Chapter 12

Project 4 Classical Physics

Experiment A: The Charge to Mass Ratio of the Electron

12A.1 Objectives
(a) To perform Lenard's classic experiment to determine $e/m$.
(b) To evaluate the ratio $e/m$ and associated errors.

12A.2 Prior Reading
Ohanian Chapter 31: FLAP module P8.1.

12A.3 Preparatory Work
(i) Describe how the current flowing in a solenoid is related to the consequent magnetic field.
(ii) For the three orthogonal vectors: $\mathbf{a} = \mathbf{b} \wedge \mathbf{c}$

$\mathbf{a}$ draw a diagram showing their relative directions.
(iii) Write the magnitude of the force experienced by an electron as it travels perpendicular to a magnetic field as a centripetal force and hence show that:

$$\frac{e}{m} = \frac{2V}{B^2 R^2}$$

(Hint: Think about the kinetic energy of the electrons: see text for notation).
(iv) From the geometry of the electron path show that the radius of curvature, $R$, is related to the deflection $b$ of the electron beam across the CRT screen by the equation:

$$R = \frac{a^2 + b^2}{2b}$$

where $a$ is the distance from the electron gun to the screen.

12A.4 Safety Procedure
This apparatus uses a relatively high voltage and you should ensure that no liquid or other moisture is in close contact with the apparatus.

12A.5 Introduction
This experiment is concerned with measuring the charge to mass ratio of the electron ($e/m$), by monitoring the effect of a magnetic field on an electron beam. In this adaption of
Lenard's method (first reported in 1900) a small cathode ray tube (CRT) is used to provide the electron beam whilst a large coil of wire, through which a current flows (solenoid), generates the necessary magnetic field. When charged particles move in a magnetic field they experience a force which deflects them from their otherwise straight path (think about an electric motor). By measuring this deflection as a function of the magnetic field the charge to mass ratio of the moving particles may be calculated.

12A.6 Background
The apparatus is shown above. First, you need to think about the coil. How is the direction of the magnetic field, B, within the solenoid related to the current flowing through the wire? The magnitude of the magnetic field within the solenoid may be found by assuming it to be infinitely long:

$$B = \mu_0 NI$$

where $I$ is the current flowing through the coil, $N$ is the number of turns per metre and $\mu_0$ is the permeability of free space. The direction of the force $F$ acting on a charge $q$ moving with a velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$ is given in vector notation by the equation below, and the deflection of the electrons will be in the direction of $-\mathbf{F}$:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$

At what position and orientation should the CRT be placed in the solenoid such that the electrons
experience the maximum force and are therefore deflected to the greatest extent? From the above vector equation, the force $F$ is perpendicular to the velocity vector $v$. Therefore the path of the electrons within the CRT will be circular, of radius $R$. To estimate the value of $a$, inspect a CRT. Since it is difficult to see all the electron gun assembly, take the value of this dimension to be $10.7\pm0.3$ cm; assume $V=470\pm30$V.

12A.7 The Experiment
You can adjust the current flowing through the solenoid, using the integrated power supply unit. Then, in calculating the magnitude of the magnetic field, $B$, you will need to assume that the solenoid is infinitely long, ie you assume that the ends are unimportant. By using the CRT as a probe, investigate the uniformity of the magnetic field along the solenoid and express your results graphically. Based on these measurements, is the above assumption reasonable and within what limits?

Measure the deflection of the electron beam across the CRT screen as a function of the current flowing through the solenoid. Determine the ratio, $e/m$, by a suitable graphical method. The deflection is best measured by sticking a piece of graph paper to the CRT and using this as a graduated scale. Compare your answer with the textbook value. Do the two values agree within the limits of experimental uncertainty?
Experiment B: Angular Momentum

12B.1 Objectives
(a) To perform experiments with a rotating system.
(b) To observe the transformation of potential energy to kinetic energy.
(c) To determine whether angular momentum is conserved.

12B.2 Prior Reading
Ohanian Chapter 13: FLAP modules P2.7 and P2.8.

12B.3 Preparatory Work
(i) Write down an expression relating linear velocity and angular velocity.
(ii) Explain the term, “moment of inertia”.
(iii) Derive an expression for the moment of inertia, $I_d$, of a uniform disc of mass $M$ and radius $R$.
(iv) Derive an expression for moment of inertia, $I_a$, of a uniform annulus of mass $M$, inner radius $R_i$ and outer radius $R_o$.

12B.4 Safety Procedures
You should be careful with the rotating plate, since its edges may cause injury.

12B.5 Introduction
In this experiment you will investigate the conservation of angular momentum and the energy losses in a mechanical system that includes friction. A disc is provided which can rotate about a vertical axis. In the first part of the experiment a string is wound around the hub of the disc. It then passes over a pulley and is attached to a mass. If the mass is allowed to fall it will make the disc rotate. You are asked to compare the loss of potential energy of the mass with the gain in kinetic energy of the disc.

In the second part of the experiment a second disc is dropped on top of the spinning disc. By measuring the change in angular velocity the conservation of angular momentum can be investigated. The change in energy of the system is also found.

12B.6 Calculation of the Moment of Inertia of the Discs
The kinetic energy of a rotating disc is $I\omega^2/2$ where $I$ is its moment of inertia and $\omega$ its angular velocity. Use the mass values stamped on the components to calculate the moment of inertia $I_1$ of the disc that can rotate about a vertical axis and $I_2$ of the flat disc with masses added near its outer
edge. $I_1$ and $I_2$ are the values about an axis through the centre of each disc and perpendicular to the plane of the disc. Will significant errors occur if you neglect the hub of the first disc and the hole in the centre of the second?

12B.7 Comparison of Potential and Kinetic Energies
Tie a small loop at one end of a cord and fasten a mass to the other end. Slip the loop over the peg on the hub of the rotatable disc and pass the cord over the pulley at the edge of the bench; then rotate the disc so that the cord is coiled around the hub. Let the mass $m$ drop through a height $h$ and then measure the successive times for a marker on the disc to pass a fixed point. Plot a graph to show how the period of rotation varies with number of revolutions. Extrapolate back to find the effective period and hence $\omega$ at the instant the mass was released. Note, that in this plot the points will be half way between the integer positions. Carry out some preliminary trials to find two suitable values of $h$ for each of two values of $m$.

Compare the loss of potential energy $mgh$ with the kinetic energy gained $\frac{1}{2}I\omega^2$ in each case. Evaluate the kinetic energy of the falling mass $\frac{1}{2}mv^2$, where $v$ is its final speed. Is this important? Are the results consistent with the suggestion that the major loss process is the work done against friction?

12B.8 Conservation of Angular Momentum
Set the disc spinning at the highest rate that will enable you to measure the period of rotation, and hold the other disc horizontal with its central hole above the rotating hub. Let the second disc fall as centrally as possible and continue to record the period of rotation.

By extrapolating the data points you should be able to determine the instantaneous change in angular velocity when the second disc was added. Estimate the uncertainty in the values of $\omega$ before and after the impact. Hence calculate the kinetic energy and the angular momentum before and after impact. Repeat the experiment for a significantly different value of $\omega$. Comment on the result.
Notes: Project 4