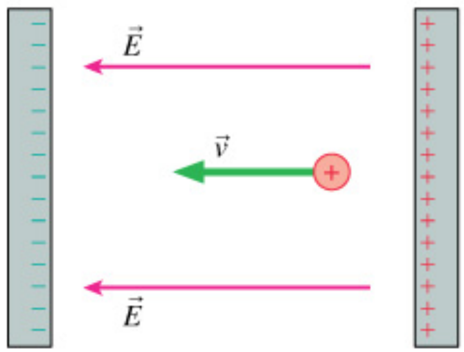
PHY294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Added problem 28.68 for 3rd MP assignment due Wed Feb. 3 as a hand-in problem**
  - **Help-room hours: 12:40-2:40 Tues; 3:00-4:00 PM Friday**
- Quizzes by iclicker (sometimes hand-written)
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

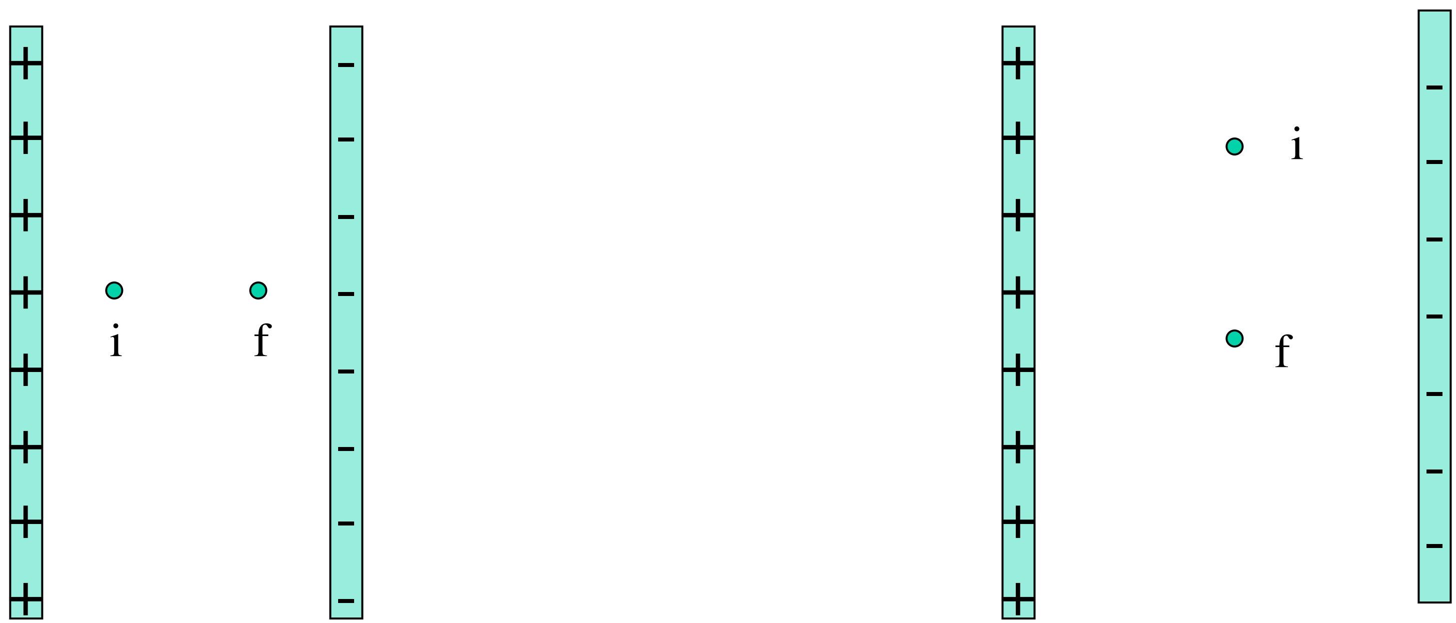
Example

- Suppose that the E field inside the capacitor is 50,000 N/C and the spacing in the capacitor is 2 mm
- I release a proton from rest from the position of the positive plate
  - what's the work done by the electric field by the time it gets to the negative plate?
  - what is the proton's speed?



The potential energy of a positive charge decreases in the direction of $\vec{E}$. The charge gains kinetic energy as it moves toward the negative plate.

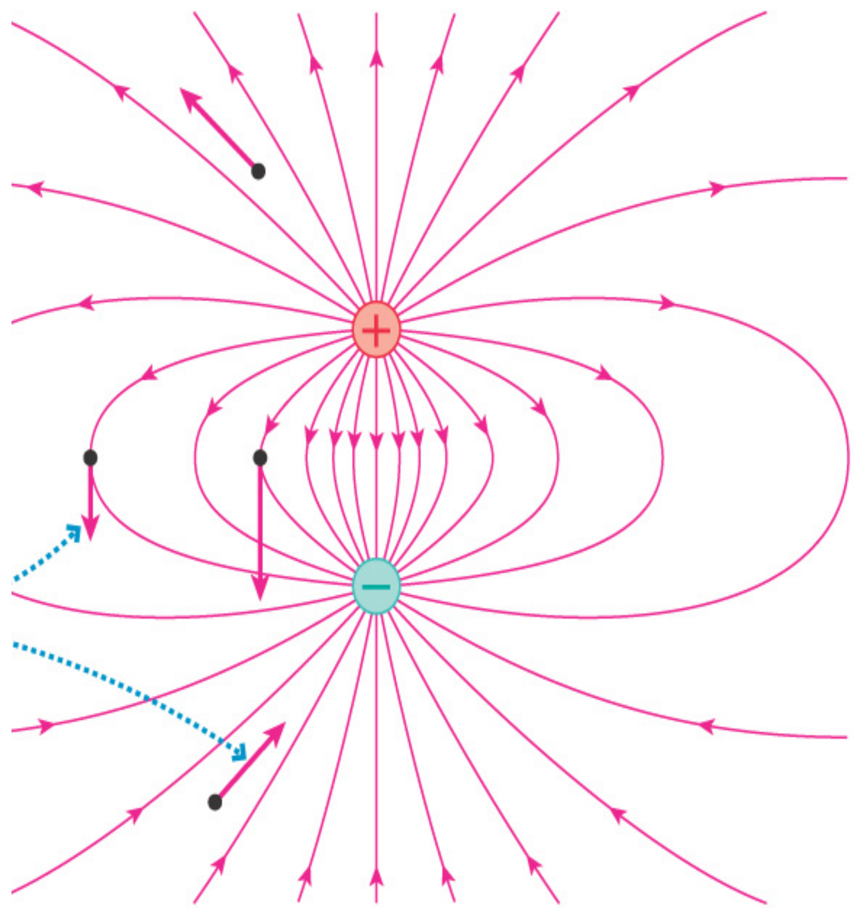
Examples



Suppose I move a positive charge from i to f in each of the two cases above. Is ΔU positive, negative or zero? What about a negative charge? Is the field doing positive or negative work? (Note that it can be easy to confuse the work done by the field and the work done by an external agent.)

Another example

- What if I move a positive charge along a field line, in the direction of the field?
  - is ΔU + or -?
- What about a negative charge?



Example

- Suppose a small positive charge is shot towards a larger fixed charge
- What happens to its speed?

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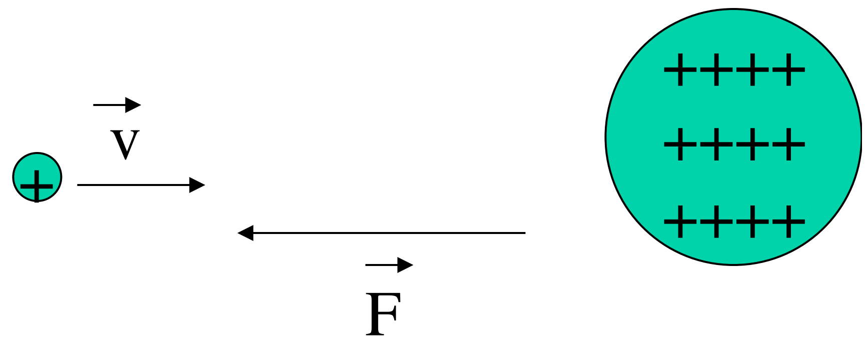
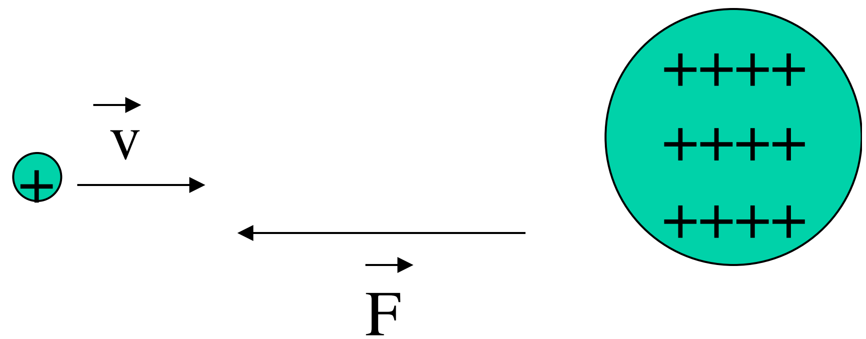
- Suppose a small positive charge is shot towards a larger fixed charge
- What happens to its speed?
  - there's a force acting on the small charge causing a negative acceleration (it's slowing down)
  - this force is varying with the distance between the two charges
  - I can calculate the work done by this force by integrating $\vec{F} \cdot d\vec{r}$
  - …or I can calculate the change in potential energy

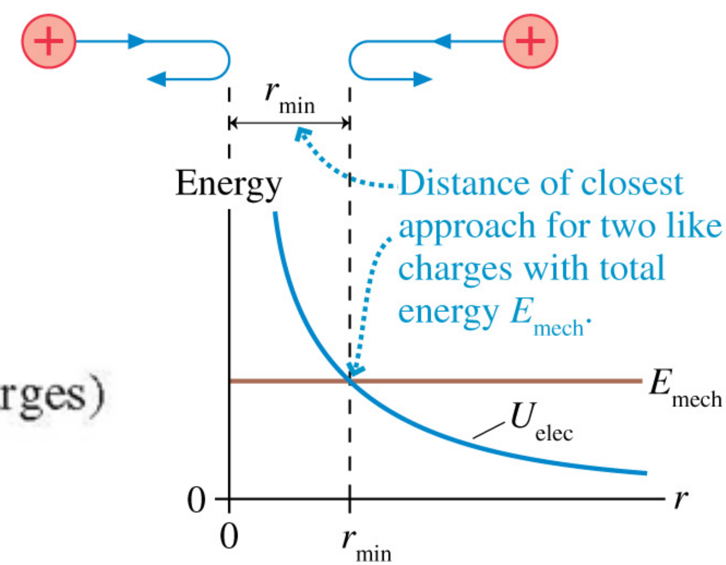


Example

- Suppose a small positive charge is shot towards a larger fixed charge
- How close does it come?
  - let's suppose the small charge is a proton and it has the velocity
    - 1.38×10^5 m/s
  - and that the fixed charge is a carbon nucleus (Z= +6e)



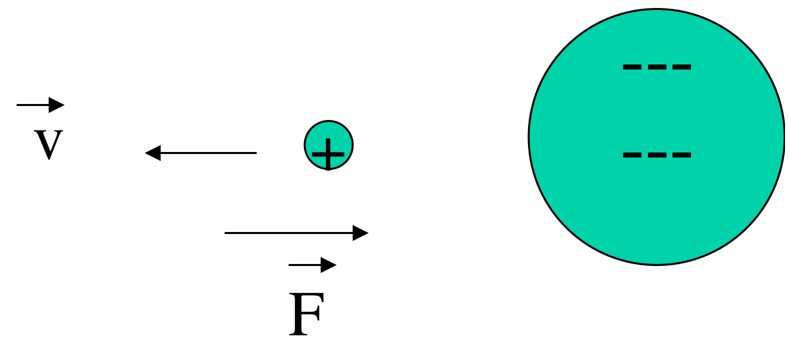
(a) Like charges



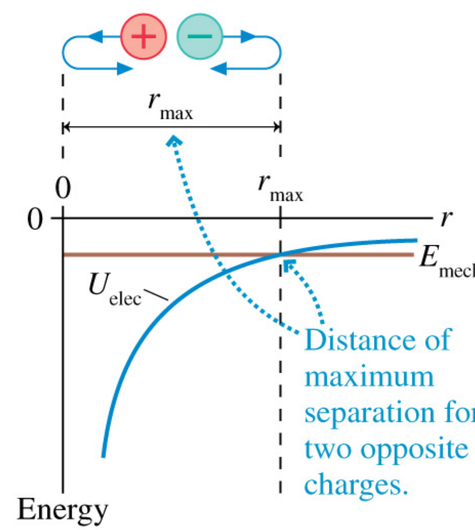
$$U_{elec} = \frac{Kq_1q_2}{r} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r} \qquad \text{(two point charges)}$$

Example

- Suppose instead we have a proton shot away from a large negative charge (equal to -6e) with the initial velocity equal the final velocity for the proton in the previous problem and starting at the distance that the proton had stopped.
- How far does it go before stopping?
  - $U_f - U_i = K_f - K_i$



(b) Opposite charges



$$U_{elec} = \frac{Kq_1q_2}{r} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r} \qquad \text{(two point charges)}$$

iclicker question

A positive and a negative charge are released from rest in vacuum. They move toward each other. As they do:

A. A positive potential energy becomes more positive.

B. A positive potential energy becomes less positive.

C. A negative potential energy becomes more negative.

D. A negative potential energy becomes less negative.

E. A positive potential energy becomes a negative potential energy.

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$$U_{elec} = \frac{Kq_1q_2}{r}$$

Opposite signs, so U is Negative.

U increases in magnitude as r decreases.

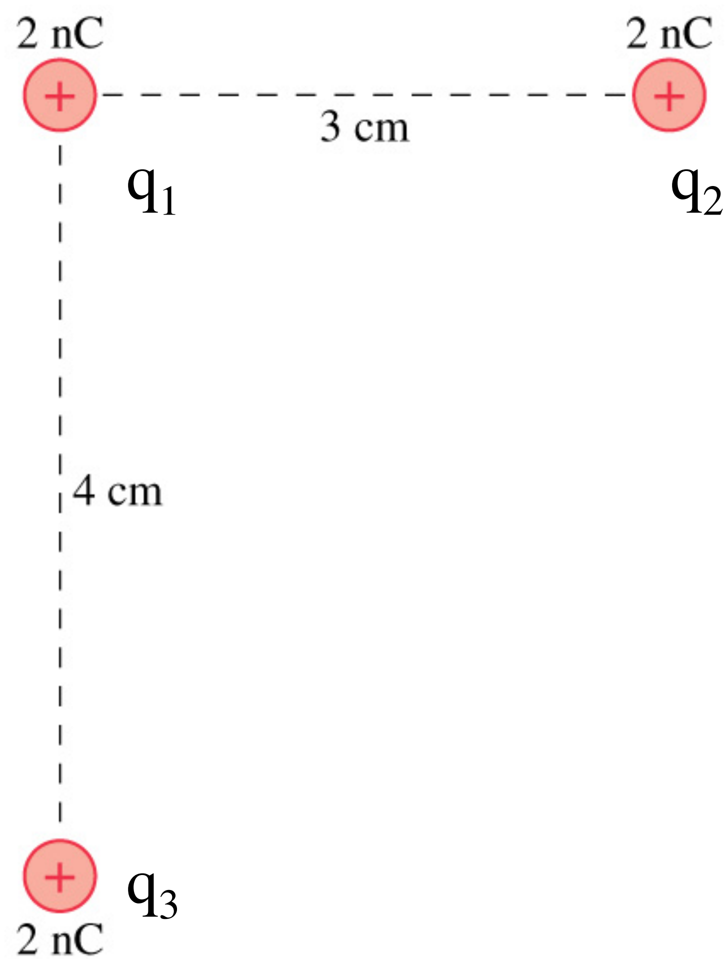
Multiple point charges

- What if I have more than 1 charge? What is the total potential energy?

$$U_{elec} = \sum_{i<j} \frac{1}{4\pi\varepsilon_o} \frac{q_i q_j}{r_{ij}}$$

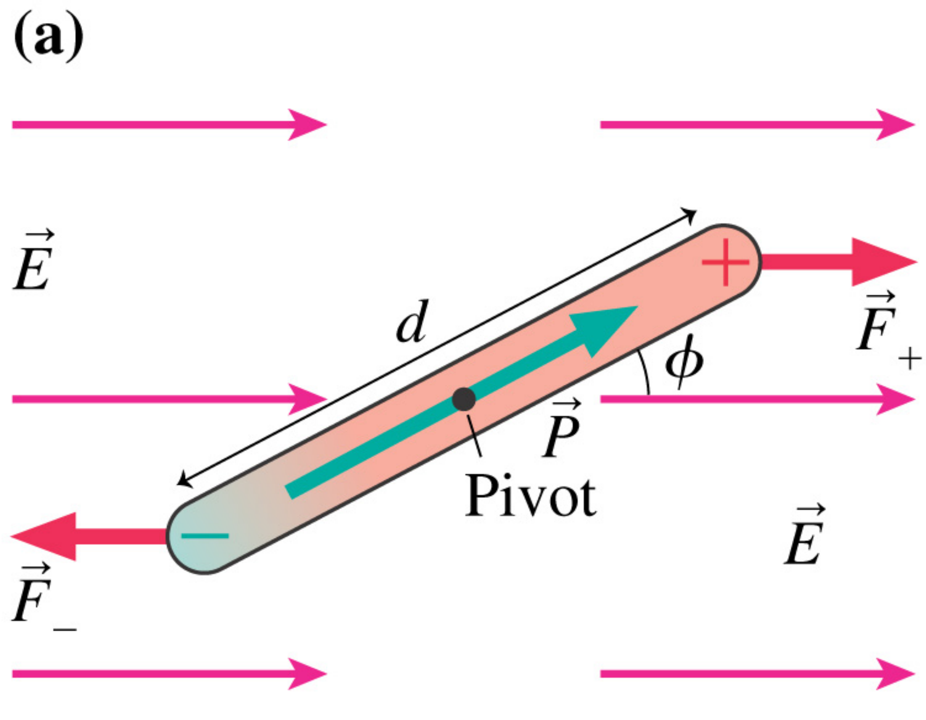
$$U_{elec} = \frac{1}{4\pi\varepsilon_o} \left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right]$$

  - what is the potential energy of these charges when they're separated by an infinite distance?
  - how much work does it take an external agent to assemble them in the positions shown?
  - $W_{external\ agent} = U_f - U_i = -W_{field}$



Our old friend, the electric dipole

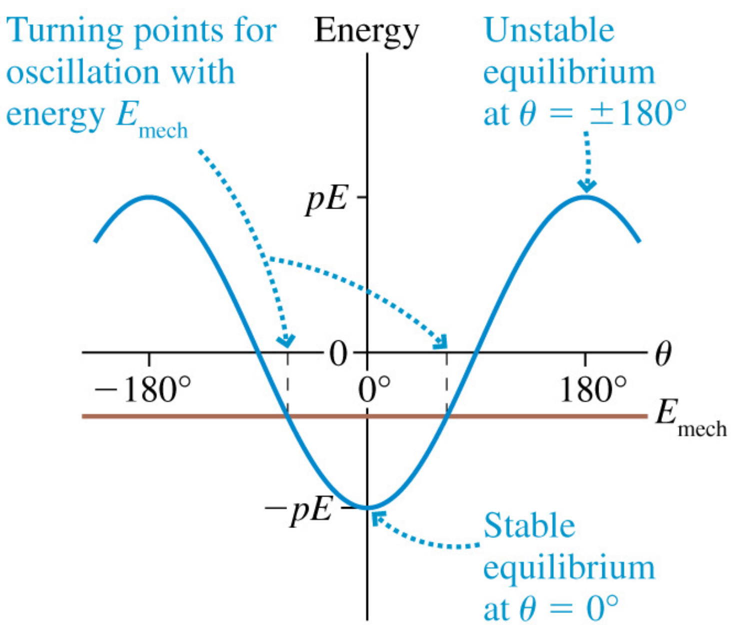
- Earlier we found that a dipole in an electric field experiences a torque that causes the dipole moment $\vec{p}$ to rotate in alignment with the electric field
- What about the work done by the electric field in causing this rotation and the change in the potential energy?

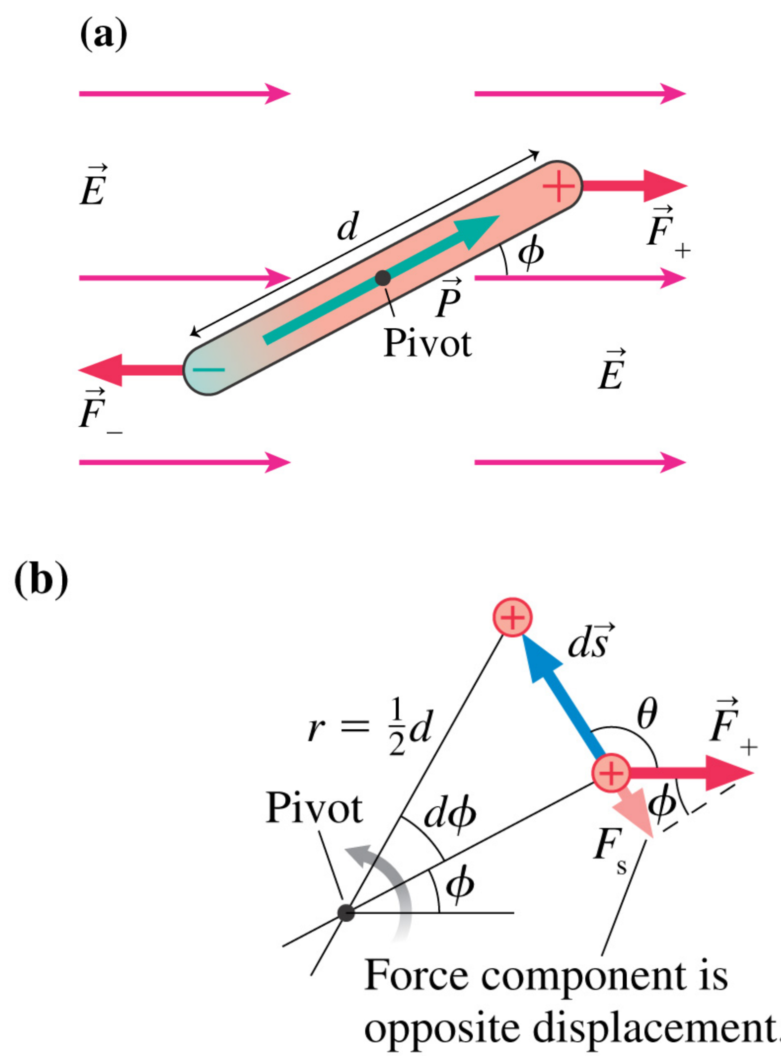


$|p| = qd$

Dipoles

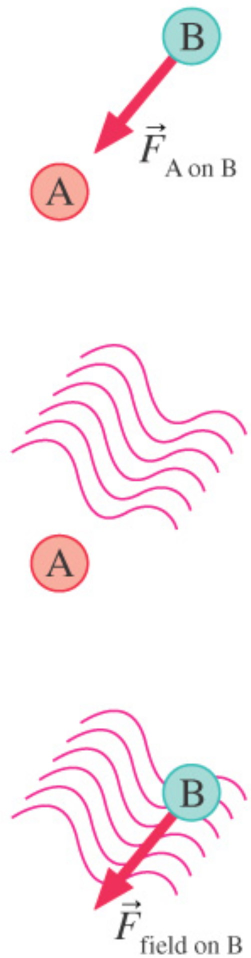
- $\Delta U_{dipole} = U_f - U_i$
  $= - W_{elec}(i\text{->}f)$
  $= -pE\cos\phi_f + pE\cos\phi_i$
- $U_{dipole} = -pE\cos\phi$
  $= -\vec{p}\cdot\vec{E}$





Back to the electric field

- So we're going to replace the idea of action at a distance by the concept of a field
- Particles don't interact directly with each other
- They create fields which then interact with the other particles
  - we will need this when we start talking about dynamic situations
- We'll be dealing with electric and magnetic fields in this course



In the Newtonian view, A exerts a force directly on B.

In Faraday's view, A alters the space around it. (The wavy lines are poetic license. We don't know what the alteration looks like.)

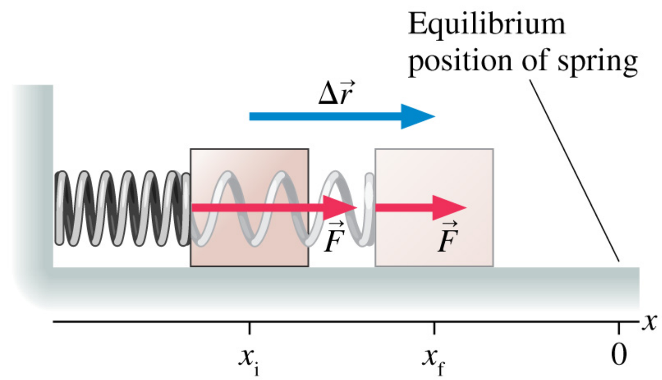
Particle B then responds to the altered space. The altered space is the agent that exerts the force on B.

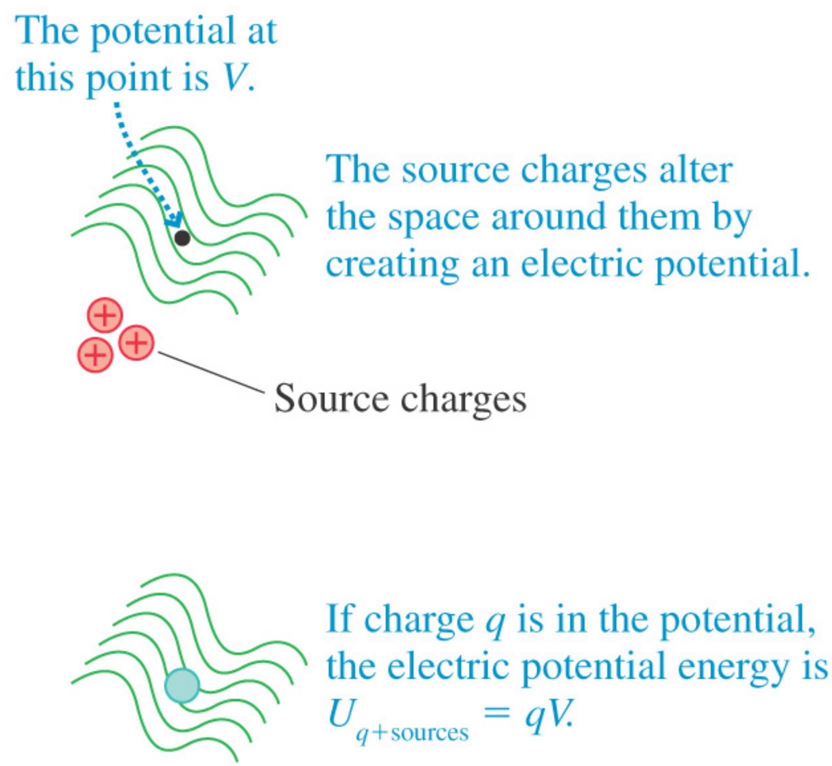
Electric potential: another abstract concept

- It's easy to understand the energy stored in a spring when it's compressed or stretched
- Harder to understand the energy stored in the interaction of charges
- Suppose I have a bunch of source charges interacting with a (test) charge q
- The potential energy is

$$U = \frac{1}{4\pi\varepsilon_o}\frac{q_{source}q}{r}$$

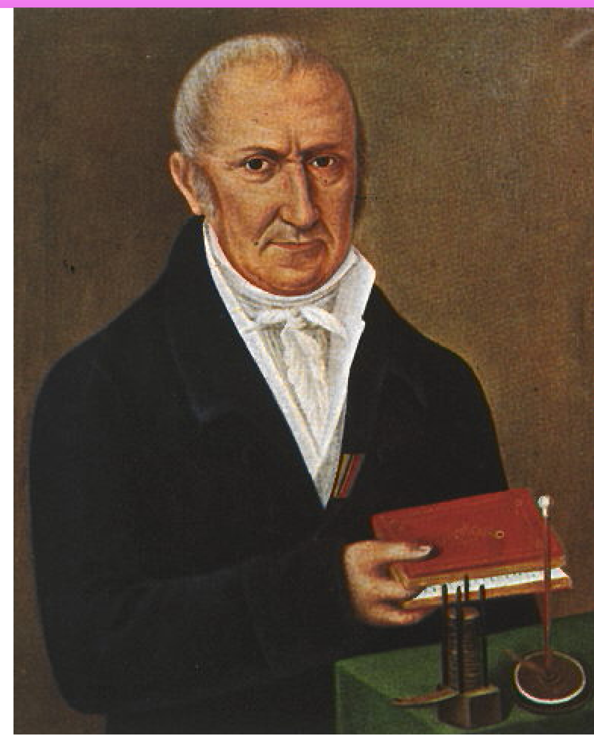
- Let me define a quantity called the electric potential (V) such that U = qV
  - V is the potential created by the source charges
  - U is the potential energy that a charge q has in the potential V

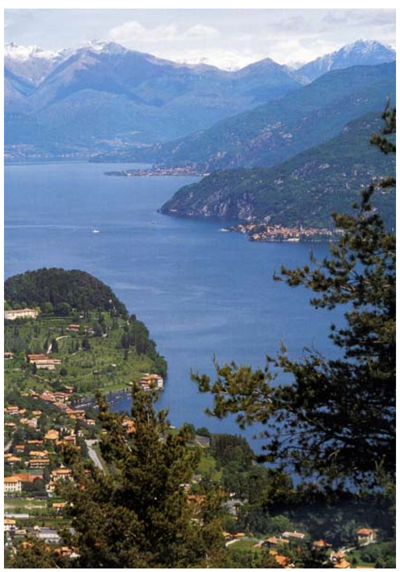




Units of potential

- Unit of electric potential is the joule per coulomb or volt (after Alessandro Volta), inventor of the electric battery
  - 1 V = 1 J/C





Lake Como, where he hung out

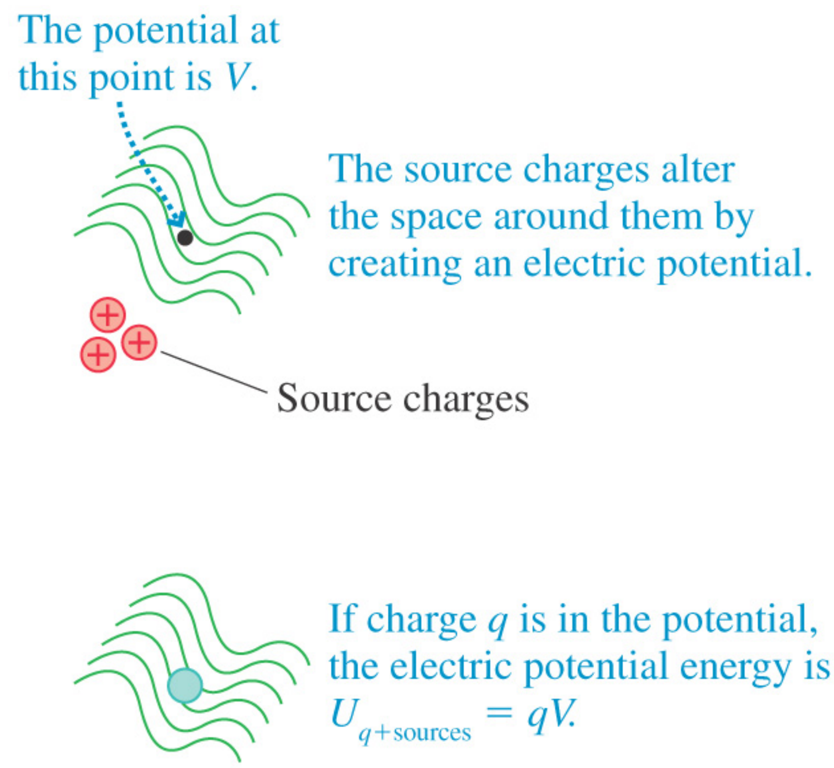
Potential of a point charge

$$U = \frac{1}{4\pi\varepsilon_o}\frac{q_{source}q}{r} = qV_{source}$$

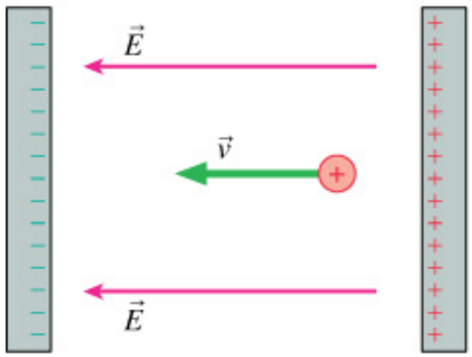
$$V_{source} = \frac{1}{4\pi\varepsilon_o}\frac{q_{source}}{r}$$

- The potential depends only the source charges and their geometry
- If we know the potential V in any region of space, we can easily determine the potential energy U=qV
- So forget the source subscript; we can simply write the potential V resulting from a point charge as

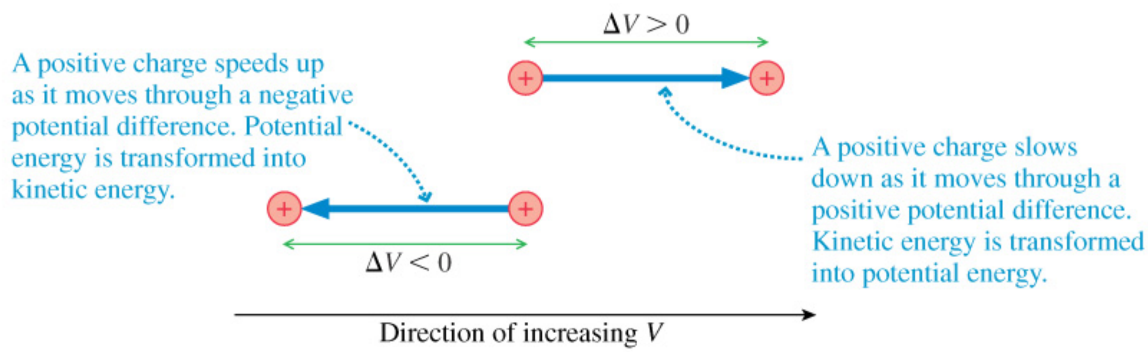
$$V = \frac{q}{4\pi\varepsilon_o r}$$

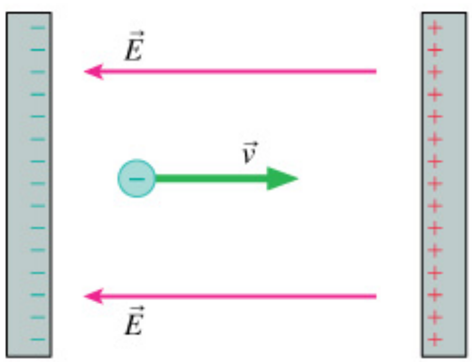


A particle moving in an electric potential



The potential energy of a positive charge decreases in the direction of $\vec{E}$. The charge gains kinetic energy as it moves toward the negative plate.





The potential energy of a negative charge decreases in the direction opposite to $\vec{E}$. The charge gains kinetic energy as it moves away from the negative plate.

The electric potential increases in the direction opposite the E field.