BRITISH PHYSICS OLYMPIAD 2009

COMPETITION

Paper 2 7^{th} November 2008

3 hours plus 15 minutes reading time

There are EIGHT questions.
The marks for each section are given on the right hand side of the page.

FOUR questions are to be attempted. Formulae sheets may be used.
QUESTION 1 IS COMPULSORY.
It is expected that students will spend 75 minutes on this question. The total mark allocated to this question is 80. Students can attempt any, or all, of the questions in this section. However the maximum total mark that will be awarded is 40.
THREE of the remaining seven questions, only, should be attempted. Students are recommended to spend 35 minutes on each of these questions. The maximum mark for each question is 20.

Important Constants

Speed of light	c	3.00×10^{8}	m s^{-1}
Planck constant	h	6.63×10^{-34}	Js
Electronic charge	e	1.60×10^{-19}	C
Mass of electron	m_e	9.11×10^{-31}	kg
Acceleration of free fall	g	9.81	ms^{-2}
Gravitational constant	G	6.67×10^{-11}	N m^{2} kg^{-2}
Sun – Earth distance	R_{SE}	1.50×10^{11}	m
Density of mercury	ρ	1.35×10^{4}	kg m^{-3}

Q1

(a) A 10 W immersion heater is placed in 0.25 kg of a liquid which is contained in a calorimeter of heat capacity 50 JK^{-1}. It is switched on, and after a time the temperature of the liquid reaches a constant value. The heater is now switched off and the rate of fall of temperature is 15 mKs^{-1}. What is the specific heat capacity of the liquid ?

[3]

(b) Comment on the following :

(i) The planets move with constant velocity in circles around the Sun.
(ii) The horizontal component of the energy of a tennis ball remains constant after being hit by a racket.
(iii) The speed of a light spot produced on a distant wall, by a rotating laser, can be greater than c, the speed of light.
(iv) The north magnetic pole is near the geographic north pole and the north pointing end of the needle of a compass always points to the north magnetic pole.
(v) The specific heat capacity of a gas at constant volume differs from that at constant pressure .
(vi) When gases expand rapidly they are cooled.

[6]

(c) A viola string 0.50 m long is tuned to A ; a frequency of 440.0 Hz..

(i) What change in length will raise its frequency to 550.0 Hz ?
(ii) If it goes out of tune and vibrates at 435.6 Hz, by what fraction, and in what sense, must the tension in the string be changed to retune it ?

[5]

(d) A man cycles to work, with the wind behind him , at 8.0 ms^{-1} and returns home, Against the wind, at 4.0 ms^{-1}. What is his average speed ?

[3]

(e) A machine gun fires bullets of mass 10g at a speed of 12 kms^{-1} . If the gunner can exert an average force of up to 80 N against the gun, calculate the maximum number of bullets that he can fire per minute.

Sketch a force – time graph of the recoil force of the gun on the shoulder of the gunner, and show, graphically, what is understood by the average force.

[5]

(f) An oil drop is observed between the plates of a capacitor.

(i) In an electric field of 0.30 MVm^{-1} a stationary drop, with one excess electron, is observed. What is the weight of the drop ?
(ii) This drop is later observed to fall with a terminal speed of 0.20 mms^{-1}, which is independent of the pd between the plates.
Explain this observation. [4]

(g) Explain qualitatively how Newton's interference rings are formed using an optical plate and a convex lens.

[4]

(h) A body, mass m, rests on a scale pan which is supported by a spring. The period of oscillation of the scale pan is 0.50 s. It is observed that when the amplitude of the oscillations is increased, and exceeds a certain value, the mass leaves the pan. Explain.
At what point in the motion does the mass initially leave the pan ?

[6]

(i) A uniform capillary tube, closed at one end, contains air trapped by a thread of mercury 85 mm long. When the tube is held horizontally, the length of the air column is 50 mm. When it is held vertically, with the closed end downwards, the length is 45 mm. Determine the atmospheric pressure.

[4]

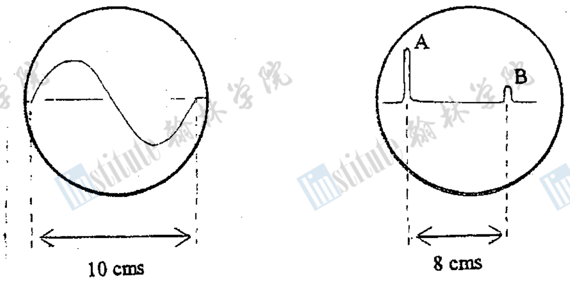

Figure 1.j

(j) A sine-form voltage of frequency 1250 Hz is applied to the Y-plates of a cathode ray oscilloscope. The trace obtained is displayed in Figure 1.j. If a radar transmitter sends out short pulses, and at the same time one applies a voltage to the Y-plates of the oscilloscope, with the time base setting unchanged, the deflection A is produced, which is shown in Figure 1.j. An object reflects the radar pulse which when received at the transmitter and amplified gives deflection B. What is the distance of the object from the transmitter ?

[3]

(k) Answer the following questions with an example where possible:

(i) Can a body to be accelerating while travelling at constant speed ?
(ii) Can a body have a constant velocity and a varying speed ?
(iii) If a body has zero velocity, can it be accelerating ?
(iv) Can a body be accelerating in a direction opposite to its velocity ?

[6]

(l) The equation

$$y = A \sin (\omega t - kx)$$

represents a plane wave travelling along the x-direction in a medium, y is the displacement of a point at position x at time t. A, k and ω are constants. Deduce the direction and speed of the wave.

If $A = 1.0 \times 10^{-7}$ m, $\omega = 6.6 \times 10^{3}$ s^{-1} and $k = 20$ m^{-1}, calculate:

(i) the speed of the wave
(ii) the maximum speed of a particle of the medium due to the wave.

[5]

(m) 20 identical electric lamps, each of 12 V, are connected in series to a 240 V mains supply. The total power consumed is 24 W.

(i) What is the resistance of each lamp ?
(ii) If one lamp is short circuited, what is the power consumed ?
(iii) When one of the lamps is tested by applying a pd of 0.10 V, a 10mA current is measured. Explain.

[6]

(n) The maximum kinetic energy of photoelectrons ejected from a tungsten surface, by light of wavelength 248 nm, is 8.6×10^{-20} J. What is the work function, in eV, of tungsten ?

[5]

(o) An electron and a positron annihilate each other to produce two γ-rays. Calculate the minimum energy of the photons ?

[3]

(p) Explain qualitatively using sound waves as an example, what is understood by:

(i) the Doppler effect
(ii) the phenomenon of beats
(iii) stationary waves

[6]

(q) What is a magnetic field line ?
Draw the magnetic field lines in a plane perpendicular to: (i) a current I in an infinite straight wire and (ii) the axis of a bar magnet at one end.

[6]

Q2

A spherical stone is dropped from the top of a cliff of height h at time $t = 0$. At the same moment another identical stone is thrown vertically upwards from the bottom of the cliff with a *positive* velocity u in the same vertical line as the first stone.

(a)

(i) After what time, T_c, will the stones collide ?

(ii) If the stones have equal speeds on collision, what is the value of u, and T_c ?

(iii) If the collision in (ii) is elastic, determine the time interval between the impacts of the stones on the ground.

[9]

(b)

(i) Sketch a fully *labelled* velocity – time graph for the motion of the two stones, on the same graph, using a full curve for the stone dropped from the cliff top and a dotted curve for the stone projected vertically upwards from the bottom of the cliff.

(ii) Sketch a fully *labelled* height– time graph for the two stones using the notation specified in (i).

[11]

Q3

(a)

A man of height $h_0 = 2.00$ m and mass m is to bungee jump from a platform situated at a height $h = 25.0$ m above a lake. One end of an elastic rope is attached to his foot and the other end is fixed to the platform. He falls vertically.

The unstretched length of rope is l_0 and its force constant is k. The rope is chosen so that his speed will be reduced to zero the instant his head reaches the water surface.

When he is at rest, in equilibrium, at the end of the rope, his head is 8.00 m above the water. Assume the centre of gravity of the man is half way up his body.

Write down an algebraic expression for :

(i) the energy equation at his lowest point

(ii) the force equation at equlibrium

(iii) Determine l_0 numerically. [10]

(b)

Determine the man's maximum:

(i) speed

(ii) acceleration

[10]

Q4

(a) (i) Determine the relationship between the decay constant λ and the half life τ of a radioactive source ?

(ii) How long would it take for 87.5% of the atoms in Pb^{209}, with a half life of 3.3 hours, to decay ?

[8]

(b) A small volume of solution, containing a radioactive isotope of sodium, has an activity of 1200 disintegrations per minute when injected the blood stream of a patient. After 30 hours the activity of a 1.00 cc sample of the blood is 0.50 disintegrations per minute. If the half life of the sodium isotope is 15 hours, determine the volume of blood in the patient's body.

[5]

(c) A point source of γ- rays has a half life of 30 minutes. The initial count rate, determined by a Geiger counter placed 2.0 m from the source, is 360 s^{-1}. The distance between the counter and the source is changed. After 90 minutes the count rate is 5.0 s^{-1}. What is distance between the source and the counter ?

[7]

Q5

(a) A uniform disk, of radius R and surface density ρ, has its centre, O, at the origin of a Cartesian coordinate system. A disk of radius $R/2$, and centre $(R/2, 0)$, together with two disks of radius $R/4$ with centres at $(0, +5R/8)$ and $(0, -5R/8)$, are removed.

(i) Confirm that the three circular holes do not overlap.

(ii) Determine the centre of gravity of the remaining object.

[8]

(b) A uniform plank OP of length l and mass M rests with P against a vertical wall. O is on the horizontal floor which has a coefficient of friction $\mu = 0.35$, such that OP makes an angle θ with the floor.

(i) Draw a diagram inserting all the forces, including the horizontal component forces, F_{HO} and F_{HP}, at O and P respectively. The vertical component at O is F_{VO} and that at P is F_{VP}.

(ii) Write down the conditions for the forces on the plank to be in equilibrium.

(iii) Obtain an expression for (F_{OV} / F_{OH}) in terms of θ in (ii) if the wall is smooth.

(iv) Deduce the smallest value of θ.

[12]

Q6

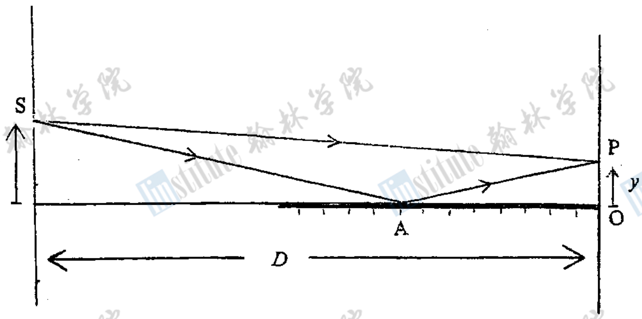

Figure 6.1

In an interference experiment a monochromatic point source of light, S, wavelength λ, produces interference fringes on a distant vertical screen, Figure 6.1. At point P on the screen the direct ray SP and the reflected ray, SAP, produced by a horizontal mirror that meets the screen at O, interfere. The distance OP = y and the source of light is a distance D from the screen. S is a vertical distance a from the horizontal line of the mirror. D is much larger than a.

(a)

(i) Explain why the reflected ray can be considered to come from the reflected image of S in the mirror.

(ii) Why is the interference pattern similar to that produced in a Young's double slit experiment ?

(iii) Explain the nature of the zero order fringe. [6]

(b)

(i) Using Pythagoras's theorem, determine the length of the two rays reaching P in terms of y, a and D. Deduce their path difference, p.

(ii) Using the approximation below, obtain a simplified expression for p.

(iii) Write down the conditions for constructive and destructive interference at P using the result obtained in (ii).

(iv) If one replaces the monochromatic source with a white light source, what is observed ?

[14]

$$[D^2 + x^2]^{1/2} = D[1 + (x/D)^2/2 + \dots] \quad \text{if } x \text{ is much smaller than } D.$$

Q7

(a)

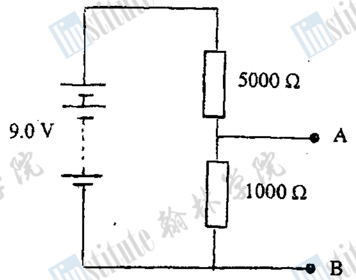

Figure 6.a

What is the final potential difference between A and B:

(i) in Figure 6.a ? What applications does this circuit have ?
(ii) if, in addition, a 500 ohm resistor is connected from A to B ?
(iii) if the 500 ohm resistor in (ii) were replaced by a 2.0 μF capacitor ?

[5]

(b)

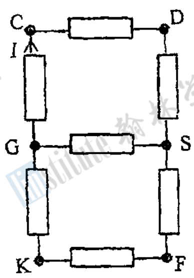

Figure7.b1

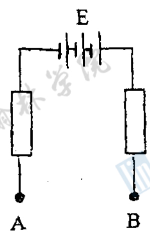

Figure 7.b2

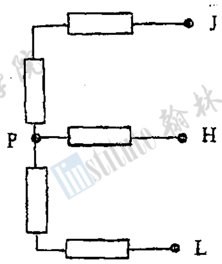

Figure 7.b3

The above electrical configurations all have resistors with resistance R. In Figure 7.b2 the batteries have total emf E. Determine the current I in Figure 7.b1 between G and C if :

(i) A, Figure 7.b2, is joined to C, Figure 7.b1, and B is joined to D
(ii) A is joined to C and B to K
(iii) in (ii) C is joined to J, Figure 7.b3, H to G and L to K
To simplify this calculation it may be helpful to consider the symmetry and compare the potentials at P and S .

[15]

Q8

(a)

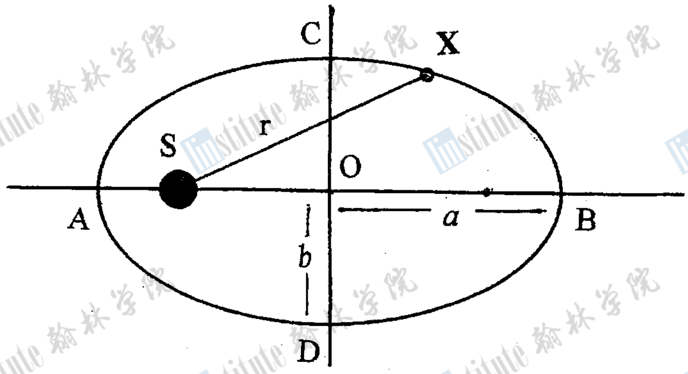

Figure 8.a

Planet X, mass m, is in an elliptical orbit, centre O, Figure 8.a, around a star S, mass M. It has a speed v when at a distance r from the centre of S. The lengths of the major and minor axes are $2a$ and $2b$.

(i) Write down an algebraic expression for the total energy E of the planet.

(ii) Deduce from (i) the point/s in the orbit where v is a maximum and a minimum.

(iii) Comment on the time to travel, clockwise, from C to D and D to C.

Kepler's Third Law states that the period T for elliptical motion is related to a by $T^2 = ka^3$, where k is a constant, for a planet, or smaller body, about a star.

(iv) Determine, in the most convenient units, k for the circular motion of the Earth about the Sun using the known values of T and a; here $a = b$ and S is at O.

(v) Halley's comet orbits the Sun about every 76 years . Calculate the length of its major axis. [10]

(b)

Kepler's Second Law states that for a body in elliptical motion about a more massive body , as in Figure 8.a, the radius vector sweeps out an area proportional to the time taken by the body to travel from one point to another in the orbit.

A space capsule is launched from a spherical planet, radius R, with no atmosphere, at L and returns to the planet at T. The angular separation between the launch point L and the termination point T, with respect to the centre of the planet O, is 2θ. The minor axis of this elliptical path is along TL, and the major axis has length $2R$, Figure 8.b.

(i) How long does the flight of the capsule take if the period for the 'complete' elliptical path is T_0?

(ii) Does the result in (i) apply to the limiting case of $\theta = 0$? Explain.

The area of an ellipse with major and minor axes of lengths $2a$ and $2b$, respectively, is πab.
$\sin(2\theta) = 2\sin\theta\cos\theta$.

[10]

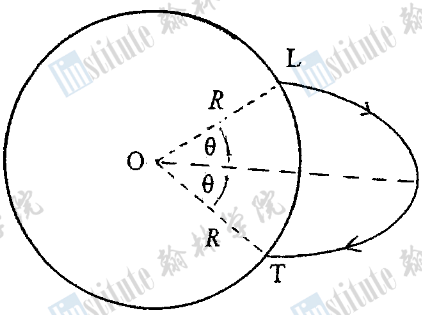

Figure 8.b