2009 AS PHYSICS COMPETITION PAPER

ONE HOUR PHYSICS COMPETITION PAPER

FRIDAY 13 th MARCH 2009

We hope teachers will set and mark the enclosed paper for their AS students, or equivalent students in Scotland. The solutions and marking scheme are contained herein. It is intended that the paper should be taken on Friday 13 th March. However if this is not possible, any date during the period 9th –16th March will be acceptable. Scripts of the Gold Medallists and requests for certificates must be posted in sufficient time to arrive by first class post on Monday 30 th March at the Olympiad Office at the University of Oxford. Any scripts arriving after this date cannot be considered for an award.

After the scripts have been marked please send those scripts with marks of 38 and above to the Oxford office, the scripts of the Gold Medal Certificate students, in order to be considered for the award of a book prize, together with the entry form, which is on the following page, and request form for certificates to:

Lorna Stevenson
BPhO Office
AS Physics Competition
Department of Physics
Clarendon Laboratory
Parks Road,
University of Oxford
Oxford OX1 3PU

We will invite the five outstanding Gold Medallists, together with their teachers, to the Physics Challenge Presentation Ceremony at The Royal Society in London on Thursday 30 April 2009. Prizes and certificates will be despatched to all remaining medallists, who are not amongst those invited to the Presentation, in May. Teachers are requested to complete the certificates according to the medal scheme specified on the last page, and present them to their students.

2009 AS PHYSICS COMPETITION

ENTRY FORM

Name of teacher ________________________________

School ________________________________

Address ________________________________

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Tel. No. ________________________________

Email ________________________________

TOTAL NUMBER OF ENTRIES __________

GOLD MEDALLISTS: Full names and marks of Gold Medallists with marks in the range 38 - 50 for consideration of the award of a book prize.

NAME	TOTAL MARK

NAME	TOTAL MARK

Please complete and return the request form for certificates.

TEACHERS' COMMENTS

We welcome comments concerning questions in this AS Physics Competition paper and suggestions for possible future challenging questions.
Comments:

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2009 AS PHYSICS CERTIFICATES

All Participating students will receive a certificate. They will be awarded Gold, Silver, Bronze and Participation Medal Certificates, based on their marks, according to the scheme below:

Medal Certificate	Gold	Silver	Bronze	Participation
Mark Range	50 – 38	37–31	30 - 20	19 – 0
No. of certs. Requested				

Total Number of Entries	

NAME OF TEACHER ______________________________

NAME OF SCHOOL ______________________________

ADDRESS OF SCHOOL ______________________________

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Please return to:

Lorna Stevenson
BPhO Office
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Department of Physics
Clarendon Laboratory
University of Oxford
Parks Road, Oxford OX1 3PU

AS COMPETITION PAPER 2009
SOLUTIONS

Total Mark/50

Marking

The mark scheme is prescriptive, but markers must make some allowances for alternative answers.

A value quoted at the end of a section must have the units included. Candidates lose a mark the first time that they fail to include a unit, but not on subsequent occasions except where it is a specific part of the question.

Significant figures are related to the number of figures given in the question. A single mark is lost the first time that there is a gross inconsistency (more than 2 sf out) in the final answer to a section.

Ecf: this is allowed in numerical sections provided that unreasonable answers are not being obtained. Ecf can not be carried through for more than one section after the first mistake (e.g. a mistake in section (d) can be carried through into section (e) but not then used in section (f)).

Section A: Multiple Choice

1. **C**
2. **D**
3. **C**
4. **B**
5. **A**

6. **D**
7. **C**
8. **B**
9. **A**
10. **B**

There are 1½ marks for each correct answer. The final multiple choice score should be **rounded up** to a whole number.

Maximum 15 marks

1. The lift travels at a constant speed so that there is no acceleration and no extra force besides the usual weight of the child. The scales would only show a different reading if the lift was accelerating.

2. To change from 36 mm to 61 mm (increase of 25 mm) the temperature increases by 100^{o}C. This is 0.25 mm per 1^{o}C. From 36 mm to 43 mm is an increase of 7 mm, corresponding to 7/0.25 or 28^{o}C increase from 0^{o}C.

3. Initial energy is KE + grav PE and this is converted to grav PE is it goes up the slope and stops.

$$½ \text{ x } 750 \text{ x } 20^2 + 750 \text{ x } 9.8 \text{ x } 5 = 750 \text{ x } 9.8 \text{ x } h$$
$$h = 25 \text{ m}$$

4. Substitute the units for c^2 and ε_o and rearrange.

$$m^2 s^{-2} = \frac{1}{\mu_0 N^{-1} C^2 m^{-2}} \quad and \quad N = kg\, m\, s^{-2}$$

5. The resistors all have the same value, so with two of them in series, the current though R is halved. It also has half the voltage, so that V x I drops to ¼ of the power.

6. This is not a very sensible arrangement for voltmeter V_1. The potentials across parallel arms of the circuit are the same. So the potential across D is 1V. Current through V_3 is 3/R (I=V/R) and that through V_2 is 2/R. Total current flow through V_1 must be 3/R + 2/R which is 5/R. Therefore potential across V_1 is 5V.

7. A steel ball bearing would have N and S poles induced, so that it would be pulled in both directions along a field line. However, the field is not uniform and the poles in the denser part of the field would draw it further into the field , or the induced poles are not diametrically opposite on the ball bearing. It would have a force directed towards X.

8. If arrows are drawn at the centre of the square for the circular field due to each wire at the corner of the square, then the field in A is zero, as are the fields in C and D. The resultant field of B is towards the right. It would not make any difference to the answer to the question if the direction of circulation of the field line around the wire was not known, as long as the student was consistent.

9. The essence of the question is in the fact that Energy/length α 1/r

   and then E α A^2
   so that A^2 α 1/r
   As r $\rightarrow$ 4r then A $\rightarrow$ A/2

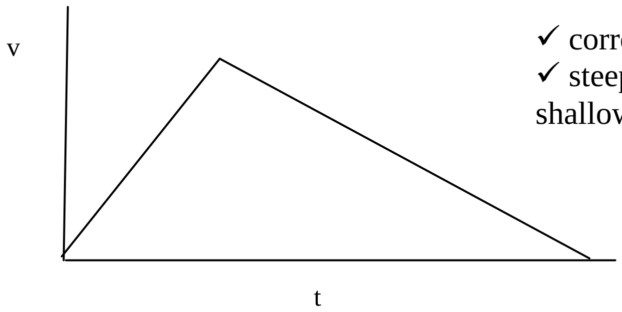
10. Not all of the counts are measures; typically only 1% of the γ would be counted by an ordinary Geiger counter. The background would shift the whole graph up the Y axis (and it is relatively small - the curve drops close to the axis - and so variations in it would not be significant). It is the random decay of the source which gives the variation.

Section B: Written Answers

Question 11.

A plane accelerates from rest to take off from a runway. There is a point of no return where the pilot will not be able to stop the plane before the end of the runway if he fails to take off. The runaway is 2 km long and the plane can accelerate at 3 ms^{-2} and can decelerate at 2 ms^{-2}. We can calculate the length of time available from the start of the take off to the point of no return.

a) Sketch a graph of the speed of the plane against time for the situation where the plane fails to take off but the whole length of the runway is used. (no values are required)



✓ correct shape
✓ steeper acceleration, shallower deceleration

[2]

b) If t_1 is the time taken for the plane to reach its maximum speed v, and t_2 is the time taken for it to decelerate before it goes beyond the end of the runway, express v in terms of t_1 and t_2.

$v = at$

so that $v = 3t_1$ ✓

and also $v = 2t_2$ ✓ [2]

c) Calculate the distance s_1 travelled by the plane whilst accelerating, in terms of t_1, and the distance s_2 travelled by the plane whilst decelerating, in terms of t_2.

$s = ½ at^2$ ✓ $s_1 = ½\, 3t_1.t_1 = 3/2\, t_1^2$ ✓ (or for s_2) $s_2 = ½\, 2t_2.t_2 = t_2^2$

(having substituted for a)

OR area under graph: $s_1 = ½\, vt_1$ ✓ and $s_1 = ½\, vt_1$ ✓ [2]

d) From your answers to (b) and (c), calculate the value of t_1, the time taken to reach the point of no return, given that the runaway is 2 km long.

$2000 = s_1 + s_2$ so, $2000 = 3/2\, t_1^2 + t_2^2$

But $t_2 = 3/2\, t_1$ so, $2000 = 3/2\, t_1^2 + 9/4\, t_1^2$ (solvable equ)✓ $t_1 = 23$ s ✓

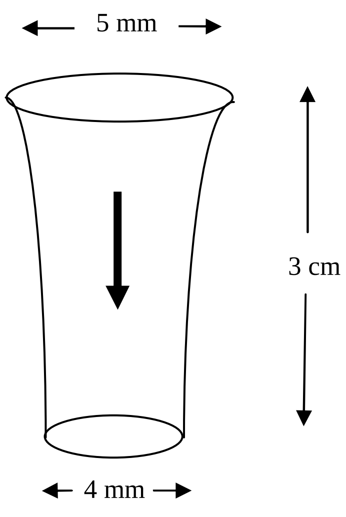
OR $2000 = s_1 + s_2$ so, $2000 = ½v_1 + ½v_2 = ½\, v(t_1 + t_2) = ½\, v^2 5/6$ ✓ (solvable equation for v)

$v = 69.3$ ms^{-1} so that $t_1 = v/3 = 23$ s ✓ [2]

/8

Question 12.

A stream of water flows vertically downwards from a running tap, as shown below. Some way down the flow, there is a 3 cm long segment of flowing water where the diameter of the circular stream reduces from d_1 = 5 mm to a diameter d_2 = 4 mm. From this we can determine the flow rate and how long it will take to fill a beaker of volume 200 cm^3. We shall assume that water is incompressible.



a) Explain why the segment of water becomes narrower.

Speed of water increases as it falls ✓ owtte

Volume flow per unit time at top = volume flow per unit time at bottom ✓ owtte

[2]

b) If the speed of the water at the top of the segment is v_1 then what is the speed v_2 of the water at the bottom of the segment expressed in terms of v_1, d_1 and d_2 ?

$v_1 \pi d_1^2 /4 = v_2 \pi d_2^2/4$

$v_2 = d_1^2/d_2^2 \, v_1$ ✓ [1]

c) Calculate the speed of the water flow at the top of the segment.
You may want to use the equation of motion $v^2 - u^2 = 2as$

$v_2^2 - v_1^2 = 2 \text{ g } s$ *so that* $(d_1^4/d_2^4) v_1^2 - v_1^2 = 2 \text{ g } s$ ✓ (some form of correct substitution)

$v_1^2(5^4/4^4 - 1) = 2 \times 9.8 \times 0.03$

$v_1 = 0.64 \text{ ms}^{-1}$ correct result ✓ ✓ [3]

d) From your answer to part (b), calculate the volume flow of water per second.

Volume rate of flow $= 0.64 \pi d_1^2/4$

$= 1.26 \times 10^{-5} \text{ m}^3\text{s}^{-1}$ ✓ ecf

$= 12.6 \text{ cm}^3\text{s}^{-1}$ [1]

e) Calculate the time taken to fill a 200 cm^3 beaker.

Time to fill beaker = volume / rate of flow

= 200 /12.6

= 16 seconds ✓ ecf [1]

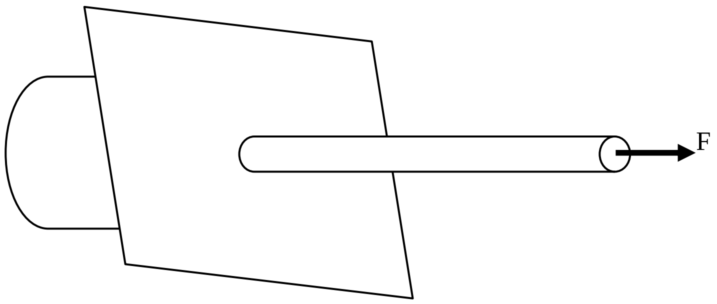
/8

Question 13.

This question requires you to consider the units of each quantity in order to follow the calculation.
In order to reduce its diameter, a wire is pulled through a small hole in a metal plate. The wire is made of metal whose specific heat capacity is 400 J kg^{-1} $^{o}C^{-1}$ and, on emerging from the hole, has a mass per unit length of 5 g per m. A steady force of 600 N is required. If all the heat generated is retained in the wire, we can calculate the rise in temperature of the wire.

Calculate all quantities using SI units (metre, kilogram, second).

a) Draw a simple sketch of the situation and mark on it the force applied to the thin wire.



Any realistic sketch ✓
[1]

b) What is the value of the work done on one metre length of the wire?

WD = F x s

= 600 J ✓ [1]

c) How much work is done on one kilogram of wire?

600 J on 5 g

So 600/0.005 = 120,000 Jkg^{-1} ✓ (ecf) [1]

d) Assuming all of the work done is converted into heat calculate the temperature rise of the wire.

Temperature rise = 120,000 Jkg^{-1}/ 400 $Jkg^{-1}$$^{o}C^{-1}$ ✓

= 300 ^{o}C ✓

[2]

If, however, the temperature of the wire were kept constant by spraying it with cold water, then we can calculate what mass of water would be needed.

Specific heat capacity of water is 4,200 J kg^{-1} $^{o}C^{-1}$

e) Calculate the mass of wire, in kilograms, that is produced each second if it emerges from the hole at a speed of 8.4 ms^{-1}.

5 g/m at 8.4 m/s will give 5 x 8.4 g/m x m/s ✓ relevant quantities used

Wire produced at 42 gs^{-1} or 0.042 kgs^{-1} ✓ (ecf)

[2]

f) Using your answer from part (c), calculate the work done on the wire each second.

120,000 J/kg x 0.042 kg/s ✓ for relevant quantities used

= 5040 Js^{-1} (ecf)

[1]

g) If the temperature rise of the water were to be 12 ^{o}C, calculate the mass of water used each second to keep the temperature constant.

Energy supplied to heat water by 12^{o}C is 12 x 4,200 = 50,400 J/kg ✓

Mass of water needed to remove the 5040 Js^{-1} from the wire is 0.1 kgs^{-1} ✓ (ecf)

[2]

/10

Question 14.

a) A laser produces light pulses of energy 5 J and duration 2 x 10^{-9} s. If the beam is circular in cross section and of diameter 2 mm, calculate the intensity (the power per unit area) of a laser pulse.

$I = 5/(2 \times 10^{-9} \times \pi \times 1.0^2 \times 10^{-6})$

$= 8.0 \times 10^{14}$ Wm^{-2} ✓

[1]

b) State one significant difference in the nature of the light emitted by a laser from that emitted by an ordinary light bulb.

Single wavelength / collimated beam / much greater intensity at a single wavelength (but not just greater intensity alone) Must be nature of light, not how it is produced [1]

c) The wavelength of the laser is 400 nm. Light can be seen either as a wave or a particle (a photon). The energy *E* of a photon of light is given by *E* = *hf*, where *f* is the frequency of the light and *h* is Planck's constant. Calculate the number of photons in a single pulse from the laser.

Planck's constant $h = 6.6 \times 10^{-34}$ Js
speed of light $c = 3.0 \times 10^8$ ms^{-1}

$E_{photon} = hc/\lambda = 6.6 \times 10^{-34} \times 3 \times 10^8 / 400 \times 10^{-9}$

$= 4.95 \times 10^{-19}$ J ✓

No of photons = $5 / (4.95 \times 10^{-19}) = 1.0 \times 10^{19}$ ✓ [2]

d) Calculate the volume of a single pulse of light from the laser, and hence the density of photons in the laser pulse.

Vol of pulse = length x π x r^2

$= 3 \times 10^8 \times 2 \times 10^9 \times \pi \times 1.0^2 \times 10^{-6} = 1.88 \times 10^{-6}$ m^3 ✓

for including length of pulse as *ct* in calculation ✓

Density of photons = $N/V = 1.0 \times 10^{19} / 1.88 \times 10^{-6} = 5.3 \times 10^{24}$ m^{-3} ✓ ecf [3]

e) If the photons in the pulse were equally spaced, rather like ball bearings packed uniformly in a box, what would be the volume occupied by a single photon?

Volume per photon $= 1/5.3 \times 10^{24}$

$= 1.9 \times 10^{-25}\ m^3$ ✓ [1]

f) If the volume occupied by a photon was a cube, what would be the length of a side of the cube?

$\ell = \sqrt[3]{1.9 \times 10^{-25}}$

$\ell = 5.7 \times 10^{-9}$ m ✓ [1]

/9