DEPARTMENT OF PHYSICS AND ASTRONOMY

Data provided: *A formula sheet and table of physical constants is attached to this paper*
Linear:linear graph paper

Autumn Semester 2010-2011

PHYSICS **3 HOURS**

Answer questions ONE, FOUR and SEVEN plus ONE other from each section, 6 in all.

Answers to different sections must be written in ***separate books,*** *the books tied together and handed in as one.*

All questions are marked out of twenty. The breakdown on the right-hand side of the paper is meant as a guide to the marks that can be obtained from each part.

SECTION A

1. COMPULSORY

(a)(i) Sketch a velocity / time graph to show the motion of a particle that accelerates from an initial speed u to a final speed v with uniform acceleration a. [1]

(ii) Using the graph, derive an equation for the displacement s of the particle in terms of time t, a and u. [2]

(iii) A car accelerates from 17 m s^{-1} to 31 m s^{-1} with a uniform acceleration of 2.5 m s^{-2}. Calculate the displacement of the car during the acceleration. [2]

(b) A fireworks rocket has a mass of 560 g and its initial acceleration is 6.0 m s^{-2} when launched vertically upwards.

(i) Calculate the magnitude of the initial thrust of the rocket. [2]

(ii) Calculate the initial acceleration of the rocket when launched horizontally. [2]

(c) In a downhill ski competition a skier (mass 75 kg) takes 52 seconds to descend a course 1750 m long with a vertical drop of 220 m. The speed of the skier at the finish line is 54 m s^{-1}. Calculate:

(i) the average speed of the skier during the descent; [1]

(ii) the percentage of the initial gravitational potential energy transformed into kinetic energy of the skier; [2]

(iii) the average frictional force exerted on the skier during the descent. [2]

(d) The vectors $\mathbf{s}_1$ and $\mathbf{s}_2$ represent two displacements, in metres:

$$\mathbf{s}_1 = 4\hat{\mathbf{x}} + 7\hat{\mathbf{y}} \quad \text{and} \quad \mathbf{s}_2 = 3\hat{\mathbf{x}} - 2\hat{\mathbf{y}}.$$

Calculate:

(i) the angle between $\mathbf{s}_1$ and the x-direction; [1]

(ii) the magnitude of the sum of $\mathbf{s}_1$ and $\mathbf{s}_2$. [2]

(e) A stone is kicked horizontally at 30 m s^{-1} of the top of a cliff 20 m high. Calculate, assuming negligible drag, the distance between the foot of the cliff and the point where the stone hits the sea. [3]

2.

(a) Define momentum and give its SI unit. [2]

(b) State Newton's third law of motion. [2]

(c) Explain the difference between *elastic* and *inelastic* collisions. [2]

(d) Two gliders with equal mass of 0.20 kg are on an air track. One is stationary; the other is moving towards it at 3.0 m s^{-1}. They collide and join together. Calculate the velocity of the gliders after the collision. [2]

(e) A spacecraft (mass 1200 kg) is attached to its booster rocket (mass 4800 kg) and both are moving in a straight line with a velocity of 500 m s^{-1}. The spacecraft is separated from the booster by a controlled explosion. The two parts separate from each other with a relative speed of 100 m s^{-1}. Calculate:

(i) the velocities of the spacecraft and the booster after they separate; [4]

(ii) the increase in total kinetic energy as a result of the separation. [3]

(f) A tennis ball (mass 0.058 kg) is moving horizontally at 40 m s^{-1} when it is returned back along its original path at 30 m s^{-1}. The ball is in contact with the tennis racket for 0.15 s. Calculate:

(i) the change in momentum of the ball as a result of its collision with the racket; [3]

(ii) the average force exerted by the racket on the ball during the collision. [2]

3.

(a) Using a vector method,

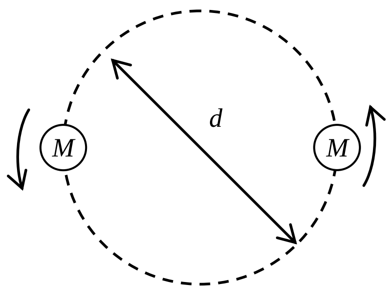
(i) show that the acceleration of a mass moving at constant speed in a circular path is towards the centre of the circle, and [2]

(ii) derive an expression for the acceleration in terms of the speed v of the particle and the radius r of its path. [4]

(b) A geostationary satellite has a circular orbit above the equator and remains in the same place relative to the surface of the Earth beneath it. Calculate the radius of the orbit of a geostationary satellite. [5]

(Mass of the Earth = 5.98×10^{24} kg)

(c) A binary star system consists of two stars of equal mass M whose centres are separated by a distance d. The stars are in uniform circular motion, with period T, around their centre of mass, at the mid-point between the stars.

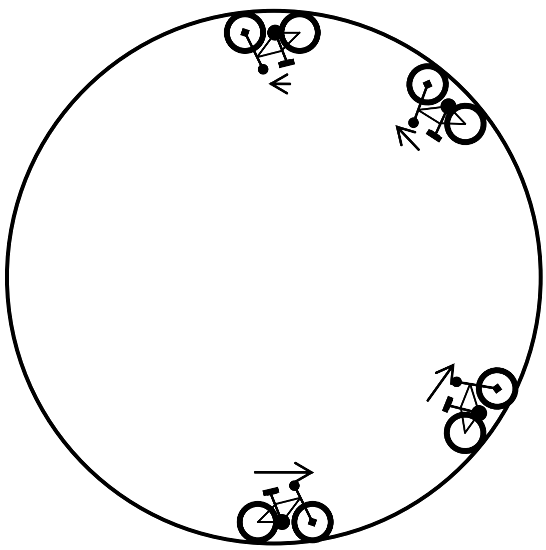


(i) Write down an expression for the gravitational force exerted by one star on the other.

(ii) Express the centripetal acceleration of one of the stars in terms of d and T.

(iii) Using (i) and (ii), derive an expression for T in terms of M, d and G. [5]

(d) A concrete pipe with an internal diameter of 4.5 m is laid horizontally on level ground. A BMX cyclist wants to 'loop-the-loop' inside the pipe, as shown in the diagram. Calculate the minimum speed of the cyclist at the highest point of the pipe if he is to complete the loop without losing contact with the inner surface of the pipe. [4]



4. COMPULSORY

(a)(i) Define electric field strength, and give its SI unit. [2]

(ii) Calculate the electric field strength and potential at a distance of 0.40 m from a point charge of 2.0×10^{-5} C. [4]

(b) Two charges of equal magnitude, one positive the other negative, are placed a fixed distance apart and isolated from any other charges. Sketch the electric field produced in the space surrounding the charges. [3]

(c) State the meaning of each of the symbols in the equation $C = \varepsilon_r \varepsilon_0 \dfrac{A}{d}$ for the capacitance of a parallel plate capacitor. [4]

(d) A sinusoidal alternating p.d. has a frequency of 50 Hz and r.m.s. value of 8.0 V.

Sketch a graph of p.d. against time for this waveform, putting approximate values on both axes. [4]

(e) Draw a labelled diagram of a simple transformer. [3]

5.

(a)(i) Define *resistivity* of a material, and give its SI unit. [2]

(ii) An aluminium wire 3.50 m long with a diameter of 0.45 mm has a resistance of 0.60 Ω. Calculate the resistivity of aluminium from these values. [3]

(b) A circuit consists of a battery (emf 12 V and negligible internal resistance) and two resistors (each of 4.0 Ω resistance) connected in series.

(i) Draw a circuit diagram of the arrangement. [1]

(ii) Calculate the current in the circuit. [2]

(iii) Calculate the power dissipated in one of the resistors. [2]

(c) The resistors in part (b) are now connected in parallel to a battery of emf 1.5 V and 1.0 Ω internal resistance. Calculate:

(i) the current in one of the resistors. [2]

(ii) the p.d. across the terminals of the cell. [2]

(d)(i) Sketch the p.d. / current characteristic of a light-emitting diode. [2]

(ii) Making reference to your graph, describe how the resistance of the light-emitting diode changes as the p.d. across it is varied. [4]

6.

(a) Define the *capacitance* of a capacitor. [1]

(b) Two capacitors, each of 220 μF capacitance, are connected in a series circuit with a battery of 5.0 V emf and negligible internal resistance. Calculate:

(i) the p.d. across each capacitor; [1]

(ii) the charge stored by each capacitor; [2]

(iii) the <u>total</u> energy stored by the capacitors. [2]

(c) A capacitor of capacitance 100 μF is charged to 6.0 V and disconnected from the power supply. A second, initially uncharged, capacitor (200 μF capacitance) is now connected in parallel with the charged 100 μF capacitor. Calculate:

(i) the initial charge on the 100 μF capacitor; [1]

(ii) the charge on the 100 μF capacitor after it has been connected to the 200 μF capacitor; [3]

(iii) the charge on the 200 μF capacitor after connection to the 100 μF capacitor. [1]

(d) A 680 μF capacitor is charged to a p.d. of 12 V, disconnected from the power supply and discharged through a resistor of 2.0 kΩ resistance.

(i) Calculate the time constant of the circuit. [2]

(ii) Sketch a graph showing the variation of discharging current with time for the circuit, putting an approximate scale on both axes. [4]

(iii) Calculate the p.d. across the capacitor 4.0 s after the start of the discharging process. [3]

7. COMPULSORY

(a) Define *specific latent heat of fusion* of a solid and give its SI unit. [3]

(b) Describe how the specific heat capacity of aluminium could be measured using an electrical method. [5]

(c) 120 g of copper rivets at 90°C is added to 100 g of water at 20°C in a polystyrene cup. The final temperature reached is 26°C

(i) Calculate the specific heat capacity of copper [4]

(ii) The value calculated is likely to be less than the expected value. State and explain two reasons why this might be so. [4]

(Specific heat capacity of water = 4200 J kg^{-1} K^{-1})

(d) The pressure of the air in a car tyre is 300 kPa at the start of a journey when the temperature of the tyre is 17°C. Stating any assumption made, calculate the tyre pressure at the end of the journey when its temperature is 37°C. [4]

8.

(a) In the gas equation $PV = \mu RT$, R represents the molar gas constant.

State the meaning of each of the other symbols in the equation and give the SI unit of each quantity. [6]

(b) State three assumptions of the kinetic theory of gases. [3]

(c) Explain how the pressure exerted on a container by the gas in it can be explained in terms of the motion of the gas molecules. [5]

(d) A meteorological balloon at sea level (pressure 1.0 x 10^5 Pa, temperature 17°C) has a volume of 20 m^3. Calculate:

(i) the number of moles of gas in the balloon; [2]

(ii) the volume of the balloon at an altitude where the pressure is 8.0×10^2 Pa and the temperature is −73°C. [4]

9.

(a) Define the coefficient of thermal conductivity of a material and state its SI unit. [4]

(b) A solid cylindrical copper bar has its temperature maintained at 100°C at one end and 20°C at the other. Sketch graphs of temperature against position along the length of the bar when

(i) the bar is perfectly lagged; [2]

(ii) the bar is unlagged. [2]

(c) A solid cylindrical aluminium bar has a cross-sectional area of 6.0 cm^2 and a length of 12 cm. When it is perfectly lagged and its end are maintained at temperatures of 100°C and 20°C, the rate of heat flow is 90 W. Calculate the coefficient of thermal conductivity of aluminium.[4]

(d) Astronomers have detected electromagnetic radiation, known as 'cosmic background radiation', which is thought to have been created early in the history of the universe. The wavelength distribution of this radiation matches that of a black body at 2.7 K.
Calculate the peak wavelength of this radiation. [2]

(e) The Sun, radius 6.96×10^8 m, emits energy at a rate of 3.85×10^{26} W. Calculate the surface temperature of the sun, assuming its emissivity (σ) is 1. [6]

END OF QUESTION PAPER