1. Answer the following questions.
   (a) What is Newton's law of universal gravitation? (3%)
   (b) What is Doppler effect? (3%)
   (c) What is the First law of thermodynamics? (4%)

2. A box (mass = m) rests on a horizontal surface with a coefficient of kinetic friction μk. The box is pulled with a force F, which acts at an angle θ above the horizontal, as shown in Fig. 1.
   (a) What acceleration results when the box is pulled with a force of magnitude F, acting at an angle θ? Assume the box remains in contact with the surface. (5%)
   (b) For a given magnitude F, what angle θ will produce the maximum acceleration? (7%)

   ![Fig. 1](image)

3. (a) Figure 2 shows a tunnel in a uniform planet of mass M and radius R. At a distance r from the center, the gravitational attraction is due only to the sphere of radius r. Thus,

   \[ F = \frac{GmM(r)}{r^2} = \frac{mg r}{R} \]

   where \( M(r) = \frac{Mr^2}{R^2} \) and \( g = \frac{GM}{R^2} \). Show that Newton's second law for the motion along the tunnel leads to the differential equation for simple harmonic motion:

   \[ \frac{d^2x}{dt^2} + \frac{g}{R} x = 0. \] (10%)

   (b) Write down the expression of the period of the oscillation? (in terms of \( g, R \) and other constants). (5%)

   ![Fig. 2](image)
4. (a) State the Gauss's law. (5%) 
(b) In a 1911 paper, Ernest Rutherford mentioned: "In order to form some idea of the forces required to deflect an α particle through a large angle, consider an atom containing a point positive Ze at its centre and surrounded by a distribution of negative electricity, -Ze uniformly distributed with a sphere of radius R. The electric field $E$ at a distance $r$ from the center for a point inside the atom is $E = \frac{Ze}{4\pi \varepsilon_0} \left( \frac{1}{r^2} - \frac{1}{R^2} \right)$." Please verify this relation. (10%) 

5. (a) What is Snell’s law? (5%) 
(b) A glass cylinder of index $n$ is surrounded by a sheath of index $n'$. The surrounding medium has index $n_0$. (see Fig. 3) Show that the maximum angle $\theta_m$ at which light will undergo total internal reflection is given by

$$n_0 \sin \theta_m = \sqrt{n'^2 - n^2}. \quad (10\%)$$

![Fig. 3](image)

6. In the Bohr model of the Hydrogen atom an electron orbits a stationary proton in a circular orbit of radius $r$.
(a) Write Newton’s second law for the circular motion and obtain an expression for the speed $v$. (in terms of mass of electron $m$, charge of electron $e$ and permittivity constant $\varepsilon_0$). (7%) 
(b) Bohr imposed the condition that the angular momentum $L$ of the electron could take on only discrete values given by $L = \frac{nh}{2\pi}$ where $n$ is an integer and $h$ is Planck's constant. Show that the radius of the $n$th allowed orbit is given by

$$r_n = \frac{nh^2}{4\pi^2kme^2}, \quad \text{where} \quad k = \frac{1}{4\pi \varepsilon_0} \quad (8\%)$$

7. (a) What is Ampere’s law? (5%) 
(b) An infinite straight wire of radius $R$ carries a current $I$. Find the magnetic field at a distance $r$ from the center of the wire for (i) $r > R$, and (ii) $r < R$. Assume that the current is uniformly distributed across the cross section of the wire. (10%)