Setlist L5 (90 minutes)

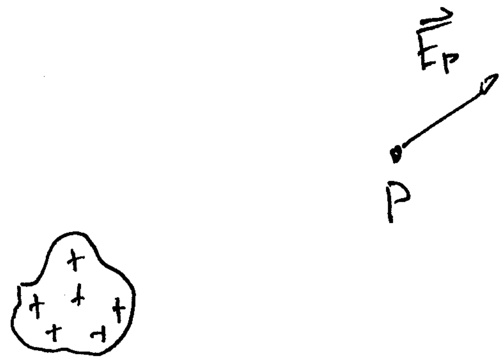
Introduction to electrostatics.
Prep: Charges and Fields PhET. Electric Field Hockey PhET

1. Last Class: Electric Field and Electric field configurations (start with slide 44 of 3 configurations)
2. Clicker Question: Unevenly charged plates. Starts with activity - C
3. Electric Field of a capacitor.
4. Motion of charge in electric fields - instead of having to sum all the forces, we only need to know the electric field acting on a charge to find the force
   - Electric Field Hockey PhET
5. Clicker Question: Charge motion entering uniform field - B
6. Electrophoresis: Get the biologists to help
7. Clicker Question: r dependence of dipole-ion charge - C
   - Show the force for dipole-dipole, remind them it's like a derivative, get r^{-4}.
8. Clicker Question: motion of dipole in non-uniform field - E
   - Ask them about a uniform field
   - Explanation of torque on a dipole
9. Electric field = 0 in a conductor: A consequence of the ability for charge to move freely.

10. Electric Fields and Electric potentials
11. Electric potential energy is the same as gravitational. You're doing work against a field.
12. Clicker Question: Moving a charge form A to B or A to C - C
13. They did a line integral! Talk to them about line integrals.
14. Conservative forces and Path integrals.
    - remember last semester when we said that any conservative force could be written as the derivative of a potential. This is the same, just fancier.
15. Electric potential energy of a point charge - derive from Force
16. The electric potential of a point charge - definition similar to electric field
17. Clicker question: equipotentials - B

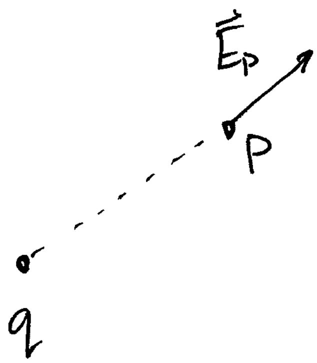
Last Class:

The electric field



$$\vec{E}_P = \frac{\vec{F}_{P\ on\ q}}{q}$$

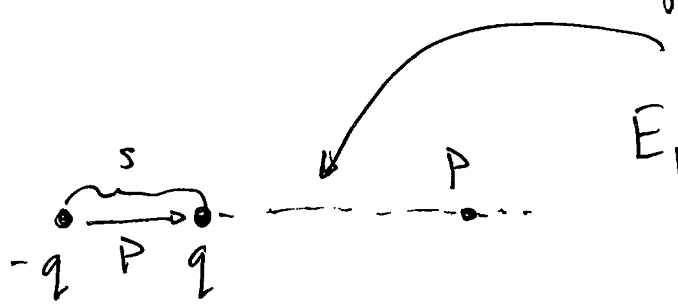
For a point charge



$$\vec{E}_P = k\frac{q}{r^2}\hat{r}$$

From superposition:

only valid for $r \gg s$ along this line.

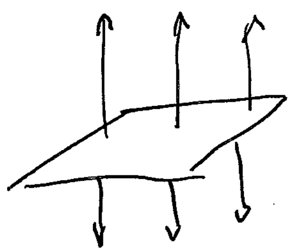


$$E_P = k\frac{2qs}{r^3}$$

$$= k\frac{2p}{r^3}$$

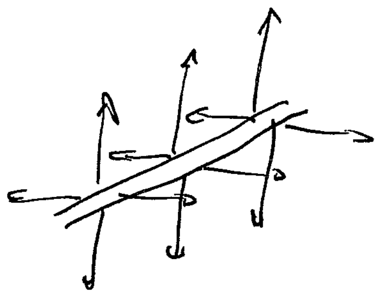
$p = qs$ dipole moment.

Other configurations:



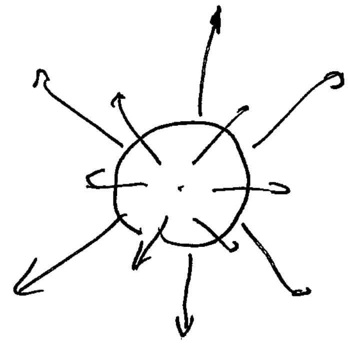
$$E_{plane} = \frac{\eta}{2\epsilon_0}$$

$$\eta = \frac{Q}{A}$$



$$E_{line} = \frac{1}{2\pi\epsilon_0}\frac{\lambda}{r}$$

$$\lambda = \frac{Q}{L}$$



$$E_{Ball} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$

Q is uniformly distributed throughout, or over surface.

Clicker Question: charge entering a constant field.

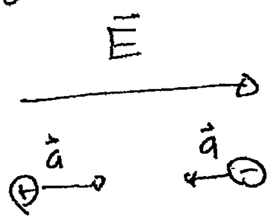
The force that a charge q feels in a electric field $\vec{E}$ is.

$$\vec{F} = q\vec{E} = m\vec{a}$$

which implies

$$\vec{a} = \frac{q}{m}\vec{E}.$$

Positive charges go in the direction of the field. Negative charges go against it.



What direction is $\vec{v}$?

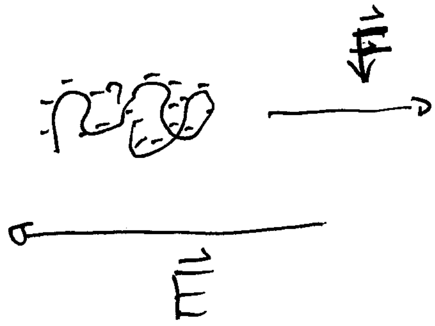
The charges don't follow field lines.

Demo: Electric field hockey

In a uniform field the trajectories look a lot like masses in a gravitational field on earth. The trajectories ~~of point~~ in non-uniform fields can be tricky.

Electrophoresis:

DNA is charged:



It will move in a electric field.

$$\vec{F} = q\vec{E}$$

The DNA feels drag:

$$\vec{F}_d = -b\vec{v}$$

This is Stoke's drag for low Reynolds number motion.

Equating forces gives

$$q\vec{E} - b\vec{v} = 0$$

$$\Rightarrow \vec{v} = \frac{q}{b}\vec{E}$$

← to high an $\vec{E}$ will cook the DNA.

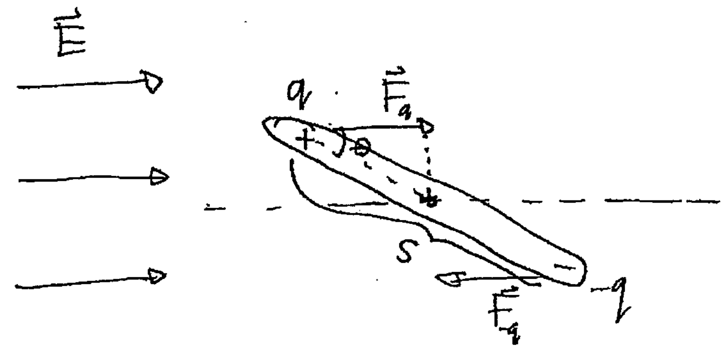
velocity depends on q + b. and $\vec{E}$.

q can't change, but $\vec{E}$ and b can if you're clever (Boreal genomics).

Motion of a dipole in an electric field.

Clicker question:	Dipole in a non-uniform field

① Let's break it down into two parts. First look at the rotation in a uniform field. Rotation implies torque.



$$\vec{\tau} = \frac{s}{2}\sin\theta\,|\vec{F}_q| + \frac{s}{2}\sin\theta\,|F_{-q}|$$

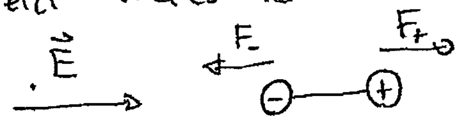
$$= s\,|F_q|\sin\theta =$$

$$= s q E \sin\theta \quad , \quad sq = p$$

$$\Rightarrow \vec{\tau} = \vec{p} \times \vec{E}$$

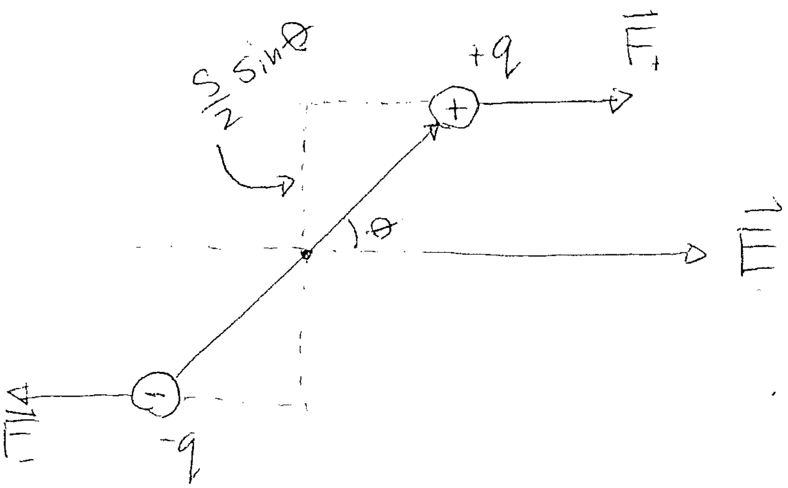
scissor demo

② Now, once the rotation has occured. In a uniform field theres no more motion.



$F_- = F_+$

Torque on a dipole:



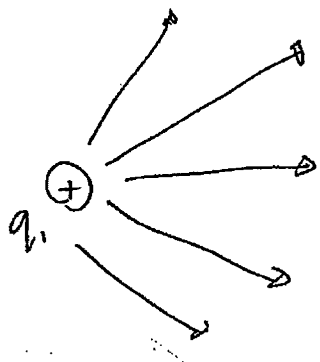
$$\tau_{net} = |F_+|\frac{s}{2}\sin\theta + |F_-|\frac{s}{2}\sin\theta$$

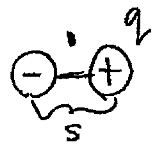
$$= qE\frac{s}{2}\sin\theta + qE\frac{s}{2}\sin\theta$$

$$= Eqs\sin\theta$$

$$= Ep\sin\theta, \quad p = qs$$

However, in a changing field, the ⊕ feels less force than the ⊖.





$$F_{net} = \left[\frac{-kq}{(r - \frac{s}{2})^2} + \frac{kq}{(r + \frac{s}{2})^2} \right] q_1$$

Or more simply,

$$F_{net} = q_1 E_{dipole}$$
$$= q_1 \frac{2kp}{r^3}$$

One can use this trick, but with a dipole field to get the dipole-dipole force.

Once we know the electric field of a complicated configuration, we can easily determine the force it has on a charge.

Potentials

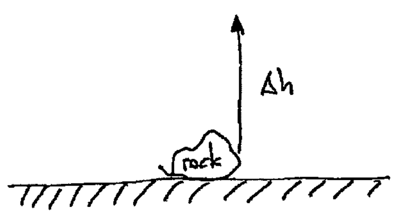
| Clicker question: kinetic energy in a capacitor |

We know that in a conservative field mechanical energy is conserved.

$$\Delta E = \Delta K + \Delta U = 0$$

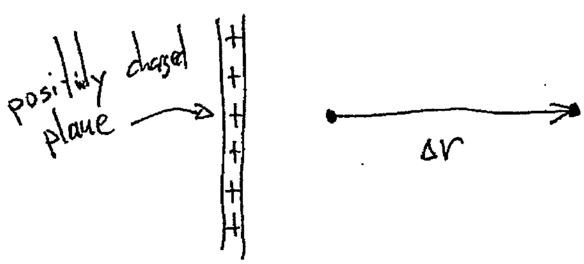
An increase in kinetic energy must be associated with a decrease in potential energy.

In a gravitational field lifting a mass is associated with an increase in potential energy.



$$\Delta U = m_{rock}\, g\, \Delta h$$

An electric field is more subtle because of the 2 charges. The change in potential energy depends on the sign of the charge.



$$\Delta U = -q\, \vec{E}\cdot\Delta\vec{r}$$ ← Be careful of which way you're going.

q can be + or −

E can be from a positive or negative source.