February 17, 2017 Physics 132 Prof. E. F. Redish

- **<u>Theme Music:</u> Charley Pride**

  Field of Dreams

- **<u>Cartoon:</u> Bob Thaves**

  Frank & Ernest

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The Equation of the Day

The Electric Field

$$\vec{E}(\vec{r}) = \frac{\vec{F}_q(\vec{r})}{q}$$

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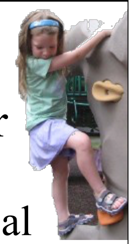
Foothold ideas: Charge – A hidden property of matter



- Matter is made up of two kinds of electrical matter (positive and negative) that usually cancel very precisely.
- Like charges repel, unlike charges attract.
- Bringing an unbalanced charge up to neutral matter polarizes it, so both kinds of charge attract neutral matter
- The total amount of charge (pos – neg) is constant.

Foothold ideas: Conductors and Insulators

- Insulators
  - In some matter, the charges they contain are bound and cannot move around freely.
  - Excess charge put onto this kind of matter tends to just sit there (like spreading peanut butter).
- Conductors
  - In some matter, charges in it can move around throughout the object.
  - Excess charge put onto this kind of matter redistributes itself or flows off (if there is a conducting path to ground).

Foothold idea: Coulomb's Law

- All objects attract each other with a force whose magnitude is given by

$$\vec{F}_{q\to Q} = -\vec{F}_{Q\to q} = \frac{k_C qQ}{r_{qQ}^2}\hat{r}_{q\to Q}$$

- k_C is put in to make the units come out right.

$$k_C = 9\times 10^9 \text{ N-m}^2/\text{C}^2$$

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Making sense of Coulomb's Law

It's about the force one point charge exerts on another

It only works for point charges!

It's proportional to the product of the two charges

$$\vec{F}_{q\to Q} = -\vec{F}_{Q\to q} = \frac{k_C qQ}{r_{qQ}^2}\hat{r}_{q\to Q}$$

The direction is correctly given if the unit vector direction matches the labels on the force and the charges include their signs.

It satisfies Newton's third law

It gets weaker as the charges get farther apart – like the square of the distance between them.

It points along the line joining the two charges (this is a unit vector – only shows direction)

Foothold ideas: Energies in charge clusters

- Atoms and molecules are made up of charges.
- The potential energy between two charges is

$$U_{12}^{elec} = \frac{k_C Q_1 Q_2}{r_{12}}$$

No vectors!

- The potential energy between many charges is

$$U_{12\ldots N}^{elec} = \sum_{i<j=1}^{N} \frac{k_C Q_i Q_j}{r_{ij}}$$

Just add up all pairs!

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Electric energy

- If we start with a system of charge q_1, q_2, ...q_N the electric potential energy of the system is

$$U_{1\ldots N}^{elec} = \sum_{i<j} \sum_{j=1}^{N} \left(\frac{k_C q_i q_j}{r_{ij}} \right)$$

Electric energy of the system of charges $q_{1,,,}q_N$

Sum over all distinct pairs of charges

Electric Potential Energy of the pair q_i, q_j

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Adding a test charge.

- We are often interested to what happens to one last charge (a "test charge") when we add it to a system of already existing charges.
- Assuming that the charges 1...N don't move when we add a charge q_0, the new electric energy after adding the charge is

$$U_{01\ldots N}^{elec} = U_{1\ldots N}^{elec} + \sum_{j=1}^{N}\left(\frac{k_C q_0 q_j}{r_{ij}}\right)$$

$$\Delta U_0^{elec} = \sum_{j=1}^{N}\left(\frac{k_C q_0 q_j}{r_{0j}}\right) = q_0\left[\sum_{j=1}^{N}\left(\frac{k_C q_j}{r_{0j}}\right)\right]$$

Why fields?

- Fields are a useful way to talk about forces that act without touching.
  - It reduces the "spookiness" of objects interacting when they are far apart. The source object creates an effect (field) everywhere and the test object measures that effect where it is. (Only psychological value)
- Fields allow us to talk about forces due to many charges that we don't know how to specify or where they are.
  - Since all matter has lots of charge we can't specify where each charge is. Summing over them all would be impossible. Talking about what fields they produce allows us to sum the effect of many charges. (Real practical value)

Foothold idea: Fields

- *Test particle*
  - We pay attention to what force it feels. We assume it does not have any affect on the source particles.
- *Source particles*
  - We pay attention to the forces they exert and assume they do not move.
- *Physical field*
  - We consider what force a test particle would feel if it were at a particular point in space and divide by its coupling strength to the force. This gives a vector at each point in space.

$$\vec{g} = \frac{1}{m}\vec{W}_{E\to m} \qquad \vec{E} = \frac{1}{q}\vec{F}_{\text{all charges }\to q} \qquad V = \frac{1}{q}U^{elec}_{\text{all charges}\to \text{q}}$$

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Units

- *Gravitational field*
  units of g = Newtons/kg
- *Electric field*
  units of E = Newtons/C (also Volts/m)
- *Electric potential*
  units of V = Joules/C = Volts

Energy = qV, so $e\Delta V$ = the energy gained by an electron (charge $e = 1.6 \times 10^{-19}$ C) in moving through a change of ΔV volts.

1 eV = 1.6×10^{-19} J

A very useful and natural unit when dealing with individual atoms and molecules!

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