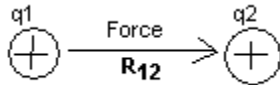


Handouts: Homework 2

Electric Force (Coulomb’s Law)

Charged particles create a force.
Recall from Physics:



$| \text{Force} | = Q_1 Q_2 / (4 \pi \epsilon_0 R^2)$ ← Electric Force acting on Q_2 due to Q_1
 R is distance from Q_1 to Q_2

Direction? \mathbf{R}_{12} ← unit vector pointing from Q_1 to Q_2
(Many books use different notation: $\mathbf{a}_{12} = \mathbf{R}_{12}$)
(Bold notation: means ‘vector’)

$\mathbf{F}_{12} = \mathbf{R}_{12} Q_1 Q_2 / (4 \pi \epsilon_0 R^2)$ Newtons ← Force pushes Q_2 away from Q_1

ϵ_0 ← electrical permittivity of free space = 8.854×10^{-12} F/m

Electric Field

Suppose Q_2 is a “unit charge” or a “test charge”. The electric field then describes what would happen to this unit test charge when it is near Q_1 ...

$\mathbf{E}_1 = \mathbf{F}_{12} / Q_2 = \mathbf{R}_{12} Q_1 / (4 \pi \epsilon_0 R^2)$ Newtons / Coulomb = Volts / meter
 \mathbf{R}_{12} is a unit vector pointing away from Q_1

Electric Field Lines start and end on charges.

Superposition

\mathbf{E} due to several charges is the sum of the \mathbf{E} due to them individually.

$$\mathbf{E} = \sum_{i=1}^N \mathbf{R}_i Q_i / (4 \pi \epsilon_0 R_i^2) \leftarrow \text{Vector summation}$$

Electric Field in Dielectric Material

$$\mathbf{E} = \sum_{i=1}^N \mathbf{R}_i Q_i / (4 \pi \epsilon R_i^2)$$

$\epsilon = \epsilon_r \epsilon_0$ F/m ← Electrical Permittivity

ϵ_r = Relative Permittivity (unitless) (see appendix E)
 Typical range: 1 (air) $< \epsilon_r < 80$ (distilled water)

Electric field is SMALLER in a dielectric material than in free space.
 Electric field represents FORCE on a charge.

Electric Flux Density

Electric flux density represents number or density of field lines.

$$\mathbf{D} = \epsilon \mathbf{E} \text{ (C/m}^2\text{)} = \sum_{i=1}^N \mathbf{R}_i Q_i / (4 \pi R_i^2)$$

The electric flux density depends only on the charges, NOT on the material.
 The electric field depends on both.

Magnetic charges

DO NOT EXIST!

Magnetic Field Lines

Magnetic fields are always CLOSED lines. (As compared to E field lines which start and end on charges.)

Caused by ferro-magnetic material – permanent magnet OR by an electric current (moving electric charges).

Magnetic Field Intensity

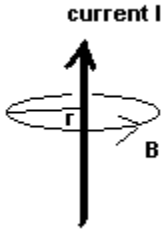
$$\mathbf{H} = I \mathbf{a}_\phi / (2 \pi P) \text{ Amperes / meter}$$

I is current in the \mathbf{z} (vertical) direction.

Right Hand Rule:

Use Right Hand Rule to determine direction of H from I: Point your right thumb in direction of I, and fingers show you H. Or put your thumb in the direction of H, and fingers show you direction of I.

Magnetic Flux Density (Biot-Savart Law)



$$\mathbf{B} = \mu \mathbf{H} \text{ Tesla}$$

μ = magnetic permeability (H/m)

$\mu_0 = 4\pi \times 10^{-7}$ Henry/meter ← Magnetic permeability of free space

μ_r = relative permeability (see Appendix E)

Typical ranges: 1 (air) < μ_r < 5000 (iron)

Speed of light (and other EM waves) is related to permittivity and permeability

$c = 1 / (\text{sqrt}(\mu_0 \epsilon_0)) = 3 \times 10^8$ m/s ← velocity of light in free space (Some books call it c_0)

Speed of light (and other EM waves) in dielectric materials (with no ‘conductivity’)

$v_p = 1 / (\text{sqrt}(\mu \epsilon))$ m/s

(some books call this “ c_ϵ ”, and some books call this “ c ”)

Static and Dynamic Fields

- Electrostatics: charges are static, \mathbf{E} field is static, no \mathbf{H} field
- Magnetostatics: currents are static, \mathbf{H} fields are static, no \mathbf{E} field
- Dynamics (!!): charges and/or currents are changing with time (dI/dt , $dq/dt \neq 0$),

\mathbf{E} and \mathbf{H} fields are both changing with time

**** Time-varying \mathbf{E} GENERATES time-varying \mathbf{H}

Time-varying \mathbf{H} GENERATES time-varying \mathbf{E} ****

NOW! Waves can propagate without wires/metal to conduct them.

Units

Charge (q or Q) = Coulomb (C) (be careful, because C is also used for capacitance)

Potential = Volt (V)

Current (I) = Ampere (A) = coulomb/sec

Resistance (R) = ohm (Ω) = Volt / Amp

Capacitance (C) = Farad = Amp-sec / volt

Inductance (L) = Henry = Volt-sec / Amp

Electric Field \mathbf{E} = Volt/meter ** vector

Electric Flux Density \mathbf{D} = coulomb/ m^2 ** vector

Electric permittivity ϵ = Farad (F) / meter

Magnetic Field \mathbf{H} = Ampere / meter ** vector

Magnetic Flux Density \mathbf{B} = tesla (T) or Weber (Wb) / m² = V-s / m² ** vector
Magnetic permeability μ = Henry (H) / meter = V-s / (A-m)