Part I (50%):

Only the answers are required in this part.
Please write down your answers on the FIRST page of the answer sheets.

1. (10%) A pair of the positive and negative charges $Q, -Q$ is placed on the y-axis with a separation d between them (see Fig. 1). In the asymptotic limit $r \gg d$, the approximate electric field $\boldsymbol{E}(r)$ is _____ .

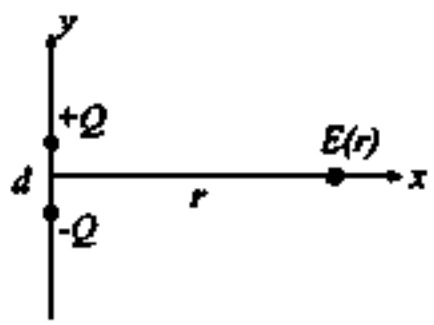

FIG. 1: An electric dipole moment at the origin.

2. (10%) An uniformly charged infinite slab, as in Fig. 2, with charge density ρ and thickness d is placed on the x-y plane. Choose an appropriate closed surface and apply the Gauss' law to it. The electric field $\boldsymbol{E}(z)$ at height of z above the slab is _____ .

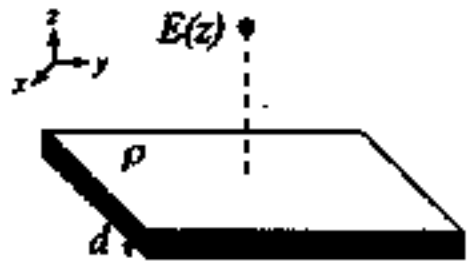

FIG. 2: A charged infinite slab with thickness d.

3. (10%) Two *perfect* spherical conductors of radius R_1, R_2 are well separated. Initially, both carry equal charge Q. Now, we connect them with a thin conducting wire (see Fig. 3). The capacitance of the wire is negligible, i.e. there is almost not charge in the wire. After the equilibrium is reached, the wire is removed. The charge Q_1 on the sphere of radius R_1 is _____ .

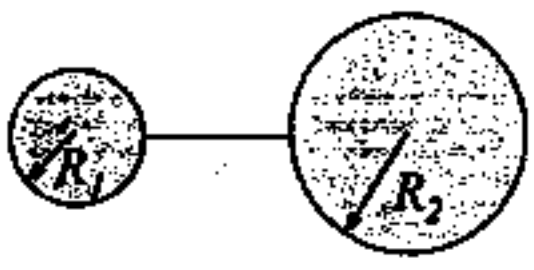

FIG. 3: Two connected conducting spheres.

4. (10%) A square circuit with current I is placed beside an infinite straight wire, which also carries current I (see Fig. 4). Notice that the current in the square loop is counterclockwise and the current in the wire is flowing upward. The width of the square is d and the distance between the wire and the near side of the square is also d. The total force on the square circuit is _____ .

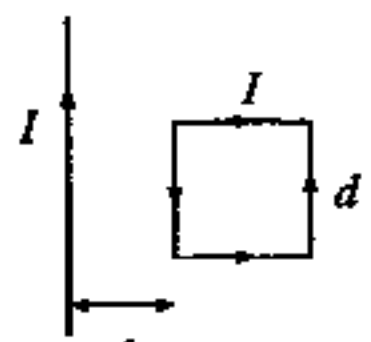

FIG. 4: The force and the torque on a magnetic dipole.

5. (10%) A square loop with resistance R is moving at constant velocity v. The magnetic field B, pointing out of the paper, is set up in a finite domain as shown in Fig. 5. As the moving loop passing through the magnetic field, the magnetic flux changes and an induced current appears. In order to keep the square loop moving at constant velocity v, a position-dependent external force $F(x)$ is necessary. Calculate the work W, _____ , which is needed to push the square circuit passing through the magnetic field.

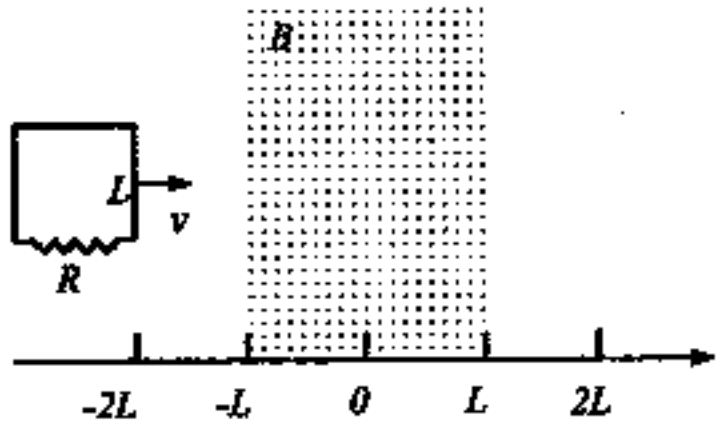

FIG. 5: A closed circuit moving through the magnetic field in a finite region.

Part II (50%):

Solve the following four problems.

Please write down your answers starting from the SECOND page of the answer sheets.

6. (10%) A particle m in Fig. 6. slides down the frictionless surface and collides with the uniform vertical rod, then sticks to it. The rod pivots about O and rotates through the angle θ before coming to rest.

(a) (2%) About which axis, is the angular momentum conserved?

(b) (3%) Find the moment of inertia of the rod about one end and perpendicular to the rod?

(c) (5%) Find the angle θ in terms of other parameters given in the figure.

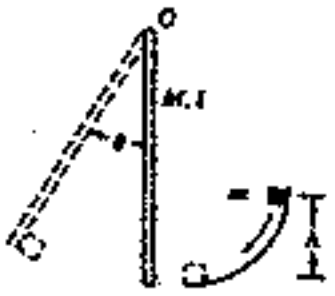

FIG. 6.

7. (16%) A sphere of radius R and mass M rolls without slipping down an incline with inclination angle θ as shown in Fig. 7.

(a) (4%) Calculate the moment of the inertia of the sphere through its center.

(b) (4%) Find the linear acceleration of the center of mass.

(c) (4%) Find the frictional force that constrains the rolling without slipping.

(d) (4%) If the sphere falls a vertical height H from the rest, what is the speed of the center?

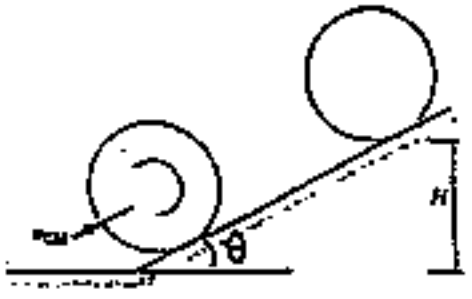

FIG. 7.

8. (12%) A 25 kg block is connected to a 30 kg block by a light string which passes over a frictionless pulley. The 30 kg block, in turn, in connected to a spring of force constant 200 N/m (Fig. 8). The coefficient of kinetic friction between the 25 kg block and inclined plane is 0.10. The spring is unstretched when the system is as shown in the figure. The 25 kg block is then pulled a distance of 20 cm down the incline (so that the 30 kg block is 40 cm above the floor) and is released from rest. Assume $g = 10.0$ m/s^2 and $\sin 37^\circ = 0.6$.

(a) (6%) What is the tension in the string before the 25 kg block is released?

(b) (6%) What is the speed of each block when the 30 kg block is 20 cm above the floor (that is, the spring is unstretched)?

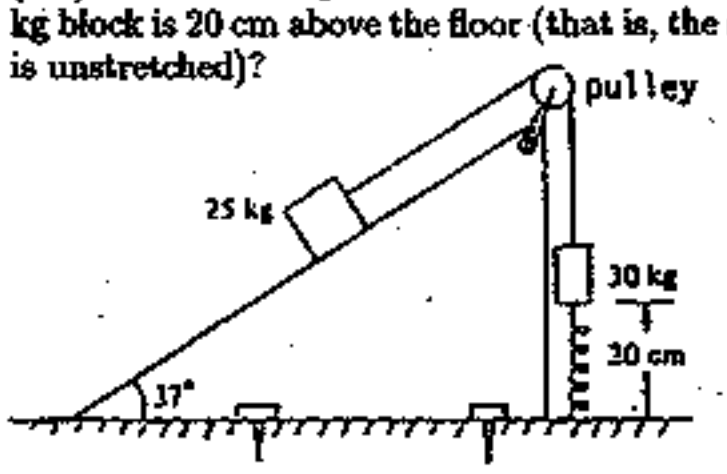

FIG. 8.

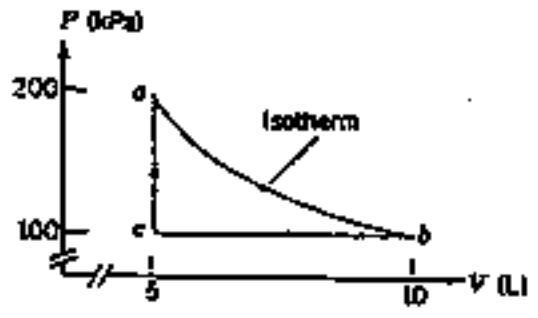

FIG. 9.

9. (12%) Two moles of ideal diatomic gas are taken around the cycle of Fig. 9. Given: $R = 8.314$ J/K-mol, $\ln 2 = 0.693$.

(a) (3%) What is the ratio of specific heats γ for the gas?

(b) (3%) Find the heat absorbed or rejected in each segment, $\overline{ab}, \overline{bc}, \overline{ca}$.

(c) (3%) Find the work done per cycle.

(d) (3%) Calculate the total efficiency.