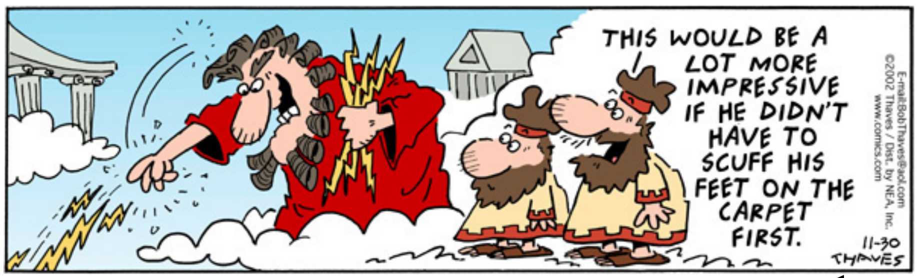
October 17, 2013 Physics 131 Prof. E. F. Redish

- **Theme Music:** **MGMT**
  Electric Feel*
- **Cartoon:** **Bob Thaves**
  Frank & Ernest



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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.

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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

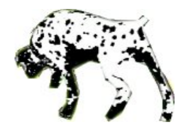
- All objects attract each other with a force whose magnitude is given by

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

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

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

Making Sense of Coulomb's Law



- Changing the test charge
- Changing the source charge
- Changing the distance
- Specifying the direction
- Interpret the sign

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

Quantifying Charge

- Need an operational definition.
- Charge is a new kind of quantity (to M, L, T, add Q).
- Choose our scale:
  A small object has a charge of 1 C (= 1 Coulomb) if two identical such charges held at a distance of 1 m exert forces of 9 x 10^9 N on each other.
- This corresponds to choosing the constant

$k_C = 9 \times 10^9$ N-m^2/C^2.

Adding forces for many charges!

$$\vec{F}_q = \vec{F}_{Q_1 \to q} + \vec{F}_{Q_2 \to q} + \vec{F}_{Q_3 \to q} + \vec{F}_{Q_4 \to q} + \ldots$$

$$\vec{F}_q = \frac{k_C q Q_1}{r_1^2}\hat{r}_1 + \frac{k_C q Q_2}{r_2^2}\hat{r}_2 + \frac{k_C q Q_3}{r_3^2}\hat{r}_3 + \frac{k_C q Q_4}{r_4^2}\hat{r}_4 + \ldots$$

where

$r_1 =$ distance from Q_1 to q $\quad$ $\hat{r}_1 =$ direction from Q_1 to q (mag. 1, no units!)

$r_2 =$ distance from Q_2 to q $\quad$ $\hat{r}_2 =$ direction from Q_2 to q (mag. 1, no units!)

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Review of Vectors (2-dimensional coordinates)

- We have 2 directions to specify. We must
  - Choose a reference point (origin)
  - Pick 2 perpendicular axes (x and y)
  - Choose a scale
- We specify our x and y directions by drawing little arrows of unit length in their positive direction. $\hat{i}, \hat{j}$
- A force vector is written

$$\vec{F} = F_x \hat{i} + F_y \hat{j} = (F_x, F_y)$$

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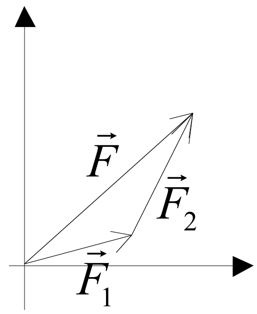
Adding Forces

- We define the sum of two vectors as if they were successive displacements.



$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

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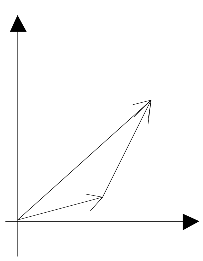
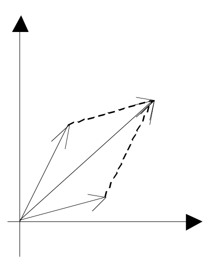
Adding Vectors: Methods

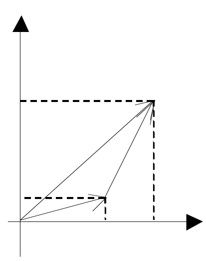
- There are 3 mathematical ways to add vectors



head to tail



parallelogram rule



add components (may use trig)

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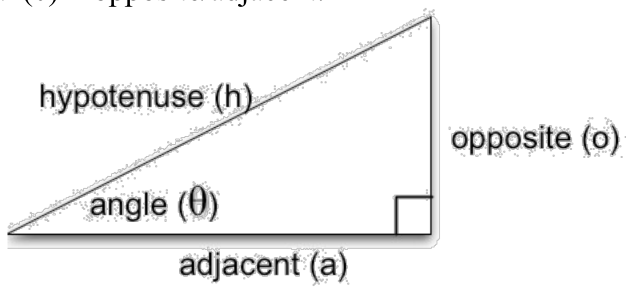
Trig review

- The ratios of a triangle's sides only depend on θ.
  - sin(θ) = opposite/hypotenuse
  - cos(θ) = adjacent/hypotenuse
  - tan(θ) = opposite/adjacent.



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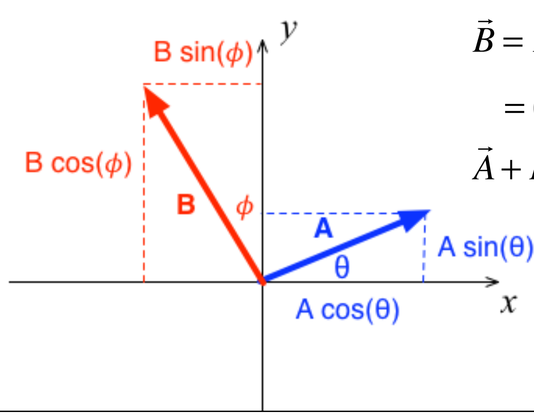
Vectors with trig – by components



$$\vec{A} = A_x\hat{i} + A_y\hat{j}$$
$$= \left(A\cos(\theta)\right)\hat{i} + \left(A\sin(\theta)\right)\hat{j}$$
$$\vec{B} = B_x\hat{i} + B_y\hat{j}$$
$$= \left(-B\sin(\phi)\right)\hat{i} + \left(B\cos(\phi)\right)\hat{j}$$
$$\vec{A} + \vec{B} = ?$$

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Foothold ideas: Electric Forces and Fields

- When we focus our attention on the electric force on a particular charge (a test charge) we see the force it feels factors into the magnitude of its charge times a factor that depends on position (and the other charges).

$$\vec{F}_{q_0}^{E\,net} = \frac{k_C q_0 q_1}{r_{01}^2}\hat{r}_{1\to 0} + \frac{k_C q_0 q_2}{r_{02}^2}\hat{r}_{2\to 0} + \frac{k_C q_0 q_3}{r_{03}^2}\hat{r}_{3\to 0} + \ldots \frac{k_C q_0 q_N}{r_{0N}^2}\hat{r}_{N\to 0}$$

$$\vec{F}_{q_0}^{E\,net} = q_0 \vec{E}(\vec{r}_0)$$

$$\vec{E}(\vec{r}_0) = \frac{k_C q_1}{r_{01}^2}\hat{r}_{1\to 0} + \frac{k_C q_2}{r_{02}^2}\hat{r}_{2\to 0} + \frac{k_C q_3}{r_{03}^2}\hat{r}_{3\to 0} + \ldots \frac{k_C q_N}{r_{0N}^2}\hat{r}_{N\to 0}$$

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Foothold ideas: Fields

- A *field* is a concept we use to describe anything that varies in space. It is a set of values assigned to each point in space (e.g., temperature or wind speed).
- A *force field* is an idea we use for non-touching forces. It puts a force vector at each point in space, summarizing the effect of all objects that would exert a force on a particular object placed at that point.
- A *gravitational*, *electric, or magnetic field* is a force field with something (a "coupling strength") divided out so the field no longer depends on what test object is used.

$$\vec{g} = \frac{\vec{F}_{\text{acting on } m}}{m} \qquad \vec{E} = \frac{\vec{F}_{\text{acting on } q}}{q}$$

Field is the value at a position in space " r " assuming that the force is measured by placing the object at r.

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Making sense

- Notice that $E = F_q/q$ does NOT depend on q!
- For one source charge

$$\vec{F}_q = \frac{k_C q Q_1}{r_1^2}\hat{r}_1 \qquad \vec{E} = \frac{\vec{F}_q}{q} = \frac{k_C Q_1}{r_1^2}\hat{r}_1$$

- For many sources

$$\vec{F}_q = \frac{k_C q Q_1}{r_1^2}\hat{r}_1 + \frac{k_C q Q_2}{r_2^2}\hat{r}_2 + \frac{k_C q Q_3}{r_3^2}\hat{r}_3 + \ldots \qquad \vec{E} = \frac{\vec{F}_q}{q} = \frac{k_C Q_1}{r_1^2}\hat{r}_1 + \frac{k_C Q_2}{r_2^2}\hat{r}_2 + \frac{k_C Q_3}{r_3^2}\hat{r}_3 + \ldots$$

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