

PHYSICS CHALLENGE 2004

A GCSE ONE HOUR PHYSICS OLYMPIAD COMPETITION PAPER

FRIDAY 12th MARCH 2004

We hope teachers will set the enclosed 1 hour paper to their final year GCSE students or the equivalent in Scotland. Xerox copies of the paper should be produced for the students. The solutions with the marking scheme are enclosed. It is intended that the paper should be taken on Friday 12th March, so that it coincides with Science Week. Originally we stated that the paper would be sat on 5th March. This is still possible if the 12th March is not convenient. However, if this is not possible, any date during the period of 5th March until 17th March will be acceptable. Scripts must be posted in sufficient time to arrive by first post on 22nd March. **Any arriving after that date cannot be considered for an award.**

There is no charge for entering the Competition

After you have marked the scripts, please send those scripts with marks exceeding 30, together with the completed form overleaf, to:

Dr. Cyril Isenberg
Physics Challenge
British Physics Olympiad Office
Department of Physics & Astronomy
University of Leicester
University Road
Leicester LE1 7RH
(Tel: 01227823768)

They will be scrutinised and grouped into gold, silver and bronze medal categories for the award of prizes and merit certificates. The form requesting commendation certificates should accompany any scripts.

We hope to invite fifteen students, the top gold award winners, together with their teachers, to the Presentation Ceremony at the Royal Society in London on Thursday 22nd April 2004. 2004 Physics Challenge Certificates and over a hundred prizes will be despatched to those students who have produced exemplary scripts but are not amongst the top gold award winners. All students who obtain above 30 marks will receive a certificate. These will be sent to their teacher who is asked to enter each student's name on a certificate.

Should it not prove possible for your students to enter the Physics Challenge Competition in March, you could still consider setting and marking the paper later in the academic year.

PHYSICS CHALLENGE 2004

ENTRY FORM

Name of Teacher _____

School _____

Address _____

BLOCK

LETTERS

Tel No _____

PLEASE

e-mail address _____

Full names of Students with more than 30 marks (first name following by surname).

	TOTAL MARK	* MARKS		TOTAL MARK	* MARKS

FURTHER ENTRIES CAN BE ATTACHED

Teachers' comments concerning the questions on the Physics Challenge paper will be gratefully received by the organising committee. Should you welcome the opportunity to help with preparation of future years' papers, please indicate below.

Comments:

Would you like to help with preparation of Physics Challenge Papers in future years?

Yes

No

PHYSICS CHALLENGE

2004

Total Mark	* Marks

Name	
School	
Town & County	

Time Allowed: One hour

Attempt as many questions as you can.

Write your answers on this question paper.

*Marks allocated for each long question are shown in brackets on the right.
Allow roughly 10 minutes for Section A, 35 minutes for the first four questions of Section B, and 15 minutes for the final question.*

You may use any calculator.

$$g=10 \text{ ms}^{-2}$$

Section A: Multiple Choice.

Tick the box, which contains the correct answer to each question. There is one mark for each question.

1. A jet aircraft burns 100 tonnes of fuel in 10 hours. One tonne is the same as 1000 kg. What is the average rate of burning fuel?

A. 2.8 kg/s	B. 2.8 N/kg	C. 2.8 J/m	D. 0.1 tonne/hr	E. 167 N/kg
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2. When a metal bar is cooled it contracts. Which statement is true?

A. Density and mass decrease	B. Density decreases, mass stays same
C. Volume increases	D. Density and mass stay the same
E. Mass stays the same, density increases	

3. A mass of 100 g, which is attached to the end of a spring is pulled down a little and released so that it oscillates. If, in the next five seconds, it passes through its rest position ten times. What, approximately, is the period of oscillation?

A. 2.5 s	B. 0.5 s	C. 1 s	D. 2 s	E. 0.2 s
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4. The electric plug on a metal toaster is incorrectly wired. Only one of the three connections is made to the correct terminal – the other two are the wrong way round. The toaster delivers a potentially lethal shock to anyone who touches the casing. Which wire is *correctly* connected?

A. Neutral	B. Live	C. Earth	D. Red wire	E. Brown wire
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5. Point Q is 3 m above and 4 m to the North of Point P. Ignoring friction, how much energy does it take to move a 5 kg sack of potatoes from P to Q?

A. 15 J	B. 20 J	C. 150 J	D. 200 J	E. 250 J
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6. A radioactive source points at a radiation detector 1 cm away. Moving the detector to 3 cm from the source greatly reduces the radiation detected. However, when a 5 mm aluminium sheet is then placed in front of the detector there is no change in the reading. The source is then removed, and the detector's reading halves. What kind of radiation was emitted?

A. alpha	B. beta	C. gamma & beta	D. alpha & beta	E. alpha & gamma
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7. A stone is released from rest and takes 2.2 s to fall from the top to the bottom of an empty well. Water is pumped into the well, and on a second occasion the stone now takes 0.8 s to drop from the top of the well to make a 'plop' as it hits the water surface. What is the depth of the water in the well?

A. 24.2 m	B. 9.8 m	C. 21 m	D. 3.2 m	E. 22.5 m
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8. An electric locomotive is connected to a 20 kV supply via an overhead wire. The return path for the current flows through the two identical parallel rails. If the engine has a power of 5 MW, what is the current in each rail?

A. 125 A	B. 250 A	C. 1.25 kA	D. 20 kV	E. 5 MW
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9. Water in a central heating system enters a 10 kW boiler at a temperature of 25°C and leaves at a temperature of 60°C. If 4200 J of energy is needed to increase the temperature of 1 kg of water by 1°C, how much water flows through the boiler each second?

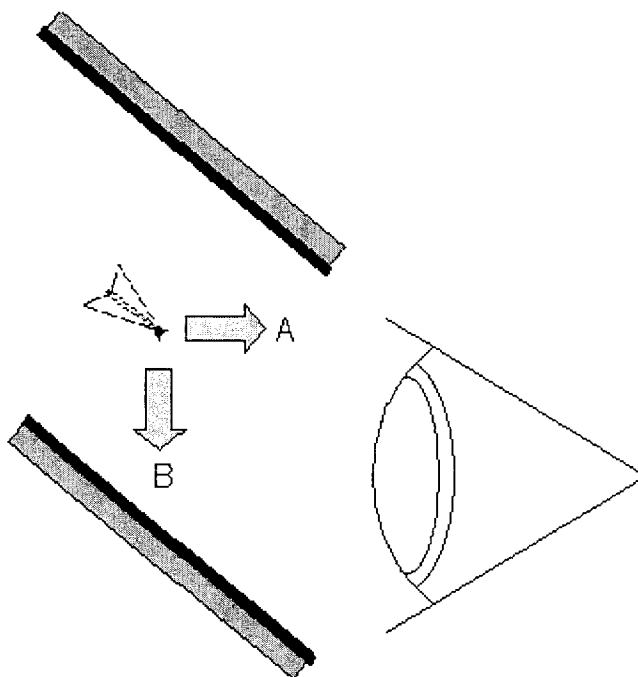
A. 35 g/s	B. 40 g/s	C. 58 g/s	D. 68 g/s	E. 95 g/s
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10. A pupil, using Einstein's famous equation $E = mc^2$, enters the mass m in grams. If the student uses the value of 3×10^8 m/s for the value of c , the speed of light in vacuum, what are the units of energy E ?

A. kilowatt	B. watt	C. megajoule	D. millijoule	E. joule
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Section B: Written Answer

11. A submariner looks into the lower mirror of a periscope. A fly has found its way between the mirrors and is buzzing around. The diagram shows the mirrors and the position of the fly.



- a) Indicate, on the diagram, the orientation and approximate position of the image of the fly at this moment. [2]
- b) If the fly were to move in the direction of the arrow A, the image of the fly would also move. Indicate, on the diagram, which way the image of the fly would move. [1]
- c) If the fly were to move from its original position in the direction of arrow B, the image of the fly would move too. Indicate, on the diagram, which way the image would move. [1]
12. Model rocket motors contain gunpowder, which is detonated electrically by a resistor attached to the explosive. When the rocket is to be fired, a current of 5 A is passed through the resistor for 0.5 s.
- a) Why does this cause the propellant to ignite?

[1]

- b) The battery pack used to provide the current has a voltage of 4 V. Calculate the energy transferred to the resistor before the propellant ignites.

[2]

A similar technique is used in theatres to produce loud bangs, bright flashes or smoke. Here a 24 V supply is used to detonate, electronically, specially constructed fireworks called pyrotechnics. For safety reasons, the explosive must detonate within 0.05 s of the current being switched on. Assume that the energy needed to detonate the pyrotechnic is the same as that needed by the detonator in the rocket.

- c) Calculate the current needed to detonate the pyrotechnic within 0.05 s.

[2]

- d) Calculate the resistance of the pyrotechnic, assuming that it remains constant.

[1]

- e) The resistor functions as the detonator in the pyrotechnic. It is a piece of thin metal wire. Will its resistance change as the current is passed? If so, will it go up or down? Why?

[2]

13. This question estimates the voltage of a thundercloud. We start with a simpler situation. Two parallel plates of metal are held 5 mm apart, and a voltage of 5000 V is maintained between the plates.



- a) State how much energy, E , would be required to move a unit coulomb charge from one plate to the other.

[2]

- b) If a coulomb of charge is transferred from one plate to another, state the relationship between the energy transferred, E , and the force, F , on the charge assuming F is constant. Determine F .

[2]

Your answer to (b) is equal in *magnitude* to the quantity called **electric field strength**, \mathcal{E} , which has units of volts per metre. This is equal to the force per coulomb of charge placed between the plates.

When the voltage is raised to 15 kV, a spark forms between the two plates.

- c) What is the electric field strength, \mathcal{E} , between the plates now?

[2]

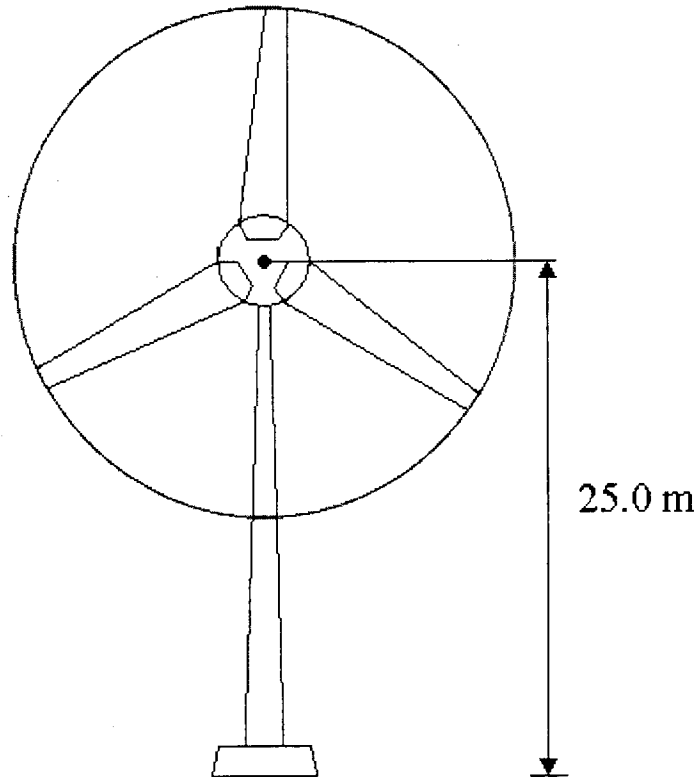
- d) What voltage would be needed to produce the same electric field strength between the ground and the base of a thundercloud at an altitude of 1500 m?

[2]

Note that the actual voltage on a thundercloud differs greatly from your answer in part (d). This is partly due to the process of spark growth. It does not form as a consequence of one event.

14. This questions concerns wind energy

The average wind speed at 25.0 m above the Earth's surface, on top of a hill, is 7.00 ms^{-1} . A wind turbine on the top of the hill has the rotational centre of its blades at 25.0 m above the ground and has blades of radius 5.00 m. The density of the air is 1.30 kgm^{-3} .



Imagine the circle described by the tips of the rotating blades.

a) What is the volume of air passing through this circle each second?

[2]

b) What is the mass of this air?

[1]

c) What is the kinetic energy of the mass of air?

[1]

- d) The turbine converts 40% of the wind energy into electrical energy. What is the power output of the generator?

The electrical power is transmitted to a farm through a cable with a resistance of 15 ohms at a voltage of 1000 V.

- e) What fraction of the power is lost in transmission?

[4]

15. In this question, you will follow the thoughts that convinced Sir Isaac Newton of the Universal Law of Gravitation.

Let us first consider an apple falling. Near the surface of the Earth an apple, when released from rest, accelerates towards the centre of the Earth at approximately 10 m/s^2 .

- a) Show that an apple will fall 5.0 m in 1.0 s.

[2]

The Greeks showed that the Moon is roughly 60 times further from the centre of the Earth than an apple at the Earth's surface. Newton expected the acceleration due to the Earth's gravitational force at the Moon's orbit to be smaller than at the surface of the Earth. The question was, how much smaller? Sixty times?

Newton had a remarkable intuition, and expected the acceleration due to gravity not to be 60 times smaller, but 60×60 times smaller; that is 3600 times smaller.

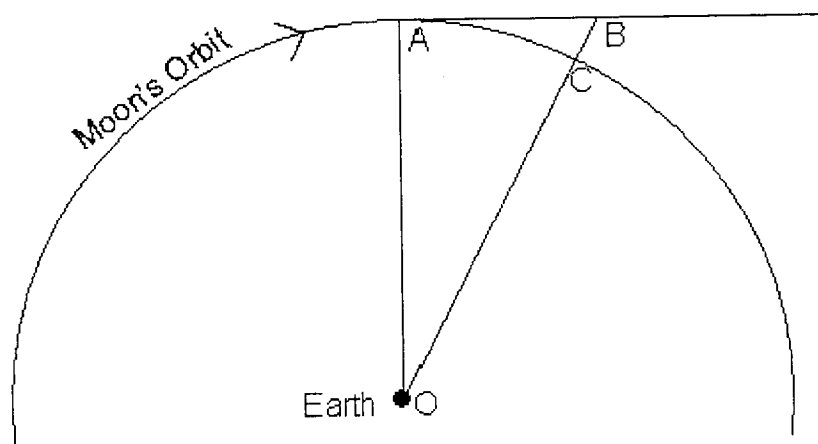
- b) Show that the Moon must fall approximately 1.4 mm towards the centre of the Earth if it initially has zero velocity in this direction.

[2]

- c) The Moon takes approximately 28 days to orbit the Earth, at a radius of 384 000 km. Show that the speed of the Moon in its orbit is approximately 1.0 km/s.

[2]

Study the diagram below, which is NOT TO SCALE.



Newton argued that if there was no gravitational acceleration at A towards the centre of the Earth at O, the Moon would continue to move along the straight line from A, that forms the tangent at A, to say, B, a point on this tangent. Therefore the Moon, in travelling in its orbit, can be considered, to a good approximation, to "fall" below B, along BO, to C.

- d) What is the distance AB if the Moon reaches point B one second after being at point A?

[1]

- e) Apply Pythagoras' Theorem to show that, using distances measured in km,

$$(1.0)^2 = 2rx + x^2,$$

where r is the radius of the Moon's orbit, OA or OC, and x is the distance the Moon "falls" in 1.0 s, BC.

[4]

- f) Use the expression in part (e) to show that a fall of 1.3 mm each second is necessary to describe the motion of the Moon in its orbit. To within the approximations made, this is equal to the answer to (b).

[2]