recommended background capabilities
general aptitude: recognising patterns, and interpolation and extrapolation

P0. Concepts; Units and Measurement

Physical quantities typically have "units", which represent measurement against some standard quantity. For example, the standard for mass at the time this test was written, is a cylinder of metal under a vacuum chamber in France. The cylinder defines a mass of 1 kg, and we can express any other mass as a multiple of 1 kg.

When performing calculations with physical quantities, we may add and subtract only quantities with the same units, to obtain a new quantity with the same units. We multiply or divide quantities with any units, but the resulting quantity will have new units, which we obtain by multiplying or dividing the units themselves. In fact, sometimes we can actually look at the units of quantities, to check if we multiplied or divided the correct things.

\# 1. Some examples have been included in the table below to demonstrate this concept. Fill in the remaining empty unshaded boxes with the correct derived units. Remember that when multiplying variables, we often leave out the multiplication sign, so the variable letters are next to each other (like in $F = ma$).

Quantity	Symbol, Calculation	Units	Alternative Name
position, length, distance	x	m (metres)	
time	t	s (seconds)	
mass	m	kg (kilograms)	
velocity, speed	$v = x \div t$	m/s	
acceleration	$a = v \div t$	m/s^2	
force	$F = ma$		N (newtons)
kinetic energy	$K = ½ mv^2$		J (joules)
potential energy	$U = Fx$		J (joules)
momentum	$p = mv$		
power	$P = U \div t$		W (watts)

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. The "period" of a pendulum is the time that it takes for the pendulum to make a complete swing. To a good approximation, for a fairly long, heavy pendulum that swings through a small angle, the period depends only on the length of the pendulum, and the strength of gravity.

We can use the units of these quantities to check whether a particular mathematical relationship between them is sensible. Let the period of the pendulum be T, measured in seconds (s). Let the length of the pendulum be l, measured in metres (m). The strength of gravity near the surface of the earth is usually called g, which is equivalent to an acceleration, measured in metres per second per second (m/s^2).

The correct mathematical relationship also includes a numerical factor without units, which we cannot use this kind of analysis to determine (but which turns out to be 2π).

Indicate which of the following relationships makes sense, according to the units. (Two quantities can only be equal if they are equal in the same units.)

$$T = 2\pi lg \qquad T = 2\pi \frac{l}{g} \qquad T = 2\pi l^2 g$$

$$T = \frac{2\pi}{lg} \qquad T = 2\pi\sqrt{\frac{l}{g}} \qquad T = 2\pi l g^2$$

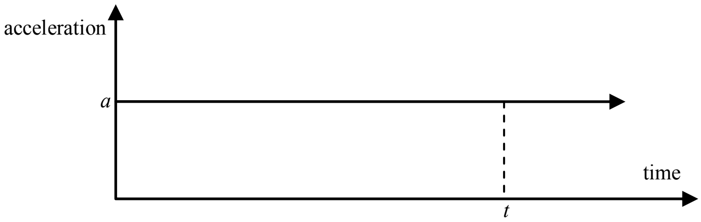
$$T = 2\pi \frac{g}{l} \qquad T = 2\pi\sqrt{\frac{g}{l}} \qquad T^2 = 2\pi \frac{l}{g}$$

Confidence: 0 | 1 | 2 | 3 | 4

P1. Motion (in one spatial dimension)

With knowledge of calculus, the simple "equations of motion" for constant acceleration scenarios are easy to derive. They are just as easy to derive without calling it "calculus". The important mathematics here is just being able to calculate areas.

The following plot represents a constant acceleration across time. We have acceleration on the vertical axis, and time on the horizontal axis. The plot is a straight line, starting at the constant acceleration a on the vertical intercept, and extending horizontally (without rising or falling). The acceleration at any particular time t will be a, because it is constant (it does not depend on time).



\# 1. The effect of acceleration on velocity is equal to the area under the plot of acceleration. If we have a starting velocity of u, then after a time t has elapsed, the new velocity will be increased by the area under the plot of acceleration, up to that time t.

Write the expression for velocity after time t, in terms of u, a, and t.

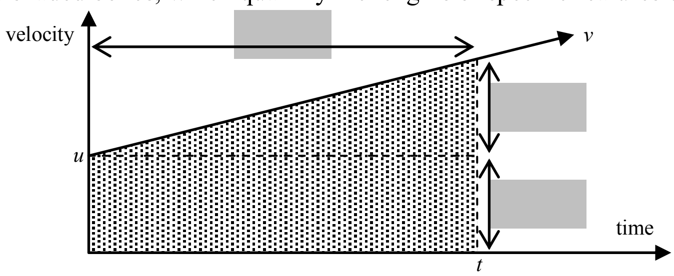
$v \quad = \quad u$ + (area under plot of a, up to time t)

$v \quad = \quad u +$

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. The following plot represents this velocity that is changing across time. We have velocity on the vertical axis, and time on the horizontal axis. The plot will be a straight line, starting at the initial velocity of u on the vertical intercept.

Fill in the shaded boxes, which quantify the lengths of specific features on the plot.



Confidence: 0 | 1 | 2 | 3 | 4

\# 3. Velocity affects position, changing it by an amount equal to the area (speckled, above) under the plot of velocity. This time, we will measure position from 0, so there is no "initial position" term (it is zero).

Write the expression for position after time t, in terms of u, a, and t.

$x \quad =$ (area under plot of v, up to time t)

$x \quad =$

Confidence: 0 | 1 | 2 | 3 | 4

P2. Force = "interaction"

Forces are interactions between objects, which can change the movement of those objects. Multiple forces can act on the same object, and when added up, if there is an overall force, it causes an acceleration which causes a change in velocity. In classical mechanics, we have a set of 3 rules.

- In the absence of force, an object maintains a constant velocity (which may be zero, or nonzero).
- Where forces are present, the overall force is equal to the mass of the object, multiplied by its resulting acceleration. ('Σ' means "sum of", in the equation below.)

$$\Sigma F = ma$$

- If object A exerts a force F on object B, then object B simultaneously exerts force $-F$ on object A.

These are often called the classical "laws of motion".

\# 1. An object falling near the surface of the earth experiences a gravitational force. In the absence of unspecified complicating factors (that is: no other forces, such as drag or friction), this gravitational force produces an acceleration of $g = 10\ \text{m/s}^2$

"Weight" refers to the gravitational force acting on an object. What is the weight of a 100 kg object, near the surface of the earth?

$$\begin{aligned} \text{weight} &= F_{\text{gravity}} \\ &= \\ &= \end{aligned}$$

Confidence: 0 | 1 | 2 | 3 | 4

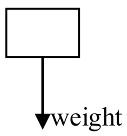
2. An object resting on the surface of the earth still experiences the same gravitational force. However, if it remains stationary, its velocity is not only constant, it is zero.

\# 1. Using the concept of forces, explain how such an object can remain stationary on the surface of the earth, despite gravity pulling the object towards the centre of the earth.

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. The diagram below represents an object experiencing a gravitational force (weight).

Copy and adjust, or simply adjust, the diagram to represent the explanation above.



Confidence: 0 | 1 | 2 | 3 | 4

\# 3. The third law of motion above states "If object A exerts a force F on object B, then object B simultaneously exerts force $-F$ on object A."

Use a diagram to show how this applies to the earth exerting a gravitational force on an object.

Confidence: 0 | 1 | 2 | 3 | 4

P3. Energy, Momentum

Combined with symmetry (the laws are the same across all space, over all time, in any direction), the laws of physics lead to various quantities that are "conserved". Two of these quantities are energy and momentum.

Conservation means that the total quantity is a constant: the total energy of the universe is constant; and the total momentum of the universe is constant. The same conservation applies to any "system" of objects we confine our interest to, as long as this system does not transfer energy or momentum in from or out to the rest of the universe.

1. Potential energy is energy associated with "configuration", or the relative position of objects. For an object a height (or altitude) h above the surface of the earth, we typically define potential energy as follows.

$$\text{surface gravitational potential energy} = U = mgh$$

Kinetic energy is energy associated with relative movement. For an object moving at a speed of v, we classically define kinetic energy as follows.

$$\text{kinetic energy} = K = \tfrac{1}{2} mv^2$$

Potential energy components and kinetic energy components together make up the total energy of a system.

1. Consider an object of mass m stationary at altitude h. What are the potential energy and kinetic energy associated with this situation?

Confidence: 0 | 1 | 2 | 3 | 4

2. The same object then falls, under the influence of gravity, towards the earth. Just as it is about to hit the surface of the earth, it reaches its greatest velocity, of v. What are the potential energy and kinetic energy associated with this situation?

Confidence: 0 | 1 | 2 | 3 | 4

3. In this case, conservation of energy means that the total initial energy must equal the total final energy. Express this mathematically, using the quantities in the previous two answers.

Confidence: 0 | 1 | 2 | 3 | 4

4. Hence (or otherwise), express the impact velocity v, of an object dropped from an altitude of h above the surface of the earth, in terms of its mass m, the altitude h, the acceleration equivalent to gravity g, and any other variables that may be relevant (if there are any).

$$v \quad =$$

Confidence: 0 | 1 | 2 | 3 | 4

2. Momentum is a quantity associated with movement, classically defined as follows.

$$\text{momentum} = p = mv$$

Like energy, momentum is conserved.

1. Consider two objects: a projectile with mass m moving horizontally at velocity v, about to impact a stationary target of mass M. What is the total momentum of these two objects?

Confidence: 0 | 1 | 2 | 3 | 4

2. After impact, the projectile becomes embedded in the target, causing the now composite object to move horizontally at a single new velocity, V. Conservation of momentum means that the total momentum must be the same before and after the impact. Hence (or otherwise), express V in terms of v, m, M, and any other variables that may be relevant (if there are any). (Hint: what is the mass of the new, composite object?)

Confidence: 0 | 1 | 2 | 3 | 4

3. This scenario describes a “perfectly inelastic” collision. This kind of collision transforms (dissipates) the mechanical kinetic energy of the original objects into other forms of energy, like sound, light and thermal energy.

1. What was the total initial kinetic energy?

Confidence: 0 | 1 | 2 | 3 | 4

2. What is the total final kinetic energy?

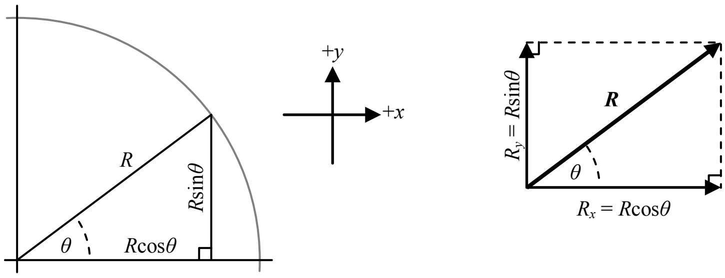
Confidence: 0 | 1 | 2 | 3 | 4

3. How much kinetic energy was dissipated in the collision?

Confidence: 0 | 1 | 2 | 3 | 4

P4. Vectors and Matrices (and motion in more than one spatial dimension)

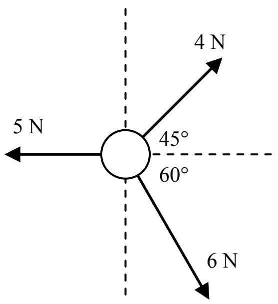
Trigonometry allows us to “resolve” (split) vector quantities into components that are in perpendicular directions.



	sin	cos
0°	0	1
30°	0.5	0.866
45°	0.707	0.707
60°	0.866	0.5
90°	1	0

The diagrams above show how to resolve vector $\boldsymbol{R}$ into its components in the x direction (R_x) and in the y direction (R_y). The exact split will depend on the θ, the angle between $\boldsymbol{R}$ and the axes.

1. In the following scenario, add up all the horizontal and vertical components to determine the overall force on the object, in each (horizontal and vertical) direction. An approximate numerical answer for each is acceptable. Approximate numerical values for the sine and cosine of specific angles are tabulated above.



Confidence: 0 | 1 | 2 | 3 | 4

2. Consider an aeroplane flying at an altitude of 1000 m, at a speed of 200 m/s. This aeroplane releases a 50 kg payload, which therefore begins to drop towards the earth, starting with a horizontal speed of 200 m/s, and a vertical speed of 0 m/s.

1. In a previous problem, we had to determine the impact velocity of an object dropped directly downward from an altitude of h above the surface of the earth. What was the expression for this?

Confidence: 0 | 1 | 2 | 3 | 4

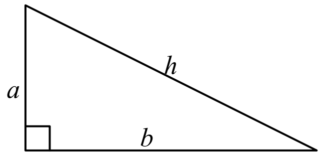
\# 2. Hence (or otherwise) calculate the numerical value of the vertical impact velocity for the payload released in the circumstances above.

Confidence: 0 | 1 | 2 | 3 | 4

\# 3. In this kind of situation, perpendicular components of velocity are independent: that is, we can consider them completely separately. Assuming that the payload incurs no drag or other unspecified complicating factors that would affect its horizontal movement, its horizontal velocity will be constant (the first "law of motion" above).

The vertical velocity of the payload will change under the influence of gravity, in the way we have calculated above. As a result, although the payload started falling with only horizontal velocity, by the time of impact, it will have that horizontal velocity, as well as the vertical velocity as above.

To combine vector components, we need to know the rule governing side lengths of right-angled triangles: the square of the hypotenuse equals the sum of the squares of the other sides.



$$h^2 = a^2 + b^2$$

What is the overall impact speed of the payload?

Confidence: 0 | 1 | 2 | 3 | 4

P5. Circular Motion

Objects with a constant velocity will move in straight lines. Changing the magnitude or the direction of velocity requires an acceleration, which requires an overall force.

An object moving in a circle is continually changing direction, and thus requires an acceleration which has a component directed towards the centre of the circle. If the object moves at a constant speed around the circle, we call this "uniform circular motion", and the acceleration is entirely directed towards the centre (it is "radial"), with no component along the circumference of the circle (which would be called a "tangential" component).

The size of the radial acceleration ("centripetal acceleration") required for uniform circular motion is

$$a_c = \frac{v^2}{r}$$

where v is the speed of the object and r is the length of the radius of the circle.

This means that for an object to undergo uniform circular motion, all the forces that act on the object must add up to the required "centripetal force", as below. The Greek letter Σ (sigma) means "sum of".

$$\sum F = F_c = \frac{mv^2}{r}$$

The concept of "*g*-force" typically refers to the force that an object (like a vehicle, or a human) experiences when it turns around a corner, or spins around a centrifuge. The comparison works, because like the force due to gravity (weight, equal to *mg* near the surface of the earth), required centripetal force is also directly proportional to mass. An object experiences a "force of 1 *g*" when it experiences a centripetal acceleration equal to *g*, or equivalently, a centripetal force equal to its weight.

1. How fast would a car need to travel around a circular track of radius 100 m, to require 1 g of lateral g-force?

Confidence: 0 | 1 | 2 | 3 | 4

2. If the lateral force is strictly perpendicular to the weight, then the overall g-force that a passenger would experience is equivalent to only about 1.4 g.

   Using the rule for side lengths of right-angled triangles (mentioned in the previous topic), calculate the amount of g-force strictly perpendicular to the weight, that corresponds to a total g-force of 2 g.

Confidence: 0 | 1 | 2 | 3 | 4

P6. Force-Based Equations of Motion

In some scenarios (like a floating object, a pendulum, or an object attached to a spring), when an object moves away from some "neutral" position, it will experience a force that pushes it back towards that neutral position. Such a force is then called a "restoring force".

"Simple harmonic motion" occurs when an object experiences a "restoring force" of a size proportional to how far it has moved from its neutral position: if it is twice as far from neutral, then the restoring force will be twice as large. We can also call this proportional relationship a "linear" relationship.

$$F = ma$$
$$a = -\omega^2 x$$

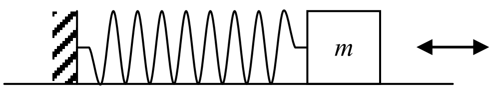
The equations above represent a linear restoring force F causing an acceleration a which is proportional to the distance from neutral, x. We can also call x the "displacement". The negative sign means that a is in the opposite direction to x. The force is proportional to displacement by a factor ω^2. We prefer to write this as a square, because the quantity ω turns out to have a particular meaning: we call it the "angular frequency".

When an object undergoes simple harmonic motion, we can describe its behaviour over time as a sinusoidal type of wave: a sine or cosine wave, for which we have three common, mathematically equivalent, forms (below).

$$x = R\sin(\omega t \pm \varphi)$$
$$x = R\cos(\omega t \pm \varphi)$$
$$x = A\cos(\omega t) + B\sin(\omega t)$$

In all of these, ω directly relates to how quickly the sinusoidal wave repeats itself (the frequency). R (or the combination of (A and B) represents the amplitude of the wave, which does not depend on the restoring force.

\# 1. Consider a mass m attached to a spring and allowed to move horizontally only, as below.



Springs that behave in an "ideal" elastic fashion provide a restoring force proportional to the displacement from their "natural" length. The factor k is called the "spring constant".

$$F_{\text{spring}} = -kx$$

Express the angular frequency ω of the simple harmonic motion that would occur in this situation, in terms of m, k, g, and any other variables that may be relevant (if there are any).

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. The elastic force is a tension or compression force that acts along the entire length of the spring. If we imagine dividing the spring into two half-springs, each half-spring would experience the same force, but the displacement from neutral position would be spread among the half-springs.

Explain whether the spring constant of half a spring is the same, greater than, or less than, the spring constant of the original spring. If it differs, by how much does it differ?

Confidence: 0 | 1 | 2 | 3 | 4

P7. Inverse-Square Formulation of Gravitation and Electrostatic Force

In "classical" physics, gravitational and electrostatic forces behave in very similar ways. Objects with mass will attract each other with gravitational force. Objects with electrical charge will attract or repel, if their charges are opposite or alike, respectively. Electrical charge may be positive or negative.

The "inverse-square" laws refer to the size of gravitational and electrostatic forces at different distances. As objects move further apart, these forces decrease in strength, as a quantity divided by the square of the distance between the objects. One way to think of this, is as if the force is spread out over the surface of a sphere.

$$F_{\text{gravitational}} = \frac{Gm_1 m_2}{r^2}$$

G is the "gravitational constant" that matches the units we use (for example, mass in kilograms and distance in metres). m_1 and m_2 are two masses, and r is the distance between them.

$$F_{\text{electrostatic}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

For electrostatic force, there are again some constant values, multiplied by q_1 and q_2 the two charges, and then divided by the square of r which is the distance between them.

1. The moon is about 380000 km from the centre of the earth. It orbits the earth approximately once every 30 days. We will try to find how far from the earth a "geostationary" satellite needs to be, to orbit once a day.

\# 1. The only significant force here is the gravitational force between the earth and the moon. Equate the expression for this gravitational force, to the expression for the required centripetal force to hold the moon in a circular orbit (for the purposes of the task, we assume that orbits are circular, and that the earth is fixed in space). Use M_E for the mass of the earth, and M_M for the mass of the moon.

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. We can calculate orbital speed v, like any other speed: dividing distance by time. The distance all the way around a circular orbit is its circumference, $2\pi r$. We shall call the time it takes to complete an orbit T, the "period". Express v in terms of r and T.

Confidence: 0 | 1 | 2 | 3 | 4

\# 3. Substitute this expression for v into the previous equation, and rearrange it make r^3 the subject.

Confidence: 0 | 1 | 2 | 3 | 4

\# 4. Based on the equation above, if T is $^1/_{30}$ of its previous value, how would we expect r^3 to change?

Confidence: 0 | 1 | 2 | 3 | 4

\# 5. Round the above number up to something easy, so we can quickly calculate approximately how r would change. Approximately how does r change, when T is $^1/_{30}$ of its previous value?

Confidence: 0 | 1 | 2 | 3 | 4

\# 6. Hence (or otherwise) estimate the altitude required for geostationary orbit.

Confidence: 0 | 1 | 2 | 3 | 4

2. Imagine a situation where the earth is hollow. A solid earth causes gravitational force equivalent to an acceleration of 10 m/s^2 at its surface, which is 6400 km from its centre. If the earth exists only as a shell between a radius of 4800 km and 6400 km (with a sphere of empty space for the central 4800 km), it will have a correspondingly smaller mass. Assume that the earth has a uniform density, and remember that the volume of a sphere with radius r, is $\frac{4}{3}\pi r^3$.

\# 1. What proportion of the mass of the solid earth would be missing, in such a hollow earth?

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. The missing amount of earth would have had a certain gravitational effect at the surface of the earth (6400 km from its centre). What acceleration would this have been equivalent to?

Confidence: 0 | 1 | 2 | 3 | 4

\# 3. Hence (or otherwise) what is the gravitational equivalent acceleration at the surface of the imaginary hollow earth? The principle of "superposition" means that performing this calculation in the way that makes the most obvious sense, is correct.

Confidence: 0 | 1 | 2 | 3 | 4

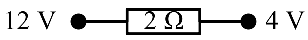
P8. Electrical Currents

In simple electrical circuits, a "current" of charged particles (typically electrons) flows down a potential difference (from high potential to low potential). Most materials have some electrical "resistance", which reduces the amount of current that flows for a given potential difference, or stops current from flowing when there is no potential difference (currents can flow through superconducting materials in the absence of potential difference). We define resistance in the following way.

$$R = \frac{V}{I}$$

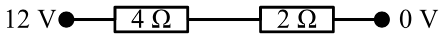
R is the resistance of a part of a circuit; V is the potential difference across that part of the circuit; I is the current that flows through that part of the circuit.

To simplify circuit analysis, we can pretend that simple circuits are made of resistive components ("resistors"), joined by wires with no resistance. The section of circuit below shows a 2 Ω resistor, with a potential difference of 12 V – 4 V = 8 V across it. A current of 8 V ÷ 2 Ω = 4 A will flow through this resistor.



Two standard circuit arrangements are the "series" arrangement (end-to-end), and the "parallel" arrangement (branching out from a point, and then back to another point, so that components are side-to-side).

1. When components are in series, the same current must flow through all the components (from one end to the other). We can call this "conservation of charge". Consider the following arrangement.



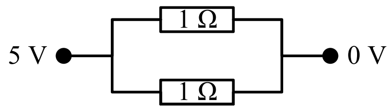
1. Make a sensible guess as to what the potential should be, between the two resistors, to make the same current flow through all the components of this section of circuit.

Confidence: 0 | 1 | 2 | 3 | 4

2. Using the definition of resistance, show that this potential gives the correct potential differences across each resistor, to indeed give a current of 2 Ω through every part of this section of circuit.

Confidence: 0 | 1 | 2 | 3 | 4

2. When components are in parallel, they are all connected to the same potential difference.



1. What is the current through each of the resistors above?

Confidence: 0 | 1 | 2 | 3 | 4

2. What is the current through the entire section of circuit above?

Confidence: 0 | 1 | 2 | 3 | 4

3. Hence (or otherwise) what is the effective (or overall) resistance of this section of circuit?

Confidence: 0 | 1 | 2 | 3 | 4

3. Extending the types of calculations above gives us two quick rules for simple circuit arrangements.

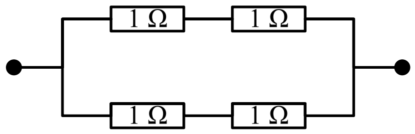
For resistors in series, the effective (or overall) resistance is the sum of individual resistances.

$$R_{\text{effective}} = R_1 + R_2 + ...$$

For resistors in parallel, the effective (or overall) resistance is the reciprocal of the sum of reciprocals of individual resistances.

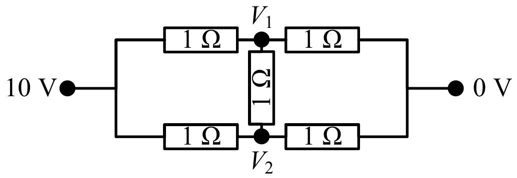
$$\frac{1}{R_{\text{effective}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$

\# 1. What is the effective resistance of the circuit below?



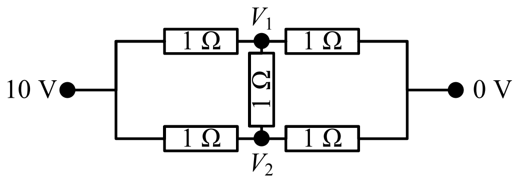
Confidence: 0 | 1 | 2 | 3 | 4

\# 2. Using estimates of the potentials at points V_1 and V_2, predict the current flowing through resistor R in the circuit below.



Confidence: 0 | 1 | 2 | 3 | 4

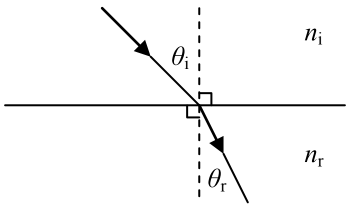
\# 3. Hence (or otherwise) estimate the effective resistance of the circuit.



Confidence: 0 | 1 | 2 | 3 | 4

P9. Electromagnetic Waves

\# 1. Light that crosses a boundary between regions of different "refractive index" (as it does when passing through air into water) undergoes "refraction", a change in direction of travel. The refractive index (n) of a medium measures how much the medium appears to slow the speed of light.



The change in direction depends on the ratio of refractive indices, and on the "angle of incidence", θ_i. Here, n_i is the refractive index of the medium from which light is incident, and n_r is the refractive index of the medium into which the light is refracted. θ_r is the "angle of refraction".

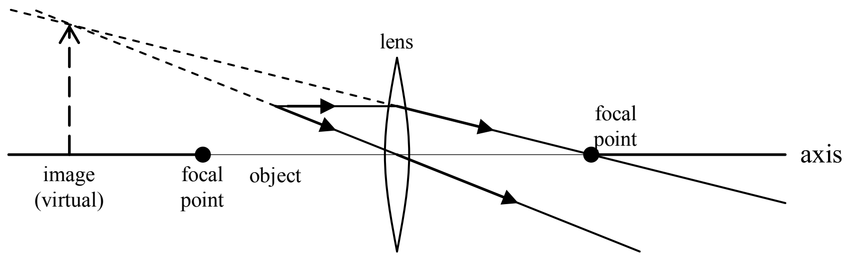
$$n_i \sin\theta_i = n_r \sin\theta_r$$

The diagram above is fairly representative of what happens when light travels from air into water (air is less optically dense than water, and so air has a lower refractive index than water).

Using a similar diagram, explain what causes pools of water to appear shallower than they are, when viewed from the air above. Alternatively and equivalently, explain what causes objects in water to appear closer to the surface than they are, when viewed from the air above.

Confidence: 0 | 1 | 2 | 3 | 4

\# 2. Ray tracing involves following the expected trajectory of light. We can use this to determine the effect of lenses and mirrors on the appearance of an object. For example, the following diagram shows how a biconvex converging lens acts as a magnifying glass.

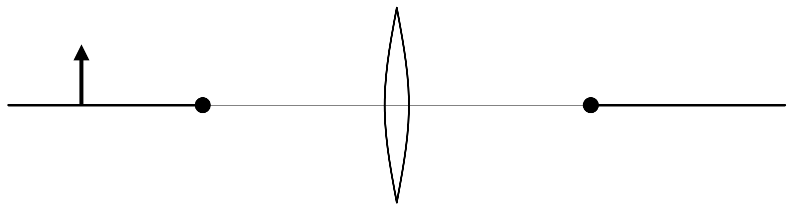


The rules for drawing approximate ray diagrams are as follows.

- Rays parallel to the axis on one side will pass through the focal point on the other side.
- Rays passing through the centre of the lens will not change direction.
- When rays from the same point on an object coincide at another point, they form an "image". The image may be "real" or "virtual", if respectively the image is on the opposite or same side of the lens as the object.

In the above example, the image is virtual, because we need to trace the rays back from the lens to find where they coincide. The light does not travel back in this direction, rather, it passes through the lens (as shown by the arrows), so that to an observer on the other side, the object appears larger (where the virtual image is). This makes the converging lens act as a magnifying glass, when the object is closer to the lens than the focal point is.

Draw a ray diagram for the following situation, showing how a converging lens will produce a real image if the object is beyond the focal point. (In this situation, we can place a screen where we expect the image to be, and the lens will project an image of the object onto the screen, making it "real".)



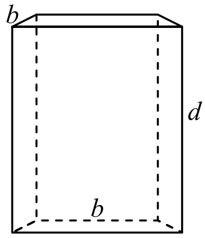
Confidence: 0 | 1 | 2 | 3 | 4

P10. Introductory Thermodynamics

Pressure is force per unit area, and we can observe its effect by comparing what happens when we hold a small sheet or panel of material up against the wind, to what happens with a larger sheet or panel.

$$P = \frac{F}{A}$$

Consider a column of water, as square-based right-angled prism (for convenience). Let this column have a depth of d, and let the side lengths of the square base be b.



1. What is the volume of this column of water?

Confidence: 0 | 1 | 2 | 3 | 4

2. Density is mass per unit volume.

$$\rho = \frac{m}{V}$$

Leave the density of water as ρ for now (we will specify its numerical value later). What is the mass m of the column of water, as described?

Confidence: 0 | 1 | 2 | 3 | 4

3. Recall that weight is the force due to gravity, and that near the surface of the earth, gravity is equivalent to an acceleration of g. If this column of water is near the surface of the earth, its weight will be mg. Substitute m with the expression containing the previous variables above.

Confidence: 0 | 1 | 2 | 3 | 4

4. If the water is still, the pressure at the bottom of the column of water must be able to support the weight of the water above it. What is the pressure at the bottom of such a column of water? (Hint: consider what area the force must be spread over, at the bottom of the column.)

Confidence: 0 | 1 | 2 | 3 | 4

5. Atmospheric pressure at the surface of the earth is approximately 100000 Pa. The density of water is approximately 1000 kg/m^3. The acceleration equivalent to gravity near the surface of the earth is approximately 10 m/s^2. Using these quantities in these units, and measuring lengths in metres, the calculation should give the correct units of pascals (Pa).

   For a diver to experience one extra "atmosphere" of pressure, what depth would the diver need to dive to?

Confidence: 0 | 1 | 2 | 3 | 4

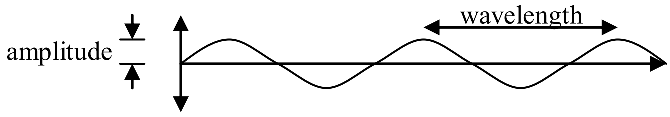
P11. Sound and More on Waves

Sound is a compression (pressure) wave that requires a medium of massive particles to propagate. Particles vibrate (move back and forth) in the medium according to the pressure changes. As a mathematical representation, we can plot either the pressure changes in the medium, or the displacement of the particles. For our purposes, a plot of displacement is more useful.

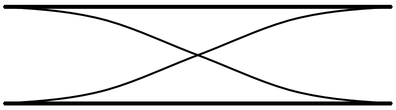
Resonance occurs when a system has some "natural" rate of vibration ("frequency" refers to the rate of vibration) which it can support with low energy loss, so that when we add energy at that frequency (or even at random), the system will vibrate predominantly at that frequency. We can call this frequency the "resonant" frequency.

When sound propagates through a medium, vibrations and pressure changes are travelling through that medium, and we can draw our plots to represent the changes across space. Sound is typically comprised of regularly repeating patterns: waves.

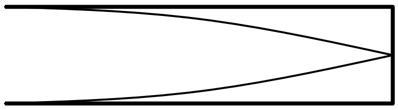
We can see two important features on spatial plots of sound waves: the wavelength (which relates to frequency and hence the pitch of a sound), and the amplitude (which relates to how loud the sound is).



1. A tube of air that is open at one or both ends can support resonance. In such tubes, the air particles at an open end will tend to undergo the greatest displacement, while the air particles at a closed end will not be displaced at all. We can plot the extremes of particle displacement as (thin lines) below.

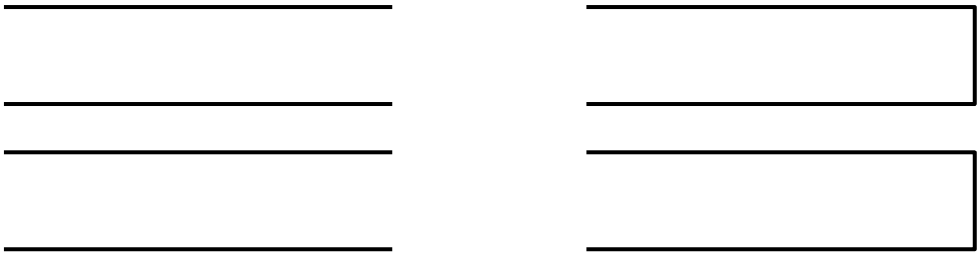


double-open-ended tube



single-open-ended tube

\# 1. The diagrams above show only the first, simplest, lowest-frequency resonant waves for each tube. Fill the diagrams below with plots of the next two resonant frequencies for each tube.



Confidence: 0 | 1 | 2 | 3 | 4

\# 2. What are the first 3 resonant wavelengths for a tube of length L, that is open at both ends?

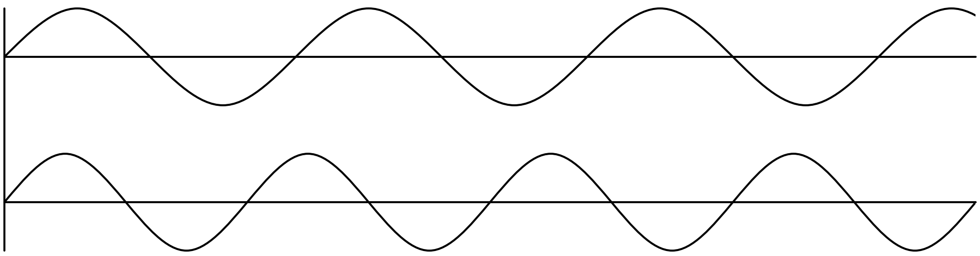
Confidence: 0 | 1 | 2 | 3 | 4

\# 3. {Predict what this question will ask, and answer it.}

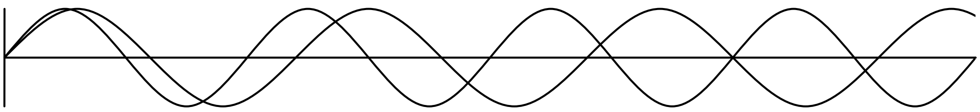
Confidence: 0 | 1 | 2 | 3 | 4

\# 2. The superposition of waves leads to constructive and destructive interference. These occur respectively when waves add together to a greater amplitude, and when they add together to a smaller amplitude.

Consider two sound waves of slightly different frequency, which may occur when two instruments are slightly out of tune. When played together, the waves will add together to give a certain effect.



What would we expect someone to hear, if these sounds of slightly different frequency and the same amplitude were played together? (Hint: if it helps, below are the same waves, overlaid.)



Confidence: 0 | 1 | 2 | 3 | 4

END