# NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

## FACULTY OF APPLIED SCIENCES

## DEPARTMENT OF APPLIED PHYSICS

**BSc(Hons) in Applied Physics PART 1**

**MECHANICS AND RELATIVITY**

**SPH 1101**

**First Semester Examination Paper**

**December 2024**

This examination paper consists of 5 pages

**Time Allowed:** **3 hours**

**Total Marks:** **100**

**Special Requirements: None**

**Examiner's Name:** **Mr T. Dube**

**INSTRUCTIONS**

**ANSWER ALL PARTS OF QUESTION 1 IN SECTION A AND ANY THREE QUESTIONS FROM SECTION B. SECTION A CARRIES 40 MARKS AND SECTION B CARRIES 60 MARKS.**

**MARK ALLOCATION**

| QUESTION | MARKS |
|---|---|
| 1. | **40** |
| 2. | **20** |
| 3. | **20** |
| 4. | **20** |
| 5. | **20** |
| 6. | **20** |
| **Maximum possible mark** | **100** |

Constants : Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ Hm$^{-1}$

Permittivity of free space, $\varepsilon_0 = 8.854 \times 10^{-12}$ F m$^{-1}$

Electronic charge , $q = 1.6022 \times 10^{-19}$ C

Universal gravitational constant, $G = 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$

## SECTION A

| | | | | |
|---|---|---|---|---|
| **1** | (a) | (i) | State Newton's Laws of motion | **3** |
| | | (ii) | Show that Newton's first Law of motion is simply a special case of the second Law.<br>Discuss the limitations of Newton's Laws of motion. | **3** |
| | | (iii) | Distinguish between inertial and non-inertial frames of reference. | **2** |
| | | (iv) | Two bodies of masses 2 g and 10 g have position vectors $(3\vec{i} + 2\vec{j} - 1\vec{k})$ *and* $(\vec{i} + \vec{j} + 3\vec{k})$<br>Find the position vectors and the distance of the center of mass from the origin | **2** |
| | **(b)** | **(i)** | Discuss the phenomenon of collision in one dimension between two particles when the collision is elastic. Hence find the velocities after collision. | **6** |
| | | **(ii)** | When the masses of colliding particles are the same and one of the particles is initially at rest | **2** |
| | | **(iii)** | A gun of mass 10 kg fires a 10 g bullet with a velocity of 1500 m/s. find the velocity with which the gun recoils. | **2** |
| | **(c)** | **(i)** | A particle moves from the position $(3\vec{i} + 3\vec{j} + 2\vec{k})$ metre to another position $(2\vec{i} + 2\vec{j} + 4\vec{k})$ metre under the influence of a force F = $(3\vec{i} + 2\vec{j} + 4\vec{k})$ newton. Calculate the work done by the force. | **5** |
| | | **(ii)** | A particle moves in the x-direction such that its coordinate x varies with time t according to the expression $x = 2 - 6t + 8t^2$ metre. Find the initial velocity of the particle. | **5** |
| | **(d)** | **(i)** | The radius of the Earth is $6.4 \times 10^6$ m and the gravitational field strength at its surface is 10 N $kg^{-1}$. At what height above the Earth's surface is the gravitational field strength equal to 2.5 N $kg^{-1}$? | **3** |
| | | **(ii)** | Calculate the force of attraction between the Earth of mass $6.0 \times 10^{24}$ kg and the Sun of mass $2.0 \times 10^{30}$ kg. | **2** |
| | | **(iii)** | Determine the gravitational potential energy of the moon with respect to the Earth given that the mass of the moon is $7.35 \times 10^{22}$ kg and the mass of the Earth is $5.98 \times 10^{24}$ kg. The Earth -moon distance is 384 400 km. | **3** |
| | | **(iv)** | What is meant by a geostationary orbit? | **2** |

## SECTION B

**2** **(a)** A mass of 800 g on spring is oscillating at 1.4 Hz. The total energy of the oscillation is 0.81 J. What is the amplitude of oscillation? **4**

**(b)** A skydiver falls from the sky through the air with a constant speed of 192 km/h (terminal velocity). If his mass is 70 kg, calculate the power of the drag force. **4**

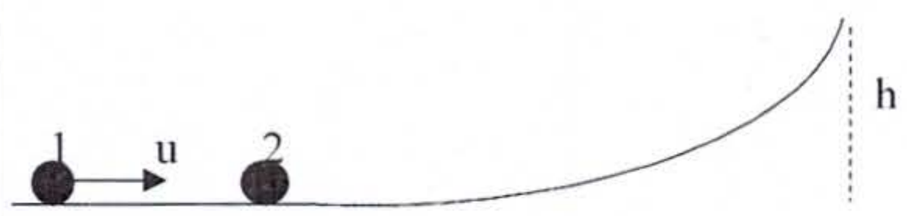
**(c)** An electron has a rest energy of 0.511 MeV and a total energy of 1.5
**(i)** MeV. Find its kinetic energy in MeV and **2**
**(ii)** Its speed as fraction of the speed of light. **2**

**(d)** Give the expression for the magnitude of the gravitational force acting on an object of mass m as a function of its distance r away from the center of a planet of mass M. derive an expression for the potential U(r) of the object, assuming that the potential energy vanishes at infinite separation. **4**

**(e)** Excited Hydrogen atoms emit light in an identifiable pattern called the Balmer series. In the light observed from a galaxy, the first Balmer emission appears at a wavelength of $7.18 \times 10^{-7}$ m. The same emission is observed from Hydrogen atoms on earth at a wavelength of $6.56 \times 10^{-7}$ m. Using the relativistic Doplar formula, determine the velocity of recession of the galaxy. **4**

**3** **(a)** In the context of a collision between two bodies, explain what is meant by terms elastic, inelastic and totally inelastic. **3**

**(b)** Two billiard balls stand on a horizontal surface next to a smooth incline of height *h* as shown in the diagram below. Ball 1 with mass $m_1$ approaches Ball 2 (initially stationary) with an initial velocity u in the positive x direction. It then makes an elastic collision with Ball 2(mass $m_2$).




**(i)** What is the speed of Ball 1 immediately after the collision and in which direction is it moving? **7**
**(ii)** What is the kinetic energy of Ball 2 after the collision? **2**
**(iii)** What is the maximum height that Ball 2 reaches up the incline after the collision, assuming it does not get to the top? **3**

**(c)** If the collision had been totally inelastic, what initial velocity would be required for both balls to reach the top of the incline after the collision? **5**

**4 (a)** A cannonball is fired at an initial speed $v_0$ and angle $\theta$ above the horizontal. Neglecting any effects due to air resistance and starting from Newton's second law, derive expressions for the vertical and horizontal distances travelled as a function of time. **8**

**(b)** Derive an expression for the time of flight for the cannonball. **2**

A 130 m high hill is located halfway between the cannon and its target.

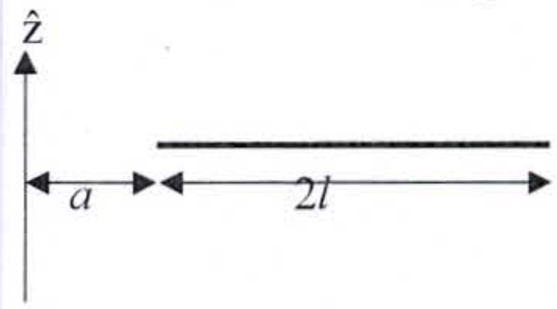
**(i)** If the cannonball is fired at an angle of $\pi/6$ and just clears the hill to strike the target, calculate the initial velocity and the distance from the cannon to the target. **5**

**(ii)** The cannon is then moved to the top of the hill and fires a cannonball horizontally with the same initial speed. What is the horizontal distance travelled when the cannonball hits the ground? **5**

**5 (a)** Define the moment of inertia of an object about a fixed rotation axis, paying particular attention to defining precisely all symbols. **5**

**(b)** Show that the moment of inertia of a thin horizontal rod of length $2l$ and mass $m$, about a vertical axis $\hat{z}$ in the vertical plane of the rod a distance $a$ from the rod (see diagram) is **7**

$$\frac{1}{3}ml^2 + m(a+l)^2$$




**(c)** The moment of inertia of a spinning skater with arms outstretched can be modelled by attaching two such horizontal rods to a uniform right circular cylinder of radius $a$, with its axis coinciding with $\hat{z}$. If the length and mass of each of her arms are 70 cm and 3 kg, the radius of her torso can be taken to be $a = 20$ cm and her total weight is 60 kg, how much faster does she spin when she brings her arms down to lie vertically by her sides? **8**

[The moment of inertia of a uniform right circular cylinder of mass M and radius a about its central axis is $\frac{1}{2}Ma^2$]

**6 (a)** The Special Theory of Relativity is based on two postulates. What are they? What is meant by an inertial frame? What is meant by an event? **6**

**(b)** An inertial frame $S'$ is moving with velocity $v$ along along the x-axis of an inertial frame $S$. Write down the Lorentz transformations which relate the coordinates $x', y', z', t'$ of S′ to the co-ordinates $x, y, z, t$ of S (assuming the two coordinate frames coincide at $t = t' = 0$) **6**

**(c)** Two civilizations are evolving on opposite sides of a galaxy whose diameter is $10^5$ light years. At time t = 0 in the galaxy frame of reference, civilization **A** launches its first interstellar spacecraft. Civilization **B** launches its first spacecraft 50 000 years later. A being from a more advanced civilization is passing through the galaxy at 0.95c on a line from **A** to **B**. Which civilization does this being judge to have first achieved interstellar travel? **8**

**END OF PAPER**