PHYSICS

2010 National Qualifying Examination

Time Allowed: 135 minutes
Hint: It's a good idea to read through the paper first!

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 answer sheet provided.
  Note: there are 10 multiple choice questions in Section A. The space for answers to Questions 11 to 30 is not used on the Answer Sheet.
- Answer Section B in the writing booklet provided *in pen*. Use pencil for diagrams and graphs only.
- 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.
- Make sure that your explanations are clear.
- All numerical answers must have correct units.

MARKS

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

Section A

Multiple Choice — 1 mark each
Marks will not be deducted for incorrect answers.
Use the multiple choice answer sheet provided.
Suggested time: 20 minutes

Question 1
A large hefty chicken and a small light quail, both flying in midair, have the same kinetic energy. Which of the following statements is true?

(A) The chicken has a greater speed than the quail.

(B) The quail has a greater speed than the chicken.

(C) The chicken and the quail have the same speed.

(D) Nothing can be inferred, the kinetic energy has nothing to do with the speed.

(E) The direction of the quail and the chicken must be taken into account before a decision can be made.

Question 2
The large hefty chicken and a small light quail, still both flying in midair with the same kinetic energy, fly directly at each other and collide head-on due to a joint navigational error, and briefly become one fowl object. Which of the following statements is true in the instant after the collision?

(A) The object moves in the same direction as the chicken's original motion.

(B) The object moves in the same direction as the quail's original motion.

(C) The object stops dead in the air.

(D) As soon as they collide they move downward with velocity $9.8\ \mathrm{m\,s^{-1}}$.

(E) It depends on how hard the chicken hits the quail.

Question 3

Lucy is measuring the acceleration due to gravity in Melbourne by dropping a ball through a vertical distance 1.00 m and timing how long it takes. The ball starts at rest, and Lucy times its fall four times. The results are: 0.47 s, 0.42 s, 0.48 s and 0.41 s. The uncertainty in her distance measurement is 1 cm and the uncertainty in the timer is 0.01 s. What is the value of g from Lucy's experiment?

(A) 8.68 $\mathrm{m\,s^{-2}}$

(B) 9.81 $\mathrm{m\,s^{-2}}$

(C) 9.88 $\mathrm{m\,s^{-2}}$

(D) 10.1 $\mathrm{m\,s^{-2}}$

(E) 11.3 $\mathrm{m\,s^{-2}}$

Question 4

The uncertainty in this value of g is

(A) at least 0.01 $\mathrm{m\,s^{-2}}$ and at most 0.03 $\mathrm{m\,s^{-2}}$.

(B) more than 0.03 $\mathrm{m\,s^{-2}}$ but at most 0.1 $\mathrm{m\,s^{-2}}$.

(C) more than 0.1 $\mathrm{m\,s^{-2}}$ but at most 0.4 $\mathrm{m\,s^{-2}}$.

(D) more than 0.4 $\mathrm{m\,s^{-2}}$ but at most 0.6 $\mathrm{m\,s^{-2}}$.

(E) more than 0.6 $\mathrm{m\,s^{-2}}$ but at most 2 $\mathrm{m\,s^{-2}}$.

Question 5

The equation below gives the expected lifetime, L, of a rooster in a Kate's chicken yard once it has begun crowing. Note that all variables (including L) are positive, and the angle θ (which represents the angular height of the sun at 7 am) varies between 0° and 90°.

$$L = \frac{TN}{(V - S)\cos\theta}$$

Which of the following will increase the life expectancy of a rooster in Kate's chicken yard?

(A) Decreasing T

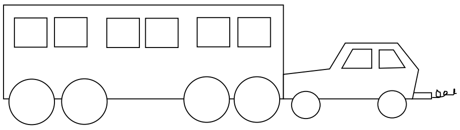
(B) Increasing V

(C) Decreasing S

(D) Decreasing θ

(E) None of the above

Question 6



A large train has ended up on the road and a small car is pushing it back to the tracks. While the small car and the large train being pushed are speeding up to cruising speed,

(A) the amount of force with which the small car pushes against the large train is equal to the amount of force with which the large train pushes back against the small car.

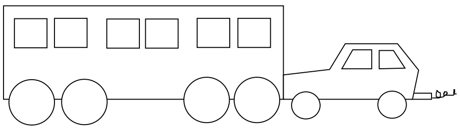
(B) the amount of force with which the small car pushes against the large train is smaller than the amount of force with which the large train pushes back against the small car.

(C) the amount of force with which the small car pushes against the large train is greater than the amount of force with which the large train pushes back against the small car.

(D) the small car's engine is running so the small car pushes against the large train, but the large train's engine is not running so it can't push back against the small car.

(E) neither the small car nor the large train exert any force on the other. The large train is pushed forward simply because it is in the way of the small car.

Question 7



A large train has ended up on the road and a small car is pushing it back to the tracks. After the small car and the large train being pushed have reached a constant cruising speed,

(A) the amount of force with which the small car pushes against the large train is equal to the amount of force with which the large train pushes back against the small car.

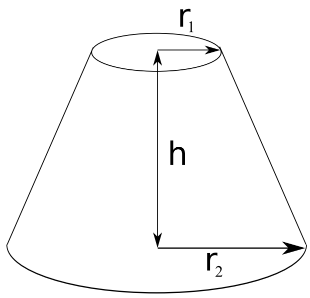
(B) the amount of force with which the small car pushes against the large train is smaller than the amount of force with which the large train pushes back against the small car.

(C) the amount of force with which the small car pushes against the large train is greater than the amount of force with which the large train pushes back against the small car.

(D) the small car's engine is running so the small car pushes against the large train, but the large train's engine is not running so it can't push back against the small car.

(E) neither the small car nor the large train exert any force on the other. The large train is pushed forward simply because it is in the way of the small car.

Question 8



The figure above shows a frustum of a cone. Which of the expressions gives the area of the curved surface?

(A) $\pi(r_1 + r_2)[h^2 + (r_2 - r_1)^2]^{1/2}$

(B) $2\pi(r_1 + r_2)$

(C) $\pi h(r_1^2 + r_1 r_2 + r_2^2)/3$

(D) $\pi(r_1^2 + r_2^2)$

(E) $\pi h(r_1 + r_2)$

Question 9

Someone analysing an electric circuit obtains the equations

$$\begin{aligned} I_1(3\,\Omega) - I_2(6\,\Omega) &= 7\,\text{V} \ , \\ I_1(2\,\Omega) + I_3(3\,\Omega) &= 28\,\text{V} \ , \\ I_2(2\,\Omega) + I_3(1\,\Omega) &= 17\,\text{V} \ . \end{aligned}$$

Note that V is the unit volts, and Ω is the unit Ohms. I_1, I_2 and I_3 are currents. Which of the following statements is true?

(A) $I_1,\ I_3 > 0\ ,\quad I_2 < 0$

(B) $I_1,\ I_3 < 0\ ,\quad I_2 > 0$

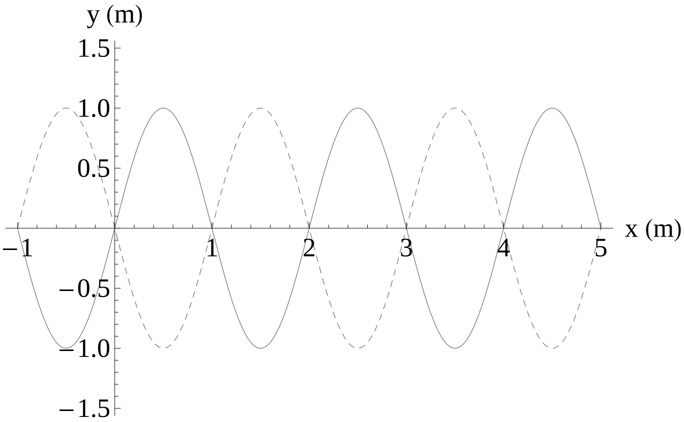
(C) $I_1,\ I_2,\ I_3 > 0$

(D) $I_3 > 0\ ,\quad I_1,\ I_2 < 0$

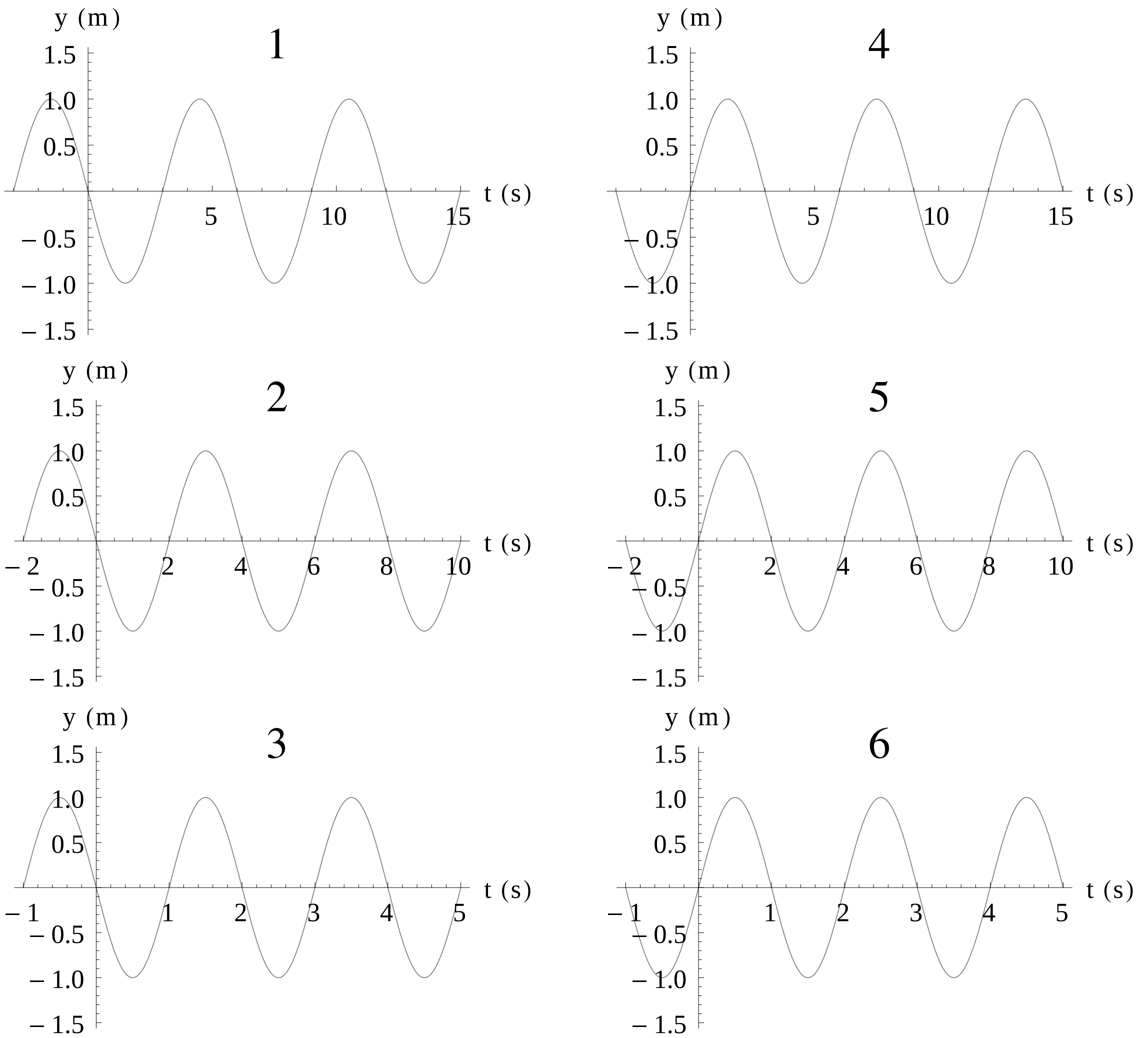
(E) $I_3 < 0\ ,\quad I_1,\ I_2 > 0$

Question 10

The figure to the right shows a travelling wave moving in the positive x–direction. At time $t = 0$ s, the wave plotted as a function of position has the shape shown by the solid curve, and at $t = 3$ s, the shape shown by the dashed curve.



The following six panels show plots as a function of time, at the position $x = 0$ m.



Which of the panels represent possible shapes of the travelling wave?

(A) 4 & 6

(B) 1 & 3

(C) 1, 2 & 3

(D) 4, 5 & 6

(E) 1 & 4

Section B

Written Answer Questions
Attempt **ALL** questions in this part.

You may be able to do later parts of a question even if you cannot do earlier parts.
Remember that if you don't try a question, you can't get any marks for it — so have a go at everything!
Suggested times to spend on each question are given. Don't be discouraged if you take longer than this — if you complete it in the time suggested consider that you've done very well.

Question 11 *Suggested time: 25 minutes*

A particle of mass m is initially travelling at constant velocity in the x–direction with momentum $\mathbf{p}_1$. This particle hits a second, initially stationary particle of mass M. After the collision both particles are moving in the x–y plane and have constant velocity. The first particle has momentum $\mathbf{p}_2$ with components p_{2x} and p_{2y} in the x– and y–directions respectively.

(a) In terms of m, M, p_1, p_{2x} and p_{2y}, find K_2, the final kinetic energy of the first particle (mass m) and K_M, the final kinetic energy of the second particle (mass M). p_1 is the magnitude of the vector $\mathbf{p}_1$.

(b) Find $Q = K_i - K_f$, the total kinetic energy before the collision minus the total kinetic energy after the collision. Show that this is of the form

$$Q = A\left(Bp_1^2 - (p_{2x} - Cp_1)^2 - p_{2y}^2\right)$$

and give expressions for A, B and C.

(c) What is the condition on Q for an elastic collision?

(d) Let p_1 take the fixed value $p_1 = p_0$. Sketch a graph of p_{2x} against p_{2y} for an elastic collision in which $M > m$. Label all intercepts.

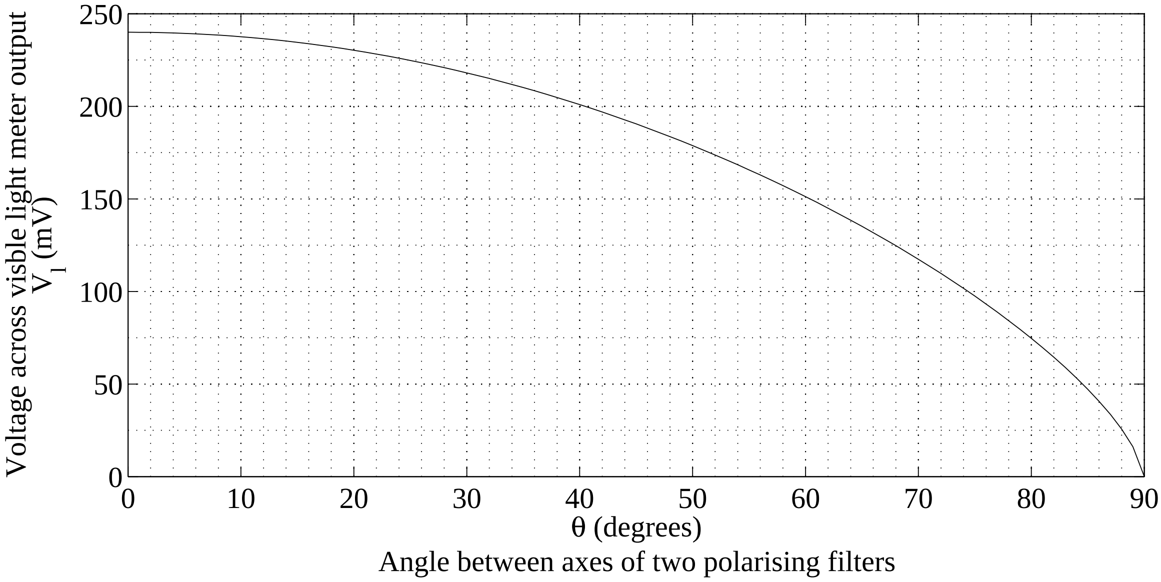
(e) What is the condition on Q for an inelastic collision?

(f) For $p_1 = p_0$ mark on your sketch for part 11d the possible values of $\mathbf{p}_2$ for an inelastic collision.

Question 12 *Suggested time: 30 minutes*

Charlotte and Ben have lots of old 100 W incandescent light bulbs that they don't like to see going to waste, but they also don't like to waste electricity so they want to find out how to run them most efficiently. They decide to compare the efficiencies of running a bulb at different input powers by comparing what they call the *output ratio*. Their definition of the output ratio is the ratio of the intensity of visible light at some fixed distance from the bulb to the electric power dissipated in the bulb.

To measure the visible light intensity they borrow a *visible light meter* a friend found in a collection of old photographic gear. This meter produces a voltage between its two output terminals that depends on the intensity of visible light incident on the detector. Its instruction booklet is long lost but a previous owner left brief hand-written instructions and the following graph.



After doing some research Charlotte finds that the intensity of light passing through two polarising filters is given by $I = I_0 \cos^2 \theta$, where I_0 is the intensity that passes through the filters when they are aligned and θ is the angle between the polarisation axes of the two filters. To make best use of the graph they decide to set up the visible light meter at a distance from the bulb such that at maximum power the light meter voltage reading V_l is just below the maximum given in the graph.

As the bulbs run on dangerous mains voltages, Ben asks his grandfather, a qualified electrician, for some help with adjusting the power of the bulb. Ben's grandfather provides them with a large variable transformer that plugs into the wall at one end and has a mains socket on the other, so that they can use a regular lamp to hold the bulb. To measure the power, he finds a plug-in power meter that can be connected between a mains plug and a mains socket and measures the power consumed by whatever is plugged into it.

Ben connects the power meter to the wall, plugs in the transformer and then plugs the lamp into the transformer output. Ben's grandfather checks it for electrical safety and then turns on the wall switch.

They choose a single bulb to use for all of their measurements. They don't have to worry about damaging it as the maximum output voltage of the transformer is the mains voltage, on which the bulb is designed to run.

Unfortunately, it is a sunny day and the voltage across the light meter is non-zero even when the bulb is off. Ben thinks that if he measures the voltage with the bulb off, he will be able to subtract this from his later measurements to find the voltage he would read if there were no sun. He does this and records 73 mV. He then takes the measurements, with the bulb on, that appear in the table below. Charlotte thinks that it would be better to close the blinds and make the room as dark as possible. She does this and takes her measurements. The following tables contain Ben's and Charlotte's data.

Ben

P_{bulb} (W)	V_{l} (mV)
9	87
20	102
42	139
62	166
79	198
100	248

Charlotte

P_{bulb} (W)	V_{l} (mV)
10	55
21	88
40	124
61	163
78	192
100	235

(a) Whose method would you use and why?

(b) Using the data acquired by the person with the better method, calculate the output ratio for each data point. The intensities you use to calculate the output ratio should be in units of I_0, i.e. express them as some number times I_0, and then just treat the I_0 as a unit.

(c) Given the values of the output ratio you calculated, at what power should they run their bulbs?

(d) Briefly suggest things that Charlotte and Ben could have done with the equipment they had to improve their results.

Question 13 *Suggested time: 20 minutes*

(a) The Earth's climate varies considerably between the hot equator and the cold poles. Explain this fact with reference to the diagram below of the Earth and Sun at an equinox.

(b) The Earth is surrounded by an atmosphere that is thin compared to its radius but still many kilometres thick, so air can flow up or down as well as across the surface of the Earth. The air high in the atmosphere at the poles is cool but warmer than than the air just above the surface which is cooled by the cold land and sea below. Similarly at the equator the air high in the atmosphere is warm but cooler than the air just above the surface which is heated by the hot land and sea below.

Sketch a diagram of the large scale flows of air in the atmosphere that result. Explain your answer.

(c) So far the effect of the rotation of the Earth has been neglected. It can be included by considering the *Coriolis force* which appears to act on all bodies in rotating frames of reference such as the Earth.

The magnitude of the component of the Coriolis force directed along the surface of the Earth is $F = m\Omega v \sin\theta$ where m is the mass of the body experiencing the force, Ω is the Earth's rotational velocity, v is the speed of the body and θ is the latitude (0° at the equator and 90° at the poles) of the body. The Coriolis force is always directed perpendicular to the velocity of the body and is directed towards the east for bodies heading towards the poles in both hemispheres.

Since we live on the surface of the Earth the winds we feel are the large scale flows of air in the lowest level of the atmosphere, and only those across the surface of the Earth.

Given your answer to part 13b, and including the Coriolis force, sketch the large scale winds across the Earth's surface. Explain your answer.

(d) Sailors describe a region right near the equator, called the *doldrums*, in which there are often long periods with no wind. Is this consistent with the above model? Explain.

(e) Just to the north and south of the doldrums are regions with very reliable winds called the *trade winds*. Using the model, predict the directions of the trade winds in the northern and southern hemispheres.

Question 14 *Suggested time: 40 minutes*

A rare waist–necked giraffe has a mild gastric upset, and it is necessary that it be treated with some giant medicine balls. The balls are spherical lozenges, and work best when they are big.

The giraffe's insides are at temperature T_G and the surrounding air is at temperature T_A. As the lozenge changes temperature as it slides down the giraffe's long, beamy neck, it will expand. The volume V of the lozenge at some temperature T is related to its volume V_A at T_A by

$$V = V_A(1 + \beta(T - T_A)) \quad ,$$

where $\beta > 0$ is a constant.

The temperature does not change linearly down the giraffe's neck, but accurate measurements have been taken many times and it is known that the temperature varies with position h from the giraffe's body as

$$T = T_G - (T_G - T_A)\frac{h^2}{N^2} \quad .$$

(a) Show that the diameter of the ball at some height h away from the giraffe's body is given by

$$d = d_A[1 + \gamma(N^2 - h^2)]^{1/3} \quad ,$$

where d_A is the initial diameter in the air and N is the length of the neck, and find the constant γ.

It is physically reasonable to assume that γ is a small quantity. The binomial approximation states that for small nx, $(1 + x)^n \simeq 1 + nx$.

(b) Write down the approximate expression for d.

The width of the neck of a waist–necked giraffe is given by

$$w = M + \zeta\left(h - \frac{N}{2}\right)^2 \quad ,$$

where M is the minimum width of the neck (at the 'waist'), and h as before is the height away from the giraffe's body, so that $h = N$ is at the very top of the neck. $\zeta > 0$ is a constant.

It is of paramount importance not to choke the waist–necked giraffe with the medicinal lozenges, as this would do more harm than good, and retrieving a stuck lozenge is not anyone's idea of a fun way to spend an afternoon. You may assume that the difference between the lozenge's width at the top of the neck d_A differs from the width at the neck-waist M only by a very small amount χ.

(c) Write down the condition for the lozenge not to get stuck in the giraffe's neck. Replace d_A with $M - \chi$, and since γ and χ are small you may neglect terms that contain a product of these two. Express your condition as an inequality with 0 on one side.

(d) In order that the lozenge not get stuck, the inequality you wrote must hold for all h between N and 0. If you solve the equation produced by making your inequality into an equality, you may or may not find a solution for h in that range. Explain why if there is **not** a solution for h somewhere in the neck, the lozenge will not get stuck.

(e) Find the maximum size of the lozenge such that it is guaranteed not to get stuck by that criterion.

(f) Check your solution for the limiting cases of $\zeta \to 0$ and $\zeta \to \infty$. Do your values make sense in these limits (they should)? Explain why or why not.

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 dishonesty. Markers' decisions are final.