AUSTRALIAN SCIENCE INNOVATIONS

PHYSICS

2017 Australian Science Olympiads Exam Solutions

Australian Science Olympiads

Time Allowed:

Reading Time: 10 minutes

Examination Time: 120 minutes

INSTRUCTIONS

- *Attempt ALL questions in both sections of this paper.*
- Permitted materials: a *non-programmable, non-graphical* calculator, blue and black pens, lead pencils, an eraser, and a ruler.
- Answer SECTION A on the MULTIPLE CHOICE ANSWER SHEET provided.
- Answer SECTION B in the answer booklet provided. Write your answers to each question on the pages indicated. If you need additional space use the spare pages at the back of the booklet. Write in pen and use pencil only for diagrams and graphs.
- You may attempt the questions in Section B in any order. Make sure that you label which parts are for which questions.
- **Do not write on this question paper. It will not be marked.**
- Do **not** staple the multiple choice answer sheet or the writing booklet to anything. They must be returned as they are.
- Ensure that your diagrams are clear and labelled.
- All numerical answers must have correct units.
- Marks will not be deducted for incorrect answers.

MARKS

Section A	10 multiple choice questions	10 marks
Section B	4 written answer questions	50 marks
		60 marks

SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

Question 1

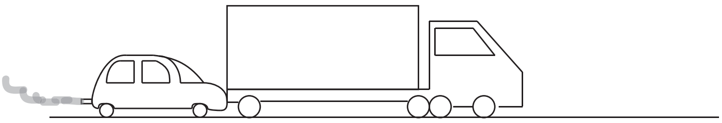
A book lies at rest on a table. The table is at rest on the surface of the Earth. The Newton's Third Law reaction force to the gravitational force of the Earth on the book is:

a. the gravitational force exerted by the Earth on the book.
b. the normal force exerted by the table on the book.
c. the gravitational force exerted by the table on the book.
d. the normal force exerted by the Earth on the table.
e. the gravitational force exerted by the book on the Earth.

Solution: e. The Newton's Third Law reaction force is the force of the same type, in this case gravitational, with the roles of the objects swapped, which means that here the force is acting on the Earth due to the book.

Question 2

A large truck breaks down out on the road and receives assistance from a small compact car as shown in the figure below.



The car driver attempts to push the truck with the car. Unfortunately, the truck driver has left the brakes on the truck, and neither vehicle moves. Why does the truck not move?

a. Because the pushing force of the car on the truck is equal to the pushing force of the truck on the car, but in the opposite direction.
b. Because the pushing force of the car on the truck is less than the pushing force of the truck on the car.
c. Because the frictional force of the ground on the truck is equal to the frictional force of the truck on the ground, but in the opposite direction.
d. Because the frictional force of the ground on the truck is greater than the frictional force of the truck on the ground.
e. Because the pushing force of the car on the truck is equal to the frictional force of the ground on the truck, but in the opposite direction.

Solution: e. As the truck is not accelerating the total force on the truck is zero. This means that the force due to the car pushing must be equal to, but in the opposite direction from, the force which is opposing the motion. This opposing force is the frictional force.

Question 3

A roller-coaster cart full of water is moving at a constant speed along a horizontal, frictionless length of track. Suddenly, a plug in the bottom of the cart is removed, and the water starts to flow downwards out of the cart. What happens to the speed of the cart while the water is flowing? Ignore air resistance in your answer.

a. The cart speeds up.

b. The cart slows down.

c. The cart speeds up until half the water is gone, then it slows down.

d. The cart slows down until half the water is gone, then it speeds up.

e. The cart's speed does not change.

Solution: e. The water flowing out of the cart does not exert a horizontal force on the cart, so the cart's speed does not change. Alternatively, the water leaving the cart does carry horizontal momentum, so the momentum of the cart does decrease. However, the mass of the cart is decreasing by the same fraction, so the speed of the cart does not change.

Question 4

The long side of a rectangular piece of paper is measured to be (30 ± 2) mm, and the short side is measured to be (20 ± 3) mm. What is the perimeter of this piece of paper, together with its uncertainty?

a. (50 ± 5) mm

b. (100 ± 3) mm

c. (100 ± 5) mm

d. (100 ± 10) mm

e. (600 ± 6) mm

Solution: d. The perimeter is twice the sum of the lengths of the two sides, so it is $(30\text{ mm} + 20\text{ mm}) \times 2 = 100$ mm. The uncertainties combine in the same way as we are adding values, so the uncertainty is $(2\text{ mm} + 3\text{ mm}) \times 2 = 10$ mm.

Question 5

As part of a recent charity fundraising event, people were asked to donate five-cent coins by placing them onto the surface of a large circle (radius 3 m). At the end of the day, the circle was completely covered by a single layer of coins. Approximately how much money was raised?

a. Five hundred dollars.

b. Five thousand dollars.

c. Fifty thousand dollars.

d. Five hundred thousand dollars.

e. Five million dollars.

Solution: b. We can estimate that the diameter of a 5c coin is 2 cm. This gives us a radius of 1 cm, which is 300 times smaller than the radius of the large circle. As area scales as the square of the length, this means that no more than $(300)^2$ coins fit in the circle. The value of these coins is $4,500. While there will be some empty space it will not be more than half empty so this gives us a good order of magnitude estimate.

Question 6

If a string of linear mass density μ (measured in $\mathrm{kg\,m^{-1}}$) is placed under a tension T (a force, measured in newtons, N), then the fundamental oscillation frequency f (measured in hertz, Hz, equivalent to cycles per second) is related to the length L of the fundamental oscillation mode of the string (measured in metres, m) by $f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$. If you plot a graph with a series of applied tensions (T) on the x-axis, and the square of the length of the fundamental oscillation mode (L^2) on the y-axis, what would you expect to see if the fundamental oscillation frequency is kept constant?

a. A straight line through the origin, with a positive slope.

b. A straight line through the origin, with a negative slope.

c. A straight line, parallel to the x-axis.

d. A parabolic curve, with a minimum at $x = 0$.

e. A parabolic curve, with a maximum at $x = 0$.

Solution: a. The relationship given can be rearranged to be $L^2 = \left(\frac{1}{2f}\right)^2 \frac{T}{\mu}$. This shows that the relationship between L^2 and T is linear with a positive slope, as the coefficient of T, $\left(\frac{1}{2f}\right)^2 \frac{1}{\mu}$, is positive. As there is no constant term the line is expected to pass through the origin.

Question 7

Four particles, each of charge $+q$, are arranged symmetrically on the x-axis about the origin as shown. A fifth particle of charge $-Q$ is placed on the positive y-axis as shown. What is the direction of the net electrostatic force on the fifth particle?

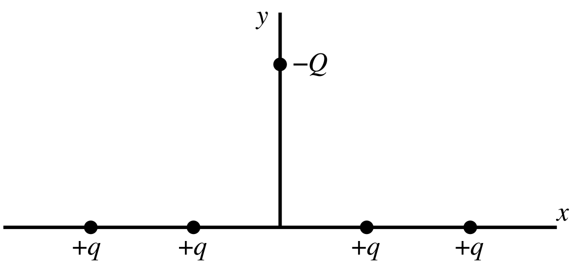
a. $\uparrow$

b. $\rightarrow$

c. $\downarrow$

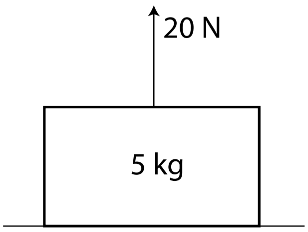
d. $\leftarrow$

e. The net electrostatic force on the particle of charge $-Q$ is zero.



Solution: c. The negative charge is attracted to each of the positive charges. The components of the attractive force along the x-axis from the inner two positive charges are, by symmetry, of equal magnitude and in opposite directions. Hence, they cancel each other. The same argument applies to the forces due to the outer two positive charges. Therefore, the total force is along the y-axis towards the positive charges.

Question 8
A block of mass 5 kg lies at rest on a horizontal surface. An upwards force of 20 N is applied to the block, as shown. Assuming $g = 10\ \mathrm{m\,s^{-2}}$, what is the weight of the block?



a. 3 kg

b. 5 kg

c. 30 N

d. 50 N

e. 5 kg – 20 N

Solution: d. The weight is the gravitational force on the block. This is $W = mg = 5\ \mathrm{kg} \times 10\ \mathrm{m\,s^{-2}} = 50\ \mathrm{N}$.

Question 9
Assuming $g = 10\ \mathrm{m\,s^{-2}}$, what is the magnitude of the normal force exerted by the surface on the block in Question 8?

a. 20 N

b. 30 N

c. 50 N

d. 70 N

e. 5 kg – 20 N

Solution: b. The normal force will prevent the block accelerating downwards. The other forces acting on the block are 50 N down due to gravity plus 20 N up due to the applied force, so, in total, 30 N down. This means that the normal force is 30 N upwards.

Question 10

An elevator is rising at constant speed. Consider the following five statements (I to V) about the situation:

I. "The tension in the elevator cable is constant."
II. "The kinetic energy of the elevator is constant."
III. "The gravitational potential energy of the Earth-elevator system is constant."
IV. "The acceleration of the elevator is zero."
V. "The mechanical energy of the Earth-elevator system is constant."

Select the correct analysis of this situation out of the options a. to e.

a. Only statements II and V are true.
b. Only statements IV and V are true.
c. Only statements I, II and III are true.
d. Only statements I, II and IV are true.
e. All five statements are true.

Solution: d.

- At constant speed the acceleration of the elevator is zero, so IV is true. This means that the total force on it is zero. As none of the other forces are changing in magnitude, the tension in the elevator cable is constant. Hence, I is true.
- At constant speed $K = \frac{1}{2}mv^2$ is constant, hence, II is true.
- As the elevator moves upwards the gravitational potential energy of the system increases, due to increasing separation. Hence, III is false.
- As the kinetic energy is constant and the gravitational potential energy is increasing, the total mechanical energy is increasing. Hence, V is false.

SECTION B: WRITTEN ANSWER QUESTIONS
USE THE ANSWER BOOKLET PROVIDED

Throughout, take the acceleration due to gravity to be $9.8\ \mathrm{m\,s^{-2}}$.

Note: Suggested times are given for Section B as a general guide only. You may take more or less time on any question – everyone is different.

Question 11

Suggested Time: 20 min

Niamh, the Milo enthusiast, is interested in the physics behind her favourite "energy food drink". To investigate, Niamh prepares to make a huge tank of chocolate milk. Niamh fills the tank of length L and height H with milk, then places a partition a distance L_V along the tank. She adds a large amount of chocolate powder to the milk to the left of the partition as shown in Figure 1 and mixes it thoroughly. The volume of milk to the left of the partition is V_C and the density of this chocolate milk is ρ_C. The remaining volume V_M of plain milk, which has density ρ_M, is to the right of the partition. The chocolate milk is denser than the plain milk.

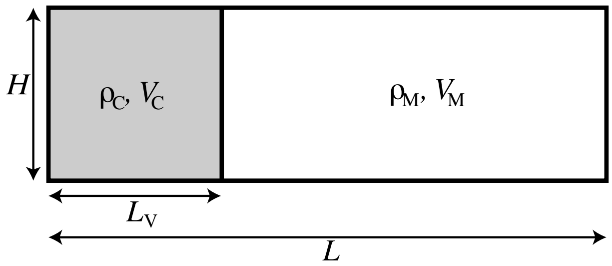
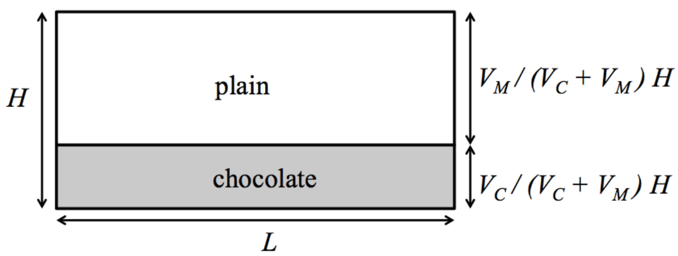


Figure 1: Tank containing chocolate milk and plain milk. View from side.

The partition is removed extremely quickly. **To begin with, it is assumed the chocolate milk does not mix with the plain milk.**

a) Draw a diagram of the contents of the tank a long time after the partition has been removed. Use the space provided on p. 2 of the Answer Booklet.

Solution:



Markers' Comments: For full credit, students needed to include labels and dimensions on their diagram. The dimensions can be obtained as the total volume of plain milk and of chocolate milk both remain constant. A very small layer of mixed milk between the chocolate milk and plain milk was accepted.

Upon removing the partition Niamh observes that the chocolate milk spreads through the tank like a wave. She constructs a basic model of the chocolate milk wave in order to find out how quickly it travels. She divides the chocolate milk behind the partition into two equal sections. When the partition is removed, the bottom section is displaced by the top section and begins to move with velocity U. This process is depicted in Figure 2.

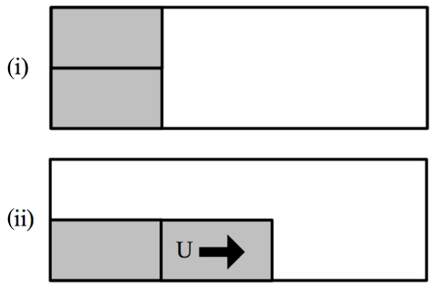
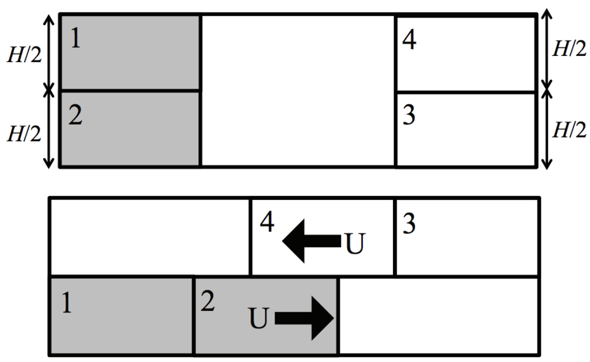


Figure 2: Niamh's model of the chocolate milk wave. (i) Before the partition is removed. (ii) after the partition is removed.

b) Find U.

Section 1 (top of choc milk) moves down and loses gravitational potential energy (GPE).
Section 2 (bottom of choc milk) moves across and gains kinetic energy.
Section 3 – plain milk of equal volume to section 2 = $V_C/2$ – is displaced upwards and gains gravitational potential energy.
Section 4 – plain milk of equal volume to section 2 = $V_C/2$ – is displaced in the opposite direction to section 2 and gains kinetic energy.



Statement of conservation of energy:

$$\text{GPE}_1 = \text{KE}_2 + \text{GPE}_3 + \text{KE}_4$$

Mass of section 1 = mass of section 2, $m_1 = m_2 = \rho_C V_C/2$
Mass of section 3 = mass of section 4, $m_3 = m_4 = \rho_M V_C/2$
The centre of section 1 moves down $H/2$, while the centre of section 3 moves up $H/2$.

$$\text{GPE}_1 = m_1 g \Delta h_1 = \rho_C \frac{V_C}{2} g \left(\frac{H}{2}\right)$$

$$\text{GPE}_3 = m_3 g \Delta h_2 = \rho_C \frac{V_M}{2} g \left(\frac{H}{2}\right)$$

Expression for kinetic energies of section 2 and section 4:

$$\text{KE}_2 = \frac{1}{2} m_2 U^2 = \frac{1}{4} \rho_C V_C U^2$$

$$\text{KE}_4 = \frac{1}{2} m_4 U^2 = \frac{1}{4} \rho_M V_C U^2$$

Putting it all together:

$$\rho_C \frac{V_C}{4} gH = \frac{1}{4} \rho_C V_C U^2 + \rho_M \frac{V_C}{4} gH + \frac{1}{4} \rho_M V_C U^2 \tag{1}$$

$$\rho_C gH - \rho_M gH = (\rho_C + \rho_M) U^2 \tag{2}$$

$$gH \frac{\rho_C - \rho_M}{\rho_C + \rho_M} = U^2 \tag{3}$$

$$\therefore U = \sqrt{gH \frac{\rho_C - \rho_M}{\rho_C + \rho_M}} \tag{4}$$

Markers' Comments:

As this model includes many effects those students who included some gravitational potential energy and some kinetic energy were given most of the available credit. Students were also given credit if they identified qualitatively that the movement of the plain milk would affect the chocolate milk wave.

Some students attempted to apply equations for motion under constant acceleration. However, these equations do not apply in this situation.

c) Two limitations of this model are that

- the chocolate milk and plain milk might mix, and
- the chocolate powder might not be completely dissolved in the chocolate milk.

Complete the table on p. 3 of the Answer Booklet by

(i) identifying any additional significant limitations of the wave model, and
(ii) briefly qualitatively discussing how each of the identified effects may affect the chocolate milk wave.

Solution:

- *Chocolate and plain milk might mix:* any mixing will dissipate the kinetic energy of the wave at a microscopic level. The velocity of the wave will be reduced. The wave will be less clearly defined.
- *Chocolate powder not completely dissolved:* any chocolate powder undissolved will settle at the bottom of the tank. If the settling speed is quite fast, then the chocolate milk powder will fall to the bottom of the milk behind the partition. When the partition is removed, milk behind the partition at the top will be less dense, and will not move as quickly to displace the bottom portion of chocolate milk. The wave will be slower and smaller. If the settling speed of the chocolate powder is not so fast, then as the wave moves along the bottom of the tank, the chocolate powder falls down out of the wave. This reduces the density difference between the fluids, and the wave will peter out.
- *Partition not raised instantaneously:* there will be a leading edge to the wave as there is more pressure on the chocolate milk at the bottom of the tank to begin with. The plain milk cannot move back towards the chocolate milk side straightaway, as in the block model.
- *Viscosity / friction / momentum transport:* the fluid on the bottom and sides of the tank (the boundary layer) is stationary. The "friction" between the wave and the sides of the tank will slow the wave down. The chocolate milk and plain milk will also exert forces on each other. The wave is not made up of two blocks!
- *Turbulence:* instabilities etc. on the edge of the wave will slow the wave down.
- *Finite tank:* there will be plain milk that needs to be "pushed" out of the way of the chocolate wave. The tank is of finite length, so the plain milk will push back off the tank edge.

Markers' Comments:

Students sometimes suggested limitations which were either not relevant or not significant. Some examples include evaporation of milk, bacteria growth or Niamh drinking the milk. Students were not required to use technical language in their answers, and successful answers often drew on personal experiences such as dissolving Milo and waves in a bath.

Question 12

Suggested Time: 25 min

Miriam the Magician likes to perform magic tricks and also studies physics. She has realised that many of her magic tricks work by appearing to break physical laws. For example, she can make it look like a large scarf appeared from nowhere.

a) Explain why claiming that the scarf appeared from nowhere is not physically reasonable.

Solution: It violates the law of conservation of matter.

Markers' Comments: The most common difficulty was students not identifying the physical principle used.

b) One place that Miriam can hide a scarf is in her hand. Estimate the largest volume of an object which Miriam could fit in a single closed hand.
Explain the calculations you used to make your estimate.

Solution: A sample calculation is as follows:

Inside a closed hand the largest space that can be made is a circular prism 2 cm in diameter and 8 cm long. Its volume is

$$\begin{aligned} V &= \pi r^2 l \\ &\approx \pi \times 1^2 \times 8\ \text{cm}^3 \\ &\approx 30\ \text{cm}^3 \\ &\approx 3 \times 10^{-5}\ \text{m}^3 \end{aligned}$$

Markers' Comments: A range of answers from around 5 cm^3 to 100 cm^3 was accepted.

Students much more commonly significantly overestimated inside-fist volume than underestimated it. Those students who described actually holding and measuring physical objects (pens, etc) always did well. Those who described visualised holding objects also generally did well.

Many explanations involved the shape used for the estimation but not how the values were estimated. Many answers had no explanation, which was a required part of the answer.

c) Miriam has a thin silk scarf which is 0.90 m long and 0.42 m wide. If she can hide this scarf in her closed hand, how thick is the material of the scarf?

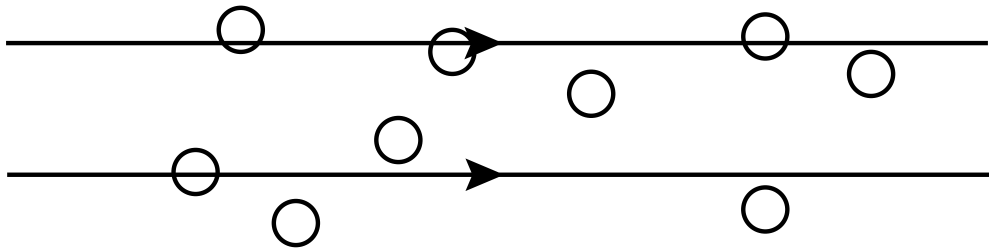
Solution: The scarf is a rectangular prism so $V = TLW$, where T is the thickness, and L and W are the length and width respectively. Hence,

$$\begin{aligned} T &= \frac{V}{LW} \\ &\approx \frac{3 \times 10^{-5}\ \text{m}^3}{0.90\ \text{m} \times 0.42\ \text{m}} \\ &\approx 8 \times 10^{-5}\ \text{m} \end{aligned}$$

Markers' Comments: The most common mistakes in this part were unit conversion mistakes which led to unreasonable answers. Despite the answers being unreasonable, very few students noticed this and corrected their work.

Some students overcomplicated the solution by attempting to model a folded or rolled scarf.

For some tricks Miriam uses mist, which is made of very many small water droplets, to hide larger objects. Miriam likes to use as little water as possible to make mist so she doesn't get her equipment wet. From her physics she knows that mist hides objects by scattering light, so that rather than passing straight through the light is reflected in random directions. The amount that light is scattered by a cloud of mist depends on the number of water droplets the light has to interact with to get through the cloud. This can be estimated by calculating the average number of droplets a light ray would pass through if it travelled on a straight path through a cloud of mist. In the diagram below the straight path near the top of the image passes through 3 droplets and the straight path lower down passes through only one droplet.



Miriam has a mist making machine which can be set to make water droplets of selected radius r. Miriam puts a volume of water V_w into the machine and fills a cube with side length a with mist.

d) (i) Identify two ways in which changing the droplet size would affect the amount that light scatters. Briefly justify your answer.

Solution:

- Larger droplet size means fewer droplets, which means less light scattered.
- A larger droplet is more likely to be intercepted by a light ray, meaning more light is scattered.

Markers' Comments: It was very common for students to not clearly describe the effects of changing r. One particularly common mistake was to use the words "change" and "increase" interchangeably. Some students also stated two effects which were exactly opposite, which is not stating two separate reasons.

Other common mistakes include:

- confusing scattering and reflection
- not understanding that the total water volume was constant
- not distinguishing between surface area and cross sectional area
- including effects which are not relevant, e.g. the curvature of droplet, the time the light takes to get through the droplet.

(ii) Find the number of mist droplets in the cloud.

Solution: The volume of water V_w makes N spherical water droplets, each with radius r. Hence,

$$V_w = N\frac{4}{3}\pi r^3$$

$$N = \frac{3V_w}{4\pi r^3}$$

Markers' Comments: The answer required is an expression, however, many students tried to use numbers from earlier parts of the question.

Students had difficulty calculating the volumes of the spheres, and sometimes gave answers that depended on the volume of the cube which does not affect the number of droplets in the cloud.

(iii) If there were only one droplet of this size in the cube, calculate the probability a light ray passing through the cube would hit it.

Solution: The probability of a ray intersecting with a droplet depends on the cross sectional area of the droplet, which is the area blocked by the droplet. Spherical droplets have is a circular cross section. The cross sectional area of the droplet is $A_d = \pi r^2$ and the cross sectional area of the cube is $A_c = a^2$. This means that the probability of the ray intersecting a droplet is

$$\begin{aligned} P &= \frac{A_d}{A_c} \\ &= \frac{\pi r^2}{a^2} \end{aligned}$$

Markers' Comments: Students found this part difficult, and many gave an answer by counting in the diagram.

(iv) For a cloud of mist to obscure all objects behind it a straight path through the mist must pass through an average of at least 7.5 droplets. If $r = 4.0 \times 10^{-6}$ m and $a = 1$ m, how much water does Miriam need to make the cloud of mist obscure all objects behind it.

Solution: For a light ray to travel through on average 7.5 droplets, the total cross sectional area of the droplets must be 7.5 times more than the cross sectional area of the cube. Hence,

$$\begin{aligned} N\pi r^2 &= 7.5a^2 \\ N &= \frac{7.5a^2}{\pi r^2} \end{aligned}$$

To form this many droplets, Miriam needs a volume of water

$$\begin{aligned} V &= N\frac{4}{3}\pi r^3 \\ &= \frac{7.5a^2}{\pi r^2}\frac{4}{3}\pi r^3 \\ &= 10a^2 r \\ &= 4 \times 10^{-5} \text{ m}^3 \\ &= 40 \text{ mL} \end{aligned}$$

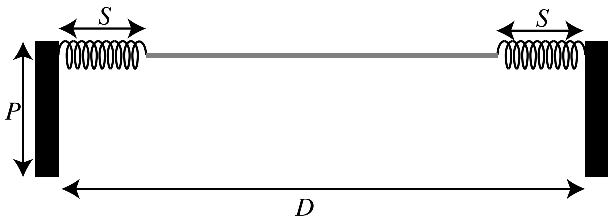
Markers' Comments: This part was better attempted than the previous two parts. It is pleasing to see students being willing to attempt all parts of a question.

There were many approximate answers and some application of formulas without students thinking about their applicability here.

Question 13

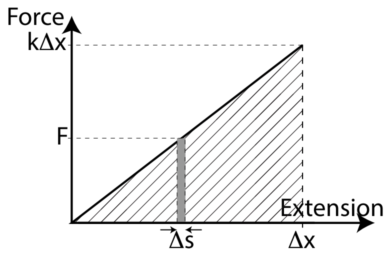
Suggested Time: 25 min

A simple, ideal, 2-dimensional model of a trampoline is shown below. Two poles of height P are fixed in the ground a distance D apart. A spring of length S is joined to each of the poles and the other ends of the springs are joined to a length of unstretchable material which is just long enough to fit between the springs. The springs and the material are assumed to have no mass.



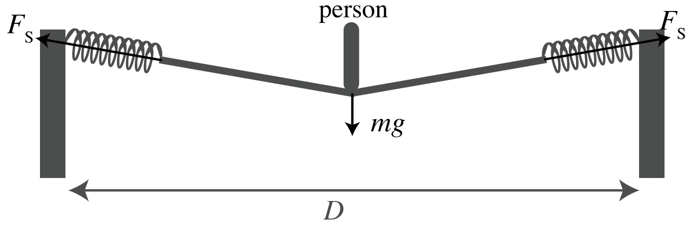
When a spring is stretched it will exert a restoring force. This force is proportional to the extension Δx of the spring, which is the extra length of the stretched spring, so $F_{\text{spring}} = -k\Delta x$.

The work done by a constant force F which moves an object a distance Δs is $W = F\Delta s$. As shown in the diagram to the right, the work done to stretch a spring by a short distance Δs is the area of the grey rectangle. Hence, the work done to stretch a spring to an extension of Δx is the area of the triangle filled with diagonal lines, $W_{\text{spring}} = \frac{1}{2}k(\Delta x)^2$.



a) On p. 6 of the Answer Booklet, sketch the shape of the springs and material, and the forces acting on the combined person and material system, if a person sits still on the centre of the trampoline.

Solution:



Markers' Comments:

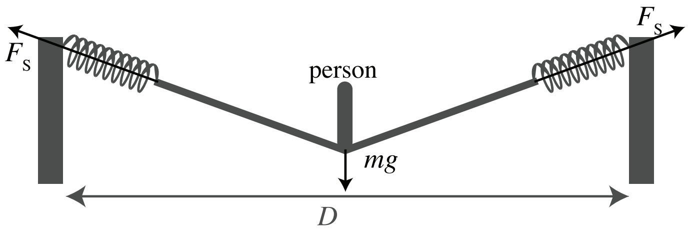
The shape of the trampoline was often drawn with curves, or with a straight section at the bottom. As we are treating the springs and material as having no mass they will form a straight line.

Students also needed to take care to draw the vectors so that it looks like the sum is zero.

The person begins jumping on the trampoline and then reaches a state where the ideal trampoline is bouncing them up into the air to a height H every bounce.

b) On p. 6 of the Answer Booklet, sketch the shape of the springs and material, and the forces acting on the combined person and material system, when the person is at the lowest point of the bounce on the trampoline. Justify the differences and similarities between sketches for parts (a) and (b).

Solution:



Similarities:

- trampoline surface makes straight lines from person to springs
- forces due to springs are along the trampoline surface
- gravitational force on person is the same
- the sum of the two spring forces is vertically upwards

Differences:
At the bottom of the bounce

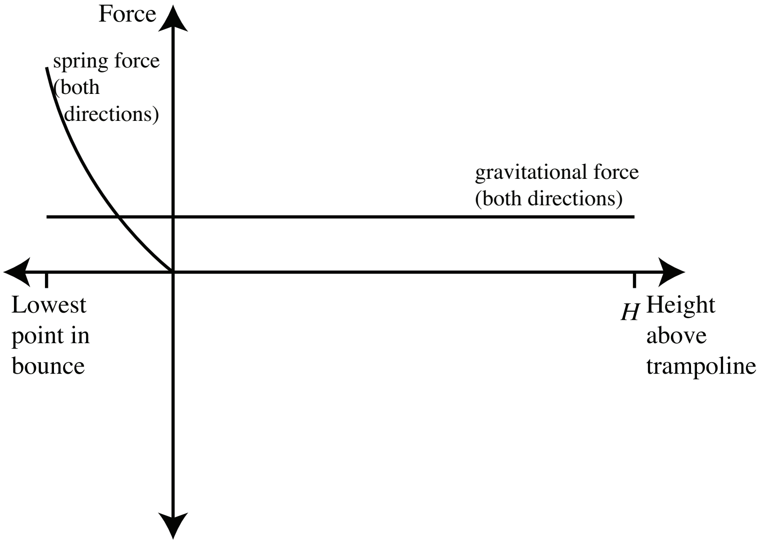
- the springs are more stretched,
- so there is a greater force exerted by the springs,
- the angle to the horizontal of the lines of the trampoline surface is larger, and
- the sum of the two spring forces is larger than the gravitational force.

Markers' Comments:

Most students gave answers which were consistent with the previous part. However, it was a common mistake to change the magnitude of the gravitational force, or to include forces which do not act on the system.

c) On the axes on p. 7 of the Answer Booklet, sketch the magnitude of each force as a function of height above the surface of the unstretched trampoline for one bounce up and down. Clearly label each curve, including the direction of motion.

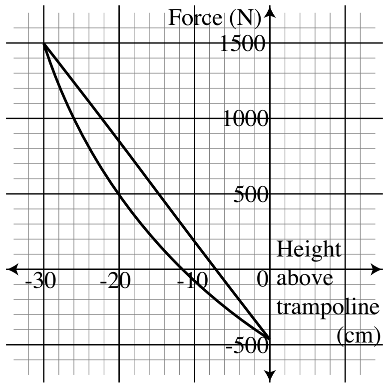
Solution:



Markers' Comments:

The common mistakes in this part were similar to those in previous parts.

A real trampoline is 3-dimensional and its springs and material are not ideal. The graph to the right shows the net force upwards on a person versus height for the part of one bounce where the person is touching the trampoline.



d) (i) Find the mass of the person on the trampoline.

Solution:

When the person is at zero height above the trampoline there is no force from the trampoline. This means that the total force is the gravitational force. Hence, the y-intercept is mg. From the graph, the y-intercept is -450 N, hence,

$$m = \frac{-450\ \text{N}}{g} = \frac{-450\ \text{N}}{9.8\ \text{m}\,\text{s}^{-2}} = 46\ \text{kg} \quad .$$

Markers' Comments:

Many students chose the wrong point from the graph.

(ii) On the graph on p. 7 of the Answer Booklet, label the two curves “moving down” and “moving up”. Justify your answer.

Solution:

There is a larger force upward when moving down than up, as then the kinetic energy will be lower after the bounce. This means that the top curve is moving down.

Markers’ Comments:

Few students justified their answer.

(iii) Estimate the area between the two curves.

Solution:

By counting there are 34 squares enclosed. The area is $34 \times 100\ \mathrm{N} \times 0.02\ \mathrm{m} = 78\ \mathrm{J}$.

Markers’ Comments:

Attempts to integrate to find the area were generally not successful.

Students had difficulty with the units for the area.

(iv) Explain the physical meaning of this area.

Solution:

This is the energy lost in one bounce.

Markers’ Comments:

Many students had difficulty with this question. This many be in part due to many students not identifying the units of the area correctly.

Question 14

Suggested Time: 30 min

The freezing and melting of rivers is a seasonal process throughout much of the world and plays a central role in the lives of the people nearby. The town of Thermos is situated on the River Kelvin. The river is clean and can be assumed to be water.

To freeze or melt, each kilogram of water must lose or gain an amount of energy known as the *latent heat of fusion*. This process takes place at the melting point of water. The specific heat capacity of a substance is the amount of energy required to raise the temperature of 1 kg of the substance by 1 kelvin. Some important values are given in the table at the end of this question.

a) The town of Thermos is 10 km long, and the townspeople are interested in the stretch of the River Kelvin next to their town. It is known that it freezes to a depth of 2.3 m each winter, and is 201 m wide as it runs past Thermos. At the start of the thawing season, the frozen part of the river is at an average of -15 degrees Celsius.

Calculate how much energy it takes to melt the ice in the 10 km stretch of the River Kelvin near the town of Thermos.

Solution:

To melt the river it must be heated to 0°C and then melted. The volume of ice on the river is $V = 4.6 \times 10^6$ m^3. This requires energy

$$\begin{aligned} Q &= m_i c_i \Delta T + m_i L \\ &= m_i (c_i \Delta T + L) \\ &= V\rho_i (c_i \Delta T + L) \\ &= 2.3 \times 201 \times 10^4\ \mathrm{m^3} \times 917\ \mathrm{kg\,m^{-3}} \left(2.11 \times 10^3\ \mathrm{J\,kg^{-1}\,K^{-1}} \times 15\ \mathrm{K} + 333 \times 10^3\ \mathrm{J\,kg^{-1}}\right) \\ &= 1.55 \times 10^{15}\ \mathrm{J} \end{aligned}$$

Markers' Comments: Students had difficulties in remembering all the terms in the expression and had some difficulties with unit conversions. Students often included the energy to either melt or heat the ice but not both, or used the specific heat capacity of water instead of ice.

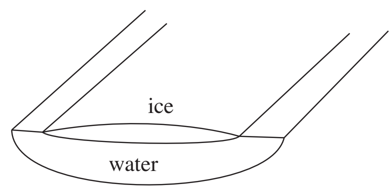
b) Using the information in the table, describe and explain the shape of the ice and water in the river during the ice melting process. Draw a diagram in the box on p. 8 of the Answer Booklet and use it in your explanation.

Solutions:

The ice floats on the water so it remains at the top of the river.

As the dirt on the river bank has a lower specific heat capacity than the ice or water it will get warmer in the Sun. Hence, it can get above 0°C which means that the ice will melt faster near the edges. Also, the dark dirt will absorb more sunlight, heating further.

The ice will also melt from underneath and from above, but not as rapidly as at the edges.



Markers' Comments: Many students did not realise that there was water under the ice, and also did not use the data provided at the end of the question to observe that the riverbank dirt would play an important role.

c) Use the supplied data to estimate the time it would take for the ice to melt if it is only heated by sunlight.

Solution:

Solar intensity is $I_s = 800\ \mathrm{W\,m^{-2}}$ in Thermos.

We assume that there is sunlight for 10 hours per day at the time of thawing, so the heat per day is

$$Q_d = 800\ \mathrm{W\,m^{-2}} \times 10\ \text{hours} \times 3600\ \mathrm{s/hour} = 2.9 \times 10^7\ \mathrm{J\,m^{-1}\,day^{-1}}$$

The total heat required is Q, so $Q = Q_d A t$, and hence,

$$\begin{aligned} t &= \frac{Q}{Q_d A} \\ &= \frac{1.55 \times 10^{15}\ \mathrm{J}}{2.9 \times 10^7\ \mathrm{J\,m^{-1}\,day^{-1}} \times 1.0 \times 10^4\ \mathrm{m} \times 201\ \mathrm{m}} \\ &= 22\ \text{days} \end{aligned}$$

Markers' Comments:

This part was generally well attempted. However, many students assumed that the Sun was shining 24 hours a day in Thermos.

This part is independent of the previous parts - give it a go even if you haven't tried the others!

d) Design an experiment that could be reasonably conducted at a school to test how long it would take to melt a frozen river. In the spaces on p. 8 and p. 9 of the Answer Booklet, state

(i) your method, the materials you would use and how you would make measurements,

Markers' Comments: No detailed solution is given for this part as there are many possible answers. The best answers described constructing a physical scale model of the river, with its bank, flowing water and ice, placing it in a temperature controlled environment and also having a controllable light source to model the Sun. The best answers also included details of how the process of melting ice was monitored and measured, and a range of other measurements.

Good answers included a diagram.

One point some of the very best answers considered was that it might be worth modelling a shorter section of river so that the thickness and width of the ice sheet could be more reasonable while still to scale.

Weaker answers mostly involved melting an approximately cubic chunk of ice.

(ii) four potential sources of uncertainty you see in your method and how you would go about minimising them, and

Markers' Comments:

In this part answers depended on the method described in the previous part, so once again no detailed solution is given.

Some commonly identified sources of uncertainty include:

- uneven illumination of the ice
- daily temperature variation not being modelled
- water under the ice being at a different temperature, and/or the flow of this water

- differences between riverbank in model and the dirt around a real river
- choice of size of the scale model
- precision/accuracy in measurements, especially of time to melt if only checking periodically.

Good descriptions of minimising uncertainty were very varied, but all clearly explained how aspects of the method or a proposed change to it would improve the model.
Many students found it difficult to identify how to reduce an effect, and instead described a change to the method which made the model less realistic.
Note that human error was not accepted as it does not identify the source of uncertainty specifically.

(iii) how the results from your experiment could be used to make a prediction for the full size River Kelvin.

Be concise - explain your thinking but feel free to use dot points. Please don't write an essay.

Markers' Comments:

Again, answer for this part depend on previous parts, so no detailed solution is given.

Good answers consider the variables which may affect the time to melt the ice, how these compare to the River Thermos and how they might scale the melting time. These were mostly expressed using proportionalities and/or equations.

Students generally gave very little detail in this part.

Data table:

Quantity	Symbol	Value
Density of water	ρ_w	$1000\ \mathrm{kg\,m^{-3}}$
Density of ice	ρ_i	$917\ \mathrm{kg\,m^{-3}}$
Latent heat of fusion of water/ice	L	$333\ \mathrm{kJ\,kg^{-1}}$
Specific heat capacity of ice	c_i	$2.11\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$
Specific heat capacity of water	c_w	$4.18\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$
Specific heat capacity of river bank dirt in Thermos	c_d	$1.1\ \mathrm{kJ\,kg^{-1}\,K^{-1}}$
Melting point of water	T_m	$273\ \mathrm{K} = 0\,^\circ\mathrm{C}$
Average daily temperature in Thermos	T_T	$278\ \mathrm{K} = 5\,^\circ\mathrm{C}$
Solar intensity in Thermos	I_S	$800\ \mathrm{W\,m^{-2}}$

Integrity of Competition

If there is evidence of collusion or other academic dishonesty, students will be disqualified. Markers' decisions are final.