A10287W1

FIRST PUBLIC EXAMINATION

Long Vacation

Preliminary Examination in Physics

Paper CP1: PHYSICS 1

also

Preliminary Examination in Physics and Philosophy

Monday 5th September 2016, 9.30 am – 12:00 pm

Time allowed: $2\frac{1}{2}$ hours

Answer **all** *of Section A and* **three** *questions from Section B.*

Start the answer to each question on a new page.

The use of approved calculators is permitted.

A list of physical constants, mathematical formulae and conversion factors accompanies this paper.

The numbers in the margin indicate the weight that the Moderators expect to assign to each part of the question.

Do NOT turn over until told that you may do so.

In answering any question on this paper you may assume the following formulae for the moments of inertia about the principal axis of a body of mass M, uniform density, and radius a: disk, $\frac{1}{2}Ma^2$; hoop, Ma^2.

Section A

1. A ball of mass m is kicked vertically upwards with velocity u. Assuming the acceleration due to gravity, g, to be a constant, obtain an expression for the velocity v at a later time t if the force due to the resistance of the air is mkv. [6]

2. A solid ball rolls without sliding on a flat surface and strikes an identical ball that is initially at rest. Show that the angle between the trajectories of the two balls after the collision is a right angle. [4]

3. Write down the Lagrangian for a point mass moving in a spherically symmetric potential $V(r)$. Use this to show how the law of conservation of angular momentum gives rise to the concept of an *effective potential*, and explain why this is useful. [5]

4. A disk is mounted on an axle through its centre and driven by a motor which may be assumed to have a constant output power. A brake on the disk generates a constant retarding force $k\dot{\theta}$. Find an expression for the rotational frequency ω_0 reached at steady state, and show that the time taken for the disk to reach a given $\dot{\theta}$ from rest is given by

$$t = \frac{I}{2k} \ln\left(1 - \frac{\dot{\theta}^2}{\omega_0^2}\right),$$

where I is the moment of inertia of the disk. [8]

5. Show the moment of inertia of a square lamina of mass m and side a about *any* axis in the plane of the lamina which passes through the centre is $\frac{1}{12}ma^2$. [7]

6. At what speed and direction would you have to move a laser source emitting at 633nm to trigger an infrared sensor moving towards you at $0.2c$, whose response begins at 1000nm? [5]

7. A π^- interacts with a proton to produce a neutron with the emission of a photon. If the proton and π^- are both stationary in the laboratory frame, what must be the energy of the photon in this frame? [5]

Section B

8. A hollow drum of diameter R, mass M, is mounted on a massless axle with diameter r. The axle is initially placed on horizontal frictionless rails, such that the drum is not in contact with the ground.

(i) At what height above the axis should you give a horizontal impulse to the drum so that it will roll along the rails without sliding? [4]

(ii) Write down expressions for the total kinetic energy and total angular momentum of the drum as it rolls. [4]

(iii) The drum rolls along the rails until the rails end, and the drum slides, while still turning, across a rough surface until it again rolls without sliding. By considering the conservation of the total angular momentum, or otherwise, determine an expression for the change in kinetic energy of the drum in terms of its angular velocity ω_0 and velocity v_0 when it is on the rails. [12]

9. A boy throws a tennis ball of mass m at speed v at the back of a small stationary truck of mass M $(>> m)$ which has no brakes. The ball bounces straight back with a perfectly elastic collision, and the boy throws another identical ball at the truck each second. Find the speed and position of the truck as a function of time. [8]

In winter, the boy throws snowballs, such that they stick to the back of the truck instead of bouncing back. Again, find the speed and position of the truck as a function of time. [9]

If the boy throws the snowballs from a height h above the ground, how fast will the truck be moving when it is out of range? [3]

10. Consider a meteorite of mass m approaching a planet of mass M. At a large distance from the planet, the meteorite has velocity v and impact parameter b. Derive expressions for the distance of closest approach, r_0 and the maximum velocity v_{max} as the meteorite passes the planet [8]

At closest approach, an explosion breaks the meteorite in half such that the two halves separate along the direction of motion, and the slower half is captured in a stable circular orbit at $r = r_0$.

(i) How much energy must be generated in the explosion? [4]

(ii) What will be the velocity of the departing fragment immediately after the explosion? [8]

11. A laser pulse is fired towards a stationary mirror a distance d away. A stationary observer located next to the laser measures the time taken for the laser pulse to return. The events are also recorded by a second observer who is moving parallel to the outgoing beam with velocity v.

(a) Sketch space-time diagrams to show how the measurements are seen in the frame of each observer. [6]

(b) Determine the time taken, according to each observer, for the laser pulse to travel to the mirror, back to the observer, and the time seen by each for the full round-trip. [10]

(c) How would your results for the second observer change if they were to travel in the opposite direction at twice the speed? [4]