Physics 202, Lecture 2

Today's Topics

- Announcements
- Electric Fields
  - More on the Electric Force (Coulomb's Law)
  - The Electric Field
  - Motion of Charged Particles in an Electric Field

Announcements

- Homework Assignment #1:
  - WebAssign (corresponds to Ch. 23 #5,10,12,15,19,26,42)
  - Due Friday, Sept 14 at 10PM

  Future assignments will be due Mondays at 10 PM.

- IMPORTANT: Exam policy revision

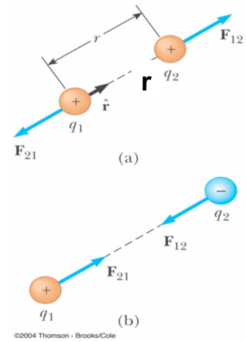
  If you have an evening class conflict, let us know right away (now!) and we will accommodate it.

  Recall exam dates: 10/1, 10/29, 11/26, 5:30-7 PM.

Coulomb's Law (Point Charges)

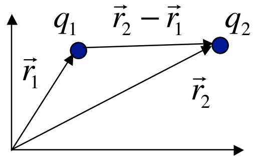
Force on q_2 by q_1: $$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2}\hat{r}$$

Force on q_1 by q_2: $$\vec{F}_{21} = -k_e \frac{q_1 q_2}{r^2}\hat{r}$$



Vector direction of F: more explicitly

Force on q_2 by q_1:

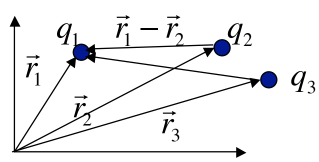


$$\vec{F}_{12} = k_e \frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|^2}\frac{(\vec{r}_2 - \vec{r}_1)}{|\vec{r}_2 - \vec{r}_1|} = k_e \frac{q_1 q_2 (\vec{r}_2 - \vec{r}_1)}{|\vec{r}_2 - \vec{r}_1|^3}$$

in the above language: $r = |\vec{r}_2 - \vec{r}_1|$ $\quad \hat{r} = \frac{\vec{r}_2 - \vec{r}_1}{|\vec{r}_2 - \vec{r}_1|}$

Coulomb's Law: Multiple charges

Many point charges: linear superposition



Force on charge 1:

$$\vec{F}_1 = \sum_i \vec{F}_{i1} = \sum_i k_e \frac{q_1 q_i}{r_{i1}^2}\hat{r}_{i1}$$

Important: vector sum!

More explicitly:

$$\vec{F}_1 = \sum_i k_e \frac{q_1 q_i}{|\vec{r}_1 - \vec{r}_i|^2}\frac{(\vec{r}_1 - \vec{r}_i)}{|\vec{r}_1 - \vec{r}_i|} = \sum_i k_e \frac{q_1 q_i (\vec{r}_1 - \vec{r}_i)}{|\vec{r}_1 - \vec{r}_i|^3}$$

Coulomb's Law: Distributions

Continuous distributions of charge: divide into Δq_i

$$\sum_i \Delta q_i \rightarrow \int dq$$

Interaction of point charge with continuous distribution:

$$\vec{F}_1 = k_e q_1 \int \frac{dq}{r^2} \hat{r}$$

Line segment (1 dimension): $dq = \lambda dx$

Surface (2 dimensions): $dq = \sigma dA$

Volume (3 dimensions): $dq = \rho dV$

more about this shortly!

Properties of the Electric Force

- **One of four fundamental forces:**
  Strong >Electromagnetic > weak >> gravity
- **Magnitude: Proportional to $1/r^2$: r doubled → ¼ F**
- **Direction: repulsive for like signs, attractive for opposite signs**

- **A conservative force (work independent of path):**

$$W = \int_{r_i}^{r_f} \vec{F} \bullet d\vec{r} = -\frac{k_e q_1 q_2}{r_f} + \frac{k_e q_1 q_2}{r_i} = (-U_f) - (-U_i)$$

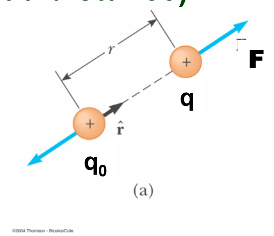
→A potential energy can be defined. (Topic of Ch. 25)

$$U = \frac{k_e q_1 q_2}{r}$$

The Electric Field

- Original (Coulomb's) view of electric force
  q applies electric force on q_0 (action at a distance)

$$\vec{F} = k_e \frac{q_0 q}{r^2} \hat{r}$$



Force on charge always proportional
to strength of that charge!

- "Modern" view of electric force:
  - q is the source of an electric field **E**
    The electric field **E** applies a force on q_0

$$\vec{F} = q_0 \underbrace{k_e \frac{q}{r^2} \hat{r}}_{\mathbf{E}} = q_0 \vec{E}$$

q: source charge
q_0: "test charge"
E independent of q_0!

Aside: Vector and Scalar Fields

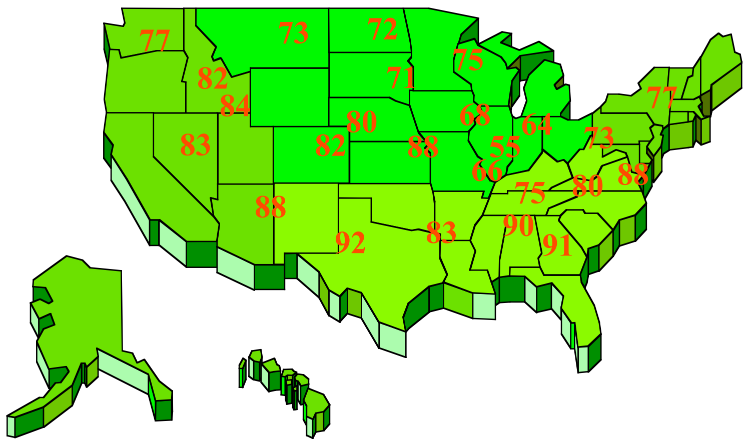
The field concept is extremely useful in physics,
both conceptually and for practical purposes

Using the concept of the electric field,
one can map the electric field anywhere in space
produced by any arbitrary charge distribution

What is a field?

- A field represents some physical quantity
  (e.g., temperature, wind speed, force)
- It can be a scalar field (e.g., temperature field)
- It can be a vector field (e.g., electric field)
- It can be a "tensor" field (e.g., spacetime curvature)

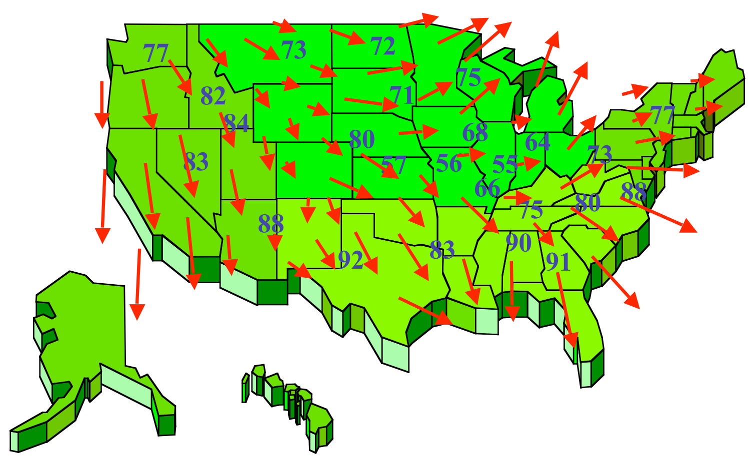
A Scalar Field



These isolated temperatures sample the scalar field
(you only learn the temperature at the point you choose,
but **T** is defined everywhere (x, y)

A Vector Field

Perhaps more interesting to know which way the wind is blowing…



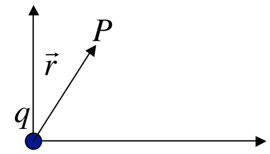
That would require a vector field
(you learn both wind speed and direction)

The Electric Field, Recap

❑ **Charge q sources an electric field E**

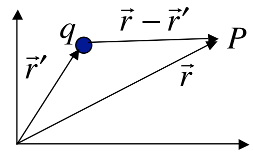
$$\vec{E}(\vec{r}) = k_e \frac{q}{r^2}\hat{r}$$

(charge at origin)



More generally,

$$\vec{E}(\vec{r}) = k_e \frac{q}{|\vec{r}-\vec{r}'|^2}\frac{(\vec{r}-\vec{r}')}{|\vec{r}-\vec{r}'|} = k_e \frac{q(\vec{r}-\vec{r}')}{|\vec{r}-\vec{r}'|^3}$$



Multiple sources:

$$\vec{E}(\vec{r}) = k_e \sum_i \frac{q_i}{r_i^2}\hat{r}_i$$

(more general)

$$\vec{E}(\vec{r}) = k_e \sum_i \frac{q_i(\vec{r}-\vec{r}_i')}{|\vec{r}-\vec{r}_i'|^3}$$

Continuous distributions:

$$\vec{E}(\vec{r}) = k_e \int \frac{dq}{r^2}\hat{r}$$

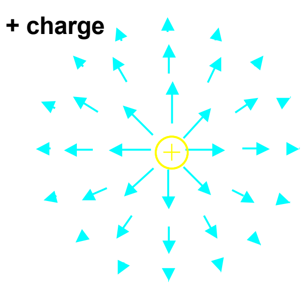
$$\vec{E}(\vec{r}) = k_e \int \frac{dq(\vec{r}-\vec{r}')}{|\vec{r}-\vec{r}'|^3}$$

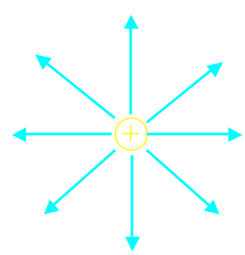
Visualizing the Electric Field

Consider the electric field of a positive point charge at the origin:

vector map

field lines





Magnitude: length of arrows

Magnitude: local density of lines

Rules for Field Lines

Property 1.

Field lines can start or terminate only on charges, never empty space.

Property 2.

Field lines of point charge go off to infinity.
(true for any localized distribution with nonzero net charge)

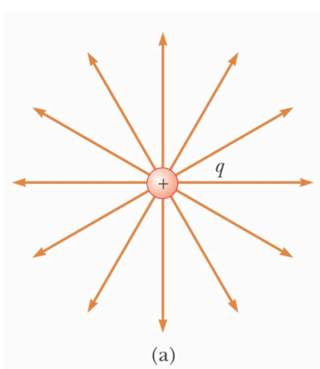
Property 3.

Field lines originate on positive charges, terminate on negative charges.

Property 4.

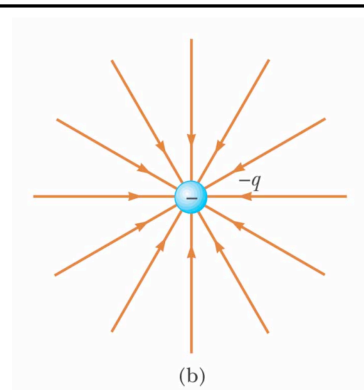
No two field lines ever cross, even when multiple charges present.

Example: Point-Like Charges



$$\vec{E}(\vec{r}) = k_e \frac{q}{r^2}\hat{r}$$

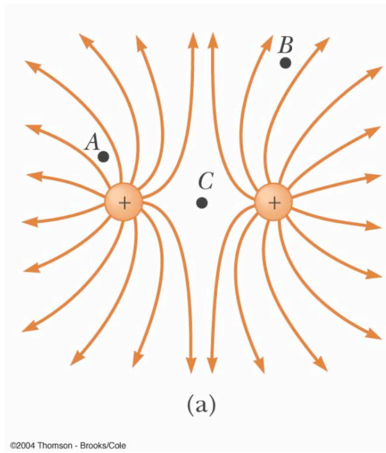
+q



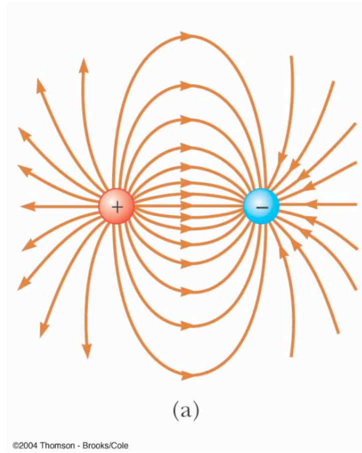
$$\vec{E}(\vec{r}) = k_e \frac{q}{r^2}\hat{r}$$

-q

Example: Two Charged Particles

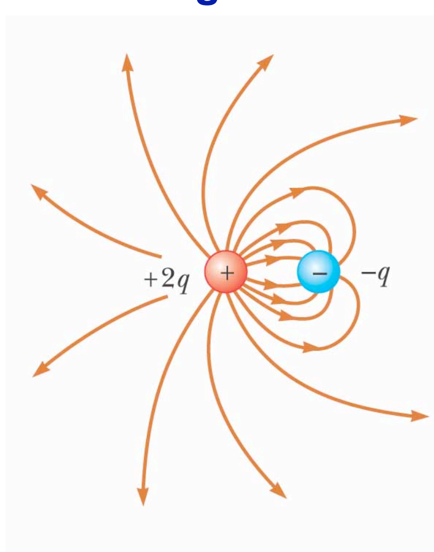


+q and +q



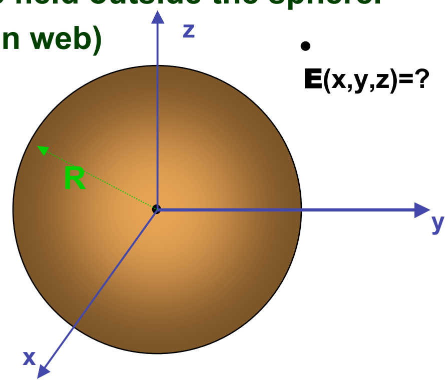
+q and -q

Two Charged Particles



Example: Uniformly Charged Sphere

- A uniformly charged sphere has a radius R and total charge Q, find the electric field outside the sphere.
- See notes (to be posted on web)



Doable but complicated with the conventional method!
➔ Please preview Ch. 24 “Gauss Law” before Tuesday!