# University of Jaffna, Sri Lanka
## General Degree Examination in Science – Level 1G, 2009
## End of Course Examination

## PHYSICS
## PHY102GC3 : Mechanics, Relativity and Structure of Matter

Answer ***five*** questions only selecting at least ***one*** question from each section.

Time: ***Three*** hours.

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|---|---|---|
| Velocity of light in vacuum (c) | = | $3 \times 10^{8}\ ms^{-1}$ |
| Charge of electron (e) | = | $1.60 \times 10^{-19}$ C |
| Planck's constant (h) | = | $6.63 \times 10^{-34}$ Js |
| Mass of proton ($m_P$) | = | $1.67 \times 10^{-27}$ kg |
| Mass of electron ($m_e$) | = | $9.11 \times 10^{-31}$ kg |
| Acceleration due to gravity at the Earth's surface (g) | = | $10.0\ ms^{-2}$ |

### SECTION – A

1. **Explain** what is meant by inertial forces.

   **Distinguish** between centripetal and centrifugal forces.

   **Derive** an expression for the centripetal acceleration of a particle in uniform circular motion in terms of its velocity and the radius of its circular path.

   A spherically shaped influenza virus particle, of mass *m* and radius *r*, is in a water suspension in an ultra centrifuge. The virus particle is at a distance *d* from the vertical axis of rotation, and the angular speed of rotation of the centrifuge is $\omega$ . The density of the virus particle is $\alpha$ times that of water.

   (a) **Identify** the forces acting on the virus particle and its acceleration

   (i) in the fram e of reference in which the centrifuge is at rest.

   (ii) in the laboratory frame.

   (b)

   (i) **Obtain** an expression for the effective acceleration ( $g_{effe}$ ) of the particle with respect to a frame of reference in which the centrifuge is at rest.

→ *Question 1 continued*

(ii) In the frame in which the centrifuge is at rest, because of the centrifugal force, particle will move in the radially outward direction. The motion will be resisted by viscous forces and the particle will reach a terminal velocity. When the particle move with terminal velocity $v$ the viscous force acting on the particle is given by $F_{vis} = 6\pi\eta vr$, where $\eta$ is the coefficient of viscosity of water. **Derive** an expression for the terminal speed of the virus particle.

(iii)If the virus particle has a mass of $6\times10^{-16} g$, diameter $10^{-5} cm$ and is at a distance 4 cm from the vertical axis of rotation of the centrifuge. If the centrifuge rotates at $10^3$ revolutions per second, **calculate** the terminal speed of the particle, taking the density of the virus particle to be 1.1 times that of water and the viscosity of the water as $10^{-2}$ g cm$^{-1}$s$^{-1}$

2. **Explain** what is meant by "*centre of mass frame*" of a system of particles.

   Consider a system of N non-interacting particles each subjected to an external force and **show** that the centre of mass of this system of particles moves as if the total mass of the particles is concentrated at that point and all external forces are applied to it.

   A particle X of mass 2m and traveling with a velocity u collides elastically with a stationary particle Y of mass 10m. After the collision the particle X is observed to be traveling with speed $v_1$ in a direction perpendicular to its original direction of motion in the laboratory frame.

   (a) **Find** the ***velocity*** of the centre of mass frame of the system of particles.

   (b) **Find** the ***velocity*** of the particles X and Y in the centre of mass frame before the collision.

   (c) **Show** that in the centre of mass frame the ***magnitude of the momentum*** of any of the particles is the same before and after the collision.

   (d) **Find** the magnitude and direction of the ***velocities*** of the particles X and Y in the centre of mass frame after the collision.

   (e) **Find** the magnitude of the ***velocity*** of the particle X in the laboratory frame after the collision.

   (f) **Find** the magnitude and direction of the ***velocity*** of the particle Y in the laboratory frame after the collision.

   (g) **What *fraction of initial kinetic energy*** is transferred from particle X to Y during the collision?

→ *Continued*

3.

(a) **Explain** the term "Moment of Inertia" of a rigid body about a given axis.

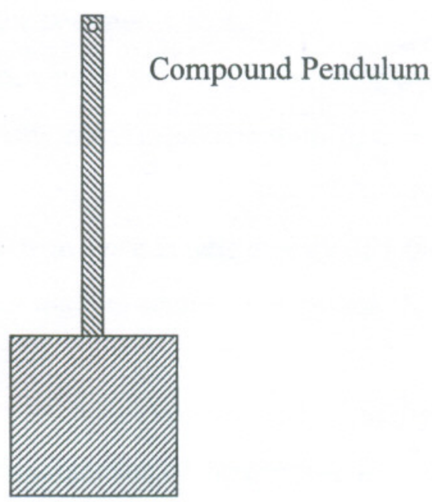
(b) **State** and **prove** the theorem of parallel axis.

(c) **Show** that the moment of inertia of a uniform square lamina of mass $M$ and edge $2a$ about an axis perpendicular to the plane of the lamina and passing through its centre is given by $I = \frac{2}{3}Ma^2$.

(d) A plane compound pendulum is made out of a uniform square plate, of mass $12m$ and edge $2a$, and a thin uniform rod, of mass $m$ length $4a$, as shown in the figure below, by rigidly fixing one end of the rod to the mid point of one edge of the plate so that the rod is perpendicular to that edge and lies in the plane of the plate. The system is hanged from the other end of the rod so as to oscillate freely in the vertical plane containing the plate and the rod.

(i) **Obtain** an expression for the moment of inertia of the system (compound pendulum) about the horizontal axis passing through the hanged end of the rod and perpendicular to the plate.

(ii) Using the principle of conservation of angular momentum or otherwise **obtain** the equation of motion of the compound pendulum and **show** that for small oscillations the system oscillates like a simple pendulum of length $\frac{110}{93}a$.

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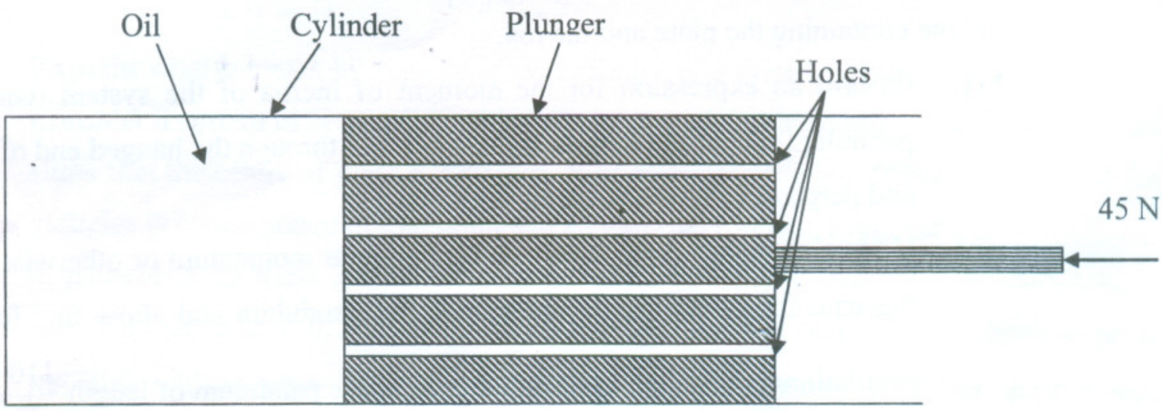
4. **What** is meant by streamline flow of a liquid?

Assuming streamline flow of a liquid through a narrow, uniform horizontal tube of radius $a$ and length $l$ **derive** an expression for the rate of flow.

A cylindrical plunger with diameter 0.08m and length 0.13 m has four narrow cylindrical horizontal holes of each diameter 5/1600m drilled parallel to the axis of the cylinder as shown in the figure below. The plunger is a close fit inside a cylindrical can containing oil, such that oil can pass only through the cylindrical holes. The plunger is subjected to a horizontal force of 45 N as shown in the figure. Assuming that the flow of oil through the four small holes is laminar, **determine** the speed with which the plunger will move. The viscosity of the oil is 0.2 $kgm^{-1}s^{-1}$.

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## SECTION – B

5.

(a) State the Einstein's postulates of special theory of relativity.

(b) Write down the Lorentz transformation equations for the spatial and time coordinates of an event described in two inertial frames $\Sigma$ and $\Sigma'$. Assume that the origins of the coordinate systems of $\Sigma$ and $\Sigma'$ coincide when $t=t'=0$ and that $\Sigma'$ moves at a uniform velocity $V$ relative to $\Sigma$ along their common x-axis.

(c) An inertial frame $\Sigma'$ moves with a velocity V with respect to another inertial frame $\Sigma$ along their common x-axis. A rod of proper length $L_0$ is at rest along the common x-axis in the $\Sigma'$ frame . Show that the length L of the rod in the $\Sigma$ frame is given by $L = L_0/\gamma$, where $\gamma$ is the Lorentz factor.

(d) A spaceship is measured to be 100m long while it is at rest with respect to an observer. If this spaceship now flies with a speed of 0.90c with respect to the observer what is length of the spaceship observed by the observer.

(e) An observer on earth sees an spaceship at an altitude of 5km moving vertically towards the earth with velocity 0.90c. What is the altitude of the spaceship as measured by an observer in the spaceship?

6. Write down the Lorentz transformations of the momentum $p$ and energy $E$ of a particle of rest mass $m_0$ between inertial frames $\Sigma$ and $\Sigma'$, the later moving with velocity $v$ relative to the former along the common x-axis.

A particle of rest mass $m_0$ travels in an inertial frame $\Sigma$ with velocity u. Write down expressions for the relativistic mass m, momentum p, energy E and kinetic energy T of the particle.

In the inertial frame $\Sigma$, an electron has a kinetic energy of 1.0MeV.

(a) Find the electron's speed and its momentum in the $\Sigma$ frame. The rest mass of electron is $0.51 MeV/c^2$

(b) $\Sigma'$ is another inertial frame which moves with velocity 0.8c with respect to the inertial frame $\Sigma$ and in the direction of the electron in the $\Sigma$ frame.

Estimate the momentum, the kinetic energy and the speed of the electron in the $\Sigma'$ frame.

→ *Continued*

## SECTION – C

7.

(a) Describe briefly the Rutherford's atomic model and the problems encountered by it.

(b) Bohr extended Rutherford's model of the atom by retaining some ideas of Rutherford and introducing some new concepts.

(i) Stating the Bohr's first postulate, show that the radii of the circular orbits of the electron in an one electron atom and its corresponding energies are given by $r_n = \frac{\epsilon_0 h^2 n^2}{\pi m_e Z e^2}$ and $E_n = -\frac{m_e e^4 Z^2}{8\epsilon_0^2 h^2 n^2}$ respectively. Here $m_e$ is the mass of the electron and $Z$ is the atomic number of the atom, $n$ is a full integer and the other symbols have their usual meaning.

(ii) Stating the Bohr's second postulate, show that the frequency of the emitted radiation when an electron goes from a higher energy state (say $n = n_2$) to a lower one (say $n = n_1$) is given by $\nu = \frac{m_e e^4 Z^2}{8\varepsilon_0^2 h^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$. Hence, estimate the Rydberg constant ($R_\infty$) for a hydrogen atom.

8.

(a) What do you understand by the terms lattice, lattice points, lattice parameters and basis in relation to the structure of solids?

(b) Distinguish and define primitive unit cell, compound unit cell and Wigner- Seitz primitive cell.

(c) Sketch a clear diagram of the face centered cubic (fcc) structure and show the primitive and compound unit cells on it.

(d) In the same diagram, indicate the primitive translation vectors and estimate the volume of the primitive cell.

(e) There are two different ways of arranging equivalent spheres in a regular array to minimize the interstitial volume. One leads to the face centered cubic structure, and the other has hexagonal symmetry. Sketch diagrams to show these two different arrangements clearly indicating which arrangement leads to which structure.

(f) Hence, estimate the axial ratio $c/a$ of an ideal hexagonal close packed structure.

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