$\oint_S E_n dA = \frac{1}{\varepsilon_0} Q_{inside}$
$\nabla \cdot E = \frac{1}{\epsilon_0}\rho | V(r) = -\int^r E \cdot dl$
$E = -\nabla V | C = \frac{Q}{V}$
$W = \frac{1}{2}CV^2 | W = \frac{\epsilon_0}{2}\int E^2 d\tau$
$V(r) = \frac{1}{4\pi\epsilon_0}\int \frac{\rho(r)}{r_s} d\tau$
Potential is continuous at boundaries
**Method of Images**

- Replace the conducting plane with a mirror image charge
- Use Gausss law on each charge in isolation
- Sum up the electric field contribution from each charge

Poisson's equation: $\nabla^2 V = -\frac{1}{\epsilon_0}\rho$
Laplace's equation: $\nabla^2 V = 0$
Laplace's equation in Cartesian:
$\frac{\delta^2 V}{\delta x^2}\frac{\delta^2 V}{\delta y^2}\frac{\delta^2 V}{\delta z^2} = 0$
Converted to PDE
$V(x,y) =$
$(Ae^{kx} + B^{-kx})(Csin(ky) + Dcos(ky))$
Laplace's equation is true if $\rho$ is zero
**Monopole Expansions**
Monopole ($V$ $1/r$)
Dipole ($V$ $1/r^2$)
Quadrupole ($V$ $1/r^3$)
Octopole ($V$ $1/r^4$)
$\rho = \sum_{i=1}^{n} q_i r_i$
$V_{mon}(r) = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$
$V_{dip}(r) = \frac{1}{4\pi\epsilon_0}\frac{\rho \cdot \hat{r}}{r^2}$
$E_{dip}(r,\theta) = \frac{\rho}{4\pi\epsilon_0 r^3}(2cos\theta\hat{r} + sin\theta\hat{\theta})$
Charge is evenly distributed across capacitor plates
$F = QE$
Volume Charge $E(r) = \frac{1}{4\pi\epsilon_0}\int \frac{\rho(r)}{r^2}\hat{r} d\tau$

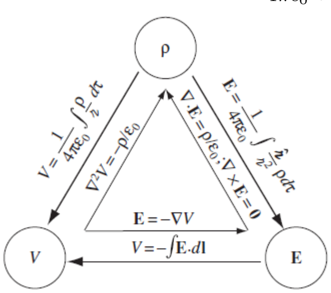

FIGURE 2.35

**Maxwell's Equations:** Electrostatics
$\nabla \cdot E = \frac{1}{\epsilon_0}\rho$
$\nabla \times E = 0$
**Maxwell's Equations:** Magnetostatics
$\nabla \cdot B = 0$
$\nabla \times B = \mu_0 J$
$p = \alpha E$ $_{(\alpha = AtomicPolarizability)}$
$p = \alpha_\perp E_\perp + \alpha_\parallel E_\parallel$ $_{(p = DipoleMoment)}$
$N = p \times E$ $_{(N = Torgue)}$
$F_{dipole} = (p \cdot \nabla)E$
$U = -p \cdot E$
$\sigma_b = P \cdot \hat{n}$ $_{(P = DipoleMomentPerUnitVolume)}$
$\rho_b = -\nabla \cdot P$ $_{(\sigma_b = SurfaceBoundChargeDensity)}$
$D = \epsilon_0 E + P$ $_{(D = ElectricDisplacement)}$
$\nabla \cdot D = \rho_f$ $_{(\rho_f = FreeCharge)}$
**Free Charge:** The free charge might consist of electrons on a conductor or ions embedded in the dielectric material or whatever; and charge, in other words, that is *not* a result of polarization. Free charge is the stuff we control.
$\oint D \cdot da = Q_{fenc}$
$D = \epsilon E$
$D^\perp_{above} - D^\perp_{below} = \sigma_f$
$E^\perp_{above} - E^\perp_{below} = \frac{1}{\epsilon_0}\sigma$
$E^\parallel_{above} - E^\parallel_{below} = 0$
$\epsilon = \epsilon_0(1 + \chi_e)$
$\epsilon_r = 1 + \chi_e = \frac{\epsilon}{\epsilon_0}$
$P = \epsilon_0 \chi_e E$
$C = \epsilon_r C_{vac}$
$\oint B \cdot dl = \mu_0 I$
$B(r) = \frac{\mu_0}{4\pi}\int \frac{I \times \hat{\mathscr{r}}}{\mathscr{r}^2} dl' = \frac{\mu_0}{4\pi} I \int \frac{dl' \times \hat{\mathscr{r}}}{\mathscr{r}^2}$
$B_{loop} = \frac{\mu_0 I}{2r}$
$B_{line} = \frac{\mu_0 I}{2\pi r}$
$B_{solenoid} = \mu_0 n I$
$\nabla \cdot J = -\frac{\delta\rho}{\delta t}$
$F_{mag} = \int I(dl \times B)$
$F_{mag} = Q(v \times B)$
$K = \frac{dI}{dl_\perp} = \sigma v$ $_{(K = SurfaceCurrentDensity)}$
$J = \frac{dI}{da_\perp} = \rho v$ $_{(J = VolumeCurrentDensity)}$
$J = \frac{1}{\mu_0}(\nabla \times B)$
$B = \nabla \times A$ $_{(A = VectorPotential)}$
$\nabla \cdot A = 0$
$\nabla^2 A = -\mu_0 J$
$A(r) = \frac{\mu_0}{4\pi}\int \frac{J(r')}{\mathscr{r}} d\tau'$
$B_{above} - B_{below} = \mu_0(K \times \hat{n})$
$A_{above} - A_{below} = 0$
$A_{dip}(r) = \frac{\mu_0}{4\pi}\frac{m \times \hat{r}}{r^2}$
$m = I\int da = Ia$ $_{(m = MagneticDipoleMoment)}$
$B_{dip}(r) = \frac{\mu_0}{4\pi}[3(m \cdot \hat{r})\hat{r} - m]$
$B_{line} = \frac{\mu_0 I}{4\pi s}(sin\theta_2 - sin\theta_1)$
$\nabla \times B = \mu_0 J$
$J_b = \nabla \times M$
$K_b = M \times \hat{n}$ $\nabla \cdot E = \frac{1}{\epsilon_0}\rho$
$\nabla \times E = -\frac{\delta B}{\delta t}$
$\nabla \cdot B = 0$
$\nabla \times B = \mu_0 J + \mu_0\epsilon_0\frac{\delta E}{\delta t}$
$N = m \times b$ $_{N = Torque}$
$F_{loop} = \nabla(m \cdot B)$
$J_b = \nabla \times M$ $_{J_b = VolumeBoundCurrent}$
$K_b = M \times \hat{n}$ $_{K_b = SurfaceBoundCurrent}$
$H \equiv \frac{1}{\mu_0}B - M$
$\nabla \times H = J_f$ | $\oint H \cdot dl = I_{f_{enc}}$
$\nabla \cdot H = -\nabla \cdot M$
$M = \chi_m H$ $_{\chi_m = MagneticSusceptibility}$
$B = \mu H$
$\mu \equiv \mu_0(1 + \chi_m)$
$F = ma = qE$
$J = \sigma(E + v \times B)$ $_{\sigma = Conductivity}$
$J = \sigma E$ $(Ohm'sLaw)$
$J_d = \epsilon_0\frac{\delta E}{\delta t}$
$I = \sigma\int E \cdot da$
$P = VI = I^2 R$
$V = IR$
$\tau = RC$
$\varepsilon \equiv \oint f \cdot dl = \oint f_s \cdot dl$ $_{\varepsilon = ElectromotiveForce}$
$\varepsilon = -\frac{d\Phi}{dt}$
$\varepsilon = IR$
A Changing magnetic field induces an electric field
Nature abhors a change in flux
$F_{mag} = \int I(dl \times B)$
$F_{mag} = Q(v \times B)$
$\Phi = LI$ $_{L = SelfInductance}$
$\varepsilon = -L\frac{dI}{dt}$
$W = \frac{1}{2}LI^2$
$W = \frac{1}{2\mu_0}\int_{allspace} B^2 d\tau$

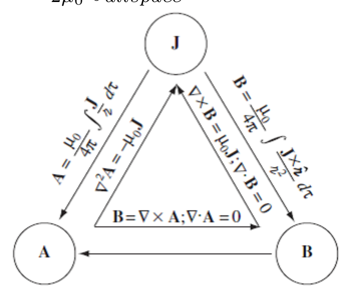

FIGURE 5.48

In homogenous linear material
$J_b = \nabla \times M = \nabla \times (\chi_m H) = \chi_m J_f$
For two coaxial cylinders with constant conductivity
$E = \frac{\lambda}{2\pi\epsilon_0 s}\hat{s}$
$I = \int J \cdot da = \frac{sigma}{\epsilon_0}\lambda L$
$V = -\int_b^a E \cdot dl$
Loop inside magnetic field
$\varepsilon = \oint f_{mag} \cdot dl = vBh$
$f_{pull} = uB$