Electrostatics and Magnetism

Charges

- Electrostatic force may be attractive or repulsive depending on the signs of the charges.
- A **ground** is a means of returning charge to the earth.
- **Static Charge Buildup/Static Electricity** occurs more significantly in drier air because lower humidity allows charge to separate.
- Unit of charge is the **coulomb:** e=1.60 x 10^{-19} C

Insulators and Conductors

- Insulator will not easily distribute charge over its surface and will not transfer that charge to another neutral object very well.
  - Molecules tend to be closely linked with their nuclei so most non-metals are insulators. Serve as dielectric materials for capacitors and prevent grounding.
- Conductor will distribute any charge approximately evenly across its surface. Used in circuits and electrochemical cells since they are able to easily transfer charge.
  - Generally, metals and ionic solutions.

Coulomb's Law

Quantifies the magnitude of electrostatic force between two charges: $F_c = {kq_1q_2}/{r^2}$

- **K** is known as **Coulomb's constant** which has a value of $8.99\ x\ 10^9 \frac{\mathrm{Nm}^2}{\mathrm{C}^2} = \frac{1}{4\pi\varepsilon_0}$
  - ε_0 is the **permittivity** of free space and is equal to 8.85 x 10^{-12}

Electric Field

- Electric Field: created by all charges and exert forces on other charges that move into the space of the field.
  - Test Charge is the stationary charge placed inside the field while the Source Charge (Q) creates the electric field.

$$Magnitude\ of\ Electric\ Field = E = \frac{F_e}{q} = \frac{kQ}{r^2}$$

- Direction is determined by placing a positive test charge inside the field. If field is positive, then it is considered repulsive and represented as lines radiated out, vice versa for negative Q.
- **Field Lines** are imaginary lines that represent how a positive test charge would move in the presence of the source charge. Point away from a positive charge and towards center for a negative charge.

Electric Potential Energy

Much like gravitational potential energy since it is dependent on the relative position of one charge with respect to another charge or collection of charges. Can also be defined as the amount of work necessary to move a test charge from infinity to a point in space in an electric field.

$$U = \frac{kQq}{r}$$

- If the charges are like, then the potential will be positive. For opposite charges, the potential will be negative
- Conservative Force

Electric Potential

Defined as the ratio between the charge's electrical potential energy and the magnitude of the charge itself $V = {}^{U}/_{q} = \frac{KQ}{r}$ V is the electric potential measured in volts [1 J/C].

- For two points at different distance within the same electric field, the **potential difference** between them is known as **voltage:**

$$\Delta V = V_b - V_a = \frac{W_{ab}}{q} \; Wab\ is\ the\ work\ needed\ to\ move\ a\ test\ charge$$

- Positive charges will spontaneously move in the direction that decreases their electric potential (negative voltage)
- Negative charges will spontaneously move in the direction that increases their electric potential (positive voltage)
- In both of the above cases, the electric potential energy is decreases since W_{ab} is negative.

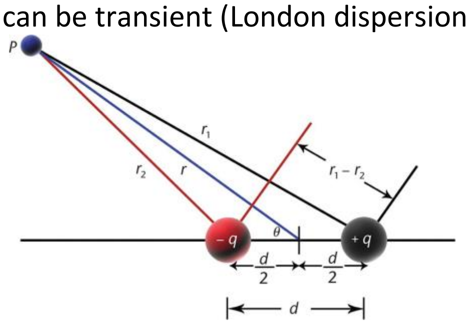
Special Cases in Electrostatics

Equipotential Lines

- A line on which the potential at every point is the same. So the potential difference between any two points is zero.
  - Will appear as concentric circles in 2D and are spheres in 3D.
  - Work will not be done as you move form point to point in the same circle
  - Work will be done if going between points on different circles.
- This is like how there is no change in gravitational energy when moving along a horizontal surface.

Electric Dipoles

Results from two equal and opposite charges being separated by a small distance, *d* from each other. These can be transient (London dispersion) or permanent.



Approximation is good for when r>>d

$$V = {}^{kq(r_2 - r_1)}/_{r_1 r_2} \approx \frac{kqd}{r^2}\cos\theta$$

- The dipole moment is the product of the separation distance and charge: $\boldsymbol{p} = q\boldsymbol{d}$

- Direction is defined differently between physics and chemists. Physicists point vector form negative charge to positive while chemist do the opposite.
- <u>Perpendicular bisector of Dipole</u> is the equipotential line that lies halfway between +q & -q. Electric potential along this plane is zero since angle is 90 degrees. Electric field on the bisector can be approximated as:

$$E = \frac{1}{4\pi\varepsilon_0}\ x\,\frac{p}{r^3}$$

  -Vector will point in the direction opposite to p (As defined by physicists)
- There is torque on the dipole when it is placed in a uniform external electric field, since there are equal and opposite charges on each side:

$$\tau = pE\sin\theta$$

  -This torque will cause the dipole moment to align with the electric field, **E**.

Magnetism

- Any moving charge creates a **magnetic field** and the units for this strength are in **Tesla** [1 T = 1 $^{\mathrm{N\cdot s}}/_{\mathrm{m\cdot C}}$] and small magnetic fields are measured in **gauss** [1 T=10^4 gauss]
- <u>Diamagnetic materials:</u> made of atoms with no unpaired electrons and have no net magnetic field.
  - These are slightly repelled by magnets (weakly antimagnetic).
  - E.g – wood, plastic, water, glass, skin
- <u>Paramagnetic materials:</u> Do have unpaired electrons so that they do generate a net magnetic dipole moment.
  - Will become very weakly magnetized in the presence of an external magnetic field. This magnetic behavior is only temporary (only occurs while in presence of magnetic field).
  - E.g – aluminum, copper and gold
- <u>Ferromagnetic Materials:</u> have unpaired electrons and permanent atomic magnetic dipoles. Oriented randomly so that the material has no net magnetic dipole naturally.
  - Will become strongly magnetized when exposed to a magnetic field or at certain temperature. E.g – iron, nickel, cobalt, bar magnets.

Magnetic Field

- For an infinitely long and straight current-carrying wire with current *I* at a perpendicular distance *r* from the wire:

$$B = \frac{\mu_0 I}{2\pi r} \quad \mu_0 = permeability\ of\ free\ space = 4\pi\ x\ 10^{-7}\ \mathrm{T}\cdot\frac{\mathrm{m}}{\mathrm{A}}$$

  - These create magnetic fields in the shape of concentric rings. Use **right hand rule** to determine direction. Point thumb in direction of current and wrap fingers around to determine orientation of magnetic field.
- For a circular loop of current-carrying wire of radius, *r*, the magnitude of the magnetic field **at the center of the circular loop** is given by:

$$B = \frac{\mu_0 I}{2r}$$

Magnetic Forces

Magnetic fields exert a force only on other moving charges. **Lorentz force** is the sum of the electrostatic and magnetic forces.

Forces on a Moving Charge

- For when a charge moves in a magnetic field: $F_B = qvB\sin\theta$
  - *v* is the velocity, *B* is the magnitude of the magnetic field and θ is the smallest angle between the velocity vector and **B**.
- Second Right Hand Rule: right thumb in direction of velocity, fingers in direction of the magnetic field lines, palm will point in direction of force vector for positive charge and back of hand will point in direction of force vector for negative charge.
  - When **v** and $\mathbf{F_B}$ are perpendicular to each other, this indicates circular motion.

Forces on a Current Carrying Wire

- For a straight wire: : $F_B = ILB\sin\theta$
  - *I* is the current, *L* is the length of the wire and *B* is the magnitude of the magnetic field, and θ is the angle between **L & B.**
- Uses same right hand rule as before.