B. Math. Hons. II Year
Semesteral Exam 2001-2002
Physics III

Date: 02-05-2002 Time: 9.45-12.45 Instructor: S. Chatterjee

Answer question 1 and any four other questions.
Distribution of marks: 25 + 18 x 4 + 3 (clarity of exposition) = 100.

1. Write down Maxwell's equations, explaining the symbols therein. In charge free space with ϵ as the dielectric constant and μ as the magnetic permeability, show that the displacement $\vec{D}$ and the magnetic induction $\vec{B}$ travel as transverse waves with velocity $v = c/\sqrt{\mu\epsilon}$ where c is the speed of light in vacuum. Also show that in electromagnetic wave propagation $\vec{D} \cdot \vec{B} = 0$. [25]

2. Show that absence of the displacement current term in one of the equations of electromagnetism violates charge conservation. Show that the introduction of the displacement current term restores charge conservation. Defining $\mathcal{E} = (\mu H^2 + \epsilon E^2)$ show that,

$$(\partial/\partial t)\mathcal{E} + div\ \vec{S} = 0 \text{ where } \vec{S} = (c/4\pi)(\vec{E} \times \vec{H}).$$

Explain the significance of the above equation. [18]

3. Consider an aluminium frame $ABCD$ (as in fig. 1), freely hanging vertically from a peg P. A constant current i_0 flows along the length of the frame as shown, along the z direction. A constant magnetic field H is applied along the y direction. If M be the mass of the frame and the wires attached to it and g be the acceleration due to gravity, find the deflection θ of the frame, when mechanical equilibrium is reached. What would be the difficulties if the frame be made of gold, silver, cobalt, nickel, wood?

Can you use this method to design a system which can give very precise displacements to objects attached to the part CD of the frame?

How much should θ be if $M = 10gms, i_0 = 3 \times 10^7$ statamps and $H = 10^3$ gauss (statamps and gauss are both units in gaussian system).

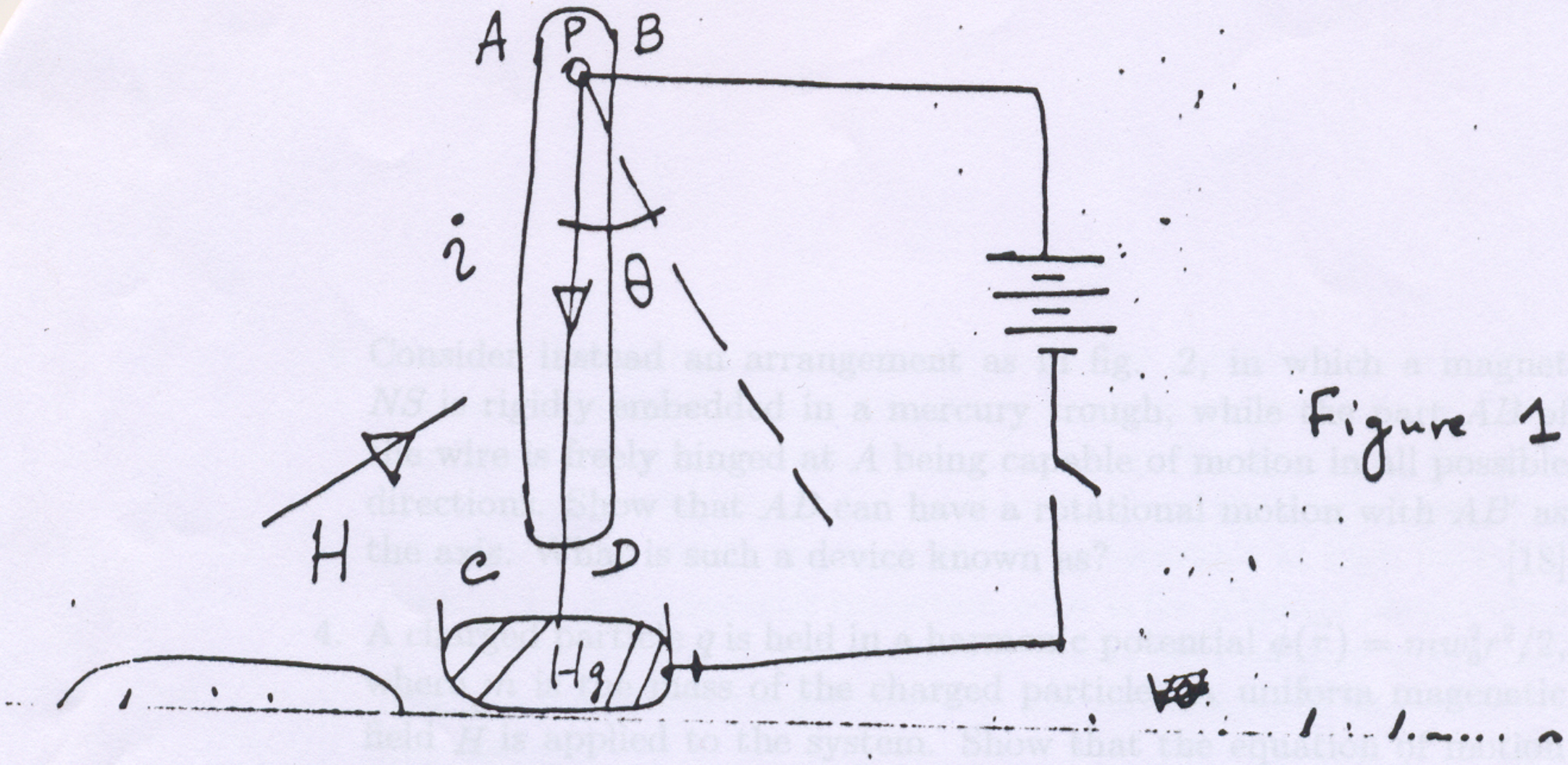

Figure 1

Consider instead an arrangement:

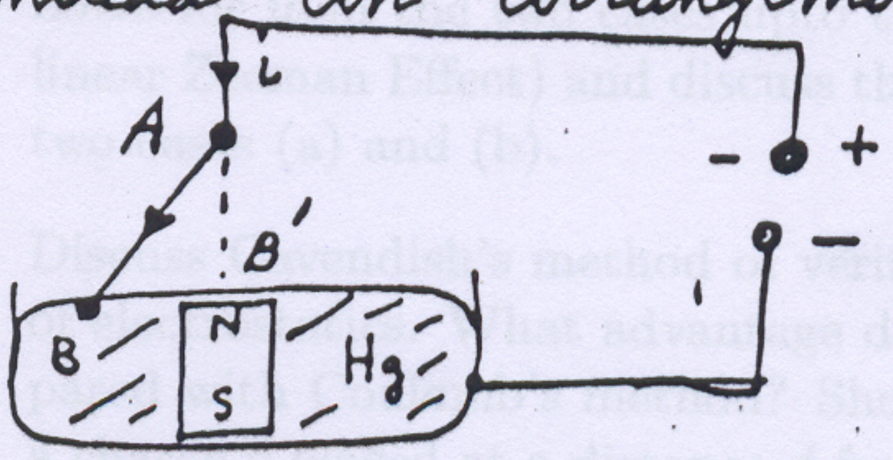

Figure 2

Consider instead an arrangement as in fig. 2, in which a magnet NS is rigidly embedded in a mercury trough, while the part AB of the wire is freely hinged at A being capable of motion in all possible directions. Show that AB can have a rotational motion with AB' as the axis. What is such a device known as? [18]

4. A charged particle q is held in a harmonic potential $\phi(\vec{r}) = mw_0^2 r^2/2$, where m is the mass of the charged particle. A uniform magenetic field $\vec{H}$ is applied to the system. Show that the equation of motion reads

$$m\frac{d^2\,\vec{r}}{dt^2} = -grad\ \phi + (q/c)[(\frac{d\,\vec{r}}{dt})\times\ \vec{H}].$$

Considering $\vec{H}$= $(H, 0, 0)$ write down the components of the equation of motion. How does the motion in the x direction differ from those in the y and z directions?

Consider a solution of the type (a) $y = r\cos wt, z = r\sin wt$ and show that the equation of motion gives:

$$w^2 = w_0^2 - (qH/mc)w$$

while for a solution (b) $y = r\cos wt, z = -r\sin wt$ one obtains a solution

$$w^2 = w_0^2 - (qH/mc)w.$$

Solve for w in the two cases upto the first order in (eH/mc) (called linear Zeeman Effect) and discuss the differences in the motion in the two cases (a) and (b). [18]

5. Discuss Cavendish's method of verification of the inverse square law of electrostatics. What advantage does this method have when compared with Coulomb's method? Show by the method of images that a charge q placed at a distance d from an infinite conductor is pulled towards the conductor with a force $q^2/(2d)^2$. Discuss (need not derive) how this force is modified if instead of a conductor, we had a dielectric of dielectric constant ϵ, while the rest of space be vacuum? [18]

6. What is the molecular (or atomic) basis for paramagnetism? When does a paramagnet undergo transition to a ferromagnetic state? Using the necessary assumptions, derive the Langevin expression for paramagnetic susceptibility and show that it follows the Curie Law at low magnetic fields, while the magnetization saturates at high fields. To account for ferromagnetic transition what is the physical phenomenon to be incorporated in the Langevin theory and explain graphically how the transition temperature to the ferromagnetic state can be calculated. [18]

7. a) Write short notes on any three of the following:
(i) Debye screening (ii) self inductance and mutual inductance (iii) Poynting vector (iv) dielectric constant.

b) Consider an infinite conductor with current i in the z-direction. Show that $r > r_0$ (cross sectional radius of the wire, the component of magnetic field in the xy plane follows $H_\phi = 2I/cr$. [18]