AUSTRALIAN SCIENCE INNOVATIONS

Australian Science Olympiads

PHYSICS

2017 Australian Science Olympiad Exam

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.
- Some parts of questions in Section B do not rely on earlier parts. Attempt later parts of questions even if earlier parts are incomplete.
- **Do not write on this question paper. It will not be marked.**
- Do **not** staple the multiple choice answer 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.

SUGGESTED TIMES

Section A	10 multiple choice questions	20 minutes
Section B	4 written answer questions	100 minutes
		120 minutes

SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

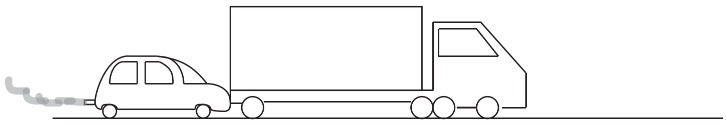
Question 1

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.

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.

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.

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

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.

Question 6

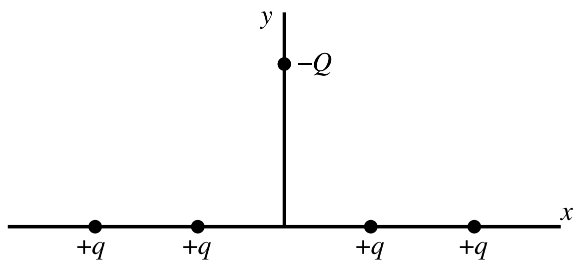
If a string of linear mass density μ (measured in $\mathrm{kg\,m^{-1}}$) is placed under a tension T (a force, measured in newtons, N), then the fundamental oscillation frequency f (measured in hertz, Hz, equivalent to cycles per second) is related to the length L of the fundamental oscillation mode 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 $x = 0$.

Question 7

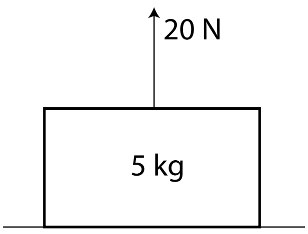
Four particles, each of charge $+q$, are arranged symmetrically on the x-axis about the origin as shown. A fifth particle of charge $-Q$ is placed on the positive y-axis as shown. What is the direction of the net electrostatic force on the fifth particle?

a. $\uparrow$
b. $\rightarrow$
c. $\downarrow$
d. $\leftarrow$
e. The net electrostatic force on the particle of charge $-Q$ is zero.



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

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

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.

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.

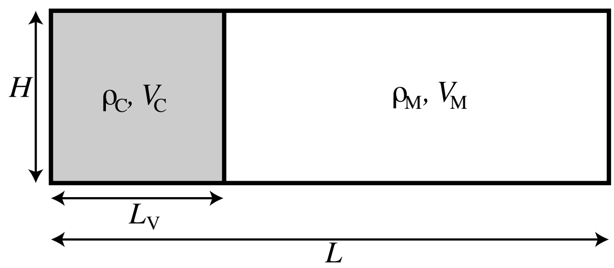


Figure 1: Tank containing chocolate milk and plain milk. View from side.

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.

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.

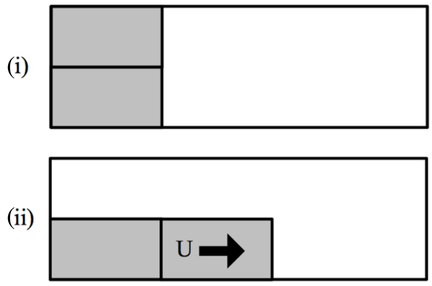


Figure 2: Niamh's model of the chocolate milk wave. (i) Before the partition is removed. (ii) after the partition is removed.

b) Find U.

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.

Question 12

Suggested Time: 25 min

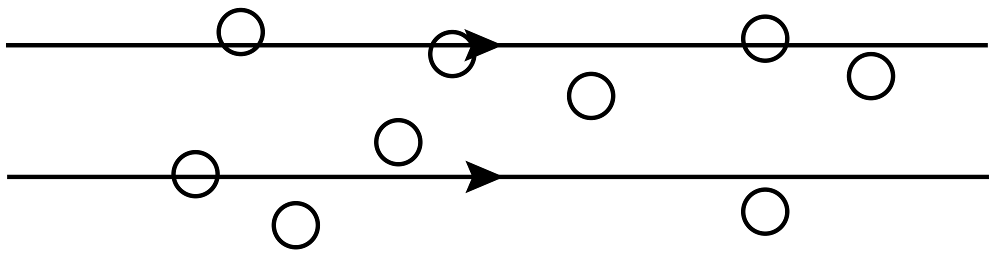
Miriam the Magician likes to perform magic tricks and also studies physics. She has realised that many of her magic tricks work by appearing to break physical laws. For example, she can make it look like a large scarf appeared from nowhere.

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

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.

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?

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.

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

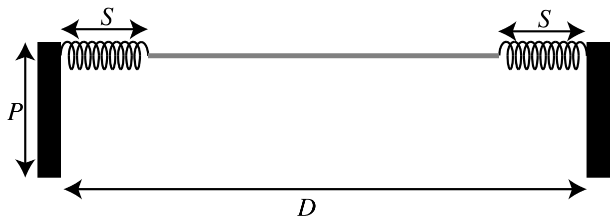
(iii) If there were only one droplet of this size in the cube, calculate the probability a light ray passing through the cube would hit it.

(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.

Question 13

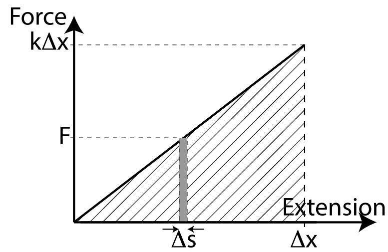
Suggested Time: 25 min

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, $W_{\text{spring}} = \frac{1}{2}k(\Delta x)^2$.



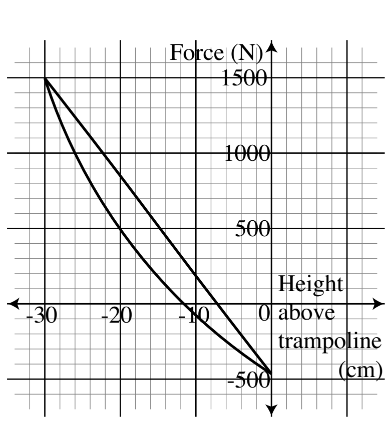
a) On p. 6 of the Answer Booklet, sketch the shape of the springs and material, and the forces acting on the combined person and material system, if a person sits still on the centre of the trampoline.

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).

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.

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.

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

(iii) Estimate the area between the two curves.

(iv) Explain the physical meaning of this area.

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.

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.

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

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,

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

   (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.

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.