Answer all questions 1-6.

1. True or False (T/F). For each question (i – viii) correct answer equals to +1 p, wrong answer -0.5 p, no answer at all 0p. However, minimum score from this exercise is 0 - you cannot lose points gained in any other exercise. No explanations are required, answer simply T or F.
   - (i) Insulator cannot be charged electrically.
   - (ii) Electric potential is a property of charge distribution and it forms a scalar field.
   - (iii) Electric field is perpendicular to the surface of a conductor.
   - (iv) The charge distribution on the surface of a conductor is always independent of the shape of the conductor.
   - (v) Capacitance is a material property.
   - (vi) In metals electric current is carried by electrons.
   - (vii) The induced electric field in insulator opposes the external electric field.
   - (viii) Kirchhoff's laws cannot be applied for circuits in which the current is time-dependent.

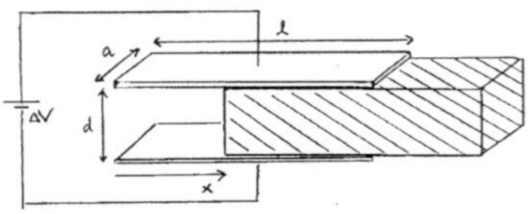
2. Let's consider a system in which an electron is placed above a uniformly charged, large, thin plate (positive surface charge density $+\eta$). The distance between the electron and the plate is a.
   (a) Where do we need to place a proton to stabilize the electron (fix its position)? Give your answer measured from the surface of the plate. (3p)
   (b) What is the force experienced by the proton? (2p)
   (c) What is the force experienced by the plate? (3p)
   Ignore gravity

3. Let's consider a hollow metal ball with inner radius a and outer radius b. The net charge of the ball is Q. There is a charge $+q$ placed at the center of the hollow

cavity. Calculate the electric field as a function of r measured from the center of the hollow ball r: $0 \rightarrow \infty$. (6p) How is Q distributed over the system? (2p)

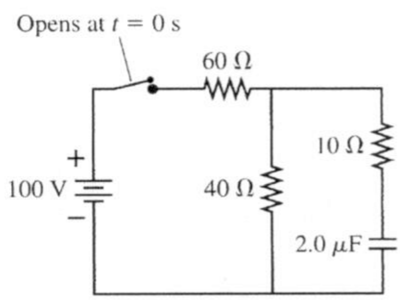
4. Consider a small ball with mass of 0.35 g and charge of +20.0 nC. The ball is allowed to move in a vertical tube (assume no friction). The ball is released in Earth gravitational field from a height of 25 cm towards another ball (charge +50.0 nC) placed at the bottom of the tube.
   (a) What is the closest distance of the balls? (4p)
   (b) What is the equilibrium position of the oscillatory motion? (2p)
   (c) Is this a harmonic oscillator? Explain your answer. (2p)

5. A battery ΔV is connected to a parallel plate capacitor. An insulator is placed between the plates as shown. The dielectric constant of the insulator is κ.
   As a function of x (see figure) what is
   (a) The capacitance of the system? (3p)
   (b) Energy stored in the capacitor? (2p)
   (c) Force experienced by the insulator?(3p)



6. The switch has been closed for a long time

   (a) What is the charge Q of the capacitor? (4p)
   (b) The switch is opened at $t = 0$. When has the charge of the capacitor decayed to 10 % of the initial charge? (4p)



$$\vec{E} = \frac{\vec{F}_0}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r} \qquad E = \frac{\eta}{2\varepsilon_0}$$

$$\vec{p} = q\,\vec{s} \qquad \vec{\tau} = \vec{p}\times\vec{E} \qquad U = -\vec{p}\cdot\vec{E}$$

$$\Phi_e = \oint_A \vec{E}\cdot d\vec{A} = \frac{Q_{\text{in}}}{\varepsilon_0}$$

$$V = \frac{U}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$$

$$\Delta V = V_b - V_a = -\int_a^b \vec{E}\cdot d\vec{s} \qquad E = \frac{\Delta V}{d}$$

$$\vec{E} = -\left(\hat{i}\,\frac{\partial V}{\partial x} + \hat{j}\,\frac{\partial V}{\partial y} + \hat{k}\,\frac{\partial V}{\partial z}\right) = -\vec{\nabla}\,V$$

$$C = \frac{Q}{\Delta V} = \varepsilon_0\,\frac{A}{d} \qquad \varepsilon = \kappa\,\varepsilon_0$$

$$U_C = \frac{Q^2}{2C} = \tfrac{1}{2}C(\Delta V)^2 \qquad u = \tfrac{1}{2}\varepsilon_0 E^2$$

$$I = \frac{dQ}{dt} = n\,e\,v_d\,A \qquad \vec{J} = n\,e\,\vec{v}_d$$

$$J = \sigma E \qquad \rho = \frac{1}{\sigma} \qquad R = \rho\,\frac{L}{A}$$

$$\Delta V = R\,I \qquad \Delta V_{\text{P}} = \mathcal{E} - I\,r$$

$$P_{\text{R}} = I^2 R = \frac{\Delta V_{\text{R}}^{\,2}}{R} \qquad P_{\text{P}} = I\,\Delta V_{\text{P}}$$

$$Q(t) = C\,\mathcal{E}(1 - e^{-t/RC}) \qquad I(t) = I_0\,e^{-t/\tau}$$

$$Q(t) = Q_0 e^{-t/RC} = Q_0 e^{-t/\tau}$$

$c = 2.9979 \times 10^{8}$ m/s
$e = 1.6022 \times 10^{-19}$ C
$\varepsilon_o = 8.8542 \times 10^{-12}$ F/m
$(4\pi\varepsilon_o)^{-1} = 8.9876 \times 10^{9}$ Nm^2/C^2
$\mu_o = 4\pi \times 10^{-7}$ H/m
$u = 1.66054 \times 10^{-27}$ kg $= 931.49$ MeV/c^2
$m_e = 9.1094 \times 10^{-31}$ kg $= 0.51100$ MeV/c^2
$m_p = 1.6726 \times 10^{-27}$ kg $= 938.3$ MeV/c^2
$m_n = 1.6749 \times 10^{-27}$ kg $= 939.6$ MeV/c^2
$h = 6.6261 \times 10^{-34}$ Js $= 4.1357 \times 10^{-15}$ eVs
$R = 8.3145$ J mol^{-1} K^{-1}
$N_A = 6.0221 \times 10^{23}$ mol^{-1}
$k = 1.3807 \times 10^{-23}$ J K^{-1}
$G = 6.673 \times 10^{-11}$ Nm^2/kg^2