PHYSICS

2016 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.
- **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.

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

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

Question 1
Why does a raindrop fall with near-constant speed during the later stages of its descent?

a. The gravitational force is constant.

b. Air resistance just balances the force of gravity.

c. The height from which the raindrop started falling is fixed in space.

d. The force of gravity is negligible for objects as small as a raindrop.

e. Gravity cannot increase the speed of a falling object to more than $9.8\ \mathrm{m\,s^{-1}}$.

Question 2
The Moon orbits the Earth. What is the Newton's Third Law reaction force to the gravitational force of the Earth on the Moon?

a. The gravitational force of the Earth on the Moon

b. The normal force of the Earth on the Moon

c. The normal force of the Moon on the Earth

d. The gravitational force of the Moon on the Earth

e. The friction force acting on the Moon

Question 3
"Slice" is the name given to the angular deviation from the straight-through direction that a golfer produces when they hit a golf ball off the tee. David derives the following formula for his slice:

$$\phi = \frac{(1-P)}{(H-L)\sin\theta} \quad .$$

In this formula, David's slice, ϕ, depends on three positive values (P, H and L) that are all less than one, with $H > L$, and an angle θ (measured in degrees) that can range between 0° and 180°.
Which of the following options will minimise David's slice?

a. Make P as small as possible, keeping the other variables constant.

b. Make H as small as possible, keeping the other variables constant.

c. Make L as small as possible, keeping the other variables constant.

d. Make θ as small as possible, keeping the other variables constant.

e. None of the above will help David minimise his slice.

Question 4

A glass-walled elevator is moving upwards with constant acceleration. At some point in the elevator's motion, a bolt breaks loose and drops from the ceiling. What is the motion of the bolt as seen by an **external** observer (i.e. one located outside the elevator)?

a. The bolt moves upwards at a constant speed.

b. The bold initially moves upwards, then slows, reverses direction and moves downwards.

c. The bolt appears to remain stationary.

d. The bolt immediately moves downwards, accelerating as it goes.

e. The bolt immediately moves downwards, at constant speed.

Question 5

The Earth and the Moon both exert gravitational forces on objects in their vicinity. Imagine a line joining the Earth to the Moon, and extending to either side, as shown below (not to scale). Consider placing an object along this line. Where along this line is the net gravitational force on the object due to the Earth and the Moon equal to zero?

a. On the far side of the Earth from the Moon.

b. Between the Earth and the Moon, but closer to the Earth than to the Moon.

c. Halfway between the Earth and the Moon.

d. Between the Earth and the Moon, but closer to the Moon than to the Earth.

e. Nowhere along the line.

Question 6

The electrostatic force F_e that an object of charge Q exerts on another object of charge q is given by Coulomb's law:

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2} \quad ,$$

where the charges of the two objects, Q and q, are measured in units of coulombs (C), and r is the distance separating the two objects.
What are the units of the constant ε_0?

a. $kg.m^3.s^{-2}.C^2$

b. $kg.m^{-3}.s^2.C^{-2}$

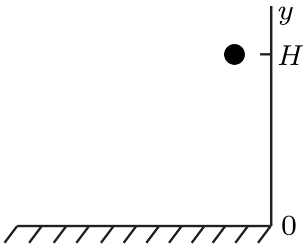
c. $kg.m.s^2.C^{-2}$

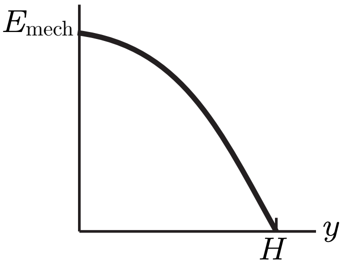
d. $s^2.C^2.kg^{-1}.m^{-3}$

e. $s^2.C^2.kg^{-1}.m^{-1}$

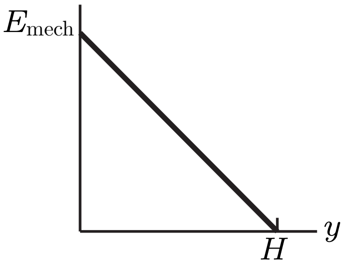
Question 7

A ball is held at a height H above a floor, as sketched in the diagram on the right. It is then released and falls to the floor. If air resistance can be ignored, which of the five graphs below (labelled a. to e. beneath each graph) correctly gives the mechanical energy E_{mech} of the Earth-ball system as a function of the altitude y of the ball?

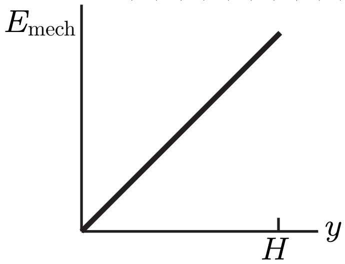




a.



b.



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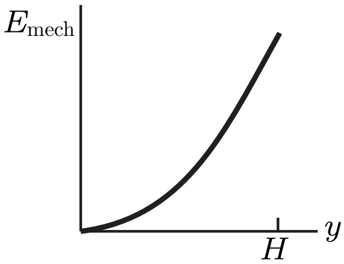

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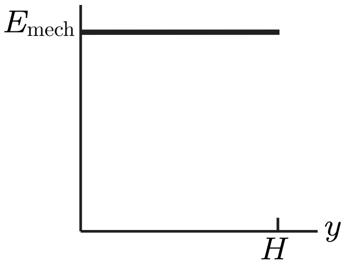


e.

Question 8

Some students are doing an experiment to calculate the spring constant of a particular spring. As part of this experiment, they suspend an object from the spring, pull it downwards, and let it go. The object then oscillates up and down, with a period of about 2 seconds. The students use a stopwatch to measure the period of oscillation. The best way to get an accurate and precise measurement of the period would be to:

a. measure the time taken for a single oscillation 10 times, and average the results.

b. measure the time taken for 10 oscillations, and divide by 10.

c. measure the time taken for a single oscillation 10 times, and average the results. Repeat this measurement three times, and average the results.

d. measure the time taken for 10 oscillations, and divide by 10. Repeat this measurement three times, and average the results.

e. All of the methods above are equivalent, and will result in the same precision in the measurement of the period of oscillation.

Question 9

A roller-coaster car is full of water, and is moving at constant velocity along a frictionless horizontal track. Someone removes a plug in the bottom of the floor, allowing the water to drain out. Ignoring air resistance, as the water drains out the car will:

a. slow down.

b. continue to move at constant velocity.

c. speed up.

d. initially slow down, then speed up.

e. initially speed up, then slow down.

Question 10

The velocity of a particle moving along the x-axis changes from v_i to v_f. For which of these values of v_i and v_f does the particle's kinetic energy increase the most?

a. $v_i = 5\ \mathrm{m\,s^{-1}}$, $v_f = 2\ \mathrm{m\,s^{-1}}$

b. $v_i = 5\ \mathrm{m\,s^{-1}}$, $v_f = -2\ \mathrm{m\,s^{-1}}$

c. $v_i = -5\ \mathrm{m\,s^{-1}}$, $v_f = -2\ \mathrm{m\,s^{-1}}$

d. $v_i = -5\ \mathrm{m\,s^{-1}}$, $v_f = 2\ \mathrm{m\,s^{-1}}$

e. $v_i = 2\ \mathrm{m\,s^{-1}}$, $v_f = -5\ \mathrm{m\,s^{-1}}$

SECTION B: WRITTEN ANSWER QUESTIONS
USE THE ANSWER BOOKLET PROVIDED

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: 25 min

The following parts of this question are unrelated and so may be completed in any order. Note that the data provided on the next page may be used for any part, as required. You must explain your reasoning for each part.

a) Calculate the amount of energy per gram of fat.

b) The typical office computer is only used one third of the time during business hours. Today a typical office computer consumes around 130 W of power.
Estimate the cost savings and reduction in greenhouse gas emissions over one year if everyone in an office of 60 people turns off their computers when they are not using them instead of leaving them on at all times, even over the weekend.

c) Estimate the energy efficiency of the conversion of sunlight into sugarcane.

d) "Kilogram per kilogram humans produce more heat than the Sun." Is this claim true?

Typical Australian Adult:

Typical adult mass	65 kg
Typical adult height	1.7 m

Dietary Guidelines:

Recommended energy intake	8700 kJ/day
Recommended daily intake of fat	30% of energy (70 g/day)
Recommended daily intake of carbohydrates (sugars, flour, etc.)	45–65% of energy (230–310 g/day)

Electricity Data:

Typical price	15 c/kWh
Typical greenhouse emissions	0.87 kg(CO_2 equiv.)/kWh

Note: 1 kWh = 1 kilowatt hour

Australian Sugar Cane Data:

Average yield of sugar cane	$9.2\ \mathrm{kg/m^2}$
Typical sugar content	15%
Typical bagasse content	30%
Typical water content	55%
Typical energy content of bagasse	19.2 MJ/kg

Note: bagasse is the by-product of crushing sugar cane to extract sugar and is often used as a fuel.

Solar System Data

Earth-Sun distance	1.5×10^{11} m
Radius of Sun	7.0×10^{5} km
Mass of Sun	2.0×10^{30} kg
Radius of Earth	6.4×10^{3} km
Mass of Earth	6.0×10^{24} kg
Typical intensity of sunlight at Earth	$1366\ \mathrm{W/m^2}$

Question 12

Suggested Time: 25 min

Angus the accountant decides to change careers and starts a bicycle building business. To make his bicycles stand out he builds them with square wheels, making sure that both wheels can sit with a side flat on the ground at the same time.

Angus rides his first bicycle proudly out of his shed turning his pedals at a constant rate.

a) (i) Sketch the trajectory of the centre of the front wheel in the space on p. 4 of the answer booklet.

(ii) On the same diagram sketch the trajectory of the centre of mass of the bicycle. In the space below the diagram explain how the trajectory of the centre of mass is related to the trajectory of the centre of the front wheel and why this is so.

(iii) For each wheel label the point about which it is rotating.

(iv) Label the points on the trajectory where the centre of mass of the bicycle is moving forward fastest. Explain your reasoning in the space provided below the diagram.

b) Calculate the ratio of the length of the path followed by the centre of mass to the distance travelled along the road.

Angus generously gives Sam one of his square wheeled bicycles for her birthday. Sam is very lazy and teaches herself to ride the bicycle so that she is only just pedalling hard enough to replace energy lost from the bike. The bike then has constant energy.

c) Describe the differences and similarities between the motion of the bicycle when Sam rides compared to when Angus rides.

After watching Sam ride the bicycle Angus realises the error of his ways, and decides to construct a racetrack specifically for his square bicycles.

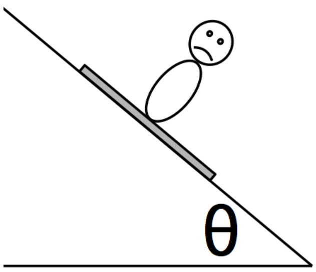
d) Draw a side view of the racetrack's surface shape to ensure the smoothest ride on one of the square wheeled bicycles.

Question 13

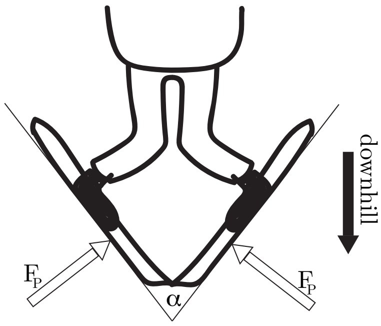
Suggested Time: 25 min

Having missed the boat for Rio 2016, Emily and Joshua are determined to qualify instead for the Winter Olympics in 2018, to be held in PyeongChang, South Korea.

Emily, being a novice skier, is sliding down a slope and desperately trying to slow down using a 'snowplough' stop. The ski slope makes an angle θ with the horizontal. By digging the inside edges of her skis into the snow while keeping them in a V-shape, Emily can stop completely. The forces due to this ploughing motion act on each ski perpendicular to the ski and along the slope. Each of these forces has magnitude F_P. Emily has a mass m.



Emily skiing down a slope.



Snowplough stop

a) (i) Which direction will the total force due to the ploughing motion be in?

(ii) Explain why the magnitude of the total force due to the ploughing motion is $2F_P \sin\frac{\alpha}{2}$ when the angle between Emily's skis is α.

b) Draw all the forces as vectors acting on Emily as she ploughs downhill on the diagram on p. 6 of the answer booklet. Include the combined effect of the ploughing forces as a single vector.

c) At what angle α between the skis will Emily continue down the hill at a constant speed?

Joshua thinks he might have a go at the slalom event so has been practising sharp turns.

d) Joshua is skiing down the slope with his skis pointing downhill and suddenly turns his skis so that they are pointing across the slope.

(i) Sketch a diagram showing Joshua's path once he has turned his skis on the diagram on p. 7 of the answer booklet.

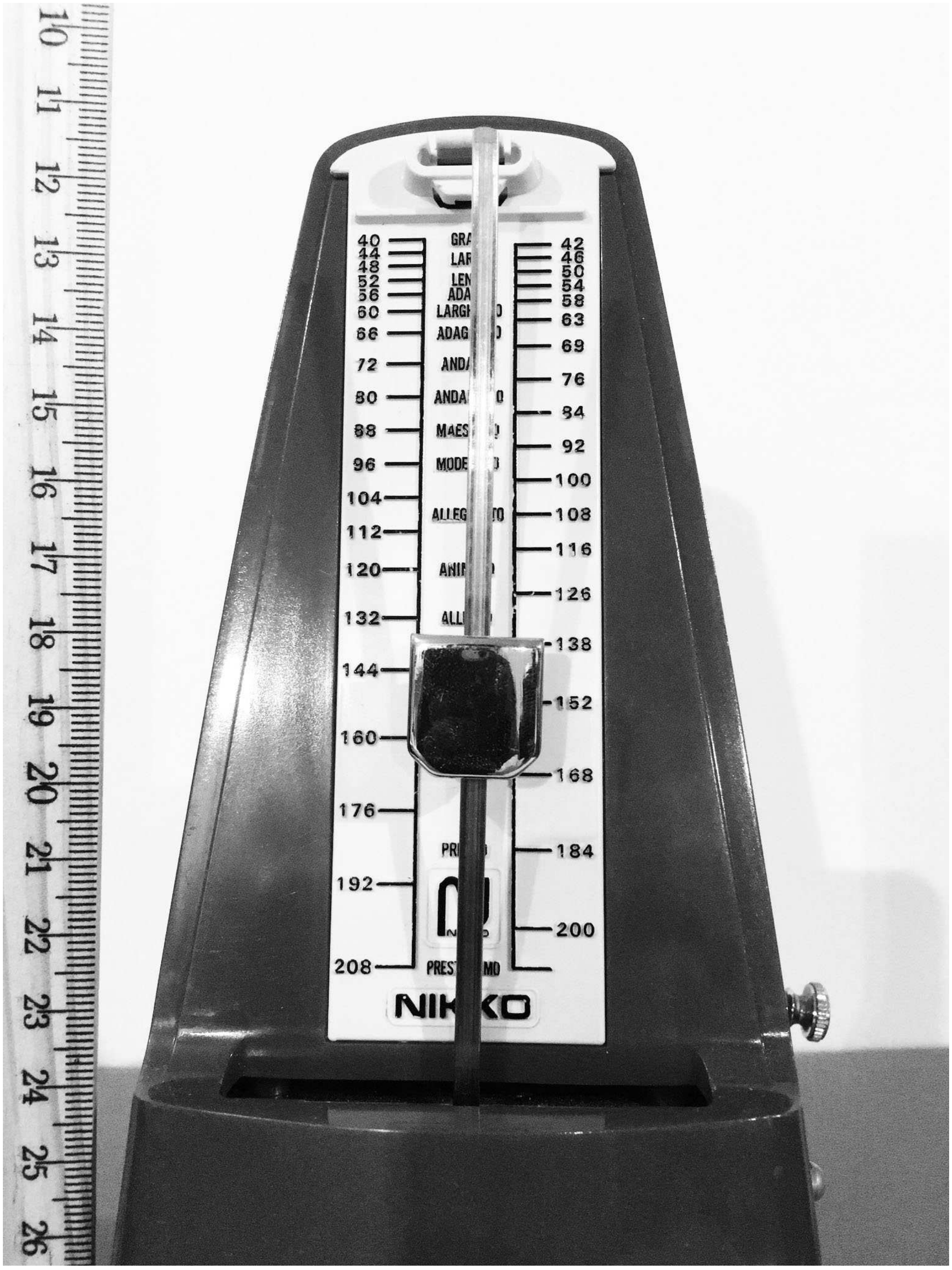
(ii) Briefly explain your reasoning. Note: another diagram might help your explanation.

e) Joshua decides to practice a different turn. He skis down the same hill and then suddenly turns his skis by 45° and then keeps them pointing in the same direction. Draw a diagram of his path on p. 7 of the answer booklet. Please point out any important features of the path.

Question 14

Suggested Time: 25 min

Metronomes are tools sometimes used by musicians to help make their tempo more consistent when playing a piece of music. The tempo is the number of beats per minute. The metronome pictured below is set to 138 beats per minute. When the vertical arm swings back and forth it produces clicks at either end of the swing. The tempo is changed by sliding the weight up or down the metal arm until the top of the weight aligns with the marking for the desired tempo.



a) Explain how you could use the image above to determine *y*, which is the distance from the top of the vertical arm to the top of the sliding weight, for any given tempo setting of the metronome.

b) Use this method to complete the table of tempos and distances *y* on p. 8 of the answer booklet.

c) A graph of *y* versus tempo has been plotted on p. 9 of the answer booklet. However, one or two of the points are not plotted correctly.

(i) Complete the graph by adding any necessary labels and markings.

(ii) Correct any points which have not been correctly plotted.

(iii) Draw a line of best fit to the data.

d) Calculate the slope of the graph and explain what information this gives about the metronome.

e) What is the lowest tempo to which the metronome could be set? Explain your reasoning.

f) The graphed data points do not lie exactly on the line of best fit. Suggest the most likely reason(s) why this may be so and give a detailed but concise explanation of the reasons for your suggestions in the allocated space on p. 9 of the answer booklet.

Integrity of Competition

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