Lecture
2/17/05

PICTURES FOR THINKING

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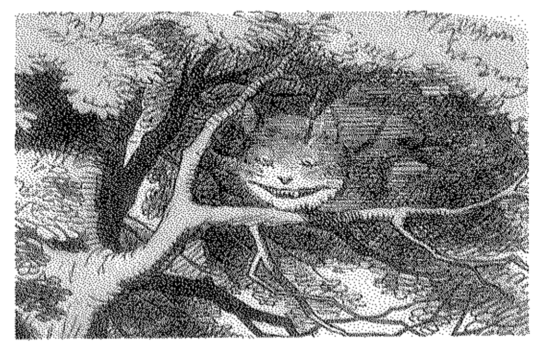
FIELDS

Defining a Field: How?

- The idea of a field is to fill space with information about what a particle would do if it found itself at any point.
- At each point in space we place an arrow showing the direction of the force a test-object would feel <u>if it were there</u>. (*Cheshire Cat principle)*
- In principle, we fill space with these arrows.
- In practice, that would make it hard to see what's going on so we only draw a few representative ones.



Defining a Field: Why?

- Electricity is a non-touching force like gravity.
  However, it is MUCH stronger than gravity.
  (38 orders of magnitude)
- As a result gravity is only noticeable
  when it comes from HUGE objects (like a planet).
- Since planets are much bigger than we are,
  you have to move distances compared to planetary radii
  to see it change much, it looks constant.
- Because the of larger strength of electricity
  it changes a lot over short distances.
  We need to have a way to keep track of this.

An example: Gravity

- At any point near the surface of the earth, if I put a test object of mass *m* it would feel a force towards the center of the earth

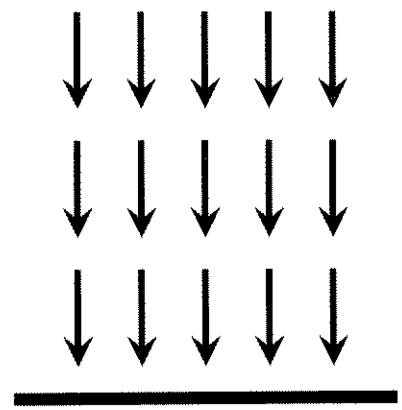
$$\vec{F}_{E\rightarrow m} = m\vec{g}$$

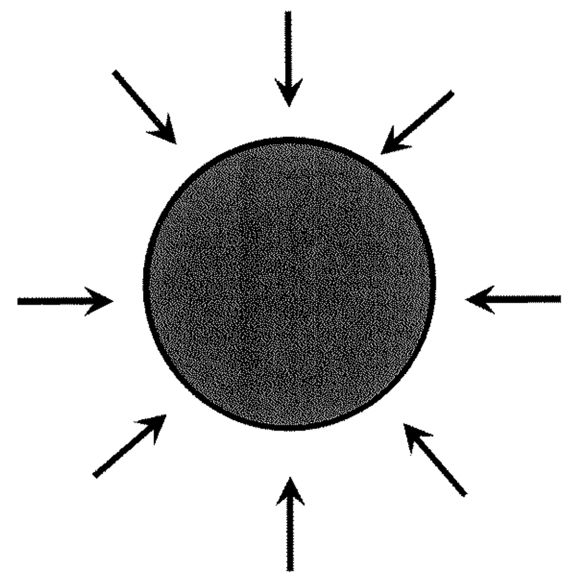
- In order to have our information not depend on our test object, we don't put the force, but the force / (mass of the test object).

$$\text{grav. field of earth} = \vec{F}_{E\rightarrow m}/m = \vec{g}$$

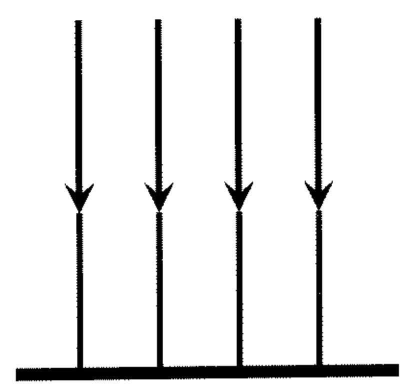
Ways to represent a field

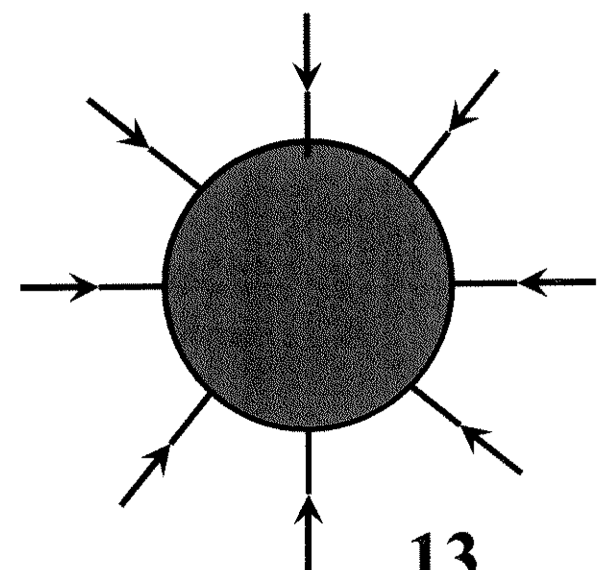
- Vector plot





- Field line





- WHERE FIELD LINES ARE CLOSE TOGETHER, THE FIELD STRENGTH (MAGNITUDE) IS GREATER
- THE OPPOSITE IS ALSO TRUE

CLICKER

ARE FIELDS REAL OR ARE THEY JUST HANDY WAYS TO REPRESENT REALITY?

1. THEY'RE REAL.
2. THEY'RE JUST [redacted] CONVENIENT PICTURES.

CLICKER

IF THERE'S NO "TEST" MASS AT A POINT, IS THE FIELD STILL THERE?

1. YES
2. NO
3. CAN'T TELL.

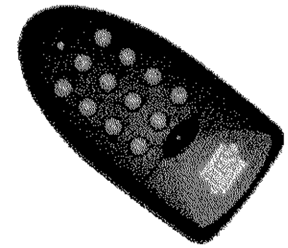
Electric Fields

- For convenience in describing the effect of lots of charges we introduce the electric field.
- The electric field at a point in space is the force a test charge would feel if it were placed at that point, divided by the magnitude of the test charge.
- The field is a vector assigned to a point in space.
- The field is <u>independent of the test charge used</u> to measure it.

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

(test charge q placed at the point $\vec{r}$)

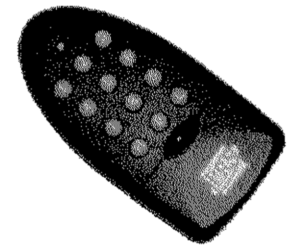
Puzzle



- When a positive charge is released from rest in a uniform electric field, it will

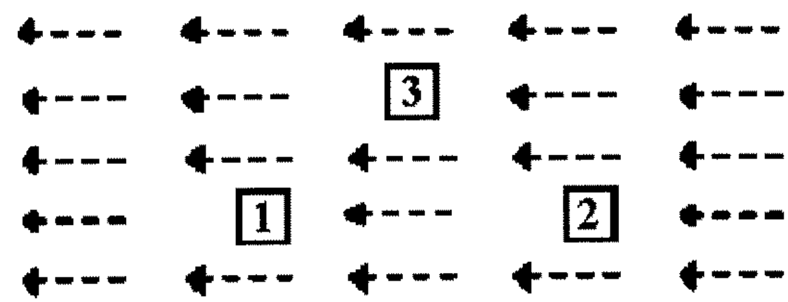
1. remain at rest in its initial position.
2. move at a constant acceleration.
3. move at a constant speed.
4. move at a constant velocity.
5. move with a linearly changing acceleration.

Puzzle



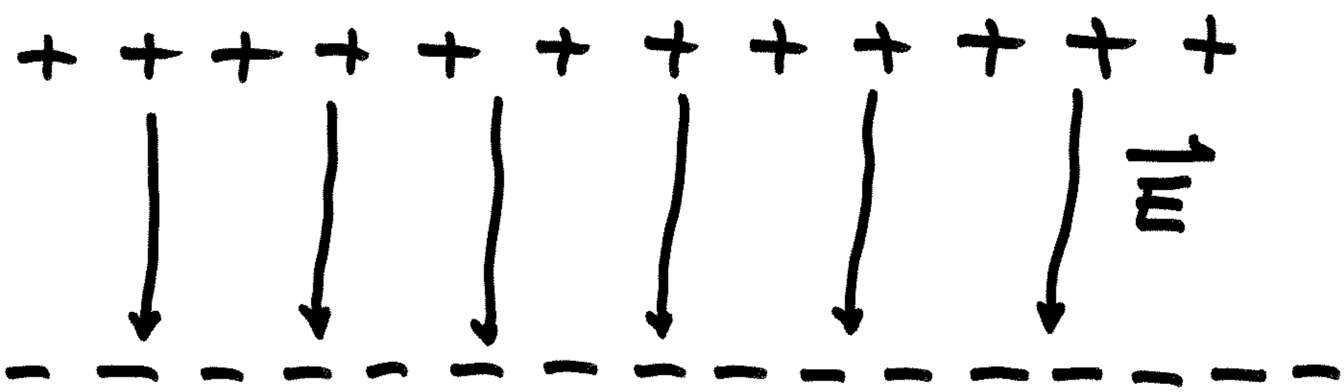
- A positive charge might be placed at one of three different locations in a region where there is a uniform electric field, as shown below.
- How do the electric force, F, on the charge at positions 1, 2, and 3 compare?

1. F greater at 1.
2. F greater at 2.
3. F greater at 3.
4. F is zero at all three places.
5. F at all three positions is the same but not zero.



UNIFORM ELECTRIC FIELD

HOW COULD ONE MAKE A UNIFORM ELECTRIC FIELD?



IF A POSITIVE CHARGE ENTERS THE REGION OF UNIFORM $\vec{E}$ FROM THE LEFT, MOVING WITH CONSTANT SPEED V_0, WHAT WOULD BE ITS TRAJECTORY?

WHAT IF IT WERE AN ELECTRON?

Work and Energy

$$\Delta\left(\tfrac{1}{2}mv^2\right) = F_{\parallel}^{net}\,\Delta s = \vec{F}^{net} \bullet \Delta\vec{s} = W^{net}$$

- Note each force in the problem might contribute to the work. Start with a FBD!
- When the work from one of the forces can be written as a change of something, we define a potential energy

$$-\Delta U_i = W_i$$

Electric Potential

- In the same way that we "removed the test charge" from Coulomb's law to define the electric field, we "remove the test charge" from the electric potential energy to create the <u>electric potential</u>, V.

$$\vec{E} = \frac{\vec{F}}{q} \qquad V = \frac{U}{q}$$

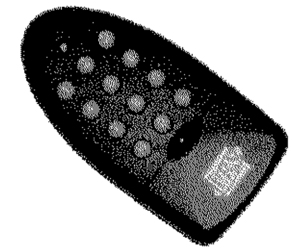
Electric Potential: Meaning

- Just like the electric field, the electric potential can be defined at any point in space.
- For any point in space, $\vec{r}$, the electric potential at the point is the negative of the work required to bring a test charge, q, from ∞ to $\vec{r}$ divided by q.
- The electric potential is a scalar (has no direction) so it's easier to work with than the E-field.

Units

- E-Field $E = {F_{on\,q}}/{q}$ $[E] = \text{N/C}$
- Potential Energy $\Delta U = -F\Delta d$ $[\Delta U] = \text{N - m} = \text{J}$
- Potential $\Delta V = \frac{\Delta U}{q}$ $[\Delta V] = \text{J/C} = \text{V}$
- Energy
  For 1 electron (charge $e = 1.6\times10^{-19}$ C)
  $\text{Energy} = e\Delta V =$ "ΔV electron volts"
  $1\ \text{eV} = 1.6\times10^{-19}\ \text{J}$

Puzzle



- When a positive charge is released from rest in a uniform electric field what happens to the <u>electric potential energy</u> of the positive charge?

1. It will increase because the charge will move in the direction of the electric field.
2. It will decrease because the charge will move in the direction opposite to the electric field.
3. It will decrease because the charge will move in the direction of the electric field.
4. It will remain constant because the electric field is uniform.
5. It will remain constant because the charge remains at rest.

CONDUCTORS

IF ALL CHARGES ARE STATIC (NOT MOVING — NO CURRENT) A CONDUCTOR IS EQUIPOTENTIAL

FIELDS AND EQUIPOTENTIAL SURFACES

- UNIFORM FIELD
- POINT CHARGE
- DIPOLE

GAUSS'S LAW

$$F = \frac{k_c q Q}{R^2}$$

$$E = \frac{F}{q} = \frac{k_c Q}{R^2}$$

CONSIDER POINT CHARGE

$$\Phi_E = EA = 4\pi k_c Q$$

$$k_c \rightarrow \frac{1}{4\pi \epsilon_0}$$

$$\Downarrow$$

$$\boxed{\Phi_E = \frac{Q}{\epsilon_0}}$$