AUSTRALIAN SCIENCE OLYMPIADS

PHYSICS

2009 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.
- Answer Section B in the writing booklet provided *in pen*. Use pencil for diagrams and graphs only.
- Use the graph paper provided in the front of the writing booklet for drawing the graph for Question 14.
- 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.

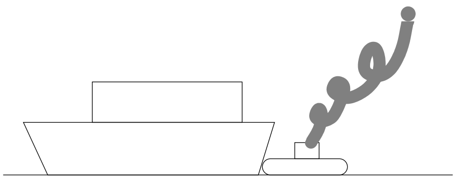
MARKS

Section A	10 multiple choice questions	10 marks
Section B	5 written answer questions	60 marks
		70 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: 15 minutes

Question 1



A large container ship is coming in to port and must be pushed by a tugboat. While the tug and the container ship being pushed are speeding up to cruising speed,

(A) the amount of force with which the tug pushes against the container ship is equal to the amount of force with which the container ship pushes back against the tug.

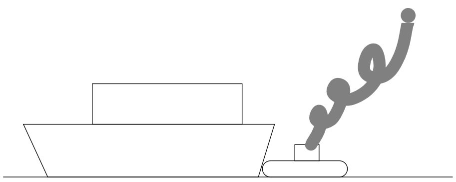
(B) the amount of force with which the tug pushes against the container ship is smaller than the amount of force with which the container ship pushes back against the tug.

(C) the amount of force with which the tug pushes against the container ship is greater than the amount of force with which the container ship pushes back against the tug.

(D) the tug's engine is running so the tug pushes against the container ship, but the container ship's engine is not running so it can't push back against the tug.

(E) neither the tug nor the container ship exert any force on the other. The container ship is pushed forward simply because it is in the way of the tug.

Question 2



A large container ship is coming in to port and must be pushed by a tugboat. After the tug and the container ship being pushed have reached a constant cruising speed,

(A) the amount of force with which the tug pushes against the container ship is equal to the amount of force with which the container ship pushes back against the tug.

(B) the amount of force with which the tug pushes against the container ship is smaller than the amount of force with which the container ship pushes back against the tug.

(C) the amount of force with which the tug pushes against the container ship is greater than the amount of force with which the container ship pushes back against the tug.

(D) the tug's engine is running so the tug pushes against the container ship, but the container ship's engine is not running so it can't push back against the tug.

(E) neither the tug nor the container ship exert any force on the other. The container ship is pushed forward simply because it is in the way of the tug.

If $y = mx + b$ then a plot of y versus x is a straight line with slope m. For the next two questions, consider the equation

$$l + l_0 = \frac{2n-1}{4}\frac{v_s}{f} \quad .$$

Question 3

What is the slope of a plot of $\frac{1}{f}$ versus l? Assume that the other quantities in the equation above are constant.

(A) $\frac{2n-1}{4}v_s$

(B) $\frac{l_0}{v_s}\frac{4}{2n-1}$

(C) The plot will not be a straight line.

(D) $\frac{4}{2n-1}\frac{1}{v_s}$

(E) $\frac{2n-1}{4}(1-l_0)v_s$

Question 4

What is the slope of a plot of f versus $\frac{1}{l}$? Assume that the other quantities in the equation above are constant.

(A) $\frac{2n-1}{4}v_s$

(B) $\frac{l_0}{v_s}\frac{4}{2n-1}$

(C) The plot will not be a straight line.

(D) $\frac{4}{2n-1}\frac{1}{v_s}$

(E) $\frac{2n-1}{4}(1-l_0)v_s$

Question 5

A large chicken catches a lightweight paper plane while both are in midair. Which of the chicken and the paper plane undergoes the smaller change in momentum?

(A) The chicken does.

(B) The paper plane does.

(C) The change in momentum is the same for both the chicken and the paper plane.

(D) You can't tell without knowing the final velocity of the combined chicken-plane mass.

(E) The result depends on the energy absorbed by the crumpling of the paper plane in the chicken's beak.

Question 6

Someone analysing an electric circuit obtains the equations

$$\begin{aligned} 10\,\mathrm{V} - I_1(15\,\Omega) - I_3(5\,\Omega) &= 0 \;, \\ 2\,\mathrm{V} - I_1(5\,\Omega) - I_3(7\,\Omega) &= 0 \;, \\ I_1 + I_3 &= I_2 \;. \end{aligned}$$

Note that V is the unit volts, and Ω is the unit Ohms. How do the **magnitudes** of the three currents I_1, I_2 and I_3 compare?

(A) $|I_3| > |I_1| > |I_2|$

(B) $|I_2| > |I_3| > |I_1|$

(C) $|I_2| > |I_1| > |I_3|$

(D) $|I_1| > |I_3| > |I_2|$

(E) $|I_1| > |I_2| > |I_3|$

Question 7

If you look through a piece of red-tinted glass, everything is seen in shades of red. Similarly, if you look through a piece of blue-tinted glass, everything will be seen in shades of blue. Consider the following statements:

(I) The tinting process makes the glass absorb the corresponding colour, i.e. red-tinted glass strongly absorbs red light, making everything appear red.

(II) The tinting process makes the glass absorb all colours except the corresponding colour, i.e. red-tinted glass will strongly absorb blue and green, but not red.

(III) If you stack the red and blue tinted pieces of glass and look through them, everything will look quite dark.

Which of these statements is/are true?

(A) I and II

(B) I and III

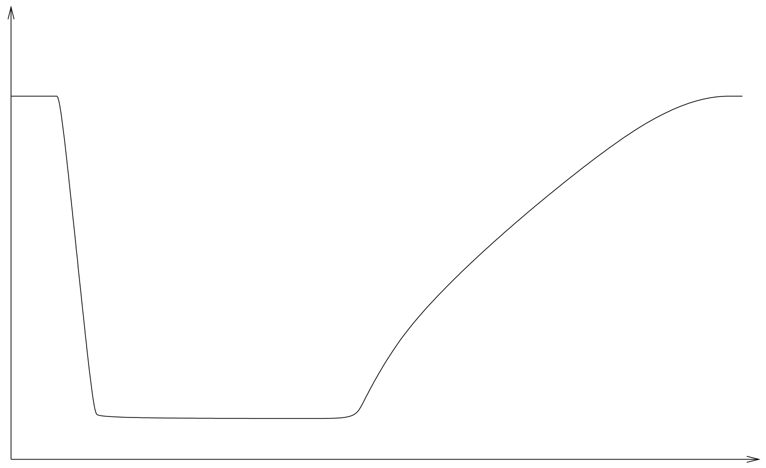
(C) II and III

(D) I only

(E) II only

Question 8

A teacher collects science projects from a class and finds that one page has fallen out. All that it contains is this plot without any axis labels or scales.



Since the plot was unlabeled the teacher has to ask the class if anyone thinks it is theirs to work out whose assignment it came from. Even though they won't get many marks for an unlabeled plot five students claim it as their work, making the following statements. To whom does it belong?

(A) I plotted the number of birds on the island versus time over many years. The number was constant for the first few years but then decreased greatly over a single year because of a disease. After that the number increased more slowly until eventually it was greater than it had originally been.

(B) I plotted the height of a swing above the ground against horizontal distance.

(C) I plotted the volume of water in a jug as I poured out a glass of water, then stopped pouring, then poured another and so on until I had poured four glasses and then filled up the jug from the tap so it had enough water for another four glasses.

(D) I added different masses of compound A to some of compound B so the total initial mass was fixed and measured how much of A was left after they reacted. I plotted the amount of A left against the amount of A I added. When I only added a little A there wasn't much left at the end, but as I added more the amount left first increased and then decreased before increasing again.

(E) I plotted the temperature of my water and ice mixture versus time. First I had room temperature water, then I added ice and stirred until the mixture reached 0 °C. It stayed at 0 °C until the ice had all melted and then slowly increased back up to room temperature.

Question 9

Delightra and her sister Gladell bought a new book together, and are arguing over who gets to read it first. Gladell offers to toss a coin, but Delightra is suspicious because Gladell seems to have been winning coin tosses an awful lot lately. Delightra says "Gladell, you're a cheat. Whatever I call, you know whether to catch it just a bit earlier or not to make sure that you win. Your coin always spins at the same rate, and you must know exactly what position to catch it." Gladell is outraged, and replies "I can't believe you think I'm cheating! Yes, my coin always spins at the same rate, but that doesn't make me a cheat. You're just jealous because I'm luckier than you!"

After complaining to her physicist mother, and making her mother observe one of Gladell's coin tosses, Delightra is told that it is completely implausible for Gladell to be cheating in this manner, as the coin rotates once for each coin-length it moves upwards. Which of the following is the best explanation of why?

(A) Although Gladell can flip the coin to the same height each time and accurately judge this height, quantum mechanics tells us that there will be some inherent uncertainty in the coin's and her hand's position, and the sum of these is greater than a coin length so the coin may flip an extra time.

(B) Even if Gladell tries to flick the coin exactly the same way each time, the small differences in the initial vertical velocity mean that the height of the toss isn't accurate to within a coin length, so it might flip an extra time before she catches it.

(C) Because the coin rotates once per coin length, the chaotic eddy currents in the air slow the coin's spin, so although Gladell can get the position right to within a coin length, the coin may have flipped an extra time.

(D) Although Gladell can flick the coin to the same height within a coin length each time, she cannot measure that constant height to within a coin length and so she can't calculate where to put her hand.

(E) Even if Gladell flicks the coin to the same height within a coin length each time, she will give it some slight horizontal velocity, so the time for which the coin is in the air changes and it might flip an extra time before she catches it.

Question 10

An equation is dimensionally correct if the quantities on both sides have the same physical dimensions, e.g. length (L), mass (M), time (T), and combinations. For example, distance, d, is a length and speed, v, is a length per unit time, so $d = vt$ is dimensionally correct if t represents a time. Equations cannot be physically correct unless they are dimensionally correct.

The average speed v of a particle in an ideal gas depends only on the mass of the particle m, the pressure P, and the number density (number of particles per unit volume) n of particles in the gas. Pressure has the dimensions $\mathrm{M\,L^{-1}\,T^{-2}}$. Which of the following equations is dimensionally correct?

(A) $v = \left(\frac{nm}{P}\right)^{1/2}$

(B) $v = \frac{P}{nm^{2/3}}$

(C) $v = \left(\frac{P}{nm}\right)^{1/2}$

(D) $v = Pnm$

(E) $v = \left(\frac{Pm}{n}\right)^{1/2}$

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: 15 minutes*

A solid object floats in water if its average density is less than that of water. If its average density is greater than the density of water it sinks. If its average density is equal to that of water then it has no nett force acting on it when it is submerged.

A boy floating in a swimming pool notices that he can float easily if he holds his breath but that as he breathes out, no matter how slowly he does it, he ends up just under water once he has finished exhaling. If he breathes out by blowing a fast stream of air directly upwards he goes under water even sooner and ends up further under water and is still moving down towards the bottom of the pool after he has finished exhaling.

The difference between the volume of air in his lungs when full and empty is V_l and he has mass m. The density of water is ρ_w and the density of air is much less than water.

(a) Draw a free body diagram showing the forces acting on the boy when his lungs are empty after breathing out slowly. Indicate the magnitude of the forces acting on the boy by the size of the arrows you draw to represent the forces.

(b) What is the boy's average density when his lungs are empty? Explain your answer.

(c) What is the boy's average density when his lungs are full?

(d) Draw a free body diagram of the boy as he is moving downwards just after he finished emptying his lungs by blowing a fast stream of air upwards. Again indicate the magnitude of the forces acting on the boy by the size of the arrows you draw to represent the forces.

(e) Why does the boy end up further under water in this case?

Question 12 *Suggested time: 25 minutes*

Ben has built a toy car. He has worked hard at reducing the friction in the wheels, so much so that it can be considered negligible. The car is, however, subject to a drag force $F_d = \kappa v^2$ where v is the speed of the car and $\kappa = 0.030\,\mathrm{kg\,m^{-1}}$. The car has mass $m = 2.5\,\mathrm{kg}$ and cross-sectional area $A = 0.06\,\mathrm{m^2}$. Take the acceleration due to gravity to be $g = 9.8\,\mathrm{m\,s^{-2}}$.

Ben places the car at the top of a ramp of length $s = 1.2\,\mathrm{m}$ inclined at an angle $\theta = 30°$ to the horizontal. He pushes it for time $t = 0.25\,\mathrm{s}$ with a force such that the nett force acting on the car is $F_p = 20.0\,\mathrm{N}$. He then lets the car travel down the ramp and along a flat track.

(a) Consider the car at time t, when Ben stops pushing and find

  (i) v_t, the speed of the car and

  (ii) s_t, the distance the car has traveled.

(b) Find an expression for v_b, the speed of the car when it reaches the bottom of the ramp. Drawing a free body diagram of the car will help you. Note that v_b is approximately $4\,\mathrm{m\,s^{-1}}$.

(c) After he has released the car, Ben notices that there is a large block on the track, a distance $d = 12.5\,\mathrm{m}$ from the bottom of the ramp. Find v, the velocity of the car when it hits the block.

Useful Information

If the acceleration of a body, a, is related to the velocity by $a = kv^2$, the velocity is related to the position, x by $v = le^{kx}$ for some constant, l.

In physics it is often useful to make approximations. This can simplify your calculations, and if the approximation you make is appropriate, it won't change your result appreciably. For example, if you know that $A = B + C$ and that C is much, much smaller than B, you may be able to say that $A = B$ and get the same result as you would have using $A = B + C$. If you make an approximation you must demonstrate that it is valid.

Question 13 *Suggested time: 15 minutes*

Elizabeth wants to find the gravitational field strength in her bedroom using a pendulum. The equation she will use assumes that the pendulum consists of a massless string attached at one end to a fixed point and at the other to a point mass, that is a mass that has no volume. It also assumes that the angle between the string and the vertical is always small.

She takes a hair ribbon, about 20 cm long, measures it with a ruler and then ties one end to her hair brush. She realises that she doesn't have enough hands to do the experiment on her own, so she asks her sister Claire to hold the other end of the ribbon. Elizabeth asks Claire to rest her arm on a book case to make sure that she holds the ribbon very still. This forms Elizabeth's pendulum.

Elizabeth pulls the hair brush to the side and counts that it passes four thick books as she pulls it. She then releases it and lets it swing. She gets out her mobile phone and uses the stopwatch on it to time the pendulum. She times ten periods instead of one because she thinks this will be more accurate. She watches to see when the pendulum reaches the fourth book because it is moving very slowly here so she has more time to press the button on her phone.

Thinking that she'll get a better result if she takes more data and plots a graph, she repeats the experiment with ribbons of different lengths, pulling it past the same four thick books before letting it go each time.

(a) Consider Elizabeth's experimental method. What did she do that could have adversely affected her results? Suggest a simple modification to the experiment that could solve each problem.

(b) Estimate the percentage uncertainty in the length for a 20 cm ribbon and for a 1 m ribbon using Elizabeth's original method. Repeat the estimate for your revised method, if it is different.

Question 14 *Suggested time: 30 minutes*

Joseph wants to measure the *latent heat of vaporization* of substance X, which is the amount of energy required per unit mass to turn substance X from a liquid to a gas at its boiling point. He begins by putting approximately 200 mL of liquid X in a beaker on a combined hotplate and scale. He inserts a thermometer, turns on the hotplate at $t = 0\,\text{min}$ and records the liquid's temperature as well as the combined mass of the liquid, beaker and thermometer every minute. After 24 minutes, there is no more liquid in the beaker. Joseph's results are shown in the table below.

Time (min)	0	1	2	3	4	5	6	7	8
Temperature (°C)	24	25	28	37	50	64	77	90	102
Mass (g)	310	310	310	310	310	310	310	310	310

Time (min)	9	10	11	12	13	14	15	16	17
Temperature (°C)	113	124	134	143	152	158	160	160	159
Mass (g)	310	310	307	307	305	302	288	264	241

Time (min)	18	19	20	21	22	23	24
Temperature (°C)	160	160	160	161	160	161	-
Mass (g)	214	190	165	138	110	79	69

Joseph notices that the temperature increases at a different rate at different temperatures. To show this variation, he plots the difference between two successive temperature measurements divided by the time between them, i.e. the rate of change of the temperature, versus the temperature at the first of these measurement times. His graph (Graph 1) is shown over the page, along with a graph (Graph 2) of the temperature of the liquid as a function of time.

(a) Explain the shape of Graph 1, by giving reasons for the initial increase, the gradual decline over a wide temperature range and the sharp decrease near 160 °C. (Hint: Graph 2 might help you interpret the regions of Graph 1.)

(b) By drawing an appropriate graph, find the average rate at which liquid X boils, in $\text{kg}\,\text{min}^{-1}$.

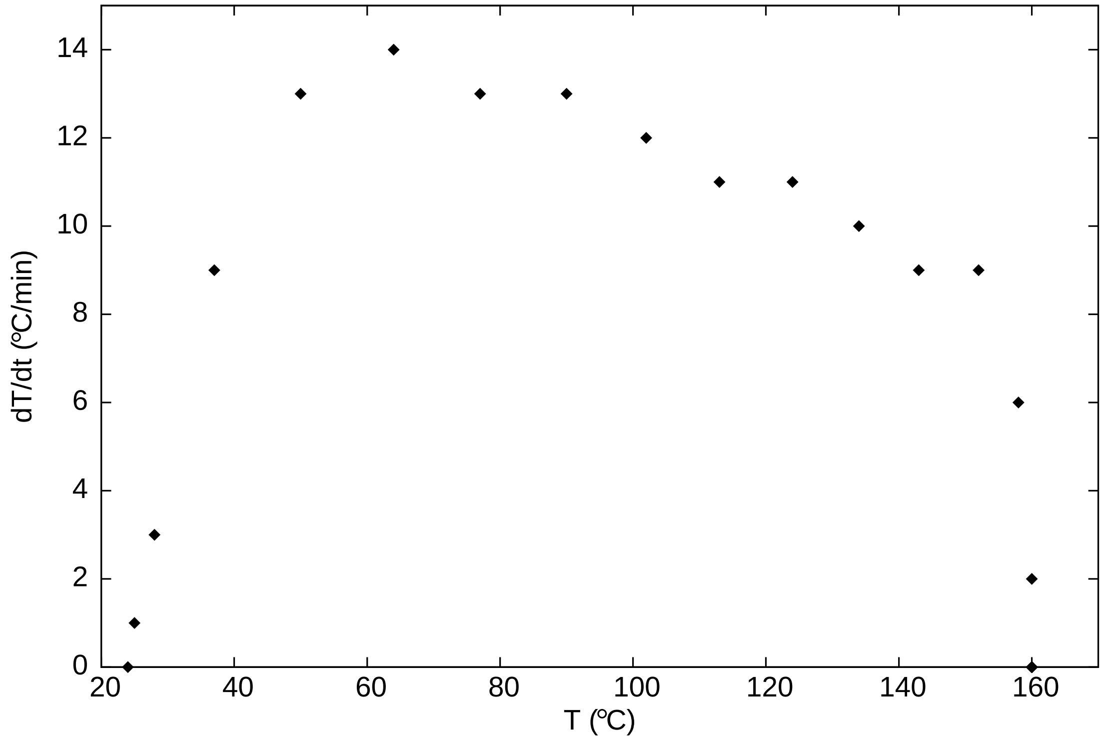
(c) In a previous experiment, Joseph measured the specific heat capacity of liquid X to be 2.19 $\text{kJ}\,\text{kg}^{-1}\,\text{K}^{-1}$. This means that it takes 2.19 kJ of energy to raise the temperature of 1 kg of liquid X by 1 K (which is equal to 1 °C).

(i) Pick the point on Graph 1 that gives the most information about the rate at which heat is transferred to the liquid at its boiling point. Explain how you chose this point and why it is the most appropriate.

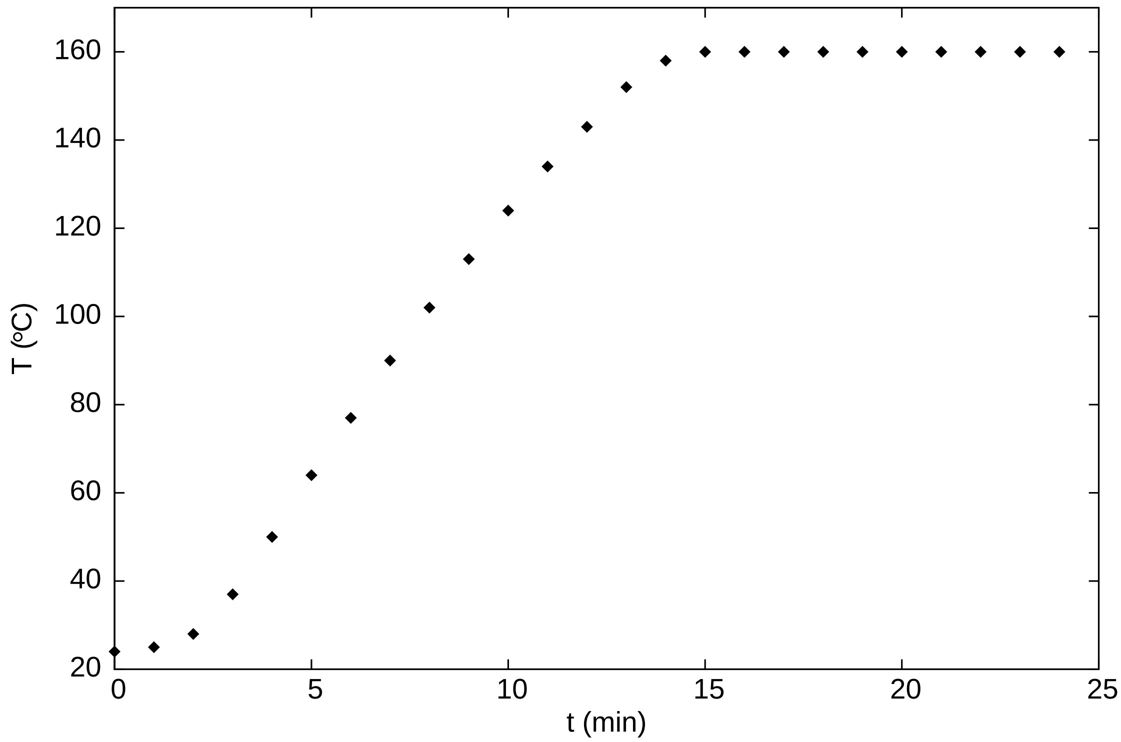
(ii) Using the information above and your answer to part (i), find the power being transferred to liquid X as it boils, in $\text{kJ}\,\text{min}^{-1}$.

(d) Using your answers to the previous parts, find the latent heat of vaporization of substance X, in $\text{kJ}\,\text{kg}^{-1}$.

Graph 1: Rate of change of temperature at different temperatures



Graph 2: Temperature of the liquid as it is heated



Question 15 *Suggested time: 20 minutes*

The intensity, power per unit area, of light falling on a surface in three dimensions can be understood by thinking about light rays coming from a point source in all directions. The total power of the light falling on a given surface is proportional to the number of rays hitting that surface. The intensity at some point is therefore proportional to the density of the rays, or how many rays pass through a given area. The total number of rays leaving the point source depends only on the total power emitted by that source.

One of the consequences of this is that the intensity due to a single point source is inversely proportional to the square of the distance from the source,

$$I \propto P_0 \frac{1}{r^2} \quad , \tag{1}$$

where P_0 is the power emitted by the source. This is because at radius r, a constant number of rays must be spread over an area of $4\pi r^2$ (the surface area of the sphere of radius r), giving a density of rays proportional to $P_0/(4\pi r^2)$.

(a) How would intensity depend on distance in a universe with only two spatial dimensions, like a sheet of paper? Explain your answer.

This concept works for some other physical quantities, such as electric field lines. The same arguments apply; the strength of the electric field due to a single point charge is inversely proportional to the square of the distance from the charge Q. The electrostatic force on an object with charge q due to the electric field of a point charge Q is

$$F = \frac{qQ}{4\pi\epsilon_0 r^2} \quad , \tag{2}$$

where ϵ_0 is a constant. Charges of opposite sign attract, and charges of the same sign repel one another.

(b) An object will move in uniform circular motion only if a centripetal force (i.e. a force acting towards the centre of the circle) is applied. The size of this force must be

$$F = \frac{mv^2}{R}, \tag{3}$$

where m is the mass of the object, v is its speed and R is the radius of the circle.

If an electron with mass m_e and charge $-e$ orbits a helium nucleus with charge $2e$ at radius R, what will the orbital speed of the orbit be? Assume that the orbit is circular.

(c) If two electrons are orbiting the helium nucleus, still at radius R, will their orbital speed be larger or smaller than that of a single electron orbiting? Explain your answer.

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.