AUSTRALIAN SCIENCE INNOVATIONS

PHYSICS

2012 Australian Science Olympiad 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 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
	Total marks for the paper	**60 marks**

SECTION A: MULTIPLE CHOICE
USE THE ANSWER SHEET PROVIDED

Question 1
Maddie throws her phone straight up. Consider the motion of the phone only after it has left Maddie's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the phone is (are):

a. a downward force of gravity along with a steadily decreasing upward force.
b. a steadily decreasing upward force from the moment it leaves Maddie's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the phone gets closer to the earth.
c. an almost constant downward force of gravity along with an upward force that steadily decreases until the phone reaches its highest point; on the way down there is only a constant downward force of gravity.
d. an almost constant downward force of gravity only.
e. none of the above. The phone falls back to the ground because of its natural tendency to rest on the surface of the earth.

Solution: d. — The only force acting on the phone is gravity.

Question 2
A wheelie bin by the side of the road is struck by an unobservant Hummer driver. The Hummer has a substantially greater mass than the wheelie bin and is moving rapidly because the driver wants to spend as much money on petrol as possible. During the collision:

a. the Hummer exerts a greater amount of force on the wheelie bin than the wheelie bin exerts on the Hummer.
b. the wheelie bin exerts a greater amount of force on the Hummer than the Hummer exerts on the wheelie bin.
c. neither exerts a force on the other, the wheelie bin is crushed simply because the driver runs it over with the Hummer.
d. the Hummer exerts a force on the wheelie bin but the wheelie bin does not exert a force on the Hummer.
e. the Hummer exerts the same amount of force on the wheelie bin as the wheelie bin exerts on the Hummer.

Solution: e. — The two forces are an action-reaction pair.

Question 3

Lachlan exerts a constant horizontal force on a heavy lounge chair that is in the wrong place. As a result, the chair moves across a horizontal floor at a constant speed v_0. The constant horizontal force applied by Lachlan:

a. has the same magnitude as the weight of the chair.

b. is greater than the weight of the chair.

c. has the same magnitude as the total force which resists the motion of the chair.

d. is greater than the total force which resists the motion of the chair.

e. is greater than either the weight of the chair or the total force which resists its motion.

Solution: c. — As the chair moves at a constant speed the nett force on the chair is zero and the force applied by Lachlan must be equal in magnitude to the resistive force.

Question 4

If Lachlan, in the previous question, doubles the constant horizontal force that he exerts on the chair to push it on the same horizontal floor, the chair then moves:

a. with a constant speed that is double the speed v_0 in the previous question.

b. with a constant speed that is greater than the speed v_0 in the previous question, but not necessarily twice as great.

c. for a while with a speed that is constant and greater than the speed v_0 in the previous question, then with a speed that increases thereafter.

d. for a while with an increasing speed, then with a constant speed thereafter.

e. with a continuously increasing speed.

Solution: e. — In this case there is a nett force acting forwards on the chair so the chair accelerates continuously.

Question 5

Colin claims to have built a refrigerator alternative which works without any power supply. It is a box with a wet blanket over it; the blanket is kept wet as a tap is allowed to drip onto its corner. How does it work?

a. It takes energy to make water evaporate and that energy comes from thermal energy in the blanket and surrounds, so the blanket and also the box stay cold.

b. The water from the tap is cold, so it keeps the box cold. If he used room temperature water it wouldn't work.

c. The drips from the tap can provide enough power to generate electricity to run a refrigerator. The blanket is just hiding the electric part.

d. Colin makes the box cold using a real fridge first and then puts the wet blanket over it, completely insulating the box so it can never warm up.

e. It doesn't, Colin is trying to scam people.

Solution: a. — When water undergoes a change of phase from a liquid to a gas to takes some energy which flows as heat from the surroundings. This means that it does work, even if the water not cold, so options b. and e. are incorrect. Option d. is not possible because there is no way to perfectly insulate anything. Option b. is not plausible because refrigerators take a lot of power to run and all the kinetic energy of the drips from a slowly dripping tap will not be enough to run one. Before refrigerators were common in Australia people did store meat in well ventilated boxes covered with wet cloth.

Question 6

Twins Anna and Tom measure each other's heights each birthday. When they were 12 Anna's height was measured as 151.5 cm and Tom's was measured as 151 cm. On their 16th birthday Anna's height is measured as 167.5 cm and Tom's is measured as 168.5 cm. The uncertainty in the height measurements is 5 mm. Between the ages of 12 and 16 Anna grew:

a. 16 cm $\pm$ 5 cm.

b. 16 cm $\pm$ 1 cm.

c. 16 cm $\pm$ 0.5 cm.

d. 16.0 cm $\pm$ 0.5 cm.

e. 16.0 cm $\pm$ 0.25 cm.

Solution: b. — The uncertainty of 5 mm in each measurement must be added to find the uncertainty in Anna's height increase.

Question 7

Twins Anna and Tom measure each other's heights each birthday. When they were 12 Anna's height was measured as 151.5 cm and Tom's was measured as 151 cm. On their 16th birthday Anna's height is measured as 167.5 cm and Tom's is measured as 168.5 cm. The uncertainty in the height measurements is 5 mm. Anna and Tom have always been very competitive about their heights, so Tom crows with glee after being measured, saying "Finally, I'm taller than you! We were always about the same height, but now I'm taller than you!" Anna responds, "You're crazy! I was *clearly* taller than you when we were 12." Which of the following statements is most correct?

a. Tom is probably right and Anna is wrong, they were about the same height at 12, with a difference of 0.5 cm $\pm$ 1.0 cm. Now the measurements show the difference to be 1.0 cm $\pm$ 1.0 cm, more accurate measurements would resolve the dispute over who is taller now.

b. Tom is probably right and Anna is wrong, they were about the same height at 12, with a difference of 0.5 cm $\pm$ 1.0 cm. Now the measurements show the difference to be 1.0 cm $\pm$ 1.0 cm, however, taking more measurements, regardless of how accurate, couldn't help resolve the dispute over who is taller now.

c. Tom is right and Anna is wrong, they were about the same height at 12, with a difference of 0.5 cm $\pm$ 0.5 cm. Now Tom is taller by 1.0 cm $\pm$ 0.5 cm.

d. Anna is right and Tom is wrong, Anna was taller at 12, with a difference of 0.5 cm $\pm$ 0.5 cm. Now Tom is taller by 1.0 cm $\pm$ 0.5 cm.

e. Anna is right and Tom is wrong, she was 0.5 cm taller than Tom when they were 12. Tom is now 1.0 cm taller than Anna.

Solutions: a. — At 12 the difference between their heights was 0.5 cm $\pm$ 1.0 cm, so Anna is wrong. At 16 the difference between their heights was 1.0 cm $\pm$ 1.0 cm, i.e. they are between 0.0 cm and 2.0 cm different, so it is likely but not certain that Tom is right. More accurate and precise measurements would be able to decrease the uncertainty.

Question 8

A big dog weighing 60 kg runs into a cat weighing 8 kg. The dog was moving at 1.5 $\mathrm{m\,s^{-1}}$, and the cat was sitting in the sun. Assume that the dog and cat continue moving together. What is the final speed of the combined cat/dog furball?

a. 0.18 $\mathrm{m\,s^{-1}}$

b. 0.75 $\mathrm{m\,s^{-1}}$

c. 1.3 $\mathrm{m\,s^{-1}}$

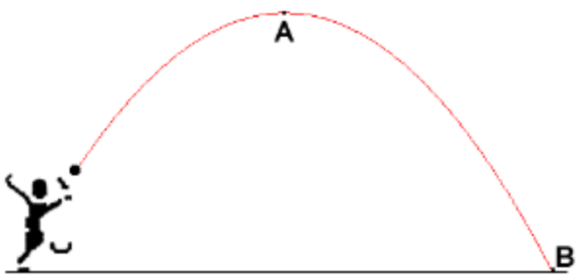
d. 1.7 $\mathrm{m\,s^{-1}}$

e. 11.3 $\mathrm{m\,s^{-1}}$

Solution: c. — This is an example of a completely inelastic collision with one of the objects stationary before the collision. Hence, the speed v of the furball can be found using conservation of momentum. The momentum before is $p_i = Mv_0$ where M is the mass of the dog and $v-$) its initial speed. The momentum after is $p_f = (M+m)v$ where m is the mass of the cat. Applying conservation of momentum $Mv_0 = (M+m)v$, so $v = Mv_0/(M+m) = 1.3\,\mathrm{m\,s^{-1}}$.

Question 9

A ball is thrown into the air and it moves in the path shown below. Ignore air resistance in this question.



At position A the ball is at the highest point in its path, position B is just before it hits the ground. Which of the following statements is true?

a. The speed of the ball at A is zero and the acceleration of the ball at B is the same as at A.

b. The speed of the ball at A is the same as the speed at B and the acceleration at B is higher than at A.

c. The speed at A is lower than the speed at B and the acceleration at A is higher than the acceleration at B.

d. The speed at A is lower than the speed at B and the acceleration at A is the same as the acceleration at B.

e. The speed at A is higher than the speed at B and the acceleration at A is the same as the acceleration at B.

Solution: d. — At all points along the path the acceleration is the constant acceleration due to gravity. At A the ball is moving horizontally but not vertically. By the time it reaches B its vertical speed is higher and its horizontal speed is the same, so its total speed is higher.

Question 10

A large rocky planet was formed from eight small rocky planets, each with radius R. Each of the small planets and the new large planet have the same density. The small rocky planets were initially so far apart that they didn't interact. The energy required to blast a planet of mass m and radius r apart is $3Gm^2/5r$, where G is a constant. How many times as much energy would be required to blast the large planet apart as to blast **all** of the eight small planets apart?

a. Half as much.

b. The same amount.

c. Twice as much.

d. 4 times as much.

e. 8 times as much.

Solution: d. — The mass of the large planet is 8 times a small one. As the density is constant $m \propto r^3$, so R increases by $\sqrt[3]{8} = 2$. The total energy required to blast apart the large planet is then $32(3GM^2/5R)$. The sum of the energies for the 8 small planets is $8(3GM^2/5R)$, which is 4 times less than the large planet.

SECTION B: WRITTEN ANSWER QUESTIONS
USE THE ANSWER BOOKLET PROVIDED

Question 11

A bungee rope has unstretched length $L = 20$ m and spring constant $k = 245\ \mathrm{N\,m^{-1}}$. The spring constant is the constant of proportionality between the force exerted by the spring and its extension x, so $F = -kx$. The potential energy stored in the spring is $U = kx^2/2$.

Mordred the bungee jumper of mass $m = 50$ kg is tied to the bungee rope and steps off a bridge over a deep gorge. The mass of the rope is negligible compared to the mass of Mordred, and the local acceleration due to gravity is $9.8\ \mathrm{m\,s^{-2}}$.

a) If Mordred were lowered over the edge gently while attached to the bungee rope, how far below the platform would he hang?
Solution: The sum of the forces on Mordred must be zero for him to be at equilibrium. Applying this to the vertical direction gives

$$\begin{aligned} \sum F_y &= 0 \\ T - mg &= 0 \\ T &= mg \quad , \end{aligned}$$

where $T = -k\Delta y$ is the restoring force exerted by the bungee rope. Hence,

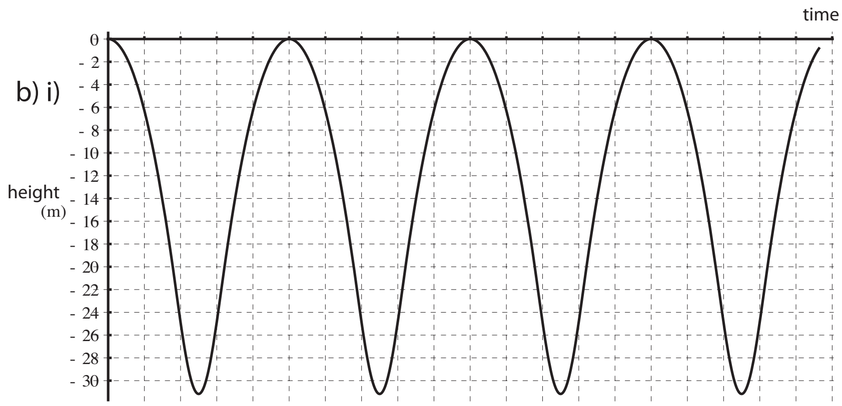
$$\begin{aligned} \Delta y &= -\frac{mg}{k} \\ &= 2\ \mathrm{m} \quad . \end{aligned}$$

Hence Mordred hangs 22 m below the platform.

Take the total potential energy of the system to be zero at this height.

If Mordred is not lowered gently, but simply steps off the platform, relying on the bungee rope to prevent him from hitting the ground, he bounces up and down as shown in the graph below.

b) i)



Height of Mordred the bungee jumper vs. time

DO NOT WRITE ANSWERS ON THIS GRAPH, THEY WILL NOT BE MARKED.

Use the copy on p. 2 of the answer booklet.

b) **Note: Use the axes supplied on p. 2 of the answer book to draw your answers to this part. DO NOT use those on p. 3, which are for part (d)**

(i) Mark the height found in part (a) and all other important points on the graph of height vs. time for Mordred the bungee jumper given on p. 2 of the answer book. The time Mordred takes to return to his initial height after stepping off the platform is T.

(ii) Sketch the velocity of Mordred the bungee jumper vs. time, marking all important points and values. Use the axes below the graph for part (b)(i) on p. 2 of the answer book. Use the same scale for time as in part (b)(i).

(iii) Sketch the acceleration of Mordred the bungee jumper vs. time, marking all important points and values. Use the axes below the graph for part (b)(ii) on p. 2 of the answer book. Use the same scale for time as in part (b)(i) and (ii).

Solution: See over the page for examples of sketches which would receive full marks.
The following calculations were required to mark important points and values on the sketches. Mordred will accelerate due to gravity alone when less than 20 m below the platform, so using kinematics his velocity will increase linearly until it reaches $v_{20\mathrm{m}} = \sqrt{2gy} = 19.8\ \mathrm{m\,s^{-1}}$.
Mordred's maximum speed is reached as he passes through the equilibrium position 22 m below the platform. This can be found by using conservation of energy considering the contributions of kinetic energy and gravitational and elastic potential energy as follows

$$\begin{aligned}
E_{\mathrm{top}} &= E_{\mathrm{eq}} \\
0 &= \frac{1}{2}mv_{\mathrm{max}}^2 + mgy + \frac{1}{2}k(\Delta y)^2 \\
v_{\mathrm{max}} &= \sqrt{-mgy - k(\Delta y)^2/2} \\
v_{\mathrm{max}} &= 20.3\ \mathrm{m\,s^{-1}} \quad .
\end{aligned}$$

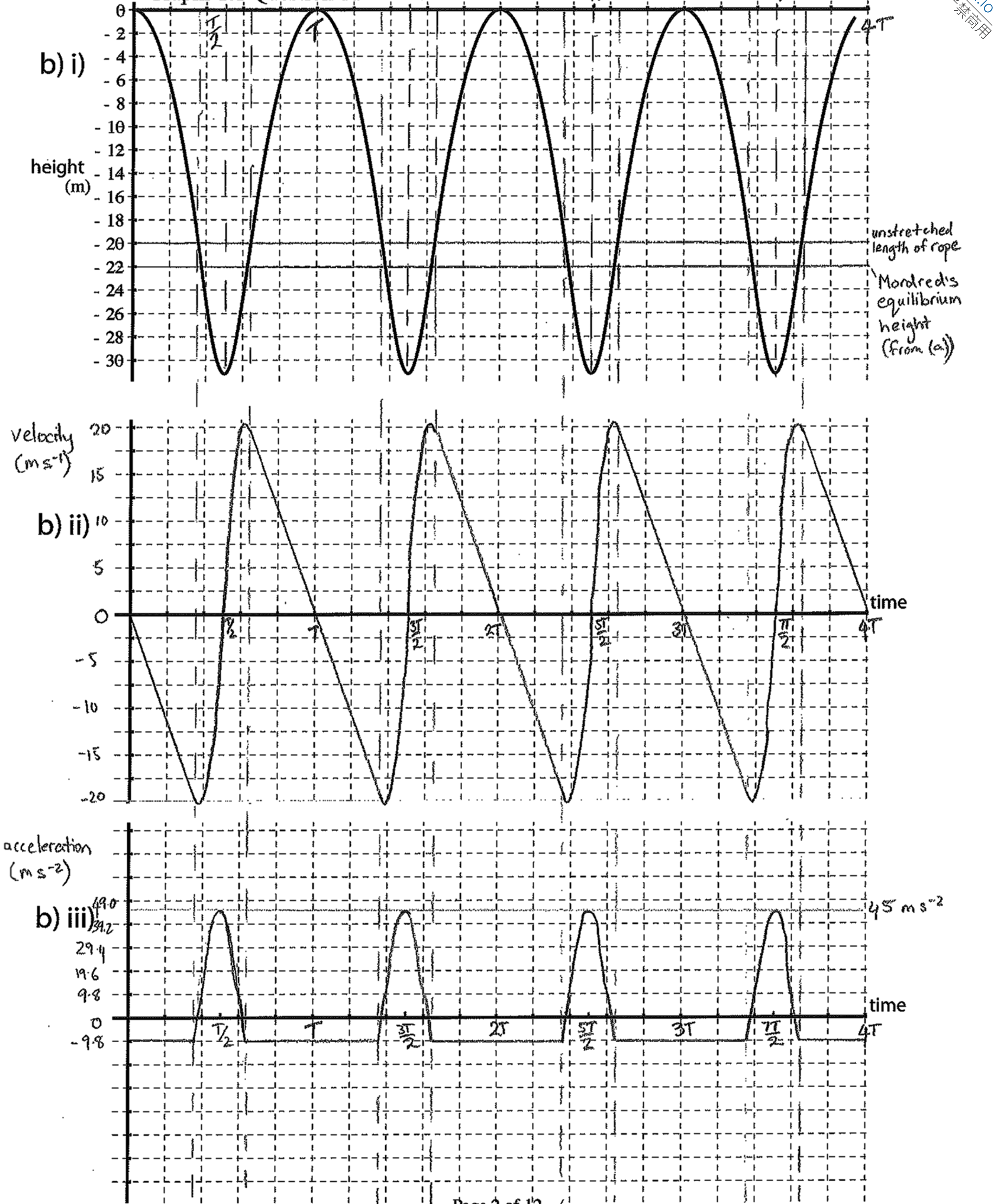
Mordred's maximum acceleration occurs at his lowest height $y = 31$ m (from the supplied graph) and is $a = k(\Delta y) - g = 45\ \mathrm{m\,s^{-2}}$ upwards.

c) How much energy was dissipated in each bounce of Mordred? Explain how you reached your conclusion.
Solution: From inspection of the supplied graph, no energy is dissipated as Mordred reaches the same height after each bounce so he must have the same amount of energy.

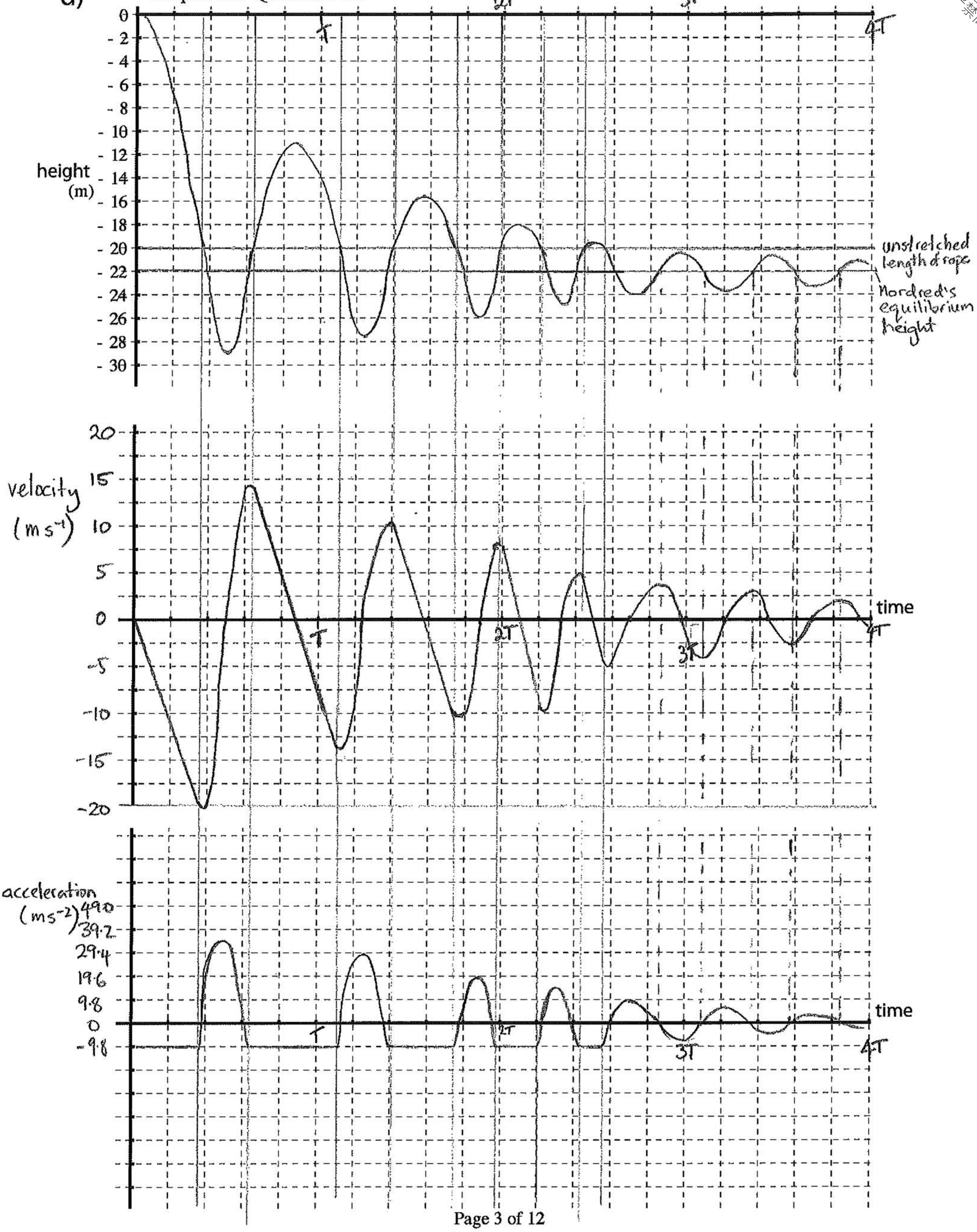
d) **Note: Use the axes supplied on p. 3 of the answer book to draw your answers to this part. DO NOT use those on p. 2, which are for part (b).**
Sketch the height, velocity and acceleration of Mordred the bungee jumper vs. time, if half the energy were dissipated in each bounce of Mordred. Use separate axes for each sketch, the same scale for time as you did in part (b), and mark all important points on your sketches.
Solution: See over two pages for examples of sketches which would receive full marks.
As Mordred reaches a lower height each bounce he spends less time with the rope slack and accelerating under gravity alone in each successive bounce.

Hint: You may need to do some calculations to find all the important points to mark on the supplied graph and your sketches.

Graphs for Question 11



d) Graphs for Question 11



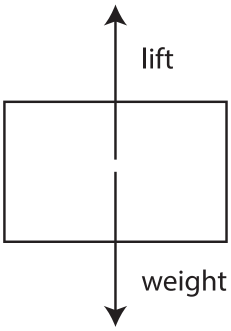
Marker’s comments:
Most students found this question difficult. Some of the common errors are described below.

- Many students confused the concepts of elastic energy stored in the stretched bungee rope and the restoring force exerted by the stretched bungee rope.
- Students often attempted to calculate values which they could read off the supplied graph, especially the times at which Mordred reached various points in his bounces, which made the question very much harder for themselves.
- Many students did not identify the two different regimes of motion, i.e. falling freely under gravity and undergoing simple harmonic motion. When Mordred is above -20 m the rope is slack and his acceleration is the acceleration due to gravity.
- Few students reached part (d) and very few of those who did realised that the amplitude does affect the time taken for each of Mordred’s bounces.

Question 12

Helicopters are useful machines which, amongst other things, facilitate the transport of pumpkins across difficult terrain. Consider a small helicopter hovering at some height above a large field of pumpkins.

a) Draw a free body diagram showing the forces acting on the helicopter.
Solution: A free body diagram of the small helicopter hovering above a large field of pumpkins is shown below.



As the helicopter is hovering there is no horizontal thrust or air resistance.

b) What is the force that acts against gravity to keep the helicopter in the air, and what exerts this force on the helicopter?
Solution: A force called lift acts against gravity to keep the helicopter in the air. As the blades pass through the air they exert a downwards force on it and by Newton's third law this air exerts a reaction force of equal magnitude upwards on the helicopter blades. This is the lift force.

The power required for the helicopter to hover is equal to the downward force applied to the air by the helicopter blades times the mean velocity, v, of the downward moving column of air beneath its rotor blades.

c) Find an expression for the rate, R, at which air flows past the blades (mass per unit time) in terms of the air velocity, v, air density, ρ, and the area swept out by the blades A.
Solution: The volume of air that flows past the blades in time t is Avt. Divide by t to find the volume rate and multiply by ρ to find the mass rate,

$$R = A\rho v \quad .$$

.

d) Show that the force exerted by the helicopter blades on the air is $F = A\rho v^2$.
Solution: The force that the air exerts on the helicopter blades has the same magnitude as the force that the blades on the air. This is equal to the rate at which the air gains momentum. Momentum is mass times velocity. Assuming the air is initially stationary, the rate at which momentum is imparted is equal to the mass rate of air flow over the blades times the final velocity of the air. This gives

$$F = Rv = A\rho v^2 \quad .$$

e) A company specialising in airlifting pumpkins owns a helicopter that can hover if its engine produces mechanical power P. Market research shows that some clients want more pumpkins airlifted at once, and the boss realises that a larger helicopter would be a good business investment. The pumpkin airlift company builds a helicopter that is 1.5 times as large in every linear dimension as their original helicopter. Using the results from the previous parts, what mechanical power P', in terms of P, is required for this larger helicopter to hover?

Solution: If the new helicopter is 1.5 times as long in every linear dimension, its mass $m' = 1.5^3 m$. The weight and therefore the lift required are both proportional to mass so increase by 1.5^3 also. Area is proportional to length squared so the new area of the blades $A' = 1.5^2 A$. The velocity of the air pushed down by the helicopter blades is found using the answer to part d) to be

$$v = \sqrt{F/A\rho} \quad .$$

As ρ is unchanged the new velocity

$$v' = \sqrt{1.5^3/1.5^2} v = 1.5^{1/2} v \quad .$$

The power $P = Fv$, so for the new helicopter

$$\begin{aligned} P' &= F'v' \\ &= 1.5^3 F 1.5^{\frac{1}{2}} v \\ &= 1.5^{3.5} P \\ &= 4.1P \end{aligned}$$

Marker's comments:

a) The two most common errors in responses to this question were including horizontal forces and including elements in the diagram other than forces acting *on* the helicopter.

b) Students' explanations were often unclear.
Some students did not understand that action-reaction pairs of forces do not act on the same body.

c) Many students used dimensional analysis which gives the same answer but does not allow them to verify that the numerical constant is 1.

d) Again, students' explanations were often unclear. Also some students used dimensional analysis, which provides a check but does not prove the validity of the relationship.

e) The velocity of the air changes with the scale of the helicopter but most students missed this effect. Many students also had difficulty calculating the change in other variables such as area and mass of the larger helicopter.

Question 13

Due to an unfortunate logistical error, I don't have a fridge, so I want to design an insulating container to keep my food cold. If I put something colder, like my milk, next to something warmer, like the rest of my house, energy flows from the warmer thing to the colder thing. This process, called *heat flow*, makes the colder thing warmer and the warmer thing colder.

I have the following model for heat flow. For two things in contact, heat can flow by a process called *conduction*. The microscopic particles in objects vibrate, with the particles in a warm object vibrating more than those in a cool object. If two objects are touching, the particles in the two objects can hit each other and share the vibrational energy between them, making the cooler object warmer and the warmer object cooler.

I want a box that allows as little heat as possible to flow from my house to my food. Use the above model to answer the following questions. You should **not** consider heat flow due to any other process. Answers without explanation will not receive credit.

a) Should I make a box that is long and narrow or should I make a cube?
Solution: The smaller the surface area, the smaller the site of heat conduction is and the slower the flow of heat. So you should make a cube as it minimises surface area for a given volume. An alternative response which was given partial credit is that a cube maximises distance to the surface compared to a rectangular prism, resulting in a thicker layer of insulation and hence a slower rate of heat flow.

b) Should I make the walls of my box thick or thin?
Solution: The thinner the walls of the box the more abrupt the change from low to high vibrational energy and the more rapid the exchange of energy between the hot and cold regions. Hence you should make the walls of your box thicker.

c) Should I put the box next to the oven or on the other side of the kitchen?
Solution: You should put the box on the other side of the kitchen as the air serves as insulation here so you want a thick layer between the hot oven and the box.

The rate of heat flow, i.e. amount of heat that flows per unit time, depends either linearly or inversely on the surface area of the box, A; the thickness of the walls, s; the difference in temperature between the food inside the box and the house outside the box, ΔT; and a property of the box called the thermal conductivity, k.

d) Using the ideas from the model above, write down an equation for the rate of heat flow, H.
Solution:

$$H = \frac{k\Delta TA}{s}$$

Every physical quantity has dimensions and the dimensions of a quantity give some information about that quantity. We want to find the dimensions of thermal conductivity. The dimensions on each side of every physical equation are identical. Most physical quantities have dimensions which can be expressed as a combination of the five following dimensions:
length, L, mass, M, time, T, charge, Q and temperature, K.
Pure numbers, such as π, have no dimensions.
For example, the speed of light, c, is a measure of length per unit time, and has dimensions of LT^{-1}.

e) Write down an equation you know that has energy in it.

Solution: Some common correct answers were

$$E = mc^2$$
$$E = mgh$$
$$E = \frac{1}{2}mv^2$$

f) Use this equation to find the dimensions of energy and hence the dimensions of the rate of heat flow (amount of heat that flows per unit time).
Solution: The dimension of heat flow are $[M][L]^2[T]^{-3}$.
As many students are unfamiliar with physical dimensions the expression for the correct S.I. units of $\mathrm{kg\,m^2\,s^{-3}}$ was given partial credit.

g) Find the dimensions of thermal conductivity.
Solution: The dimension of thermal conductivity $[M][L][T]^{-3}[K]^{-1}$.
As many students are unfamiliar with physical dimensions the expression for the correct S.I. units of $\mathrm{kg\,m\,s^{-3}\,K^{-1}}$ was given partial credit.

Marker's comments:

- In part a) many students thought the surface area should be maximised rather than minimised.
- Many students gave the correct answers to parts a), b) and c) but did not explain it using the model provided.
- The most common errors in responses to part d) were
  - omission of any of ΔT, A or s,
  - stating $H \propto s$, and
  - using $1/k$ in place of k.
- Parts e), f) and g) were generally answered well apart from errors carried from earlier parts.

Question 14

The students in a year six class want to find out how fast sound travels and you've been asked to advise them how they can best measure the speed of sound in air themselves.

The class teacher tells you that their school is next to a disused railway track and the school has the use of a 1 km long stretch of the land it runs along in exchange for maintaining the gardens. The ground is flat and the track is straight. They can't buy any equipment but they do have access to plenty of basic sports equipment like stopwatches and the trundle wheels used to mark out sports fields. The teacher also says that he thinks one of the other classes did something like this a few years ago but all he can remember is that the kids were really excited because they got to pop balloons to make a big sound.

The speed of sound in air is around $3 \times 10^2\ \mathrm{m\,s^{-1}}$.

a) What advice would you give the class?
Write down the method you would recommend and why you are recommending it. The class specifically asked you to address all of the following points in what you write:

- how to use any measuring devices carefully, as the class wants help to make the most accurate measurements they can
- any special techniques that can be used to make their result better
- any better ways to produce sound than popping a balloon
- will wind make a difference to their answer
- once measurements have been taken, how will the class calculate the results
- the accuracy of their result, i.e. an estimate of the error in their final result

Solution:

Good solutions to this question were clearly set out procedures for making the measurements and how to analyse the data. The premise is to make a sound accompanying a visible signal, and to time the difference in travel time over the railway corridor of the two signals. Marks were awarded for choices of measuring equipment such as stopwatches accompanied by discussion of how to use them effectively and reduce the error due to reaction time. Starter pistols were a good choice to increase the clarity of the sound, and solutions involving relaying signals from end to end to further increase the effective distance are possible. The wind will affect the result by increasing or decreasing the transit time, although this will not be significant if the wind is light. Descriptions of calculation of the speed from the distance and time measurements which matched the method described were awarded credit. The estimate of errors, taking into account a reasonable reaction time for a stopwatch (around 0.2 s), as well as any modifications based on the specific method, were accepted; the overall accuracy is limited primarily by the time measurement which has a much higher relative error than the distance. Synchronicity problems can also be significant if the method relies upon chains of events. Credit was given here for an estimate matching the experimental method.

After the method for the exercise is explained to the class, one student sticks up his hand and says that he's seen movies where people can tell trains are coming a long way off by listening to the train tracks, because the sound travels through them faster. He wants to know whether they could measure the speed of sound in the train tracks too. After a quick internet search you find that the speed of sound in steel is around $6\ \mathrm{km\,s^{-1}}$.

b) Is there any reason why the class couldn't also measure the speed of sound in the railway tracks? If so, explain why, if not, explain how to vary the method and also estimate the uncertainty in their result.

Solution: As sounds travels at $v_t = 6\ \mathrm{km\,s^{-1}}$ through the tracks and the maximum available length of track is $l = 1$ km the maximum travel time for the sound is $t_{\max} = l/v_t \approx 0.2$ s. As the time for the sound to propagate would be measured with stopwatches and have an uncertainty of around 0.2 s the uncertainty in any attempted determination of the velocity would be at least as large as the velocity. Hence, it is not possible to sensibly measure the speed of sound in the railway tracks.

Marker's comments:

This question was well done in general. A variety of methods were described, with some students identifying a clear, easy to use procedure with a correct accompanying analysis. Students displayed considerable creativity and thought about chaining responses of students at different ends to increase the time, with good discussions of the effects on the uncertainty of the results. Many students had different ideas about the speed of, for example, dropping a flag or dropping an arm to signal receipt of a signal. The uncertainties were generally well calculated, with most students able to identify the most significant factors in their described methods. Some students used only the equipment mentioned in the question without thinking further about what sports equipment may be available. Many answers could have been improved by a clearer description of how to perform the experiment as appropriate to the primary school audience. Students who attempted the second part either understood the idea of the uncertainty and obtained a reasonable conclusion from a brief calculation, or described only a possible method and did not consider the error analysis. It should be noted that the question specifically stated that the school was unable to purchase any more sophisticated equipment, and so answers which specified that they should do so were not given much credit for the method, although credit was still given for the analysis and calculations as appropriate.

Integrity of Competition

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