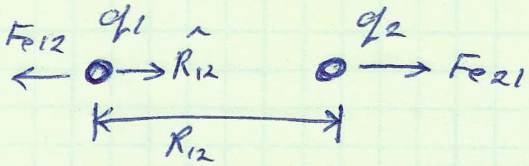
- Class information sheet
- Syllabus – handout
- Motivation to study electromagnetics:
  - foundation for optics, circuits, RF, communication, etc
  - understanding from one field can be applied to many others
    - e.g. reflections, impedance, wave behavior, etc.
  - one of the four fundamental forces:
    - nuclear (strong), EM, weak, gravity

- Electric fields
  - Surrounds charged particles
  - causes forces on other charged particles



$$\boxed{\vec{F}_{e21} = \hat{R}_{12} \frac{q_1 q_2}{4\pi \epsilon_0 R_{12}^2} \quad \text{Coulomb's Law}}$$

notation: bold → vector, sometimes use $\vec{X}$ (arrow)
$\hat{x}$ "hat" → unit vector
X_{ab} → "from a to b" or "caused on a by b"

Electric field intensity

$$\vec{E} = \hat{R} \frac{q}{4\pi \epsilon_0 R^2}$$

force on another charge q'

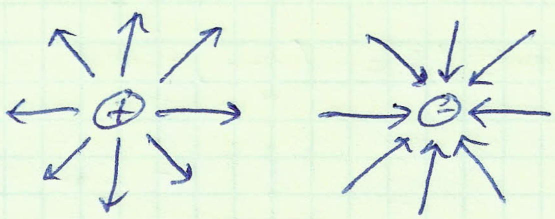
$$\vec{F}_e = q' \vec{E}$$

constants

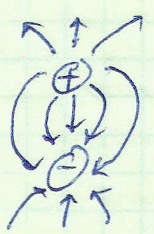
$e = 1.6 \times 10^{-19}$ C
electronic charge

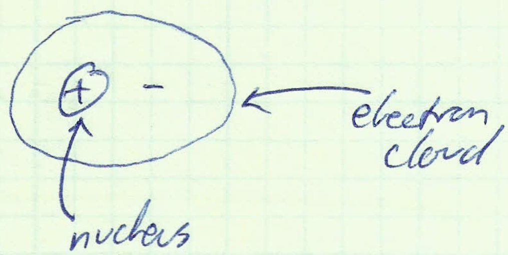
$\epsilon_0 = 8.854 \times 10^{-12}$ F/m
electric permittivity of free space

- Conservation of electric charge
  - charge (net, total) cannot be created or destroyed
- Principle of linear superposition
  - total vector electric field is due to the vector sum of electric fields from all sources
- Field lines

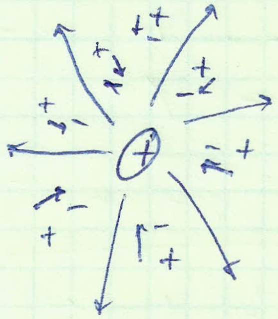


Electric dipole   polarized atom





Electric field screening by dielectric material



$$E = \hat{R}\frac{q}{4\pi\epsilon R^2}$$

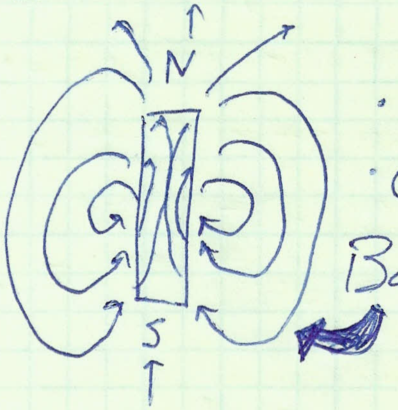
$$\epsilon = \epsilon_r \epsilon_0$$

ϵ_r ← relative permittivity

- Electric flux density

$$\vec{D} = \epsilon \vec{E}$$

• Magnetic Fields



- No magnetic monopoles
- Caused by currents – macroscopic or microscopic (spins)

$$B = \hat{\phi}\frac{\mu_0 I}{2\pi R}$$

$\mu_0 = 4\pi \times 10^{-7}$ H/m permeability of free space

$\mu = \mu_r \mu_0$

μ_r ← relative permeability

Right hand rule

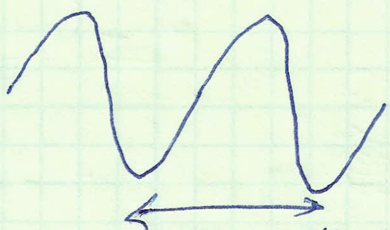
$\vec{B} = \mu \vec{H}$

H = magnetic field intensity

- Waves
  - Can transfer energy and information
  - travel with velocity (3×10^8 m/s for light in free space)
  - often can apply linearity
    - when one wave doesn't affect others
    - treat each independently, add results
  - types: plane, cylindrical, spherical, surface
  - general form

$$y(x,t) = A \cos\left(\underset{\text{period}}{\frac{2\pi t}{T}} - \underset{\text{wavelength}}{\frac{2\pi x}{\lambda}} - \phi_0\right)$$

set y = constant
find $\frac{dx}{dt}$



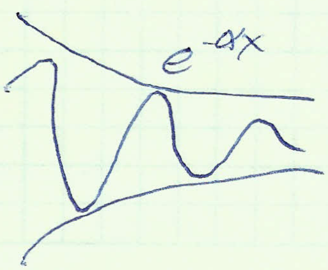
- waves move with phase velocity $\frac{dx}{dt} = \frac{\lambda}{T} = u_p$
- waves have a frequency $f = \frac{1}{T}$ (in Hz)

$$u_p = f\lambda = c = 3 \times 10^8 \text{ m/s} \text{ for EM waves in free space}$$

angular velocity $\omega = 2\pi f$
wavenumber $\beta = \frac{2\pi}{\lambda}$

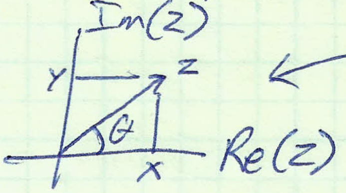
- Lossy medium

$$y(x,t) = A e^{-\alpha x} \cos(\omega t - \beta x + \phi_0)$$



Complex numbers

$z = x + jy \qquad j = \sqrt{-1}$



"complex plane"

$z = |z| e^{j\theta} = |z|(\cos\theta + j\sin\theta)$

$|z| = \sqrt[+]{x^2 + y^2}$

$\theta = \tan^{-1}(y/x)$

complex conjugate $z^* = x - jy = |z| e^{-j\theta}$

$|z| = \sqrt[+]{z z^*}$

phasors

time domain $V(t) = V_0 \cos(\omega t + \phi)$

phasor representation $V(t) = \mathrm{Re}\left[V_0 e^{j(\omega t + \phi)}\right]$

$\downarrow$

$\tilde{V} e^{j\omega t}$

extract mag/phase
separate from time variation $\longrightarrow$ $\tilde{V} = V_0 e^{j\phi}$

Makes differentiation or integration easier

$\frac{d}{dt}\left(\tilde{V} e^{j\omega t}\right) = j\omega \tilde{V} e^{j\omega t}$

don't need to keep track of arbitrary sines, cosines