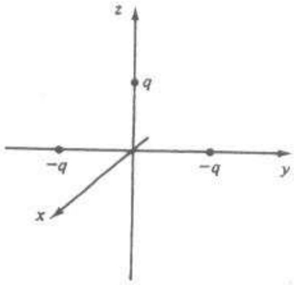
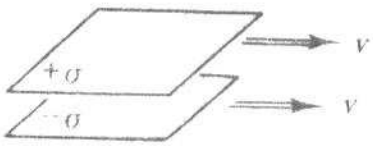
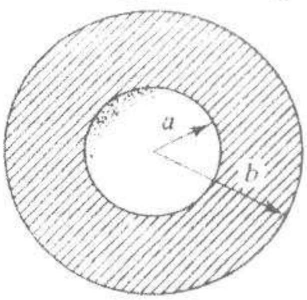
1. Three point charges are situated as shown in below, each a distance d from the origin. Find the approximate potential and electric field at points far from the origin. Express your answer in spherical coordinates, and include the two lowest orders in the multiple expansion. (20%)



2. A large parallel-plate capacitor with uniform surface charge σ on the upper plate and $-\sigma$ on the lower is moving with constant speed V as shown in below.
(a) Find the magnetic field between the plates and also above and below them. (5%)
(b) Find the magnetic force per unit area on the upper plate, including its direction. (5%)
(c) At what speed V would the magnetic force balance the electric force? (5%)

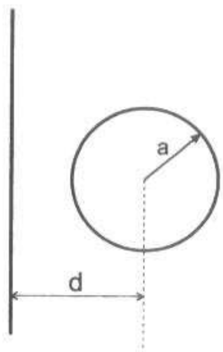


3. A spherical conductor, of radius a, carries a charge Q (as in below). It is surrounded by linear dielectric material of susceptibility χ_e, out of a radius b. Find the energy of the configuration. (15%)



4 (15%) Find the mutual inductance between the straight wire and the coplanar circular wire shown in the figure. *Hint* : Put the origin of the coordinate system at the center of the circle. Using cylindrical coordinates, you will need

$$\int_0^{\pi} \frac{d\phi}{d + r\cos\phi} = \frac{\pi}{\sqrt{d^2 - r^2}}, \quad d > r > 0 \ .$$

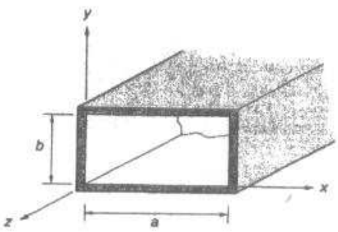


5 Let us consider two lossless dielectric media, 1 and 2, of parameters ϵ_1 and μ_1, and ϵ_2 and μ_2, respectively, separated by a planar interface. Let the incident wave, with an electric field E_{1i} and of angular frequency ω, propagate in medium 1 toward the interface, normal to it, with the vector $\boldsymbol{E}$ parallel to the x axis.

(a) (10%) Calculate the reflection and transmission coefficients in terms of the intrinsic impedences η_1 and η_2.

(b) (5%) Derive the condition for the position where the electric field in the medium 1 assumes a maximum value if $\eta_2 > \eta_1$.

6 Consider a hollow, perfectly conducting rectangular waveguide pipe, filled with a perfect dielectric of parameters ϵ and μ, as in the figure. Let the complex vectors $\boldsymbol{E}$ and $\boldsymbol{H}$ in the waveguide be of the form $\boldsymbol{E}_{\text{tot}} = \boldsymbol{E}(x,y)e^{-\gamma z}$, and $\boldsymbol{H}_{\text{tot}} = \boldsymbol{H}(x,y)e^{-\gamma z}$. Here γ is the propagation coefficient in the z direction. We allow γ to be complex.



(a) (10%) Derive the expressions of E_x, E_y, H_x, and H_y for TE_{mn} modes.

(b) (10%) What is the cut off frequency f_c and group velocity of TE_{mn} modes?