

Physics 1: Motion in Fields

Time allowed: 3 hours

Exercise 1: / 5 marks

2019 Session

Take mass of an electron, $m = 9.1 \times 10^{-31}$ kg, charge of electron, $e = -1.6 \times 10^{-19}$ C,
 $k = 9.0 \times 10^9$ in SI units.

1. Rutherford came up with a planetary model for the hydrogen atom. The electron performs circular motion around the nucleus which is a proton. The electrostatic force on the electron is attractive and along the line joining the electron and the proton and of magnitude, $f = k \frac{e^2}{r^2}$. The gravitational attraction is negligible compared to this electrostatic force.

- 1-1- Make a sketch diagram to show the force on the electron. 0.5 mk
1-2- Show that the motion of the electron is uniform. 0.5 mk
1-3- Write the expression for the speed, v , of the electron in terms of k , e , r and m . 0.5 mk
1-4- Express its kinetic energy in terms of the same parameters. 0.5 mk
1-5- Express the total mechanical energy in terms of k , e and r given that the potential energy is $E_P = -k \frac{e^2}{r}$. What is its limit as r approaches infinity? (0.25 mk + 0.25 mk)

2. Different experimental observations led Niels Bohr to formulate a hypothesis that the electron can only move on certain circles whose radii, r_n , obey to the relation $v_n \times r_n = n \times K \frac{1}{m}$.

K : universal constant = 1.054×10^{-34} J s.

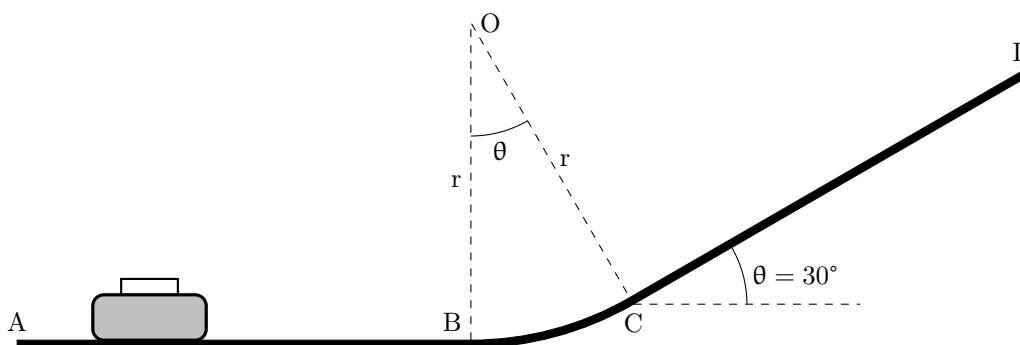
n : integer: $n \geq 1$.

v_n : speed of electron on circle on radius r_n .

- 2-1- Work out an expression for r_n in terms of k , K , m , e and n . 0.5 mk
2-2- Work out an expression for the total mechanical energy, E_n of the electron on a circle of radius, r_n in terms of the same parameters. Express E_n in terms of E_1 1 mk
2-3- Calculate E_1 and E_2 in electron-volts. What phenomenon could cause the energy of the electron to change from E_1 to E_2 ? 1 mk

Exercise 2: / 4 marks

In an auto-testing workshop, a cart of mass 60 kg starts from a point, A and moves under the action of an electrically sustained engine force, $\vec{F}$ parallel to a rail and attains a velocity of 9 km h^{-1} at point, B which is 6 m from A. The path ABCD has three parts. AB is linear and horizontal. BC is an arc of a circle of centre, O and radius, r while CD is linear and inclined to the horizontal. Resistive forces are equivalent to a single force, $\vec{f}$ whose magnitude is 8 % of the weight. See figure.





- 1- What is the value of the acceleration over AB? 1 mk
- 2- How long does the cart take to cover AB and what is the size of the force, $\vec{F}$? 0.5 mk $\times$ 2
- 3- Over CD the force acts along the tangent to the arc of the circle. How must the size of the engine force be modified such that the cart moves over this section with constant velocity? 1 mk
- 4- The engine is stopped at point, C and the cart moves up to point, D, stops and moves backwards. Work out the acceleration of the cart as it ascends to D and as it moves backwards. 0.5 mk $\times$ 2

Exercise 3: / 5 marks

A satellite of mass, m is in orbit around the earth. The interactions between the satellite and other planets is negligible and the earth can be considered as a sphere of radius, R and mass M .

- 1- Write an expression for the force between the satellite and the earth in terms of the two masses and the height, h of the orbit from the surface of the earth. 1 mk
- 2- Denoting the gravitational field strength at the surface of the earth by g_0 , rewrite the expression for the force in terms of g_0 0.5 mk
- 3- Using the dynamics of the motion, work out an expression for the period of the motion of the satellite. 1.5 mk
- 4- If the gravitational field strength of the earth in the orbit is $1/25$ of g_0 , determine the height, h of the orbit from the surface of the earth and the value of the period. 1 mk
- 5- In which sense and by how much should the height be varied so that the satellite becomes geostationary? 1 mk

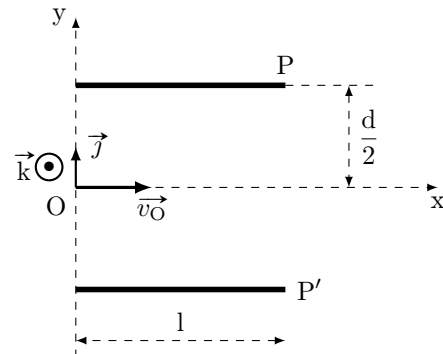
You are given $R = 6380 \text{ km}$; $g_0 = 8.80 \text{ m s}^{-2}$ and the duration of a day to be 86164 s .

Exercise 4: / 6 Points

A system for deflecting charged particles is set up using two parallel plates, P and P' each of length, l and separated by d . A homogeneous beam of electrons each of mass, m and carrying a charge, q enters between the plates at O with the velocity $\vec{v}_O = v_O \vec{e}$. See figure.

A potential difference is maintained across the plates $U_{PP'} = -U$ ($U > 0$).

- 1- Sketch a diagram to show electric field between the plates. 0.5 mk
- 2- Work out a value for the field strength and express the coordinates of the electric field, $\vec{E}$ in the frame $(O, \vec{e}, \vec{j}, \vec{k})$. 0.5 mk
- 3- Write the relation between the acceleration, $\vec{a}$ and the electric field, $\vec{E}$. 0.5 mk
- 4- Write the Cartesian equation for the trajectory. 1 mk



- 5- The electron in the beam emerge from the plates at a point S.
 - 5-1- Determine the coordinates of the exit point S. 0.5 mk
 - 5-2- Determine the coordinates of the velocity $\vec{v}_S$ at S and the angle, α the velocity makes with the (Ox) axis. 1 mk
 - 5-3- Calculate the time, τ spent by the electrons between the plates and the deviation, y_S . 2 mks
- You are given $U = 400 \text{ V}$; $v_O = 10^7 \text{ m/s}$; $d = l = 4 \text{ cm}$.