The University Of Sheffield.

DEPARTMENT OF PHYSICS AND ASTRONOMY

Autumn Semester 2006-2007

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.*

A formula sheet and table of physical constants is attached to this paper.

All questions are marked out of ten. 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.

TURN OVER

SECTION A

1. COMPULSORY

(a) The resistance of a resistance thermometer is 6.750 Ω at the triple point of water and 7.166 Ω at room temperature. What is the room temperature on the scale of the resistance thermometer? [2]

(b) What is the heat capacity of a 3 kg solid cylinder of pure gold? [1]

(c) How many ***vibrational*** degrees of freedom are there for a diatomic gas molecule? [1]

(d) Calculate the mean translational kinetic energy for the molecules of an ideal gas at 400 K. [2]

(e) An electrical heater of negligible heat capacity and of power 0.50 W is lowered into a vessel of liquid nitrogen at its boiling point (77 K). Calculate the mass of nitrogen boiled off in 3.0 s. [2]

(f) What do you understand by a ***black body***? [2]

Specific heat capacity of gold = 132 J kg^{-1} K^{-1}.
Triple point of water = 273.16 K.
Boltzmann constant, $k = 1.38 \times 10^{-23}$ J K^{-1}.
Specific latent heat of vaporization of nitrogen = 21 J kg^{-1}.

2.

(a) State ***two*** assumptions made in the simple kinetic theory of an ideal gas. [2]

(b) A cylinder of volume 0.080 m^3 contains oxygen at a temperature of 280 K and a pressure of 90 kPa.

Calculate the mass of oxygen in the cylinder. [2]

(c) Explain what is meant by the ***scale height*** of a planetary atmosphere. Estimate its value for an imaginary planet whose surface gravitational field strength is 25 N kg^{-1} and which has an atmosphere composed of molecular hydrogen at a temperature of 75 K. [4]

(d) Sketch a labelled graph showing typical variation of the Earth's atmospheric pressure with height. [2]

Molar gas constant, R = 8.3 J K^{-1} mol^{-1}.
Molar mass of oxygen = 0.032 kg mol^{-1}.
Mass of hydrogen molecule = 3.3×10^{-27} kg.
Boltzmann constant, $k = 1.38 \times 10^{-23}$ J K^{-1}.

3.

(a) Explain what is meant by the term ***temperature gradient***. [2]

(b) Outline an experiment to measure the thermal conductivity of a good conductor, showing how the result is calculated from the measurements. [5]

(c) The two ends of a lagged magnesium rod, of cross-sectional area 1.0 cm^2, are maintained at 80°C and 20°C respectively. If the mean rate of heat flow in the rod is 3.0 W, calculate the length of the rod. [3]

[Thermal conductivity of magnesium = 150 W m^{-1} K^{-1}.]

SECTION B

4. COMPULSORY

(a) How is the SI unit of charge, the coulomb, ***defined***? [1]

(b) The repulsive force between two point electric charges, 2.0 mm apart, is 9.0 nN. Find the force if the charges are moved to a new separation of 6.0 mm. [1]

(c) A 4.0 μF capacitor is connected in series with a 3.0 μF capacitor. Calculate the total capacitance of the combination. [1]

(d) What do you understand by a ***non-ohmic*** conductor? [2]

(e) Calculate the resistance ***per unit length*** of a gold wire of cross-sectional area 0.10 mm^2. [2]

(f) Find the acceleration of an electron placed in a uniform electric field of 100 V m^{-1}. [1]

(g) State Lenz's law. What deeper physical principle does this law derive from? [2]

Specific charge of the electron (e/m) = 1.76×10^{11} C kg^{-1}.
Resistivity of gold = 24 nΩ m.

5.

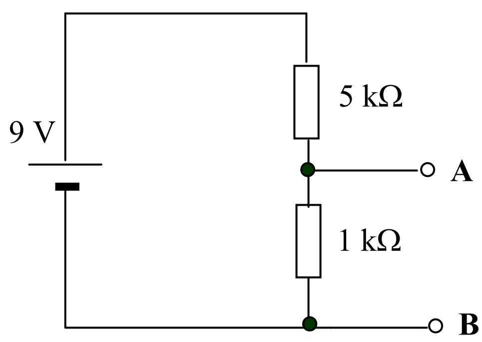
What is the final potential difference between A and B in the circuit below:

(a) in the circuit as shown; [3]

(b) if an additional 500 Ω resistor were connected between A and B; [4]

(c) if the 500 Ω resistor were replaced by a 2.0 μF capacitor? [1]

(d) For what purposes would the circuit in (a) be useful, and what is it called? [2]



6.

(a) A straight conductor of length 50 mm carries a current of 1.5 A and experiences a force of 4.5 mN when placed in a uniform magnetic field of flux density 90 mT. What is the angle between the direction of the magnetic field and that of the conductor? [4]

(b) A proton travelling at 2.0 Mm s^{-1} moves at right angles to a magnetic field of 0.25 T. Find the radius of the circular arc that it describes. [4]

(c) If the field in part (b) is generated by a long solenoid having 6000 turns per metre, determine the solenoid current needed to create the field. [2]

Elementary charge, $e = 1.6 \times 10^{-19}$ C.
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg.
Magnetic space constant, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}.

TURN OVER

SECTION C

7. COMPULSORY

(a) Two cars are travelling at 50 km h^{-1} and 45 km h^{-1}, with the slower one 700 m ahead of the other. How long does it take for the two cars to be level? [1]

(b) A body of mass 150 g fixed to a string length 120 mm is whirled at constant speed in the vertical plane.

i) How fast must the body be moving for the string to be just taut when the body is at its highest point?

ii) What is the tension in the string when the body is at its lowest point? [2]

(c) A ball of mass 0.13 kg is thrown horizontally from the top of a 35 m high building with a velocity of 14 m s^{-1}.

i) How far has it travelled horizontally when it hits the ground?
ii) What is its kinetic energy on impact? [2]

(d) A jet engine of thrust 250 kN is mounted first on a sledge of mass 13×10^{3} kg, then on a vertical takeoff vehicle of the same mass. Calculate the acceleration in both cases. [1]

(e) The Sun has mass 3.3×10^{5} times that of the Earth and is 440 times further away from the Earth than the Moon. What is the ratio of the gravitational forces from the Sun and Earth on the Moon? [1]

(f) A spring with a spring constant of 400 N m^{-1} is compressed by 7 mm.

i) How much energy is stored?
ii) If the spring on release propels a body of mass 30 g vertically, how high does the body go? [2]

(g) A child ice skater, mass 30 kg and travelling at 3 m s^{-1} collides with a stationary adult of mass 80 kg. After the collision the child is stationary: how fast is the adult travelling? [1]

$\left[g = 9.81 \text{ m s}^{-2}\right]$

8.

Starting from the definition of acceleration as rate of change of velocity, **derive** the three equations

$$v = v_0 + at\ ,$$

$$x = v_0 t + \frac{at^2}{2} \text{ and}$$

$$v^2 = v_0^2 + 2ax,$$

explaining the meaning of the symbols and stating the main assumption made. [2]

From the first equation **derive** equations for the time of flight

i) when an object is thrown vertically upwards, and
ii) when it is thrown at an angle θ to the horizontal. [1.5]

From $v^2 = v_0^2 + 2ax$ **derive** equations for

iii) the maximum height achieved by an object thrown vertically upwards, and
iv) the maximum height achieved by an object thrown at θ to the horizontal. [1.5]

Hence **derive** an expression for the range of a projectile fired with velocity v_0 at θ to the horizontal and **prove** that the range is greatest when $\theta = 45^\circ$. [1.5]

A ball is thrown from the top of a cliff of height 260 m with a velocity of 25 m s^{-1} at 60° to the horizontal. Calculate

v) the time for the ball to reach maximum height, [1]
vi) the time for it to fall from there to the ground below, and hence [1.5]
vii) the horizontal range. [1]

TURN OVER

9.

What is the work done when a body, acted on by a force F, is moved through a distance x against this force? What is the significance of the sign in this equation? [1]

Distinguish between reversible and non-reversible processes. What name is given to the work done above in a reversible process, if the body is stationary at the beginning and end of the process? [1.5]

Calculate the work done in accelerating a body of mass m from v_0 to v_f, and **hence** obtain an expression for the kinetic energy of a body. [1.5]

Use the equations of motion to obtain an expression for the total energy of a body moving under gravity as a function of height, and show that the same result follows from the conservation of potential plus kinetic energy. [2]

(a) In a particular waterfall, 3000 m^3 of water falls through 30 m every second. What power is released? [1]

(b) A tsunami can be approximately modelled as a wall of water 3 m high and 4 m wide moving at 12 m s^{-1}. Calculate and compare the kinetic and potential energies for a 1 m section of the wave. [1.5]

(c) An aircraft of mass 2×10^4 kg is powered by a jet engine of thrust 150 kN and flies at 900 km h^{-1}. How long does it take for the engine to provide an amount of energy equal to the aircraft's kinetic energy? [1.5]

[The density of water is 1000 kg m^{-3}.]

END OF QUESTION PAPER