Multiple Choice Answers

Question #	Answer	Question #	Answer
1.	D	6.	B
2.	A	7.	B
3.	A	8.	E
4.	C	9.	B
5.	C	10.	B

PHYSICS

Solutions to the2007 National Qualifying Examination

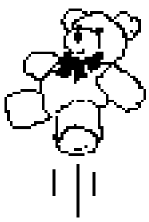
Markers comments follow each question.

SECTION A

Multiple Choice - 1 mark each
Marks will not be deducted for incorrect answers.
Use the Multiple Choice Answer Sheet provided

Correct answers are in bold, brief explanations and markers comments are given below.

Question 1.
A girl throws a teddy bear straight up. Consider the motion of the bear only after it has left the girl'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 bear is (are):

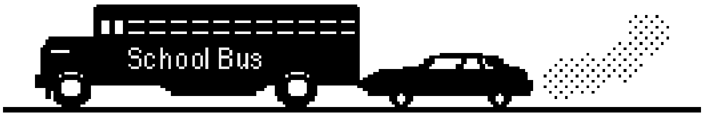


(A) a downward force of gravity along with a steadily decreasing upward force.
(B) a steadily decreasing upward force from the moment it leaves the girl's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the bear gets closer to the earth.
(C) an almost constant downward force of gravity along with an upward force that steadily decreases until the bear 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 bear falls back to the ground because of its natural tendency to rest on the surface of the earth.

This question is looking for the common misconception that there is always a force in the direction of motion, and many students did give answers indicating that they held this misconception. 33% of students answered this question correctly. The most common answer given was c.

Question 2.

A school bus breaks down and receives a push back to the garage from a small compact car as shown in the diagram.



While the car, still pushing the bus, is speeding up to get up to cruising speed:

(A) the amount of force with which the car pushes against the bus is equal to that with which the bus pushes back against the car.
(B) the amount of force with which the car pushes against the bus is smaller than that with which the bus pushes back against the car.
(C) the amount of force with which the car pushes against the bus is greater than that with which the bus pushes back against the car.
(D) the car's engine is running so the car pushes against the bus, but the bus's engine is not running so the bus can't push back against the car. The bus is pushed forward simply because it is in the way of the car.
(E) neither the car nor the bus exert any force on the other. The bus is pushed forward simply because it is in the way of the car.

This question requires students to correctly use Newton's third law – for each force there is an equal and opposite reaction force. The pair of forces have equal magnitude regardless of whether either object is accelerating. 33% of students answered this question correctly, indicating that many cannot correctly apply (or cease to believe in) Newton's third law when acceleration is involved. The most commonly given answer was c, with more than 50% of students choosing this distractor.

Question 3.

A school bus breaks down and receives a push back to the garage from a small compact car as shown in the diagram.

After the car reaches the constant cruising speed at which the driver wishes to push the bus;

(A) the amount of force with which the car pushes against the bus is equal to that with which the bus pushes back against the car.
(B) the amount of force with which the car pushes against the bus is less than that with which the bus pushes back against the car.
(C) the amount of force with which the car pushes against the bus is greater than that with which the bus pushes back against the car.
(D) the car's engine is running so the car pushes against the bus, but the bus's engine is not running so the bus can't push back against the car. The bus is pushed forward simply because it is in the way of the car.
(E) neither the car nor the bus exert any force on the other. The bus is pushed forward simply because it is in the way of the car.

This is again an example of Newton's third law. For this question more than 70% of students chose the correct answer, indicating that most students can/will apply Newton's third law when acceleration is not involved.

Question 4.
A large bus and a small car collide and stick together. Which one undergoes the larger change in momentum?

(A) The car.
(B) The bus.
(C) The momentum change is the same for both vehicles.
(D) You can't tell without knowing the final velocity of the combined masses.
(E) The result depends on the energy absorbed by the crumpling bodies of the vehicles on impact.

This is a conservation of momentum / Newton's third law question. 33% of students answered correctly, and this was the most commonly given answer, followed closely by d. and then a.

Question 5.
A woman is standing on a set of bathroom scales, measuring her weight, in an elevator. Her weight as shown on the scales is *W* before the elevator starts to move. She presses the down button. As the elevator starts to go down, the weight shown on the scales is:

(A) More than *W*
(B) Equal to *W*
(C) Less than *W*
(D) You can't tell without knowing the velocity the lift is moving at
(E) You can't tell without knowing the acceleration of the lift

This question requires an understanding of the normal force. This question should be easy if students take the time to draw a free body diagram and consider the nett force and acceleration, and most students (72%) did answer this question correctly.

Question 6.
A woman is standing on a set of bathroom scales, measuring her weight, in an elevator. Her weight as shown on the scales is *W* before the elevator starts to move. She presses the down button. When the lift is moving down at a constant speed, the weight shown on the scales is:

(A) More than *W*
(B) Equal to *W*
(C) Less than *W*
(D) You can't tell without knowing the velocity the lift is moving at
(E) You can't tell without knowing the acceleration of the lift

Again, students needed to consider the forces acting and in this case the lack of acceleration. Most students also answered this question correctly (76%), more than for the previous question again indicating that some students are confused by forces in accelerating systems.

Question 7.
A boy is swinging a ball attached to a string around in a horizontal circle with constant speed. Consider the following forces:

I. a gravitational force downwards
II. a force directed towards the boy at the centre of the circle
III. a force in the direction of motion of the ball
IV. a force directed outwards away from the boy at the centre of the circle

Which of the above forces is (are) acting on the ball?

(A) I only.
(B) I and II.
(C) I and III.
(D) I, II, and III.
(E) I, III, and IV.

This question looks for two misconceptions – that there is always a force in the direction of motion and that there is an outwards acting (centrifugal)force acting on objects in circular motion. The most common answer was e (37% of students), the next most common was d and only 20% of students chose the correct answer.

Question 8.

A boy is swinging a ball attached to a string around in a horizontal circle with constant speed. Consider the following forces:

I. a gravitational force downwards
II. a force directed towards the boy at the centre of the circle
III. a force in the direction of motion of the ball
IV. a force directed outwards away from the boy at the centre of the circle

Which of the above forces does work on the ball?

(A) I and II.
(B) II only.
(C) I, II, and III.
(D) I, III, and IV.
(E) none of these forces does work on the ball.

This question looks at the relationship between force and work. Many students do not recognise that work is only done by the component of a force in the direction of displacement. In this case only two of the forces listed actually exist, and the other two are both perpendicular to the displacement at all times. The most common answer was e (29%), however b and d were only slightly less popular choices.

Question 9.

The speed of light in vacuum, *c*, depends on two fundamental constants, the permeability of free space, μ_o, and the permittivity of free space, ε_o. The speed of light is given by $c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$.

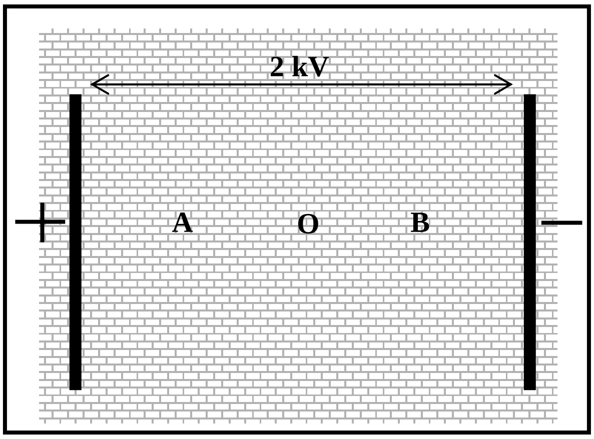
The units of ε_o are $N^{-1}.C^2.m^{-2}$.
The units for μ_o are:

(A) $kg^{-1}m^{-1}C^2$
(B) $kg.m.C^{-2}$
(C) $kg.m.s^{-4}.C^{-2}$
(D) $kg^{-1}s^{-3}C^{-2}$
(E) $kg^2.m^2.C^{-4}$

This question is asking students to perform basic dimensional analysis to find the units of a constant they are unlikely to be familiar with. This required students to be able to break down N into its basic units, and know the units for velocity. The correct answer was chosen by the most students (29%) but was closely followed by c with a significant number choosing the other options indicating guessing.

Question 10.

Some factories use dust precipitators in their chimneys to remove airborne pollutants. In one such precipitator a pair of plates is placed in the square chimney with a potential difference of 2 kV between them as shown.



Consider a particle with a small negative charge at rest at one of the three positions, A, O and B, marked on the diagram. The particle will:

(A) have greatest potential energy at A.
(B) have greatest potential energy at B.
(C) have greatest potential energy at O
(D) have the same potential energy at A and B
(E) have the same potential energy at A, B and O.

This question looks at whether students understand potential energy. Even if they have not met electric potential energy, they should still be able to deduce the correct answer from the behaviour of a charged particle released near other charges and applying conservation of energy. The correct answer was chosen by 41% of students, with a scatter across the other answers.

SECTION B

Written Answer Questions
Attempt ONLY 4 questions. ONLY 4 questions will be marked.

Read each question completely.
You may be able to do later parts of a question even if you cannot do the early parts!
Remember that no answer can only get no marks, so even if you are unsure, have a go!

The marks for each question part are given, each question is worth a total of 10 marks.

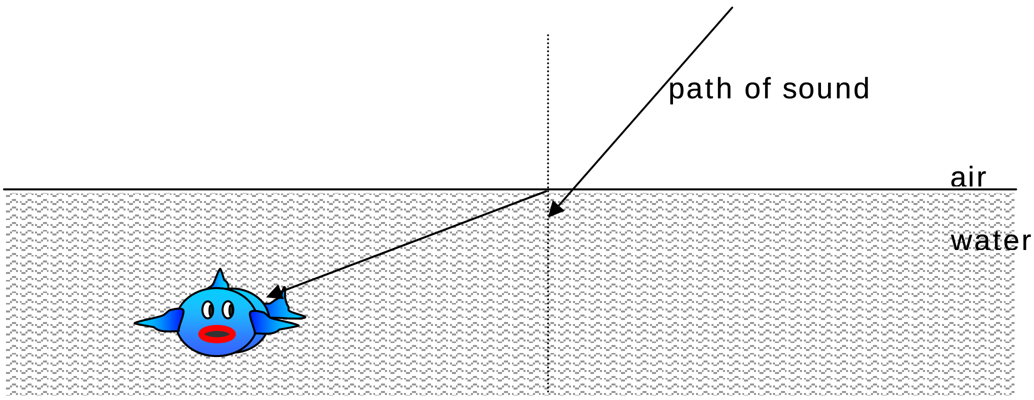
Solution to Question 11.

Graham has gone fishing, and is sitting quietly waiting for a fish to bite, but nothing is happening. So Graham turns on the radio to try to find some music to encourage the fish. The first piece of music Graham finds is a bass guitar solo, which has a very low frequency. Graham doesn't like the sound of that, so he finds another station which is playing a selection of soprano duets, which are much higher frequency.

a. Which music will travel from the radio to the fish faster, and why? (1 mark)

Velocity does not depend on frequency (to a very good first approximation at least), hence both types of music will take the same time to reach the fish. This question was intended to catch students misusing the dispersion relation $v = f\lambda$

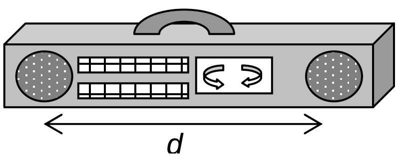
The path of the sound bends when it reaches the surface of the water, as shown.



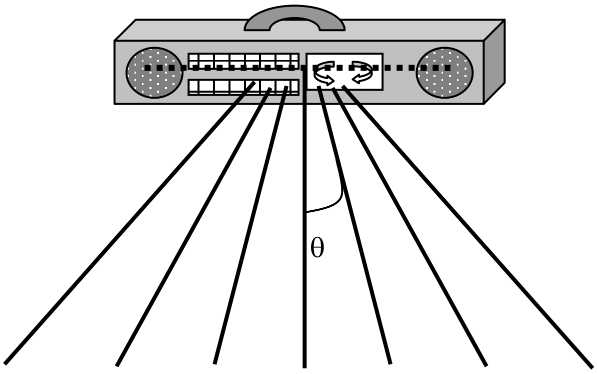
b. Describe and explain what happens to the frequency, the wavelength and the speed of the sound when it moves from the air to the water. (2 marks)

The frequency does not change when the sound wave enters the water, however both velocity and wavelength do change, as velocity depends on the medium and wavelength depends on velocity (frequency depends on the source, hence it does not change). Students may either remember that sound travels faster in water, and hence both velocity and wavelength must increase, or this can be deduced from Snell's law, and noting that the ray bends away from the normal to the surface.

Graham's radio has 2 speakers, separated by a distance *d* as shown.



c. Draw a diagram showing where there will be constructive interference between the sound from the two speakers when the first station (the one with the bass guitar solo) is playing. Make sure you label your diagram carefully. Consider only the interference pattern in air. (3 marks)



Constructive interference occurs along lines for which the path difference between the two speakers is an integer multiple of wavelengths, such that dsinθ = mλ (see diagram) where m = 0. ±1, ±2….

d. How does the interference pattern change when Graham changes to the second station (the one playing soprano duets)? (1 mark)

When the frequency increases the wavelength decreases (speed in unchanged as the medium is the same), hence the angle between lines of constructive interference decreases and the pattern is less "spread out".

e. For a given wavelength of sound from the speakers, what must be the minimum separation, *d*, in terms of the wavelength λ, for complete destructive interference to occur? Why? (1 mark)

For destructive interference to occur there must be a path difference of (nλ/2) where n = 1, 3, 5…, the greatest possible path difference is along the line joining the speakers, hence the speakers must be spaced at least λ/2 apart for complete destructive interference.

Graham leans over the water to try to see some fish, and accidentally drops his radio in. The radio keeps playing under the water.

f. How would the interference pattern from part (c) change with the radio under the water? Why? (2 marks)

When Graham drops the radio into the water the wavelength increases due to the increase in wave speed, hence the angles between lines of constructive interference increase and the pattern "spreads out".

Marker's comments

Many students attempted this question and obtained some marks, although very few obtained more than around half marks. Many students treated the problem as if the waves of interest were light waves rather than sound waves, and assumed the light would slow down in water, etc.
At part a. many student incorrectly invoked $v = f\lambda$, and stated that as frequency was changing the velocity was changing. This is a very common misconception among high school and even first year university students – it is not the frequency or wavelength that determines the velocity of a wave, but rather the properties of the medium. For the case of sound waves it is the bulk modulus and the density.

At part b. many students claimed that as water is more dense the waves speed up – this is incorrect, waves travel more slowly in a more dense medium. The sound does in fact travel faster, but it is because the bulk modulus is much greater for air than water. Some students did correctly say that waves slow down in amore dense medium, and these received partial marks. Many students also said that all three of frequency, wavelength and velocity change.
At part c. most students were able to show at least one point at which constructive interference occurred, however for full marks it was necessary to show lines along which it occurs, not just a single point or a few points.
At part d. many students answered correctly, although often did not give coherent reasoning, so many obtained partial marks only. Marks were given where answers were consistent with part a.
At part e. many students answered correctly, although showed no reasoning. Partial marks were given in this case.
At part f. many students guessed that the pattern became more or less spread out, however few gave any reason. Marks were given where answers were consistent with what the student had written at part b.

Solution to Question 12.

Molly the ant falls from a height h above a conveyor belt which is moving at a constant, very high, velocity v_c, and she bounces off at an angle θ to the horizontal. Molly has a mass m and the coefficient of kinetic friction between Molly and the belt is μ.

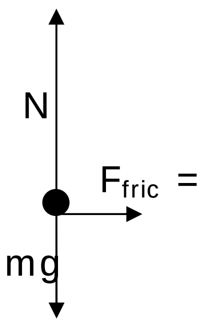
a. Find an expression for the velocity with which Molly hits the conveyor belt. (1 mark)

Solution:
Applying conservation of energy

$$mgh = \frac{1}{2}mv^2$$
$$v^2 = 2gh$$
$$v = \sqrt{2gh}$$

b. Draw a diagram showing all the forces acting on Molly during her collision with the conveyor belt. Indicate on your diagram the relative sizes of the forces in the vertical direction. (2 marks)

Solution:



Impulse, I, is the change in momentum, $\Delta\mathbf{p}$, of an object caused by a force, $\mathbf{F}$, and is equal to the average force multiplied by the time, Δt, over which it acts. Hence $I = \Delta\mathbf{p} = \mathbf{F}.\Delta t$.

c. Write down an expression for the change in momentum of Molly in the horizontal and vertical directions in terms of the forces on your diagram and the time the collision takes, Δt. (2 marks)

Solution:
In the horizontal direction
$$\Delta p_x = F_x \Delta t = F_{fric}\Delta t = \mu N \Delta t.$$
In the vertical direction
$$\Delta p_y = F_y \Delta t = (N - mg)\Delta t.$$

d. Find expressions for Molly's final velocity in the horizontal and vertical directions. (2 marks)

Solution:
In the x direction
$\Delta p_x = p_{x\,final} - p_{x\,inital}$
$\mu N \Delta t = m v_x - 0$
$v_x = \frac{\mu N \Delta t}{m}.$
In the y direction
$\Delta p_y = p_{y\,final} - p_{y\,inital}$
$(N - mg)\Delta t = m v_y + \sqrt{2gh}$
$v_y = \frac{N - mg}{m}\Delta t - \sqrt{2gh}.$

e. If the average size of the normal force that Molly experiences during the collision is equal to 2*mg*, find an expression for the time the collision takes, Δt. (3 marks)

Solution:
Since she bounces off the conveyer belt at an angle θ
$\tan\theta = \frac{v_y}{v_x}.$
The average normal force is $N = 2mg$ so
$v_x = \frac{2\mu mg\Delta t}{m}$
$v_x = 2\mu g\Delta t,$
and
$v_y = \frac{2mg - mg}{m}\Delta t - \sqrt{2gh}$
$v_y = g\Delta t - \sqrt{2gh}.$
Combining these gives
$\tan\theta = \frac{g\Delta t - \sqrt{2gh}}{2\mu g\Delta t}$
$2\mu\tan\theta g\Delta t = g\Delta t - \sqrt{2gh}$
$g\Delta t(1 - 2\mu\tan\theta) = \sqrt{2gh}$
$\Delta t = \sqrt{\frac{2h}{g}}\frac{1}{1 - 2\mu\tan\theta}.$

Marker’s comments:

Most students managed to write down something for part a), however many substituted g=9.8 which is incorrect as the numeric value requires its units, and also completely unnecessary as there were no numerical values given or required in this question. Some students wrote *v* in terms of some time *t* which was undefined. It was of some concern that a significant minority of students wrote answers which equated velocity with kinetic energy, or force, suggesting that they did not understand the basics of mechanics.

Part b) was very poorly done in general. Many students seemed unfamiliar with the idea of a force diagram, adding arrows for velocities, momenta, and energies as well as forces. Most students seem to have a misconception that the force in the horizontal direction is due to some ‘motion force’ or ‘belt force’ working *against* the frictional force. A large number of students also claimed that the normal force and gravitational force were equal, even though this clearly would not cause Molly to bounce.

Part c) was answered reasonably well, given the mistakes made in the previous sections. However, some students didn’t use the supplied information and gave expressions which were not momentum but velocity or something similar.

Part d) was not attempted by a number of students, but those who understood part c) generally used the right approach. Common errors were failure to remember the initial velocity, ascribing an initial velocity to the horizontal direction as well, and inclusion of a spurious horizontal force at this stage. Also, many students wrote $F_{fric} = \mu mg$ instead of $F_{fric} = \mu N$.

Part e) was not well done. Few students got this part correct. Many people tried to rearrange a single equation to get the time in terms of effectively unknown velocities, and some tried to divide without correctly substituting terms. A number of students came up with numerical answers, which implies that they did not have much idea how to attempt the question.

Solution to Question 13.

In any collision the sum of the momenta of all the bodies involved should be the same immediately before and after the collision. In an elastic collision the same is true for the sum of the kinetic energies of the bodies.

a. If a small blob with a small mass *m* has a velocity *v* directly towards an extremely heavy wall, and the ensuing collision is elastic, what is the approximate final velocity of the blob? (1 mark)

Solution:
In words:
When the blob collides with the wall it will bounce off the wall and change direction. Since momentum is conserved in the collision, and the wall is so very much heavier than the blob the velocity of the wall will be very small after the collision, even if all (or twice) the momentum of the blob is imparted to the wall. Since the kinetic energy of the wall is proportional to its velocity squared its kinetic energy will be almost zero after the collision (compared to the kinetic energy of the blob before the collision). The collision is elastic so kinetic energy is conserved, which means the kinetic energy of the blob must be almost the same before and after. Hence the velocity of the blob after the collision is $-v$.

Or with some equations:
The mass of the wall (and the Earth to which it is connected) is very much greater than the mass of the blob. $M \gg m$.
Assume that the wall is not moving so its initial velocity $V_i = 0$.
Momentum is conserved, that is

$$mv + MV_i = mv_f + MV_f,$$

$$m(v - v_f) = MV_f.$$

Kinetic energy is also conserved, so

$$\frac{1}{2}mv^2 + \frac{1}{2}MV_i^2 = \frac{1}{2}mv_f^2 + \frac{1}{2}MV_f^2,$$

$$m(v^2 - v_f^2) = \frac{(MV_f)^2}{M},$$

$$m(v^2 - v_f^2) = \frac{m^2(v - v_f)^2}{M}$$

$$v + v_f = \frac{m}{M}(v - v_f).$$

Since $\frac{m}{M} \ll 1$ this implies that

$$v - v_f \approx 0,$$

so

$$v_f \approx -v.$$

There is a box with lots and lots and lots of these blobs with mass *m*, all moving with different speeds in different directions so that the total momentum is initially (approximately) zero. The box is held firmly in place. Assume that all collisions are elastic.

b. What happens to the total kinetic energy of all the blobs? Why? (2 marks)

Solution:
- In any collision between blobs the kinetic energy is conserved so the total kinetic energy doesn't change.
- In collision between a blob and a box wall the direction of the velocity of the blob changes but its kinetic energy doesn't (using the answer to a.) so the total kinetic energy of the blobs doesn't change.

Since there isn't any other way of transferring energy the total kinetic energy of all the blobs in the box remains the same.

c. What happens to the total momentum of the all the blobs? Why? (2 marks)

Solution:

- In any collision between blobs the momentum is conserved so the total momentum doesn't change.
- In collision between a blob and a box wall the direction of the velocity of the blob changes so its momentum changes. However, since there are so many blobs, all moving in different directions and having lots of collisions with the walls if there is one collision of a blob with velocity $\boldsymbol{v}$ with one wall then there will soon be a collision of a blob with velocity $-\boldsymbol{v}$ with the opposite wall. So on average the total momentum remains approximately the same. Note that the momentum of one blob only contributes a very small amount to the total because of the large number of blobs so the total won't deviate far from zero.

Since there isn't any other way of transferring momentum the total momentum of all the blobs in the box remains approximately zero.

If there were a hole in the side of the box that the blobs could escape through and the initial distribution of velocities of the blobs were the same as before:

d. What happens to the total kinetic energy of the blobs left in the box? Why? (1 mark)

Solution:
Every blob that leaves the box has some kinetic energy so the total kinetic energy of the blobs left behind decreases by that amount. The total kinetic energy of the blobs left in the box will decrease.

e. What happens to the total momentum of the blobs left in the box? Why? (2 marks)

Solution:

- All the blobs leaving through the hole will have a momentum with a component in the direction perpendicular to the side which has the hole in. Hence the total momentum of the blobs which have left the box will be approximately in the direction perpendicular to the hole, pointing out of the box. Call this momentum $\boldsymbol{p}_{out}$.
- However, had the hole not been there the blobs would have collided with the wall and each would have had the component of its momentum in the perpendicular direction reversed. This means that if there were no hole the total momentum of the blobs that have left the box would have been in the direction perpendicular to the hole, pointing into the box. This momentum, $\boldsymbol{p}_{onh} = -\boldsymbol{p}_{out}$.
- Since the total momentum of all the blobs would have been zero if there were no hole, the total momentum of the blobs remaining in the box must be the negative of $\boldsymbol{p}_{onh}$. So the total momentum of those remaining $\boldsymbol{p}_{in} = -\boldsymbol{p}_{onh} = \boldsymbol{p}_{out}$.

The total momentum of the blobs remaining in the box will increase in the direction perpendicular to the side of the box with the hole pointing out of the box.

Note that this means that the box is exerting a force on the blobs.

When a blown up balloon is released before it is tied up it shoots off away from the hand of the person holding it.

f. Why does the balloon shoot off in the direction that it does? (2 marks)

Solution:

- A balloon is filled with air, a gas which is made up of lots of molecules.
- When the balloon is released it is like putting a hole in the side of it.
- The air is compressed inside the balloon so more molecules come out than go in.
- This means that, as in part e., the total momentum of the molecules of air in the balloon will increase in the direction towards the opening. In other words, there is a force acting on the air towards the opening.
- Since the force is applied by the balloon wall there is a reaction force experienced by the balloon, directed away from the opening.

The balloon shoots away from the end with the opening (and the hand of the person holding it) because of the force on the balloon of the air inside it.

Marker's comments about Question 13.

Many students did not assume that all the collisions were elastic despite it being explicitly stated in the question and an explanation of the term being given.

Many students did not understand that the momentum change of the box or wall due to a collision with a blob wasn't zero.

Many students demonstrated a lack of understanding of vectors and scalars, and whether kinetic energy and momentum are vector or scalar quantities. Some of these students thought that if $\boldsymbol{p}_{tot} = 0$ then $K_{tot} = 0$ also.

Too many students gave dimensionally incorrect answers, equating quantities like mass, velocity, momentum, energy and dimensionless ratios.

A number of students thought that a blob leaving a box was an inelastic collision, or that it would leave all of its momentum or kinetic energy behind.

Not all students understood that to leave the box by the hole a blob must have a component of its momentum in the direction towards the hole.

Some students believed that the force accelerating the balloon was from the hand as it was the reaction force associated with air from the balloon hitting the hand.

Overall: No student achieved full mark but each part of the question was answered correctly by some students.
The great majority of students attempting this question responded to all parts of the question, even when their answers to the earlier parts were substantially incorrect.

Question 14.

Newton's law of cooling says that the rate of cooling of an object is proportional to the temperature difference between the object and its environment, hence a cup of tea cools off faster in a cold room than in a warm room. The equation that describes the temperature as a function of time is:

$$T_{tea}(t) - T_{room} = (T_{tea}(0) - T_{room})\, e^{-kt},$$

where $T_{tea}(t)$ is the temperature of the tea at any time t, T_{room} is the temperature of the room, $T_{tea}(0)$ is the initial temperature of the tea at $t = 0$ and k is a constant.

a. What are the units of the constant k? (1 mark)

The units for k must be s^{-1} if t is in s (or min^{-1} if t in minutes as below) as the exponent (kt) must be dimensionless.

A particular cup of tea is made in a room at 15°C. The temperature of the tea is measured as a function of time and the results are shown in the table below.

t (minutes)	10	20	30	40	50	60	70	80
T_{tea} (°C)	65	49	38	30	25	22	20	18

b. Plot an appropriate graph **on the graph paper provided** that will allow you to find the constant k using the table of data given above. (5 marks)

Note that a straight line graph has the form $y = mx + c$ where m is the gradient and c is the intercept, and y and x are functions of the data.

To get a straight line we need to take the natural logarithm of both sides, which gives us

$$\ln(T_{tea}(t) - T_{room}) = \ln[(T_{tea}(0) - T_{room})\, e^{-kt}]$$
$$= \ln(T_{tea}(0) - T_{room}) + \ln(e^{-kt})$$
$$= \ln(T_{tea}(0) - T_{room}) - kt$$

We wish to find k from the gradient, hence the appropriate plot will be $\ln(T_{tea}(t) - T_{room})$ against t, which will have a gradient $-k$.
See graph below.

c. Find the constant k. Remember to show all your working. (2 marks)

The gradient can be calculated by taking the rise over the run for two points on the line of best fit as shown on the graph, and is found to be -0.04 min^{-1}, hence $k = 0.04\ min^{-1}$.

d. What was the initial temperature of the tea? (1 mark)

This can be found either using the original equation and the value for k along with any data point, or preferably by reading the intercept on the graph for $t = 0$. The initial temperature is approximately 90°C.

e. How long will it take for the tea to reach a cold 16°C? (1 mark)

Same method as part d – either read from the graph after first finding the ln (16°C – 15°C), or using the equation, it will take approximately 110 minutes.

Markers comments:

At part a most students either said that k has no units because it is a constant (perhaps if we had given "no units because it's a constant" as a distractor in MCQ9 many students would have chosen this option), or that k had units of $K.s^{-1}$, presumable believing k to be the gradient of a graph of t vs T, which is consistent with their attempts art parts b and c. Most students simply plotted time against temperature and hence were unable to answer part c by finding the gradient. The plot they obtained was a curve. Some still continued to attempt to take a gradient even though the graph was obviously not a straight line. Partial marks were given for finding k using the equation – full marks were not given for this as the question asked them to use their graph.
At part d and e marks were given where students either used their graph or the equation given to find the time / temperature required, however only partial marks were given where students plotted a curve and attempted to extrapolate, no marks were given where no working was shown.

Question 15.
(Graham)
This question consists of three unrelated parts. Answers should be clear, concise, and written in **COMPLETE** sentences. Answers longer than the length limits **WILL NOT BE MARKED**. Attempting to reduce the size of your handwriting so that you can fit more in will likely make your handwriting unreadable, in which case you will be given **ZERO MARKS**.

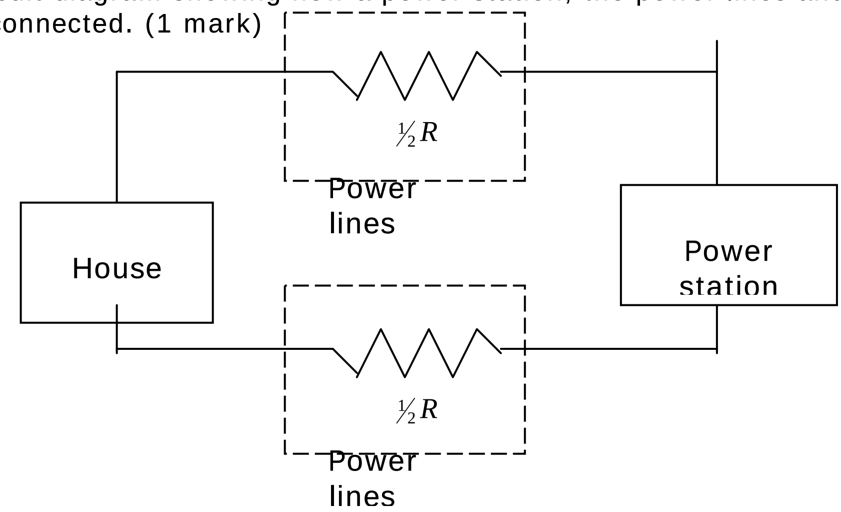
Part I.

a. Is energy conserved in an inelastic collision? Why / why not? Give an example of how energy may be transferred in an inelastic collision. (Max 6 lines) (3 marks)

Total energy is conserved in any process. In an inelastic collision, only the total kinetic energy is not conserved. For example, the lost kinetic energy could become thermal or sound energy. (4 lines)

Part II.
Electricity transmission lines do not transmit energy perfectly, there are some losses because the power lines themselves have resistance.

b. Draw a circuit diagram showing how a power station, the power lines and a single home would be connected. (1 mark)



Where *R* is the resistance of the power lines.

The power dissipated by an element in a circuit is $P = IV$, where I is the current flowing through the circuit element, and V is the potential drop across the element (the potential drop would be negative for an element supplying power). For a resistor, the power dissipated can be written as $P = I^2R$ or $P = \frac{V^2}{R}$.

c. Given that the power station is providing a fixed amount of power, should the power station's voltage output be increased or decreased (or does it not have any effect) to reduce the power losses due to the resistance of the transmission lines? Justify your answer. (Max 6 lines) (4 marks)

Increasing the voltage output of the power station will reduce the power losses through the power lines. The power lost through the power lines is given by I^2R, and hence increases as *I* increases. As the power station's power output is given by $P = IV$, increasing its voltage will reduce the current it produces, which is the same current flowing through the power lines. (6 lines)

The resolution to the apparent paradox that the power drop, *P*, across the power lines is both proportional to the square of *V*, and to the square of *I*, is that *V*, the potential drop across the power lines is not the same as the voltage output of the power station, however the current that passes through the power station is the

same current that passes through the power lines. As the current output of the power station reduces, the voltage drop across the power lines would also reduce.

Part III.

d. When a positron (like an electron, but with positive charge) and an electron (negative charge) collide, they annihilate and produce light. Could a neutron (no charge) and an antiproton (like a proton, but with negative charge) annihilate and produce light? Why / why not? Justify your answer. (Max 4 lines) (2 marks)

When a positron and an electron annihilate, the initial charge is zero, and they produce light, which has no charge. The net charge of a neutron and an antiproton is negative, so for them to annihilate to produce light would violate conservation of charge. (4 lines)

Marker's comments:

Part I tested the student's understanding of the principle of conservation of energy. While a large proportion of students understood that energy was conserved, many were unable to provide an appropriate example of energy conservation in an inelastic collision, instead providing an example of energy conservation in an elastic collision. Other common mistakes included stating that energy is conserved in an inelastic collision because momentum conserved, or simply that energy is only conserved in elastic collisions.

In the circuit diagram in Part II, many students attempted to include elements not asked for in the question, such as transformers or additional houses. In many cases, these unnecessary elements were added incorrectly, causing the student to lose marks.

The two most common mistakes in the second half of Part II involved assuming that the resistance of the power lines was changing, and/or misunderstanding the meaning of the variable *V* in the provided equations. This led to students, with reference to the equation $P = \frac{V^2}{R}$, arguing that the potential of the power station should be reduced, because as *P*, the power output of the power station is fixed, reducing *V* would reduce the resistance, *R* of the power lines, and hence reduce the power losses.

One of the most common mistakes for Part III was arguing that because the neutron had no charge, it therefore couldn't react with the antiproton, or that because there was no electrostatic attractive force between the neutron and antiproton, there would be no way for the particles to gain enough energy to annihilate and produce light.

Question 16.

Hazel and Lilly decide to test the claims of compact fluorescent light bulb manufacturers in order to find out whether these devices really do save energy. To do this, they need to measure the energy used by a standard incandescent light bulb (which claims to consume energy at a rate of 100 W) in some time, and then compare this with the measured energy use of a compact fluorescent light bulb (which claims to consume energy at a rate of 18 W for the same light output) over the same time.

Being environmentally-minded, Hazel and Lilly don't have many unnecessary devices in their home. Their only clock is a standard analogue wall clock with a second hand, and the only way that they can measure energy usage is to read their electricity meter, which can be read to a precision of ±0.1 kWh. The units on the meter, kWh, are kilowatt-hours; 1 kWh is the amount of energy that would be used by a device consuming 1000 W for one hour.

a. Write out a method for Hazel and Lilly to follow in their experiment that would allow them to test the power consumptions of the light bulbs. They are interested both in the relative consumption of the bulbs and the performance compared to the manufacturer's claims. Include important details such as how, with what, for how long, etc., and detail any necessary calculations. (4 marks)

Solution:

Whilst the basic method is relatively simple, the restrictions of the measuring devices necessitate a careful check of the experimental conditions. Firstly, the only power meter measures the total power flowing consumed by their entire house. To correct for this, either all devices must be turned off for the duration of the experiment, or a control run for the same period without a light turned on must be performed.

A light bulb must be plugged into the socket, and the switch turned on, with the time from the wall clock noted. The meter reading must also be taken at this stage. Next the bulb must be allowed to run for some length of time, and then turned off and the meter and clock read again. The difference in the readings is the total energy consumed in the house over that period.

An important consideration is the time required for the experiment. It is necessary to consider the expected readings after a known time. For the 100W light bulb, for every hour of operation, one expects that 0.1kWh of energy be consumed. This is at the limit of reading of the electricity meter, and so it is clear that a much longer time is required. At least 10 hours should be used, and then the error is 10%, which is not very good but not completely unreasonable. When testing the compact fluorescent, it would take more than 5 hours just to change the reading by one scale division. Much more time, say 50 hours, would therefore be required to achieve an acceptable error margin.

As a consequence of the extremely long timescales in this experiment, it is very unlikely that it will be possible to disconnect all other electrical appliances, such as refrigerators, for the entire duration. Consequently it is probably best to take a control measurement, for the same period of the test run, and work out a power dissipation rate for the other household items which can then be subtracted from the reading.

Ideally, this would be done a number of times, and an average measurement taken. Hazel and Lilly should avoid turning on other appliances which draw substantial power and are not strictly necessary. By allowing only those appliances which always run to remain plugged in, they will minimize additional errors in their baseline measurement.

The measurements, also, could be conducted a number of times and averages taken in an attempt to reduce effects of unusually large or small power drain into other appliances, or supply voltage fluctuations, etc. Also, different bulbs should be used to obtain an average over the batch. It is also necessary to check that the brightness of the bulbs is similar.

After the measurements of the total energy consumed and the time are made, the power dissipated by each light globe can be found by dividing the total energy consumed by the time, making sure that the units are consistent. Dividing kWh by hours will yield a power in kW, which may be converted to W. This value is then compared with the manufacturer's specifications and the other bulb.

b. Explain the major sources of uncertainty in Hazel and Lilly's experiment, and hence estimate the precision of their final results. (3 marks)

Solution:

The major sources of uncertainty in their experiment are the precision of the electricity meter and the unknown fluctuations in the power consumption of everything else in the house. Note that the clock may be read to one second in tens of hours; the average quartz wall clock is at least this accurate, and so the relative error here is one part in tens of thousands. This is completely insignificant compared with the likely 5-10% error in the energy reading. The fluctuations in general usage over the period compared with the period when the baseline was measured are potentially significant, and it is difficult to estimate them. Even if the alternative of turning everything else off were followed, there would still be some residual power consumption from wiring losses, etc. This is not a practical option in any case. In addition, the supply voltage itself varies, sometimes on timescales not dissimilar to that of the experiment. It is likely that this would be averaged out, but not certain. The absence of any objective way of measuring the light output of the bulbs necessarily introduces some uncertainty, although it is difficult to quantify.

In any case, the precision of their results is likely to end up at about ±10%.

c. Suggest possible changes to this experiment that would increase the accuracy of their results, whilst using the same electricity meter. (1 mark)

Solution:

Anything that was not mentioned in the previous part, and which could conceivably improve the results, is acceptable here. For instance,

- the time over which the experiment is performed could be increased.
- the experiment could be repeated multiple times and averages taken.
- other extraneous devices could be unplugged to reduce the overall power used, increasing the fraction of the measurement which represents useful information.
- repeating the experiment with multiple bulbs to remove ‘outlier bulb’ effects.
- using many light sockets simultaneously to increase the power consumption, and reduce the time necessary to perform the experiment.
- trying different sockets to eliminate wiring/socket effects.
- making sure that the control and actual runs are performed on days with similar temperatures, which means that the fridge, a major contributor to the additional power consumption, is using about the same amount of energy.

It is sometimes claimed that it uses less power to leave a fluorescent light on than to switch it on and off many times during the course of the day.

d. Explain what could be done to thoroughly test this claim using the previous apparatus and general method. Think about some of the factors to do with the switching that could affect the results. (2 marks)

Solution:

The basic idea would be to repeat the experiment, first with a bulb on for a set time (say 20 hours) and then for the same bulb switched on and off every hour or so. Calculations of the power used are the same as in part a. Many different runs could be performed:

- Toggling the state of the light every hour.
- Rapidly switching the light on and off for a ten minutes each hour.
- Leaving the light on most of the time, and switching it off for a few minutes each hour.
- Switching on the light for ten minutes every quarter of an hour.

The important thing is that the different total amounts of switching, and different rates of switching are examined and compared with a bulb constantly on. It would be advantageous to have multiple bulbs and switch them all in the same way to increase the total power used, as the comparison is between two relatively small quantities with relatively large errors, and so the more signal the better. Longer times would also be useful.

Marker's comments:

Students seemed to find this question difficult, as they did not write enough of the right sort of information. In part a), when asked to detail a method, most students ignored many factors, usually including important details. The clearest example is the length of time. The majority of students chose one hour, often without any attempt at justification; this choice is not sensible because it does not allow for any reasonable measurement of the energy used by the fluorescent bulb given the electricity meter's scale. Most students mentioned a value of time and many said that other appliances should be turned off, but most missed the idea of comparing the brightness of the bulbs, and few talked about repeating the experiment, or about using more light bulbs in parallel.

Part b) was reasonably poorly answered, with some students correctly citing the meter as the primary source of inaccuracy, but many failing to mention other important things. Some students focussed on the clock, because it is analogue; this is not sensible here as it is far more accurate than other factors in this experiment, as it has a scale in seconds. Many students did not provide a sensible estimate of the uncertainty, although a good fraction of those who used a very short timescale in part a) correctly stated that their uncertainty would be huge. Part c) was generally well answered, most students identified an area of improvement for the experiment. Answers to part d) suffered from the same problem as those to part a), in that most students were not specific enough about the method. Many students interpreted the request to "think about some of the factors to do with the switching that could affect the results" to mean that they should postulate a reason for the difference; whilst this statement was meant to be a guide as to the sorts of things to consider in the answer, it was excellent and interesting to see that those who interpreted it that way came up with creative ideas from their knowledge or experience, despite this being a topic about which no knowledge would be expected.

Integrity of the Competition

To ensure the integrity of the competition and to identify outstanding students the competition organisers reserve the right to re-examine or disqualify any student or group of students before determining a mark or award where there is evidence of collusion or other academic