$ ) has a significant effect on the rate of heat transfer because it directly reflects the efficiency of heat exchange between the surface and the air. This coefficient depends on factors like fluid flow, turbulence, and material properties.

**Question 2.** [Incorrect] Increasing the air flow speed around the plate increases the rate of convection. Faster-moving air helps to remove the heated air around the plate more quickly, enhancing heat transfer by creating a steeper temperature gradient. This is why fans are often used to increase convection.

**Question 3.** [Incorrect] The thermal conductivity of the plate affects how heat flows within the plate but not the rate of energy transfer by radiation. Radiative heat transfer depends on surface properties and temperature, not on how heat is conducted through the material. Thermal conductivity would have more of an impact on conduction rather than radiation.

**Question 4.** [Incorrect] The density of the liquid does not directly influence the temperature difference  $\Delta t$ . It is the specific heat capacity that determines how much energy is required to raise the temperature of the liquid. A higher density might increase the mass of liquid passing through, but it would also mean that more energy is required to heat the liquid, not less.

**Question 5.** [Incorrect] This expression does not make sense in terms of units or physics. It incorrectly inverts the terms and leads to an expression where mass, specific heat capacity, and velocity are in the wrong relationship. The temperature rise is proportional to the car's kinetic energy and inversely proportional to the mass and specific heat capacity of the brake discs.

**Question 6.** [Incorrect] While both specific heat capacity and latent heat involve energy, latent heat can be much larger in magnitude compared to the energy required for temperature changes via specific heat capacity. Latent heat is responsible for phase changes, which often require large amounts of energy to overcome the molecular bonds. It's important to note that during phase changes, temperature doesn't increase until the phase change is complete.

**Question 7.** [Correct] Calculating the molar mass as  $44 \text{ g mol}^{-1}$  and multiplying by how many moles we have ( $2.2 \text{ kg} / 0.0044 \text{ kg}$ ) now can be used to calculate the total number of molecules, by multiplying by the Avogadro constant.

**Question 8.** [Incorrect] This is a correct assumption. In the kinetic theory, the **duration** of each collision between a gas particle and the container walls is assumed to be negligibly short, meaning the contact with the walls happens almost instantaneously. This allows the model to simplify the analysis of pressure, where the focus is on the momentum change of the particles upon collision with the walls.

**Question 9.** [Incorrect] This option suggests that the ball observes a momentum change in the vertical direction, pointing downwards. The ball is moving upwards and towards the wall, hits the wall, then continues moving upwards and away from the wall.

**Question 10.** [Incorrect] The intercept (at 0,0) is correct given we would expect the internal energy of a gas to be zero when the temperature is zero (in Kelvin) since it will not be moving (no kinetic energy), and the assumption is there is no potential energy (from the ideal gas law derivation). However, the gradient of the line is nonlinear, possibly quadratic, which we would not expect from the ideal gas law equation.

## **5. Thermodynamics, static pressure and fluid dynamics**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Incorrect] The volume does not need to remain constant in either closed or isolated systems. Both systems can experience changes in volume, depending on the process. For example, if a closed system is heated, the gas may expand, increasing its volume. Volume is therefore not a variable that must be held constant in both system types.

**Question 2.** [Incorrect] While it's true that at equilibrium the forward and reverse reaction rates are equal, this description doesn't fully explain why equilibrium corresponds to maximum entropy. The key point is that equilibrium represents the most probable distribution of energy and particles, which leads to maximum entropy. Focus on the system's energy distribution rather than just the balance of reaction rates.

**Question 3.** [Incorrect] The COP of a refrigerator should be greater than 1.0. Use the relationship between the temperatures of the hot and cold reservoirs to calculate the COP:  $COP = \frac{T_c}{T_h - T_c}$ . Since the engine's efficiency is 0.33, this means that  $\eta = \frac{T_h - T_c}{T_h}$ , and the COP will be higher. Revisit how the temperature difference affects the performance of a refrigerator.

**Question 4.** [Incorrect] While incompressible fluids do not significantly change in volume, the reason is not due to the size of the fluid molecules. Instead, it relates to the incompressibility of the fluid due to strong intermolecular forces that prevent significant reduction in volume, even when pressure is applied.

**Question 5.** [Incorrect] In a hydraulic system, the pressure applied to the smaller piston is transmitted equally to the larger piston according to Pascal's Principle. The force on the larger piston is amplified based on the area ratio of the two pistons. This answer likely comes from incorrectly assuming a linear relationship between the diameters of the pistons, rather than using the areas (which depend on the square of the radius).

**Question 6.** [Correct] Laminar flow is characterised by smooth, parallel layers of fluid with little mixing between them, while turbulent flow is chaotic, with swirling eddies and irregular fluid motion. This is the fundamental difference between these two types of flow. The transition between them is determined by factors such as fluid velocity, viscosity, and the geometry of the flow system.

**Question 7.** [Incorrect] The pressure at a given point in a fluid column does depend on the weight of the fluid above it, but it's more precise to say it depends on the height of the column, the density of the fluid, and the gravitational field strength. The height of the column is important, but so is the type of fluid (density) and gravity's effect on it.

**Question 8.** [Correct] According to the continuity equation, for an incompressible fluid, the product of the cross-sectional area and the fluid velocity must remain constant. Therefore, when the pipe narrows (decreases in diameter), the velocity of the fluid must increase to maintain the same flow rate.

**Question 9.** [Incorrect] Remember that according to Bernoulli's principle, pressure decreases as fluid velocity increases when the cross-sectional area decreases. Review your calculations for velocity and how they relate to pressure. This involves calculating the velocity at point B using the continuity equation  $A_A V_A = A_B V_B$ . Have you considered how height is changing across the pipe and how this impacts the Bernoulli equation?

**Question 10.** [Correct] You correctly applied Stokes' Law and the concepts of buoyancy and weight to calculate the terminal velocity of the sphere!

**If you picked 'B':**

**Question 1.** [Incorrect] Pressure is also a variable that can change in both closed and isolated systems. Pressure may increase or decrease as temperature or volume changes, depending on the specific conditions of the process. Since pressure does not have to remain constant in either type of system, it's not the correct answer.

**Question 2.** [Incorrect] Minimising energy does not necessarily maximise entropy. In fact, equilibrium represents a state of maximum entropy, not minimum energy. Entropy is a measure of disorder, not energy dissipation.

**Question 3.** [Correct] Using the equation  $COP = \frac{T_c}{T_h - T_c}$  and knowing the efficiency is related to temperature difference  $\eta = \frac{T_h - T_c}{T_h}$ , you should arrive at a COP close to 2.

**Question 4.** [Incorrect] This is a key part of the explanation related to Pascal's Principle, which states that pressure in a confined fluid is transmitted equally in all directions. However, the constant motion of molecules is not what makes a fluid incompressible - it explains how pressure is distributed. The focus of the question is on the incompressibility of the fluid itself.

**Question 5.** [Incorrect] In a hydraulic system, pressure PPP is the same throughout, and the relationship between force and area is key. The force on the larger piston should be much greater due to the larger surface area. To find the correct force, calculate the area of both pistons using  $A = \pi r^2$ , and apply the ratio of the areas to the force. Be careful with the difference between diameters and areas!

**Question 6.** [Incorrect] This answer combines elements that are true but misapplies them. Laminar flow does indeed depend on viscosity, but it typically occurs at low velocities and higher viscosities. Turbulent flow, on the other hand, usually occurs at high velocities and in lower-viscosity fluids, but it can also arise in high-viscosity fluids if the velocity is high enough.

**Question 7.** [Incorrect] Pressure in a fluid column is not constant at all depths. In fact, pressure increases with depth due to the increasing weight of the fluid above. This is why deeper depths in a fluid have higher pressure. Instruments like barometers rely on measuring changes in the height of a column of fluid (usually mercury) to assess atmospheric pressure.

**Question 8.** [Incorrect] While it is true that pressure may drop in a narrower section of a pipe due to the Bernoulli principle, this does not directly mean that the velocity decreases or increases. Consider how to apply the continuity equation can be applied to this scenario.

**Question 9.** [Correct] You correctly applied Bernoulli's equation, recognizing that the fluid's velocity increases as it flows into a narrower pipe, leading to a decrease in pressure.

**Question 10.** [Incorrect] Ensure you carefully apply Stokes' Law and account for the balance between weight, buoyancy, and drag force. Double-check your calculations to see how changes in parameters can affect the outcome. First, calculate the volume of the sphere, then calculate the weight of the sphere ( $F_g$ ). Calculate the buoyant force ( $F_b$ ) then finally use the terminal velocity equation to calculate  $F_d$  which is equal to Stoke's law.



**If you picked 'C':**

**Question 1.** [Incorrect] While temperature can remain constant in certain processes, it is not necessarily held constant in both closed and isolated systems. In a closed system, energy can be transferred, causing the temperature to change. Even in an isolated system, temperature can change due to internal processes.

**Question 2.** [Correct] At equilibrium, the system is in a state where energy is distributed in the most probable way, resulting in maximum disorder (maximum entropy). The second law of thermodynamics states that systems tend to evolve towards states of maximum entropy, which is why equilibrium corresponds to maximum entropy.

**Question 3.** [Incorrect] A COP of 3.0 suggests you might be overestimating the effect of the temperature difference. When calculating the COP using  $COP = \frac{T_c}{T_h - T_c}$ , remember that the efficiency of the engine provides you with a ratio between the hot and cold temperatures. Revisit the relationship between  $\eta = \frac{T_h - T_c}{T_h}$  and the COP to improve your calculation.

**Question 4.** [Correct] In an incompressible fluid, the volume remains constant when pressure is applied, which means that any applied force results in an undiminished transmission of pressure throughout the system. This is how hydraulic systems work, as the pressure is fully transmitted to other parts of the system without being absorbed by changes in the fluid's volume.

**Question 5.** [Correct] You correctly used Pascal's Principle to recognize that the pressure in the hydraulic system is transmitted equally throughout the fluid. Since the area depends on the square of the radius, the larger piston's area is significantly bigger than that of the smaller piston, leading to a much greater force of 5,000 N.

**Question 6.** [Incorrect] It's true that laminar flow experiences less resistance and friction compared to turbulent flow, which generates energy losses due to its chaotic eddies. However, this doesn't fully explain the nature of the flows themselves. The key difference is in the behaviour of fluid layers: laminar flow involves smooth, organised layers, while turbulent flow is disorganised and chaotic. This disorganisation causes energy losses but doesn't solely define the flow type.

**Question 7.** [Correct] The pressure depends on the depth and the fluid density (whilst the gravitation field remains constant, a good approximation here).

**Question 8.** [Incorrect] This statement contradicts the continuity equation. For an incompressible fluid, the flow rate (which is the product of cross-sectional area and fluid velocity) must remain constant. Thus, if the diameter of the pipe changes, the velocity must also change to compensate. Consider how changes in cross-sectional area impact fluid velocity.

**Question 9.** [Incorrect] You need to use the continuity equation to first calculate the velocity at point B. Then you can rearrange the Bernoulli equation to calculate  $P_b$ . Have you considered how height is changing across the pipe and how this impacts the Bernoulli equation?

**Question 10.** [Incorrect] While this might seem like a reasonable velocity, it does not match the balance of forces acting on the sphere. Re-evaluate how buoyant force and drag force interact at terminal velocity according to Stokes' Law. The calculations should reflect the balance of forces accurately. Calculate the buoyant force ( $F_b$ ) then finally use the terminal velocity equation to calculate  $F_d$  which is equal to Stoke's law.

**If you picked 'D':**

**Question 1.** [Correct] The amount of gas (n moles or N molecules) is held constant in both closed and isolated systems. In both cases, no mass can enter or leave the system, so the number of moles of gas remains fixed. This is a key characteristic of both closed and isolated systems.

**Question 2.** [Incorrect] The concentrations of reactants and products do not have to be equal at equilibrium. Instead, equilibrium is defined by the balance between the forward and reverse reaction rates. The system stops evolving once maximum entropy is reached, but this does not require equal concentrations of reactants and products.

**Question 3.** [Incorrect] A COP of 4.0 would suggest a much larger temperature difference between the hot and cold reservoirs than is consistent with an efficiency of 0.33. Review how the efficiency formula  $\eta = \frac{T_h - T_c}{T_h}$  works and how it relates to the COP formula  $COP = \frac{T_c}{T_h - T_c}$ . The COP should be smaller with the given efficiency, as the temperature difference isn't large enough to support such a high COP.

**Question 4.** [Incorrect] Incompressible fluids do not undergo significant changes in density when pressure is applied. Fluids with significant density changes under pressure would be considered compressible, and thus would not perfectly transmit pressure.

**Question 5.** [Incorrect] The ram cylinder certainly will transmit the same pressure and increase the applied force, however, this is a particularly large number! The ratio of the applied force to ram force will depend on the ratio of the surface areas which depends on the radius squared of the cylinders.

**Question 6.** [Incorrect] It's correct that laminar flow generally occurs at low speeds, with smooth, parallel layers of fluid. However, while turbulent flow does occur at higher velocities, it doesn't require "extremely" high speeds—just high enough for the fluid's inertia to overcome viscous forces, leading to chaotic flow. The threshold between laminar and turbulent flow is often described using the Reynolds number, which balances velocity, viscosity, and the dimensions of the flow system.

**Question 7.** [Incorrect] It is true the pressure varies linearly with height (or depth), however, the gradient of the relationship will be scaled based on the fluid density (and gravitation field strength).

**Question 8.** [Incorrect] The continuity equation applies to all incompressible fluids, regardless of viscosity. While viscosity affects the overall flow characteristics and may introduce additional factors like flow resistance, it does not change the fundamental relationship described by the continuity equation. When the pipe narrows, the velocity must increase, regardless of the fluid's viscosity. It's important to separate the concepts of viscosity and flow rate.

**Question 9.** [Incorrect] This answer suggests that the pressure remains constant, which does not apply when the diameter of the pipe changes. According to Bernoulli's principle, the pressure will drop when fluid flows from a wider to a narrower section.

**Question 10.** [Incorrect] This answer is too high given the parameters. Consider the effects of viscosity and how they reduce the terminal velocity of the sphere in the fluid. Revisiting Stokes' Law and the concept of terminal velocity will help clarify the correct relationship. Calculate the buoyant force ( $F_b$ ) then finally use the terminal velocity equation to calculate  $F_d$  which is equal to Stoke's law.

## **6. Scalars, vectors, couples and equilibrium**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Incorrect] Weight is a vector quantity because it has both magnitude and direction (the force due to gravity acting on a mass). However, work is a scalar quantity because it only has magnitude (the product of force and displacement in the direction of the force). Be sure to differentiate between vectors (which have direction) and scalars (which do not).

**Question 2.** [Incorrect] This option suggests that the net result is a vector point below the horizontal. This cannot be possible if both vectors are acting horizontally with one pointing above the horizontal.

**Question 3.** [Incorrect] Kinetic energy has the base unit  $\text{kg m}^2 \text{s}^{-2}$ , which is equivalent to joules, but momentum has the base unit  $\text{kg m s}^{-1}$ . Momentum involves mass and velocity, while kinetic energy involves mass and velocity squared. The squaring of the velocity means the direction of the velocity is lost since  $-1^2 = 1^2 = 1$  (no direction information).

**Question 4.** [Incorrect] The maximum possible resultant occurs when the two forces act in the same direction. In this case, the sum of the two forces is  $6 \text{ N} + 10 \text{ N} = 16$ , which is the largest possible resultant. Since forces can be added directly when aligned, 16 N is a valid result.

**Question 5.** [Correct] Even without calculation or using a scale drawing, we would expect this to be a sensible answer since we can see the arrow point up and arrow point left (of the same size) which must be balanced by one arrow pointing in the opposite direction (who has the same vertical and horizontal components).

**Question 6.** [Correct] By taking the torques about the left leg as the pivot, you found that the right leg must exert a force of 275 N to balance the system. Remember, torque is the product of force and distance from the pivot, and we ensure equilibrium by setting the sum of the clockwise torques equal to the counterclockwise torques.

**Question 7.** [Incorrect] A couple does consist of two equal forces, but they must be *opposite* in direction, not parallel in the same direction. Also, the unit  $\text{Nm}^{-1}$  (material stiffness) is incorrect for a couple. The correct unit for a couple, which produces rotational motion, is the newton-meter (Nm), the same as for torque.

**Question 8.** [Incorrect] Even though the forces are equal and opposite, the torque (moment of the couple) is not zero because the forces are acting at different points, creating a rotational effect.

**Question 9.** [Incorrect] This collection of vectors will result in some clockwise rotation and therefore there would not be an equilibrium.

**Question 10.** [Correct] The frictional force creates a moment of 150 N m about the centre of gravity. Since the block is sliding to the right and friction opposes the motion, the moment caused by friction is in the clockwise direction

**If you picked 'B':**

**Question 1.** [Incorrect] Force is a vector quantity because it has both magnitude and direction, but energy is a scalar quantity since it only has magnitude. Remember, energy (like kinetic or potential energy) does not involve direction. Can you think of another example of a scalar quantity similar to energy?

**Question 2.** [Incorrect] This option suggests that the net result is a vector point above the horizontal acting to the left. This cannot be possible if both vectors are acting horizontally to the right.

**Question 3.** [Incorrect] Kinetic energy has the base unit  $\text{kg m}^2 \text{s}^{-2}$ , but Young's modulus (a measure of stiffness) has units of Pa (pascals), or  $\text{kg m}^{-1} \text{s}^{-2}$ , which are different. Young's modulus is a measure of stress over strain, so its units differ from those of energy. Think about the physical meaning of each quantity and its associated dimensions.

**Question 4.** [Incorrect] The resultant force could also be smaller if the forces are not acting in the same direction. In fact, the minimum resultant occurs when the forces are opposite, where  $10 \text{ N} - 6 \text{ N} = 4 \text{ N}$ , so a value between 4 N and 16 N, such as 8 N, is possible.

**Question 5.** [Incorrect] It's not far away from equilibrium, since the vertical components of two arrows are equal and opposite, however, their vertical components would not be enough to counteract the large horizontal arrow to the right.

**Question 6.** [Incorrect] Remember that the total torque needs to be balanced by the force from the right leg at 2 meters away from the left end. Be sure to divide the total torque by the distance (2 meters) to get the correct force.

**Question 7.** [Incorrect] A couple does not produce translational motion. Instead, it causes pure rotational motion without any net force in a particular direction. Translational motion occurs when a net force is applied, but a couple's forces are balanced, producing only rotation. The unit of a couple is indeed Nm, but be sure to link it to rotational motion, not translational.

**Question 8.** [Incorrect] You may have mistakenly used only half the distance between the forces. Remember that the total distance between the two applied forces is 0.4 meters.

**Question 9.** [Correct] If you add the 4 N and 2 N vectors tip-to-tail, in order to close the vector loop, a 4.5 N vector is required to point in this direction to ensure equilibrium.

**Question 10.** [Incorrect] The magnitude of 150 Nm is correct, but the direction is not. The moment of the frictional force must oppose the direction of the applied force. Since the block is moving right and friction acts in the opposite direction, the moment caused by friction about the centre of gravity will rotate the block in a clockwise direction, not anticlockwise. Think about the effect of friction and how it resists the motion.

**If you picked 'C':**

**Question 1.** [Correct] Both displacement and momentum are vector quantities. Displacement refers to a change in position and has both magnitude and direction, while momentum (the product of mass and velocity) also has both.

**Question 2.** [Incorrect] This option suggests that the net result is a vector point below the horizontal acting to the left. This cannot be possible if both vectors are acting horizontally to the right with one point above the horizontal.

**Question 3.** [Correct] Both work done and the moment of a couple share the same base unit  $\text{kg m}^2 \text{s}^{-2}$ , which is equivalent to joules (a unit of energy). Work done is a form of energy transfer, while the moment of a couple represents a rotational equivalent, both involving force and distance. This shows the relationship between linear and rotational quantities.

**Question 4.** [Incorrect] While this value is smaller than either force, it's still within the range of possible resultants. When two forces act at an angle, the resultant can be less than their maximum sum but greater than their difference. As long as the magnitude lies between 4 N and 16 N, like 5 N, it's possible.

**Question 5.** [Incorrect] Without calculation we can see this system would not be in equilibrium since there are two vertical components above the horizontal which would be not counteracted. It is also likely (without calculation) that the horizontal components are not balanced.

**Question 6.** [Incorrect] Close, but not correct. The force exerted by the right leg should be lower. Carefully consider the distribution of forces and remember to balance the torques about the left leg as your pivot point.

**Question 7.** [Correct] While it's true that a couple produces rotational motion, the unit  $\text{Nm}^{-1}$  is incorrect. The correct unit is Nm (newton-meter), as a couple is essentially a form of torque. Nm measures rotational force, while  $\text{Nm}^{-1}$  would imply something very different, possibly related to material stiffness (such as the spring constant in Hooke's Law).

**Question 8.** [Incorrect] You may have used the distance from one force to the centre instead of the total distance between the two forces. Be sure to use the full distance between the points where the forces are applied (which is 0.4 meters), not just the radius from the centre to one force.

**Question 9.** [Incorrect] If you were to add the 4 N and 2 N tip-to-tail, they would point in a similar direction to the 4.5 N. As such, all three vectors would add together to cause movement in the top-right direction, rather than add together to give zero. What would the third vector have to look like in order to cancel out the sum of the 4 N and 2 N vectors?

**Question 10.** [Incorrect] The value of 300 Nm is too high. It seems you may have used the total height of the block (1.5 m) instead of half the height (0.75 m) when calculating the moment. Remember that friction acts at the base of the block, and the moment arm is the perpendicular distance from the point of application to the centre of gravity, which is half the height. Additionally, the moment should be clockwise, not anticlockwise.

**If you picked 'D':**

**Question 1.** [Incorrect] Acceleration is a vector quantity because it involves a change in velocity (which includes direction), but power is a scalar quantity. Power represents the rate of doing work and only has magnitude, not direction. Can you think of why power, even though it involves energy transfer, does not need to be directional?

**Question 2.** [Correct] Without any calculation, we can infer this must be the right answer since the two vectors are both acting to the right-hand side, one horizontal and one with a small angle above the horizontal. The result must be a larger vector (since horizontal components will be added together) with a small vertical component from vector P. You could confirm this through a scale drawing or by approximating the lengths and angles involved.

**Question 3.** [Incorrect] Work done has the base unit  $\text{kg m}^2 \text{s}^{-2}$  (joules), but pressure has units of pascals (Pa), which are  $\text{kg m}^{-1} \text{s}^{-2}$ . Pressure measures force per unit area, so it has different dimensions than energy.

**Question 4.** [Correct] The resultant force of two forces must always lie between the sum of the forces (16 N) and their difference (4 N). A resultant of 3 N is not possible because it's smaller than the minimum possible resultant of 4 N. When considering vector addition, always check the range between the sum and difference of the forces.

**Question 5.** [Incorrect] There are no components in the left-horizontal or down-vertical planes which means this system cannot achieve equilibrium.

**Question 6.** [Incorrect] While the force at the left leg of the bench is close to this value, the right leg exerts a smaller. The total vertical forces need to sum to 700 N (the weight of the bench and the person combined), and this total force is distributed between the two legs (unevenly since the person is closer to one leg than the other).

**Question 7.** [Incorrect] While it's true that a couple produces rotational motion, the unit  $\text{Nm}^{-1}$  is incorrect. The correct unit is Nm (newton-meter), as a couple is essentially a form of torque. Nm measures rotational force, while  $\text{Nm}^{-1}$  would imply something very different, possibly related to material stiffness (such as the spring constant in Hooke's Law).

**Question 8.** [Correct] Since the forces are equal in magnitude and opposite in direction, the torque (moment of the couple) is the force multiplied by the total perpendicular distance between them. The total distance between the forces is 0.4 m, and multiplying that by 30 N gives the correct torque of 12 Nm.

**Question 9.** [Incorrect] There will be a resultant vertical component in adding these vectors together meaning there would be net movement in the vertical direction. The horizontal components of the two 5.7 N vectors would however cancel out.

**Question 10.** [Incorrect] While the direction of the moment is correct (anticlockwise), the value of 300 Nm is too high. The correct moment arm is half the height of the block, 0.75 m, not the full height of 1.5 m. Recalculate the moment using 0.75 m.

## **7. Material science, work and friction**

### Feedback Sheet



**If you picked 'A':**

**Question 1.** [Incorrect] This correctly identifies that as you get closer to J, the tensile stress increases, however, we would not expect the stress to be zero at K, as there is a weight hanging off the wire. In short, the gradient is correct, but the intersection points are not.

**Question 2.** [Incorrect] This requires some sensible approximations on 1) The mass of the baby and 2) the height the baby might be able to jump (which is roughly equivalent to the extension or compression of the spring). Based on these estimates, you can use the  $F = kx$  equation to calculate the spring constant  $k$ . This range means you have likely underestimated the weight force of the baby and/or overestimated their jumping distance.

**Question 3.** [Incorrect] X is indeed stiffer than Y since the gradient of its line (for most of the graph) is much greater than that of Y's. The gradient will give the Young modulus which is proportional to 'stiffness' or the spring constant.

**Question 4.** [Incorrect] A speed of  $2 \text{ ms}^{-1}$  would result in a very short jump height, much lower than what is typical for an average human jump. Think about the height that an average person can jump – it is usually around 0.5 to 1 metre. You can use the equations of motion to estimate the speed required to reach such a height. Use the relationship of kinetic energy to gravitational potential energy to help you.

**Question 5.** [Correct] The motor is 80% efficient, so 80% of the electrical energy is transferred into useful work – lifting the object – while 20% is lost as heat, sound, or other forms of non-useful energy. This option accurately reflects energy transfer, energy efficiency, and the conservation of energy principles.

**Question 6.** [Incorrect] Friction reduces the net work done, as it opposes motion and takes away energy from the system. Therefore, more energy would be required to overcome friction, but the net work done after accounting for friction will be less than 433 J.

**Question 7.** [Correct] After the initial momentum transfer from the kick to the ball, it will have its largest velocity, positive since it will be moving upwards. As gravity does work against the ball, it reduces its positive velocity, eventually hitting zero at its maximum height. Gravity continues to do work against the ball so the ball's velocity continues to grow in the negative direction (toward the ground). The gradient is linear since  $v = u + at$ ,  $v$  is proportional to  $t$ .

**Question 8.** [Incorrect] Think about how much energy is transferred to the water after accounting for the 20% system efficiency. Since only a fraction of the 1.5 W solar power is useful, the mass of the water should be recalculated using the gravitational potential energy equation  $E = mgh$ .

**Question 9.** [Incorrect] Remember that the work-energy principle states that the work done on an object is equal to its change in kinetic energy. Since the object is initially at rest and ends with a velocity  $v$ , its final kinetic energy is  $\frac{1}{2}mv^2$ . Make sure to consider how the force and velocity relate through the change in energy, not directly through their product. Hint, use  $v^2 = u^2 + 2as$ , to calculate 's', along with rearrange  $F=ma$  to substitute in for 'a'.

**Question 10.** [Incorrect] Remember, the boat will only move at a constant speed when the power output of the engine is entirely used to counteract the drag force, use power = force x velocity, to relate this drag to the power output of the boat.

**If you picked 'B':**

**Question 1.** [Incorrect] This predicts the tensile stress increases as we move down the wire. However, the stress is caused by the weight force of gravity pulling mass downwards. So, the more mass below a section of wire, the larger the tensile stress would be.

**Question 2.** [Incorrect] This requires some sensible approximations on 1) The mass of the baby and 2) the height the baby might be able to jump (which is roughly equivalent to the extension or compression of the spring). Based on these estimates, you can use the  $F = kx$  equation to calculate the spring constant  $k$ . This range means you have likely underestimated the weight force of the baby and/or overestimated their jumping distance.

**Question 3.** [Incorrect] The gradient will give the Young modulus which is proportional to 'stiffness' or the spring constant. X has (on average) a much greater gradient than Y.

**Question 4.** [Correct] A speed of around  $4 \text{ ms}^{-1}$  is a reasonable estimate for a person jumping from a standing position. Using the equation  $v^2 = 2gh$  to calculate the velocity required to reach a typical jump height of around 0.8 m supports this estimate.

**Question 5.** [Incorrect] While energy is indeed conserved, not all of the input energy is transferred to lifting the object. Due to inefficiency, some of the energy is converted into waste energy forms like heat and sound. Only 80% of the input energy contributes to lifting the object.

**Question 6.** [Incorrect] The horizontal component of the applied force does matter for work done, but friction reduces the effective work done by opposing the motion. Without friction, the work done would be 433 J, but friction means the net work done will be less than this value.

**Question 7.** [Incorrect] Velocity does indeed vary linearly with acceleration, however, if the velocity is always positive the ball would never come back to the ground so this cannot be the right graph. Velocity is growing with time (it is getting faster) which could only happen with an external force (e.g. an engine). Finally, we would not expect velocity to begin at zero, since the initial momentum transfer of a kick would result in a high initial velocity.

**Question 8.** [Correct] Correct, this captures that only 20% of the 1.5 W is doing useful work every second. Each second, then,  $mgh = \text{work done}$  can be rearranged to calculate mass.

**Question 9.** [Incorrect] While this expression looks similar to the product of force and velocity, it's important to recognise that the velocity changes as the object accelerates. The work done is related to the change in kinetic energy, which involves the square of the final velocity, rather than a direct product of force and velocity. Hint, use  $v^2 = u^2 + 2as$ , to calculate 's', along with rearrange  $F=ma$  to substitute in for 'a'.

**Question 10.** [Correct] To find the maximum speed, we can relate the engine's power to the drag force. The boat moves at a constant speed when the power output of the engine is entirely used to counteract the drag force.

**If you picked 'C':**

**Question 1.** [Incorrect] This would be the case if the wire has negligible mass, but since it does not, the top part of the wire (closer to J) should experience large tensile stress forces because of the greater mass below it.

**Question 2.** [Correct] A reasonable guess for a baby's mass would be 10-20 kg (weight force is 9.81 times this) and the ability to jump 15-30 cm. The average of these ranges would give an answer of  $650 \text{ N m}^{-1}$ .

**Question 3.** [Correct] The line of Y shows that as soon as it reaches the end of the limit of proportionality, it fractures which is characteristic of brittle material. X on the other hand displays clear elastic/plastic behaviour before fracturing, likely indicating a 'strong' or possibly partially 'ductile' material.

**Question 4.** [Incorrect] A speed of  $8 \text{ ms}^{-1}$  is quite fast and would result in an unrealistically high jump for a person. While it is plausible for athletes in extreme conditions (such as in sprinting), this speed is too high for a typical vertical jump from a standing position. Use the relationship of kinetic energy to gravitational potential energy to help you.

**Question 5.** [Incorrect] This option correctly identifies that 80% of the input energy is transferred to lifting the object, but it wrongly assumes no energy is lost to the surroundings. Some energy, particularly heat, will dissipate into the environment, which is why the motor is not 100% efficient.

**Question 6.** [Correct] Friction opposes the motion, reducing the net work done compared to the ideal case where friction is absent. In the ideal case, the work done would be 433 J, but with friction present, the net work is less than 433 J, as energy is dissipated due to friction.

**Question 7.** [Incorrect] This graph indicates that velocity begins at zero, which we would not expect since the initial momentum transfer of a kick would result in a high initial velocity. Velocity is always positive the ball would never come back to the ground so this cannot be the right graph. Finally, velocity varies non-linearly over time, which we would not expect from  $v = u + at$ .

**Question 8.** [Incorrect] This suggests that too much energy is being transferred to the water. The system is only 20% efficient, meaning that only 0.3 W is used to lift the water. Recalculate the mass using the gravitational potential energy formula, and make sure to account for the efficiency factor. Remember, we can convert potential energy into power by dividing 'mgh' by time. This would then be equal to the  $1.5 \text{ W} \times 0.2$ . Also note,  $1 \text{ W}$  is  $1 \text{ Js}^{-1}$ .

**Question 9.** [Incorrect] This expression assumes that the object did not begin at a zero velocity, the work done will be an average of zero (at no velocity) and  $mv^2$  (at the last moment of acceleration). Hint, use  $v^2 = u^2 + 2as$ , to calculate 's', along with rearrange  $F=ma$  to substitute in for 'a'.

**Question 10.** [Incorrect] Remember, the boat will only move at a constant speed when the power output of the engine is entirely used to counteract the drag force, use power = force x velocity, to relate this drag to the power output of the boat.

**If you picked 'D':**

**Question 1.** [Correct] Correct, the closer to J you get, the more weight is below the wire given we cannot consider it to be of negligible weight this means this section of wire will be subjected to great stress as the cross-sectional area is constant.

**Question 2.** [Incorrect] This requires some sensible approximations on 1) The mass of the baby and 2) the height the baby might be able to jump (which is roughly equivalent to the extension or compression of the spring). Based on these estimates, you can use the  $F = k \times$  equation to calculate the spring constant  $k$ . This range means you have likely overestimated the weight force of the baby and/or underestimated their jumping distance.

**Question 3.** [Incorrect] The maximum tensile stress is the highest stress achieved without breaking, X clearly is capable of withstanding greater stresses than Y before breaking.

**Question 4.** [Incorrect]  $10 \text{ ms}^{-1}$  is not a reasonable estimate for a person jumping from a standing position. This speed would correspond to a very large jump height (nearly 10 meters), far beyond what an average human can achieve in a vertical jump. Reconsider how height and speed are related for vertical motion. Use the relationship of kinetic energy to gravitational potential energy to help you.

**Question 5.** [Incorrect] This option suggests that 100% of the input energy is transferred to lifting the object, but this would only be true if the motor were perfectly efficient. However, due to the motor's 80% efficiency, some energy is lost in the conversion process, typically as heat and sound.

**Question 6.** [Incorrect] Friction does affect the net work done. While the horizontal component of the applied force contributes to the work done, friction opposes this, reducing the total amount of work compared to the ideal scenario without friction.

**Question 7.** [Incorrect] The velocity is a positive number which is what we would expect, and it varies linearly, again, as expected. However, halfway through its trajectory, it reaches zero velocity and begins to increase again, however, we would expect it to reverse direction (which would be negative) so have a look again!

**Question 8.** [Incorrect] This suggests that too much energy is being transferred to the water. The system is only 20% efficient, meaning that only 0.3 W is used to lift the water. Recalculate the mass using the gravitational potential energy formula, and make sure to account for the efficiency factor. Remember, we can convert potential energy into power by dividing 'mgh' by time. This would then be equal to the  $1.5 \text{ W} \times 0.2$ . Also note,  $1 \text{ W}$  is  $1 \text{ Js}^{-1}$ .

**Question 9.** [Correct] You correctly used the work-energy principle, which states that the work done on the object is equal to the change in kinetic energy. Since the object starts from rest and ends with a velocity  $v$ , the work done is equal to the object's final kinetic energy, which is  $\frac{1}{2}mv^2$ .

**Question 10.** [Incorrect] Remember, the boat will only move at a constant speed when the power output of the engine is entirely used to counteract the drag force, use power = force  $\times$  velocity, to relate this drag to the power output of the boat.

## **8. Projectile motion, Newton's laws and momentum**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Correct] Acceleration due to gravity is always acting on the firework throughout its motion, both while it's going up and coming back down. Even at the highest point, where the velocity becomes zero momentarily, the acceleration due to gravity remains constant at approximately  $9.8 \text{ ms}^{-1}$ .

**Question 2.** [Incorrect] The gravitational acceleration on the Moon is much weaker than Earth's, but not enough to reach such a height with a total flight time of just 4.0 s. Consider using a suitable SUVAT equation to get displacement, e.g.,  $s = ut + \frac{1}{2}at^2$ , and consider the values for  $u$ ,  $a$  and  $t$ .

**Question 3.** [Incorrect] 10 m seems like too small a distance for the third second of the object's fall. Remember, the object is accelerating due to gravity, so it falls further with each passing second. Try calculating the total distance fallen by the end of the second and third seconds using the formula for distance under constant acceleration:

$$s = \frac{1}{2}gt^2.$$

**Question 4.** [Incorrect] 28 m is too large. Perhaps you mistakenly doubled the time or used incorrect values for acceleration due to gravity. The ball spends half the time going up and half the time coming down. Try calculating the height reached at the top using  $s = ut + \frac{1}{2}at^2$ , and then double it to get the total distance.

**Question 5.** [Correct] Given that halfway through its journey, the object has its maximum velocity, we would expect the distance travelled per second to be greatest, hence the largest gradient at this point. After this maximum velocity, it remains positive but decreases in magnitude. Therefore, we continue positive displacement, but at a decreasing rate.

**Question 6.** [Incorrect] Momentum is a vector quantity, and since X and Y have different masses and velocities in different directions, their initial momenta are not the same. Y has both horizontal and vertical components, while X has only vertical momentum.

**Question 7.** [Incorrect] The time to fall depends only on the vertical motion, and since all three objects are dropped from the same height and experience the same gravitational acceleration, they hit the ground at the same time.

**Question 8.** [Incorrect] This answer assumes that the mass of the object influences how quickly it falls, but that's not the case in free fall (with negligible air resistance). Both objects experience the same gravitational acceleration, regardless of their mass. To reattempt: think about what determines how fast an object falls vertically when only gravity is acting on it.

**Question 9.** [Incorrect] This answer seems plausible because drag acts upward to balance the weight, allowing the parachutist to descend at constant speed. However, the drag force and the weight do not form a third-law pair. Newton's third law requires that the two forces act on different objects, and here, both drag and weight act on the parachutist. To rethink: try to focus on what force the Earth experiences as a reaction to the gravitational pull on the parachutist.

**Question 10.** [Correct] To solve this, you correctly calculated the time it takes for the pellet to travel between the discs, which is  $2.00 \text{ m} / 300 \text{ ms}^{-1} = 0.00667 \text{ s}$ . The discs rotate by  $45^\circ$  (which is  $1/8$  of a full revolution) in this time. By multiplying  $0.00667 \text{ s}$  by 8, you find the time for one complete revolution and then you can determine how many revolutions occur per second.

**If you picked 'B':**

**Question 1.** [Incorrect] Think about the point at the top of the firework's trajectory. At that point, the rocket momentarily comes to rest before falling back down, so the velocity is zero for an instant. Consider how velocity behaves during upward and downward motion, and re-evaluate which quantity is never zero.

**Question 2.** [Incorrect] Make sure you're using the correct value for gravity on the Moon, which is much lower than on Earth. Recalculate using  $g = 1.6 \text{ ms}^{-2}$  and the proper time of 2.0 s for reaching the maximum height.

**Question 3.** [Incorrect] 20 m would be the distance covered if the object were moving at a constant speed, but it's accelerating. Make sure to account for the increasing distance covered each second due to acceleration by gravity. You should calculate the distance fallen by the end of both the second and third seconds and then subtract to find the distance covered during just the third second.

**Question 4.** [Correct] The ball travels 7 m upwards and 7 m back down, for a total distance of 14 m.

**Question 5.** [Incorrect] Whilst some aspects of the gradient appear reasonable, the second half of the journey, when velocity is positive but decreases in magnitude, should still lead to positive displacement (since you are still moving away from the starting point), but this graph suggests you are moving backwards, along the path you have taken to get back to the starting point.

**Question 6.** [Incorrect] Both X and Y have the same vertical component of velocity, so they will reach their maximum heights at the same time. The presence of horizontal velocity for Y does not affect the time to reach maximum height.

**Question 7.** [Incorrect] The time to hit the ground depends only on the vertical motion, not the horizontal velocity. Since both V and W start from the same height and fall freely under gravity, they will hit the ground simultaneously, despite their different horizontal velocities.

**Question 8.** [Incorrect] This answer might come from the idea that X has some initial velocity, but remember, its initial velocity is purely horizontal. The vertical component of X's motion is identical to Y's, since they both start at the same height and are influenced only by gravity. Horizontal motion doesn't affect how quickly something falls. Review how projectile motion separates horizontal and vertical components.

**Question 9.** [Incorrect] While the tension in the parachute strings supports the parachutist and affects the descent, this is not a third-law pair with the parachutist's weight. Tension and weight act on the same object (the parachutist), and Newton's third law describes forces between two different objects. Think again about what object is exerting the force of weight and what must experience the equal and opposite force.

**Question 10.** [Incorrect] The key is recognising that  $45^\circ$  is just  $1/8$  of a full revolution. Be sure to multiply the time it takes for this partial rotation by 8 to find the time for one full revolution, then calculate the number of revolutions per second.

**If you picked 'C':**

**Question 1.** [Incorrect] Momentum is related to both the mass and velocity of the firework. Since the velocity becomes zero at the top of the trajectory, the momentum also drops to zero momentarily. Try thinking about which other quantity does not depend on the rocket's velocity and remains constant throughout the motion.

**Question 2.** [Incorrect] Consider using a suitable SUVAT equation to get displacement, e.g.,  $s = ut + \frac{1}{2}at^2$ , and consider the values for  $u$ ,  $a$  and  $t$ .

**Question 3.** [Correct] By calculating the total distance fallen by the end of the second and third seconds using  $s = \frac{1}{2}gt^2$ , and subtracting you get the distance travel between 2 and 3 seconds.

**Question 4.** [Incorrect] 7.1 m still underestimates the total distance. The ball travels upwards and downwards, covering the same distance in each direction. Be sure you calculate the height at the peak of the motion using  $s = ut + \frac{1}{2}at^2$ , and then remember to double it for the total distance covered by the ball.

**Question 5.** [Incorrect] The second half of the journey, when velocity is positive but decreases in magnitude, which therefore still leads to a positive displacement (since you are still moving away from the starting point) but this graph suggests you are moving backwards, along the path you have taken to get back to the starting point.

**Question 6.** [Incorrect] Y's vertical component of velocity is the same as X's, so they both reach the same maximum height, not half.

**Question 7.** [Correct] All three objects experience the same gravitational acceleration and start from the same height. The time for an object to hit the floor depends **only** on the vertical motion, which is independent of any horizontal velocity. Since all three objects fall from the same height, they will hit the floor at the same time. The total speed of each object at the moment of impact is the vector sum of the vertical and horizontal velocities. Since W has the greatest horizontal component, it will have the largest resultant velocity when it hits the floor.

**Question 8.** [Incorrect] This suggests that Y falls significantly faster than X, but in reality, both experience the same gravitational acceleration, regardless of their mass. Reattempt with that in mind and focus on how gravity affects objects in free fall.

**Question 9.** [Correct] Newton's third law of motion states that for every action, there is an equal and opposite reaction. The weight of the parachutist is the gravitational force exerted by the Earth on the parachutist. According to the third law, the reaction to this force is the gravitational force that the parachutist exerts on the Earth. These forces are equal in magnitude but act in opposite directions. The key is to recognise that forces in a Newton's third law pair always act on two different objects, in this case, the parachutist and the Earth.

**Question 10.** [Incorrect] The pellet travels between the discs in 0.00667 s (2 m / 300 ms<sup>-1</sup>), and during this time, the discs rotate by 45° (which is 1/8 of a full revolution). Be sure to multiply the time for this partial rotation by 8 to get the full revolution time before determining the number of revolutions per second.



**If you picked 'D':**

**Question 1.** [Incorrect] The kinetic energy of the firework depends on its velocity. As the rocket slows down and reaches the peak of its flight, its velocity decreases to zero, meaning the kinetic energy also becomes zero at that point. Consider which quantity is independent of the firework's changing speed and is always present in its motion.

**Question 2.** [Correct] By using the kinematic equation  $h = \frac{1}{2}gt^2$  with the Moon's gravity and half of the total flight time (2.0 s), the maximum height is approximately 3 m.

**Question 3.** [Incorrect] 45 m is much too large. The object is falling faster with each second due to gravity, but not by that much. To find the distance fallen during the third second, you should first find the total distance by the end of 3 seconds, then subtract the distance fallen in the first 2 seconds.

**Question 4.** [Incorrect] 5.9 m is an underestimate. You might have calculated the distance travelled by the ball during only half of the flight (the upward journey). Remember that the ball has to travel both upwards and downwards, so you need to consider the total time of 2.4 seconds and use the correct kinematic formula to find the height reached at the top of the motion. Try using  $v = u + at$  to find the velocity at launch.

**Question 5.** [Incorrect] This graph captures the long-term behaviour of an always positive velocity, that is, that displacement is always increasing. However, the gradient is very large at the beginning and end of the displacement-time graph, which indicates a large velocity, but in fact, the velocity is very small at these points. The gradient of this graph is therefore not correct.

**Question 6.** [Correct] Since both have the same initial vertical velocity, the time for them to rise to their maximum height and fall back to the ground is the same. Horizontal motion doesn't affect the time: Y also has a horizontal component of velocity, but horizontal motion does not affect the time of flight in projectile motion because gravity only acts vertically.

**Question 7.** [Incorrect] Although U has the greatest vertical velocity at the moment of impact (since it only has vertical motion), U and W has both vertical and horizontal velocity. As a result, U's or W's total speed (combining horizontal and vertical components) will be greater than U's, which only has vertical velocity.

**Question 8.** [Correct] The horizontal motion of ball X does not affect the time it takes to fall to the ground. Both balls experience the same vertical acceleration due to gravity, which is independent of their mass or horizontal velocity. Therefore, they will both hit the ground simultaneously. This concept is rooted in the fact that the vertical and horizontal motions are independent of each other in projectile motion, assuming negligible air resistance.

**Question 9.** [Incorrect] The lift force is related to the aerodynamic forces acting on the parachute, but this is not the reaction force to the parachutist's weight. Newton's third law says the reaction force to the parachutist's weight must act on a different object, in this case, the Earth. Review how action-reaction pairs work: they act on different objects but are equal in magnitude and opposite in direction.

**Question 10.** [Incorrect] The pellet travels between the discs in 0.00667 s ( $2 \text{ m} / 300 \text{ ms}^{-1}$ ), and during this time, the discs rotate by  $45^\circ$  (which is  $1/8$  of a full revolution). Be sure to multiply the time for this partial rotation by 8 to get the full revolution time before determining the number of revolutions per second.

## **9. Waves**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Incorrect] This suggests that the water molecules themselves move outward with the energy, but this isn't what happens. The molecules oscillate near their equilibrium positions, transferring energy to neighbouring molecules. The energy spreads out as a wave, not the water molecules themselves.

**Question 2.** [Incorrect] This answer confuses the wave speed with the motion of an individual particle in the medium. In a longitudinal wave, the **wave speed** is the speed at which the disturbance (energy) moves through the medium, not the speed of the individual particles. The particles themselves oscillate back and forth around their equilibrium positions, but they do not travel at the wave speed.

**Question 3.** [Correct] When light passes from one medium to another (such as from air to water), its velocity and wavelength change, but its frequency remains constant. This is because the frequency of light is determined by its source and does not change when light enters a new medium. The velocity decreases as light enters a denser medium like water, and since frequency remains the same, the wavelength must decrease in order to satisfy the wave equation.

**Question 4.** [Incorrect] Maximum intensity occurs when the filters are fully aligned or when  $\theta$  is a full 180 degrees (or  $\pi$  radians). Remember that at  $\theta = \frac{\pi}{2}$  ( $90^\circ$ ),  $\cos^2\left(\frac{\pi}{2}\right) = 0$ , meaning no light passes through.

**Question 5.** [Incorrect] This path difference is too large for the third dark fringe. It corresponds to a higher-order dark fringe. Try reviewing how the path difference for dark fringes increases in steps, and work out which step corresponds to the third dark fringe in the sequence.

**Question 6.** [Incorrect] This description might suggest a pattern produced by multiple slits, such as in a double-slit experiment. However, in the case of a single narrow slit, the pattern includes a wide central maximum with progressively narrower side fringes rather than equally spaced light and dark fringes. Consider how diffraction leads to varying fringe widths rather than uniform spacing.

**Question 7.** [Incorrect] This option would increase the fringe separation. The fringe separation in a double-slit experiment is inversely proportional to the distance between the slits. When the separation between the slits decreases, the angle of diffraction increases, resulting in wider fringes. Consider how the geometry of the setup affects the interference pattern.

**Question 8.** [Correct] Coherency refers to the correlation between the phases of waves at different points in space and time. For interference studies, it is crucial that the light waves maintain a constant phase relationship, allowing for stable and predictable interference patterns. Coherent light sources, such as lasers, produce consistent and well-defined patterns necessary for observing interference.

**Question 9.** [Incorrect] This answer highlights the atomic structure of materials, but it doesn't accurately explain the concept of natural frequency. While the movement of atoms is relevant, the ability to vibrate at a specific frequency must depend on the restrictions on their movements.

**Question 10.** [Correct] Decreasing the kinetic energy (and therefore momentum,  $p$ ) of the electrons increases their de Broglie wavelength ( $p = \frac{h}{\lambda}$ ). A longer wavelength would lead to a broader spread of the diffraction pattern.

**If you picked 'B':**

**Question 1.** [Incorrect] The molecules do not travel outward with the wave; they only oscillate around their equilibrium positions. The wave energy moves outward, but the particles don't. Think about how the motion of each particle is localised, with only the disturbance moving through the medium.

**Question 2.** [Correct] This tells you that each particle in the wave oscillates with a period of 1.5 milliseconds. This is the time taken for one complete oscillation (compression and rarefaction cycle) of a particle in the wave.

**Question 3.** [Incorrect] This is close, but there's a key misunderstanding here. The frequency of light remains the same when it passes from one medium to another; it is the wavelength that changes. Since the speed of light decreases in water, and frequency remains constant, the wavelength must shorten to satisfy the wave equation.

**Question 4.** [Incorrect] The angles  $\frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}$  correspond to points where  $\cos^2(\theta) = 0$ , which means no light passes through the second filter (minimum intensity). Maximum intensity happens at  $\theta = 0, \pi, 2\pi, \dots$  where  $\cos^2(\theta) = 1$ .

**Question 5.** [Correct] The third dark fringe corresponds to destructive interference, where the path difference between the two waves must be an odd multiple of half the wavelength, i.e.,  $(m + \frac{1}{2})\lambda$ , where  $m$  is an integer. For the third dark fringe,  $m = 2$ , leading to a path difference of  $2.5\lambda$ .

**Question 6.** [Incorrect] This option is misleading because it incorrectly describes the central maximum as narrow. In a single-slit diffraction pattern, the central maximum is quite wide and is the most intense part of the pattern, with the side fringes being narrower. Think about the relationships between the slit width, wavelength, and the resulting diffraction pattern.

**Question 7.** [Incorrect] This change would increase the fringe separation. As you move the screen further away from the slits, the light waves spread out more before they reach the screen, leading to greater separation between the fringes. Reflect on how the distance impacts the interference pattern and whether it makes the fringes closer together or further apart.

**Question 8.** [Incorrect] This is a significant property of lasers, but it is not the most crucial for interference studies. Monochromaticity means that the laser emits light of a single wavelength, which is important for producing clear interference patterns. However, without coherency, even monochromatic light cannot create stable interference fringes.

**Question 9.** [Correct] They possess elastic properties that allow them to store and release energy. Different materials and different geometries will exhibit different elastic properties and hence vibrate at different natural frequencies.

**Question 10.** [Incorrect] Protons have a much greater mass than electrons, so with the same velocity their de Broglie wavelength is much shorter because they carry much more momentum ( $p = \frac{h}{\lambda}$ ). It is, however, possible to reproduce this result with protons if the speed of the protons was to be reduced by a factor of 42.8 (based on the square root of the mass ratio of protons to electrons).

**If you picked 'C':**

**Question 1.** [Correct] When the pebble disturbs the water, the molecules at the point of impact are displaced from their equilibrium position. As they attempt to return to equilibrium, they disturb neighbouring molecules, passing the disturbance along. This is how energy (the wave) moves outward, even though the water molecules themselves don't move far from their original positions. The wave transmits energy through the medium by displacing particles, which then try to return to equilibrium.

**Question 2.** [Incorrect] This answer suggests that the particles are oscillating in phase over a relatively large distance, but this isn't correct. The distance between two particles that are in phase depends on the wavelength, which can be calculated as  $330 \text{ m}^{-1}/660 \text{ Hz} = 0.5 \text{ m}$ .

**Question 3.** [Incorrect] When light enters a denser medium like water, its velocity decreases. The frequency remains constant, and the wavelength shortens to accommodate the decrease in velocity.

**Question 4.** [Correct] The maximum intensity of light after passing through two polarising filters occurs when the angle  $\theta$  between the filters is a multiple of  $\pi$ . This is because the light's intensity after passing through the second polariser is proportional to  $\cos^2(\theta)$ , and  $\cos^2(\theta)$  reaches its maximum value of 1 when  $\theta = 0, \pi, 2\pi$ .

**Question 5.** [Incorrect] You're close! This path difference is for a dark fringe, but it corresponds to an earlier fringe than the one being asked for. Destructive interference creates dark fringes at specific path differences. Consider how the path difference progresses for each successive dark fringe.

**Question 6.** [Incorrect] While the central maximum is bright, the description of "a few bright fringes" does not accurately represent the continuous nature of the diffraction pattern from a narrow slit. The wide central maximum and the narrower side fringes are key features.

**Question 7.** [Correct] Higher frequency light corresponds to shorter wavelengths. Since fringe separation is directly related to the wavelength of the light used, fringe separation decreases as the wavelength becomes shorter.

**Question 8.** [Incorrect] While intensity is important in determining the visibility of interference patterns, it is not the most critical property for interference studies. A higher intensity can enhance the visibility of fringes, but without coherence, the interference pattern will not be stable. Reflect on how intensity relates to the quality of interference rather than the fundamental requirements for producing it.

**Question 9.** [Incorrect] This option misrepresents the behaviour of materials regarding sound. While many materials can absorb sound energy, this does not relate to the concept of natural frequency. Instead, materials with a natural frequency resonate at specific frequencies rather than absorb all frequencies.

**Question 10.** [Incorrect] While using a crystalline sample with wider atomic spacing would change the angles at which diffraction occurs and therefore the resulting diffraction pattern (this is the field of x-ray crystallography, for example), it would also require the sample to be different from the one you might wish to study! The wider spacing could lead to a change in the pattern, and possibly by happenstance a similar observation to what is seen here, but it does not directly correlate.

**If you picked 'D':**

**Question 1.** [Incorrect] While it's true that molecules interact with their neighbours, they don't form a "path" of direct contact. Instead, each molecule moves temporarily from its equilibrium position, affecting its neighbours and passing the disturbance along. Reconsider how energy is transmitted as a wave, where neighbouring particles are disturbed and return to equilibrium.

**Question 2.** [Incorrect] This suggests that the particle changes direction every time it oscillates, which could seem reasonable because of the frequency. However, the particle actually completes one full oscillation (one cycle of compression and rarefaction) per period. Since it changes direction twice per cycle (once at each extreme of motion), it would change direction **1,320 times per second** at this frequency.

**Question 3.** [Incorrect] When light enters a denser medium like water, its velocity decreases. The frequency remains constant, and the wavelength shortens to accommodate the decrease in velocity.

**Question 4.** [Incorrect] You're on the right track by recognising that maximum intensity occurs at multiples of  $\pi$ , but this answer skips the first maximum at  $\theta = \pi$ . The first maximum after  $\theta = 0$  is at  $\theta = \pi$  not  $2\pi$ .

**Question 5.** [Incorrect] You're thinking along the right lines, but this path difference corresponds to a different fringe in the pattern. Remember that the path difference for dark fringes follows a specific rule for destructive interference. Think about how the path difference increases for higher-order dark fringes, and revisit the condition for destructive interference.

**Question 6.** [Correct] When monochromatic light passes through a very narrow slit, it creates a diffraction pattern characterised by a wide central maximum that is the brightest part of the pattern. The side fringes, which are the secondary maxima, are narrower and decrease in intensity as you move away from the centre. This pattern results from the wave nature of light and the interference of waves emerging from different parts of the slit.

**Question 7.** [Incorrect] This option would increase the fringe separation. Longer wavelengths create a wider separation between the interference fringes. Think about the relationship between wavelength and fringe spacing, and how changing the wavelength affects the resulting pattern on the screen.

**Question 8.** [Incorrect] Polarisation is a relevant property, particularly in certain types of interference experiments, but it is not the most essential property for general interference studies. While polarised light can influence interference patterns in specific setups, coherency is the key factor that allows for consistent and clear interference effects.

**Question 9.** [Incorrect] While rigidity is a property of some materials, it does not explain the concept of natural frequency. In fact, materials that do not deform under stress typically do not exhibit resonance. Natural frequency is associated with the ability of materials to deform and return to their original shape, which is essential for vibration. Consider how elasticity plays a more significant role than rigidity in determining natural frequencies.

**Question 10.** [Incorrect] Moving the screen closer would decrease the separation distance between fringes based on the fringe equation  $w = \frac{\lambda D}{s}$ .

## **10. Circular motion and SHM**

### Feedback Sheet

**If you picked 'A':**

**Question 1.** [Incorrect] While 1.37 radians might seem like a reasonable angle, it does not represent the total angle covered in one full lap around the track, rather, this is approximately  $78.5^\circ$ . Consider how many radians correspond to a full circle ( $360^\circ$ ).

**Question 2.** [Correct] When the string breaks, the mass will no longer experience the centripetal force that kept it moving in a circle. According to Newton's first law of motion, an object in motion will continue in a straight line at constant velocity unless acted upon by an external force. Therefore, the mass will move in a straight line tangent to the circular path at the point where it was released.

**Question 3.** [Incorrect] Almost, but not quite. Momentum depends on velocity, which is a vector quantity, meaning both magnitude and direction matter. While the magnitude of velocity (speed) is constant, the direction changes continuously as the particle moves along the circle. Since the velocity is changing direction, the momentum is not constant. Think about how momentum is affected by both speed and direction.

**Question 4.** [Incorrect] This graph suggests that velocity is greatest at larger displacements. This is not true as at large displacement, the system's energy is transferred into potential energy (e.g., gravitational potential if it was a pendulum). Similarly, it suggests that the velocity is always positive, in which case, the oscillator could not move back and forth periodically.

**Question 5.** [Incorrect] This expression is close. Recall that the horizontal component of lift provides the centripetal force required for circular motion, which is  $\frac{mv^2}{r}$ . The vertical component balances the weight ( $mg$ ), and using these relations leads to the correct formula for  $\tan\theta$ .

**Question 6.** [Incorrect] The time period  $T$  is inversely related to the frequency, given by  $T = 1/f$ . So, if the frequency is doubled, the time period is halved, not doubled.

**Question 7.** [Incorrect] In a dampened system, it should be harder to vibrate atoms so we would not expect the resonance peak to be larger than the undampened system. Hence, damping removes energy from the system, making it harder for the material to maintain large oscillations.

**Question 8.** [Correct] Kinetic energy is given by  $\frac{1}{2}mv^2$ , where  $v = \omega x$  and ' $x$ ' is the current displacement from equilibrium. We therefore expect two features, 1) The gradient of the curve should vary as  $x^2$  (a parabola) and 2) at large displacements where the direction of motion changes, velocity is momentarily zero, and hence kinetic energy is zero at maximum displacement.

**Question 9.** [Incorrect] While it might seem intuitive, the acceleration is actually at its maximum value at the turning points (like Q). In SHM, acceleration is given by  $a = -\omega^2 x$ , where  $x$  is the displacement from the equilibrium position. At maximum displacement (like at Q),  $x$  is at its maximum, which makes the acceleration maximum, not minimum.

**Question 10.** [Incorrect] We would expect to see resonance (high amplitude) when the driver frequency matches the resonance frequency of Y, which will happen when the thread length is the same for both X and Y. Amplitude would rise as we get close to resonance and fall as we move away from it once again. This graph however shows exponential growth in amplitude, displaying no resonance peak.



**If you picked 'B':**

**Question 1.** [Incorrect] Although it is a valid angular measure, it does not represent a complete lap around a circle, instead 3.14 (or  $\pi$ ) radians correspond to half a circle.

**Question 2.** [Incorrect] This option is incorrect because once the string breaks, the mass no longer has the centripetal force needed to maintain circular motion. The mass will not continue in a curved path; it will instead move in a straight line.

**Question 3.** [Incorrect] The force on the particle is centripetal, meaning it acts towards the centre of the circular path. In contrast, the particle's direction of motion is always tangential to the circle. For circular motion, the force and the direction of motion are perpendicular to each other. Rethink how forces cause circular motion—hint: the force is what keeps the particle in the circular path!

**Question 4.** [Correct] We would expect velocity to be momentarily zero at maximum displacement since the simple harmonic oscillator will change direction. Similarly, it should be maximum at zero displacement (the equilibrium position; greatest kinetic energy and least potential energy). Graph B correctly captures these features.

**Question 5.** [Incorrect] This expression implies that the radius is directly proportional to  $\tan\theta$ , which is not accurate. In reality, for a given speed, a larger radius of the turn reduces the banking angle. Review how the centripetal force ( $\frac{mv^2}{r}$ ) is provided by the horizontal component of lift and how the vertical component balances the aircraft's weight ( $mg$ ).

**Question 6.** [Incorrect] The total energy in SHM is given by  $E = \frac{1}{2}m\omega^2A^2$ . If the frequency is doubled, the angular frequency  $\omega$  also doubles, and since the energy depends on  $\omega^2$ , the total energy increases by a factor of four, not two.

**Question 7.** [Incorrect] This graph shows a reduction in peak amplitude as expected, however, we would expect a broadening of the amplitude response curve - the amplitude response curve becomes broader around the resonance frequency in a damped system. This means that the system responds over a wider range of frequencies, but with lower peak amplitude

**Question 8.** [Incorrect] Kinetic energy is given by  $\frac{1}{2}mv^2$ , where  $v = \omega x$  and 'x' is the current displacement from equilibrium. This graph shows a linear relationship, rather than the expected parabola ( $x^2$ ) relationship. It does however show zero kinetic energy at maximum displacement, which is expected behaviour.

**Question 9.** [Correct] When the mass is at position Q (the maximum displacement in SHM), it momentarily comes to rest before changing direction. At this point, the velocity is zero, and since kinetic energy is given by the equation  $KE = \frac{1}{2}mv^2$ , the kinetic energy is at its minimum value (specifically, it is zero). This is a key characteristic of simple harmonic motion, where kinetic energy is highest at the equilibrium position and zero at the extreme positions.

**Question 10.** [Incorrect] We would expect to see resonance (high amplitude) when the driver frequency matches the resonance frequency of Y, which will happen when the thread length is the same for both X and Y. Amplitude would rise as we get close to resonance and fall as we move away from it once again. This graph however shows exponential growth in amplitude, displaying no resonance peak.

**If you picked 'C':**

**Question 1.** [Correct] Completing one full lap around a circle corresponds to an angle of  $2\pi$  radians, which is approximately 6.28 radians. Radians as a unit are fundamental to circular motion.

**Question 2.** [Incorrect] After the string breaks, the mass will not move towards the centre of the circle; instead, it will continue moving in a straight line, tangent to the circle. The centripetal force that pulls the mass towards the centre is lost once the string breaks.

**Question 3.** [Correct] The particle is moving with uniform speed, meaning its speed does not change. Since kinetic energy depends on speed (not velocity), the kinetic energy remains constant. Remember that although the direction of velocity changes, speed is a scalar quantity, so the kinetic energy stays the same.

**Question 4.** [Incorrect] This graph suggests velocity does not change with displacement which cannot be the case. As displacement varies, so does the kinetic energy in order to keep total system energy constant. At large displacements, we would expect larger potential energies and therefore, lower kinetic energy (hence lower velocities at large displacements).

**Question 5.** [Incorrect] This formula has the correct elements but is inverted in relation to how they should be arranged. A higher speed or smaller radius requires a larger banking angle, while a larger gravitational acceleration requires a smaller angle for the same speed and radius. Revisit the breakdown of the vertical and horizontal components of lift. The horizontal component of lift provides the centripetal force required for circular motion, which is  $\frac{mv^2}{r}$ . The vertical component balances the weight ( $mg$ ).

**Question 6.** [Correct] The maximum velocity in simple harmonic motion (SHM) is given by  $v_{max} = \omega A$ , where  $\omega$  is the angular frequency and  $A$  is the amplitude. Since  $\omega = 2\pi f$  and the frequency is doubled, the maximum velocity also doubles, whilst the amplitude is constant.

**Question 7.** [Incorrect] In a dampened system, it should be harder to vibrate atoms so we would not expect the resonance peak to be larger than the undampened system. Hence, damping removes energy from the system, making it harder for the material to maintain large oscillations

**Question 8.** [Incorrect] Kinetic energy is given by  $\frac{1}{2}mv^2$ , where  $v = \omega x$  and 'x' is the current displacement from equilibrium. This graph shows a linear relationship, rather than the expected parabola ( $x^2$ ) relationship. Therefore, we would expect zero kinetic energy at maximum displacement, not maximum kinetic energy (which occurs at zero displacement).

**Question 9.** [Incorrect] At position Q, the potential energy of the mass-spring system is at its maximum value. Potential energy in a spring system is given by  $PE = \frac{1}{2}kx^2$ . At Q, where the displacement  $x$  is maximum, the potential energy is also maximum, contrasting with kinetic energy, which is zero at that point.

**Question 10.** [Correct] We would expect to see resonance (high amplitude) when the driver frequency matches the resonance frequency of Y, which will happen when the thread length is the same for both X and Y. Amplitude would rise as we get close to resonance and fall as we move away from it once again.

**If you picked 'D':**

**Question 1.** [Incorrect] While 360 degrees corresponds to a full circle, it is not expressed in radians. Remember that  $360^\circ$  is equivalent to  $2\pi$  radians, or about 6.28 radians.

**Question 2.** [Incorrect] The mass will not follow an elliptical or spiralling path once the string breaks. It will move in a straight line at the point of release, due to its inertia.

**Question 3.** [Incorrect] Not quite. The force on the particle is directed inward, toward the centre of the circular path (centripetal force). However, the displacement of the particle is tangential to the circle at any given point in time. Force and displacement are not in the same direction in circular motion.

**Question 4.** [Incorrect] This graph suggests that velocity is greatest at larger displacements. This is not true as at large displacement, the system's energy is transferred into potential energy. It does, however, capture that velocity changes sign (positive to negative) which indicates oscillation.

**Question 5.** [Correct] The horizontal component of the lift provides the centripetal force needed for the circular motion, while the vertical component balances the aircraft's weight. Using this, you can derive  $\tan\theta = \text{'opposite'} / \text{'adjacent'}$ , which shows that the banking angle depends on the square of the speed, the radius of the circular path, and the acceleration due to gravity.

**Question 6.** [Incorrect] The maximum acceleration in SHM is given by  $a_{\max} = \omega^2 A$ , where  $\omega = 2\pi f$ . Since the angular frequency  $\omega$  depends on the frequency, doubling the frequency results in quadrupling the maximum acceleration because it depends on  $\omega^2$ .

**Question 7.** [Correct] This graph captures the three main observations comparing an undamped and damped system. 1) **Reduction in overall amplitude of vibrations:** in a damped system, the overall amplitude of vibration at all frequencies is reduced compared to the undamped system. This occurs because damping dissipates energy, which results in a lower steady-state response for a given driving force. 2) **Broadening of the amplitude response curve:** the amplitude response curve becomes broader around the resonance frequency in a damped system. This means that the system responds over a wider range of frequencies, but with lower peak amplitude. 3) **Decrease in resonance frequency:** the resonance frequency shifts slightly lower in a damped system. Damping causes a reduction in the system's natural frequency because it alters the effective stiffness and inertia balance in the oscillating system.

**Question 8.** [Incorrect] Kinetic energy is given by  $\frac{1}{2}mv^2$ , where  $v = \omega x$  and 'x' is the current displacement from equilibrium. This graph shows an exponential decay response, which is incorrect. Similarly, kinetic energy should be zero at maximum displacement in order for velocity to reverse direction.

**Question 9.** [Incorrect] The resultant force exerted by the springs is also at its maximum when the mass is at position Q. In SHM, the restoring force is proportional to the displacement from the equilibrium position (given by Hooke's Law:  $F = -kx$ ). Therefore, at maximum displacement (at Q), the resultant force is at its maximum value, not minimum.

**Question 10.** [Incorrect] We would expect to see resonance (high amplitude) when the driver frequency matches the resonance frequency of Y, which will happen when the thread length is the same for both X and Y. This graph, however, begins with a large amplitude which reduces to a minimum, and rises again.