National Physics Olympiad, 2014

BdPhO, Group-C

March 7, 2014

Total time - 2hrs , Marks -24

You have to show all your intermediate calculations on the pages provided. Otherwise you will not get awards for your efforts.

Various Physical Constants

- Avogadro's Number $N_A = \ 6.02 \times 10^{23}$ mole^{-1}
- electronic charge $e = 1.6 \times 10^{-19}$ C
- Planck's constant $h = 6.63 \times 10^{-34}$ J s

1. **Heavenly Collisions** (total 3 marks)

   Two identical heavy point-like objects with mass M each are at rest , separated by a distance D.

   (a) What is the total energy of the system initially? (0.5 marks)

   (b) Find the expression for the speed of the individual particle once they start moving and have a separation x between them (0.5 marks)

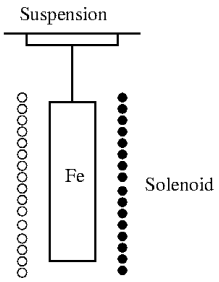
(c) Find the time for them to collide under the influence of mutual gravitational force. (2 marks)

2. **Einstein deHass experiment** (Total 5 marks) (a) Consider a particle of mass m and with charge q moving with uniform speed in a circle (as in the Bohr model for hydrogen atom) whose radius is R. Then a crude approximation for the current is given by

$$I = q/T$$

where T is the period of revolution for the charged particle along the circle.

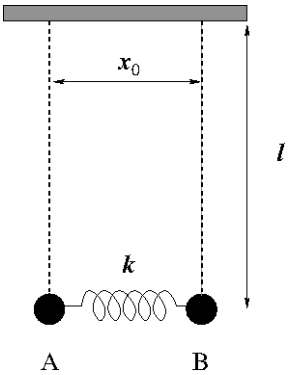
Find the relation between the angular momentum of the particle and the magnetic moment of the "loop". (1 mark)



(b) An unmagnetized iron magnet do not carry any net magnetic moment as all the atomic magnets are oriented in a random direction. However if a strong magnetic field along the axis of an unmagnetized iron bar the magnetic moments all get oriented (assuming very low temperature for the rod). Consider one such iron rod suspended vertically using a very fine thread and inside a long solenoid which produces a uniform magnetic field inside it (as shown in the figure). The white dots denote current going into the plane of the figure while the black dots represent current coming out of the plane of the figure. In what direction will the suspended vertical iron rod will rotate if the magnetic field is applied to the rod using the current configuration shown in the figure? (You might want to state in terms of angular momentum pointing up of down on the figure). Provide a physical reason behind your answer. (2 Mark)

(c) If the radius of the suspended (cylindrical) iron bar is R=1.0 mm, estimate T - the period of rotation of the cylinder. Assume that iron atoms each have an orbital angular momentum of (in accordance with Bohr model) $\hbar \equiv \frac{h}{2\pi}$ and they become completely alligned in the external magnetic field. The molar mass of iron is given as $M = 0.0558$ kg/mol. (2 marks)

3. **Coupled Pendulum** (Total 6 marks)



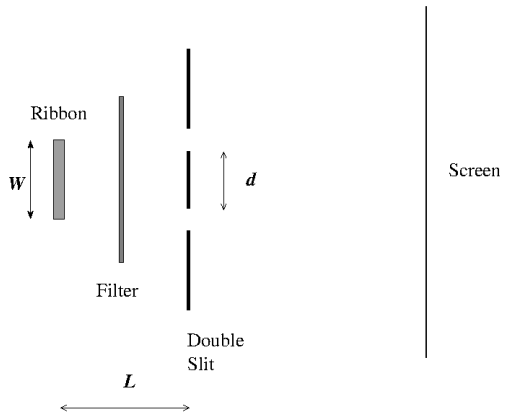
Two identical simple pendula A and B are suspended next to each other from a room where the separation between their suspension points is x_0. The effective length for each of the pendulum is l. The point masses are also attached by a massless spring with a spring constant k. Let the angular displacements from the vertical position for A and B be θ_A and θ_B.

(a) Evaluate the potential energy of the system as a function of θ_A and θ_B , assuming the potential energy to be zero when $\theta_A = \theta_B = 0$. (1 Mark)

(b) Since this is a conservative system, the energy of this system will be a constant. Differentiate the total energy with respect to time t (noting that both θ_A , θ_B both vary independently as functions of t) and find the equations of motion for the system. (2 marks)

(c) For small oscillations we can replace the trigonometric functions by their Taylor expansions. Find the oscillation frequencies of this system of double pendula and identify the modes of oscillation. (3 marks)

4. **Blurred Images** (Total 3 marks)



An opaque screen has two very narrow parallel slits which are separated by a distance d. The screen is illuminated by a straight bright tube of width W which is placed at a distance L away from the screen with the parallel slits. A filter is placed in between them so that only light of wavelength λ falls on the slits. Now if one changes the separation between the slits is changed continually, then it is found that for $d = d_0$ the interference fringes on the observation screen, placed at a large distance disappears. What is the value of W (in terms of other quantities)?

5. **Freezing and Boiling** (Total 4 marks)

The heat released by the cooling of one mole of H_2O from 25^0 C to 0^0C and subsequent freezing in a refrigerating machine (which has the maximum theoretical efficiency) is transferred to a second mole of H_2O at 25^0 C - heating it to 100^OC.

(a) How many moles of H_2O is converted to steam at 100^OC?(2.5 marks)
(b) How much work must be done by the refrigerator? (1.5 marks)

The latent heat of fusion for H_2O is 6.02 kJ/mole while the latent heat of boiling for H_2O is 40.68 kJ/mole.

6. **Data Analysis** (Total 3 marks)
   Given the following set of data find the best ***graphical*** fit according to the relation $y = Ax^2 + b$. You have to show all your intermediate steps and the results in **this page** and plot the data in the provided graph sheet in the next page

x	0.5	1	1.5	2.0	2.5	3.0
y	1.20	1.10	2.35	3.05	4.40	5.50