Lecture 12
(Electric Field Lines and Dipoles)

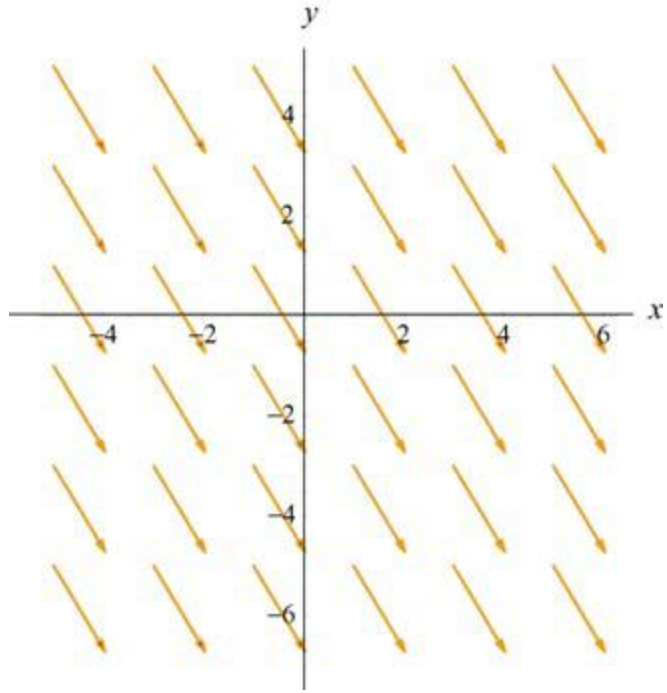
Physics 161-01 Spring 2012

Douglas Fields

Vector Fields

- Let's examine a few vector fields
  - Constant field (no dependence on position)

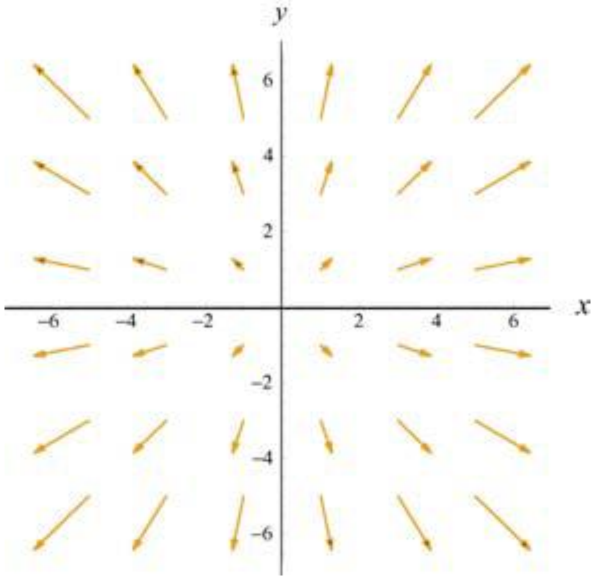
$$\vec{v} = 3\hat{i} - 5\hat{j}$$



Vector Fields

- Let's examine a few vector fields
  - Field proportional to position vector:

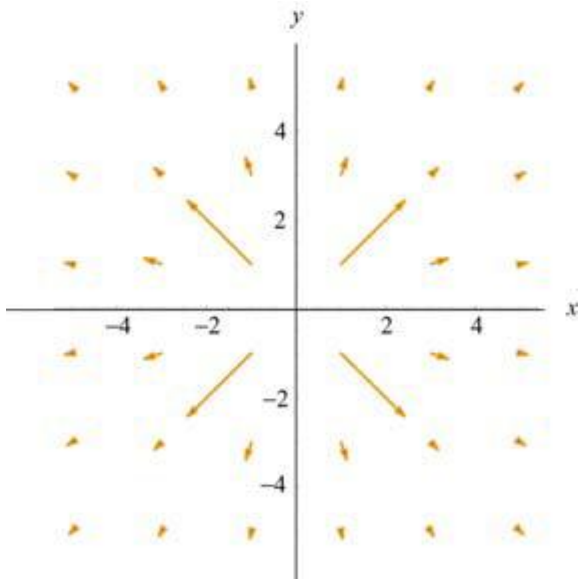
$$\vec{v} = k\vec{r}$$

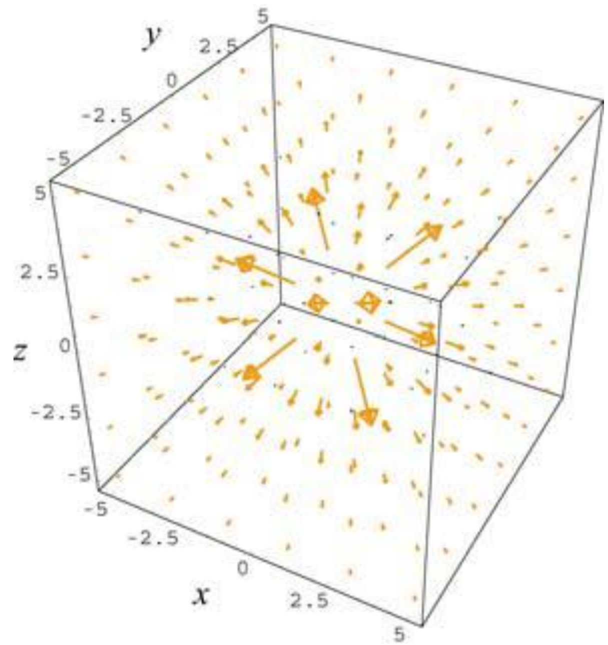


Vector Fields

- Let’s examine a few vector fields
  - Field inversely proportional to position vector^2:

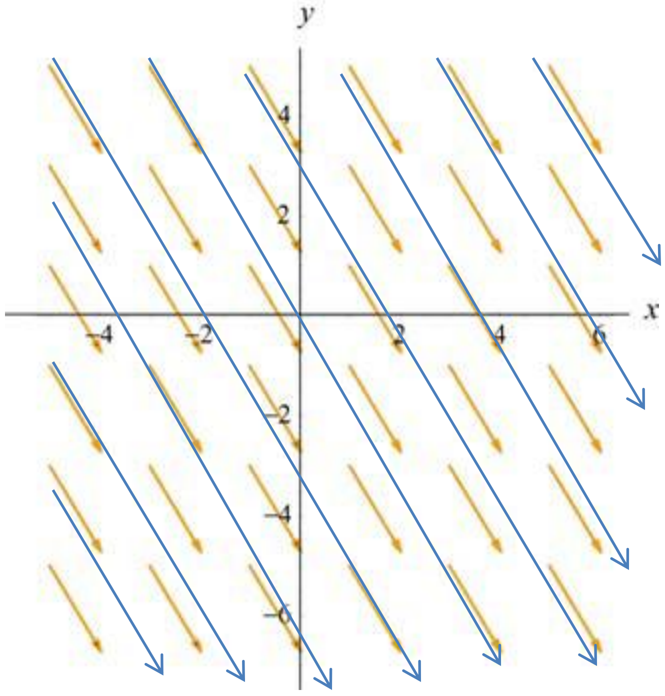
$$\vec{v} = \frac{k\hat{r}}{r^2} = \frac{k\vec{r}}{r^3}$$





Field Lines

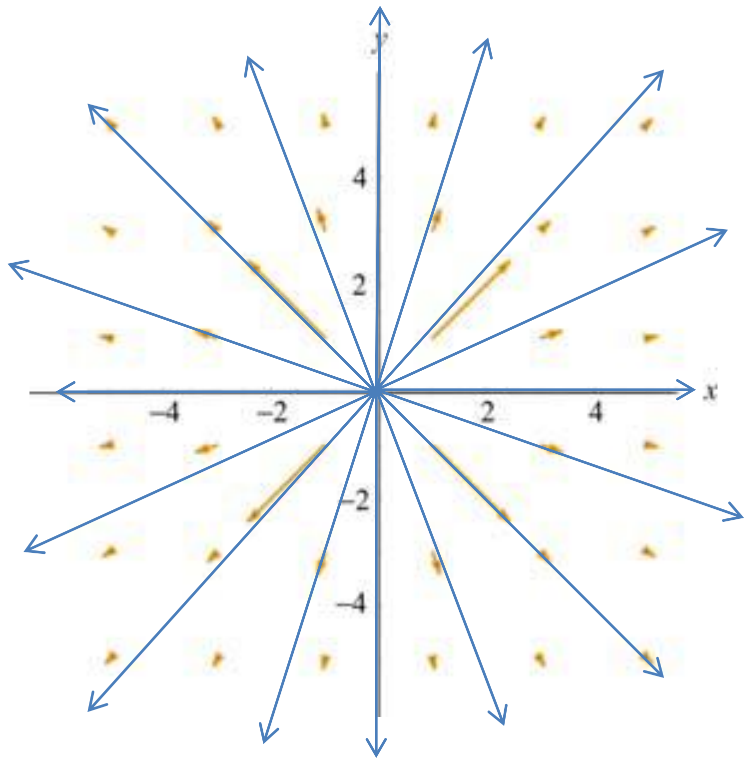
- There is another way to visualize vector fields:
  - Start at any point in space, draw a short line in the direction of the field at that point, stop and repeat.
- Let's look at what the field lines for a constant field look like:



Field Lines

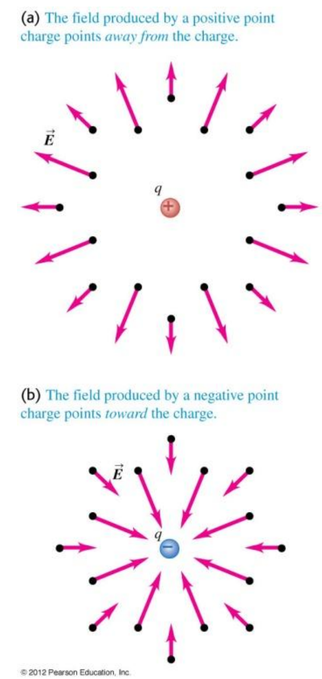
- Let’s look at what the electric field lines for a charged particle would look like:
  - Note: for positive charges, field lines originate at the charge, for negative charges they terminate at the charge.

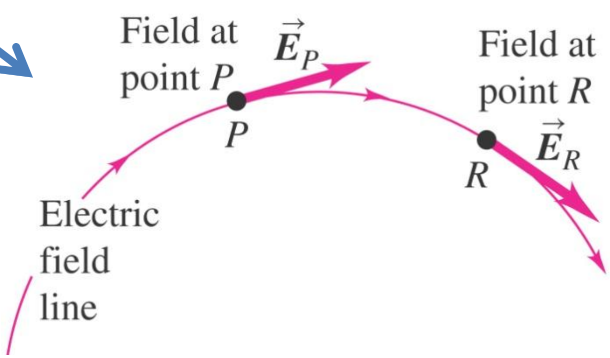
$$\vec{E} = k\frac{q}{r^2}\hat{r} = k\frac{q}{r^3}\vec{r}$$



Field Line Rules

- There are a few guidelines to drawing (and hence to understanding) electric field lines.
  - Electric field lines originate at + charge, and terminate at - charge.
  - Electric field lines are always tangential to the electric field vector at every point.
  - If there is more than one charge in a drawing, the number of lines terminating on the charges should be proportional to the magnitude of the charge.

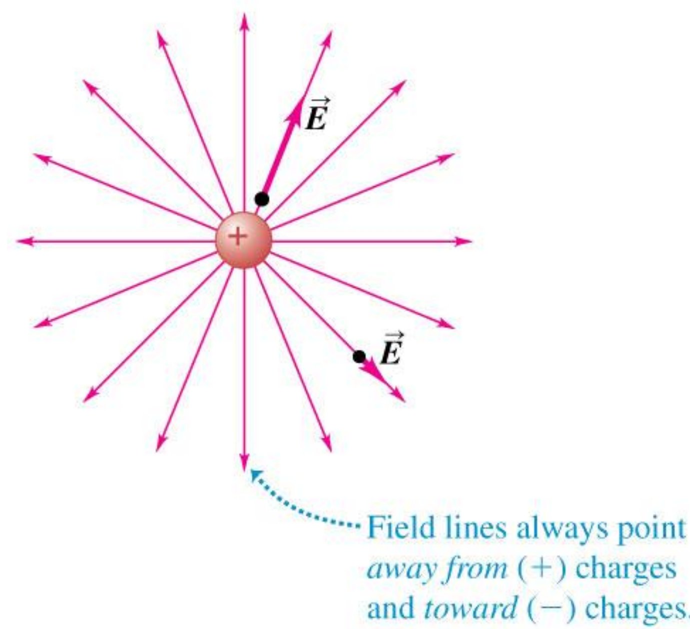




"Isolated Charge"

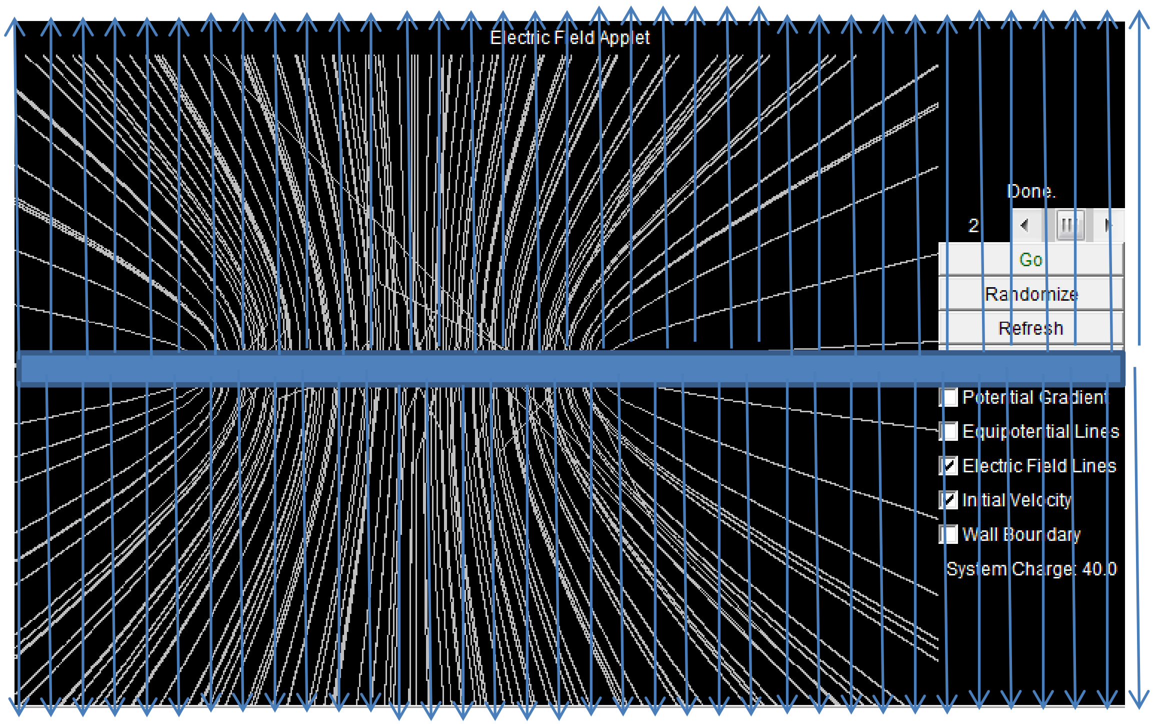
- Where do the field lines terminate (originate) for an isolated positive (negative) charge?
- At infinity. Here, this means very far compared to the drawing.

(a) A single positive charge



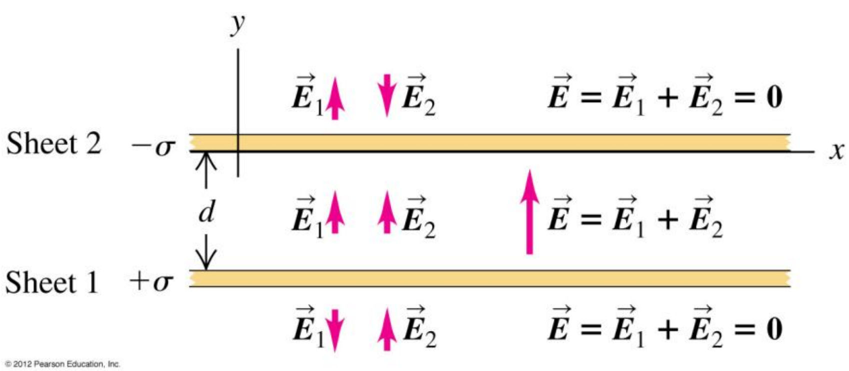
Charged Sheet

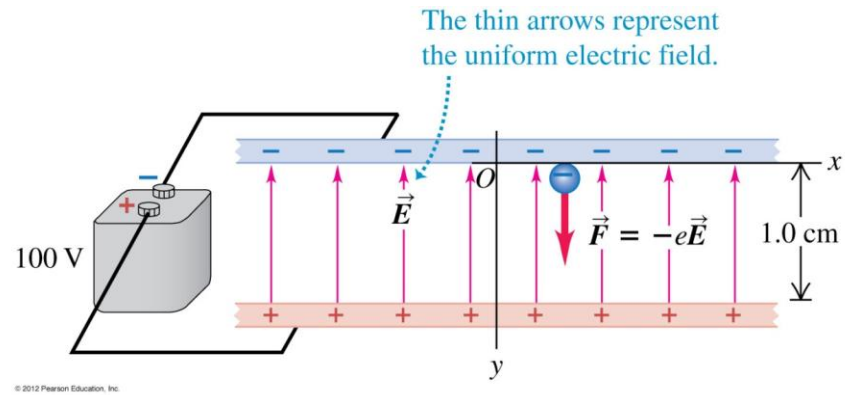
- From our discussion last time, when we derived the electric field of a disk, we can see that if we let the disk radius go to infinity, the electric field is constant – it doesn't depend on the distance away from the sheet.



Two Charged Sheets

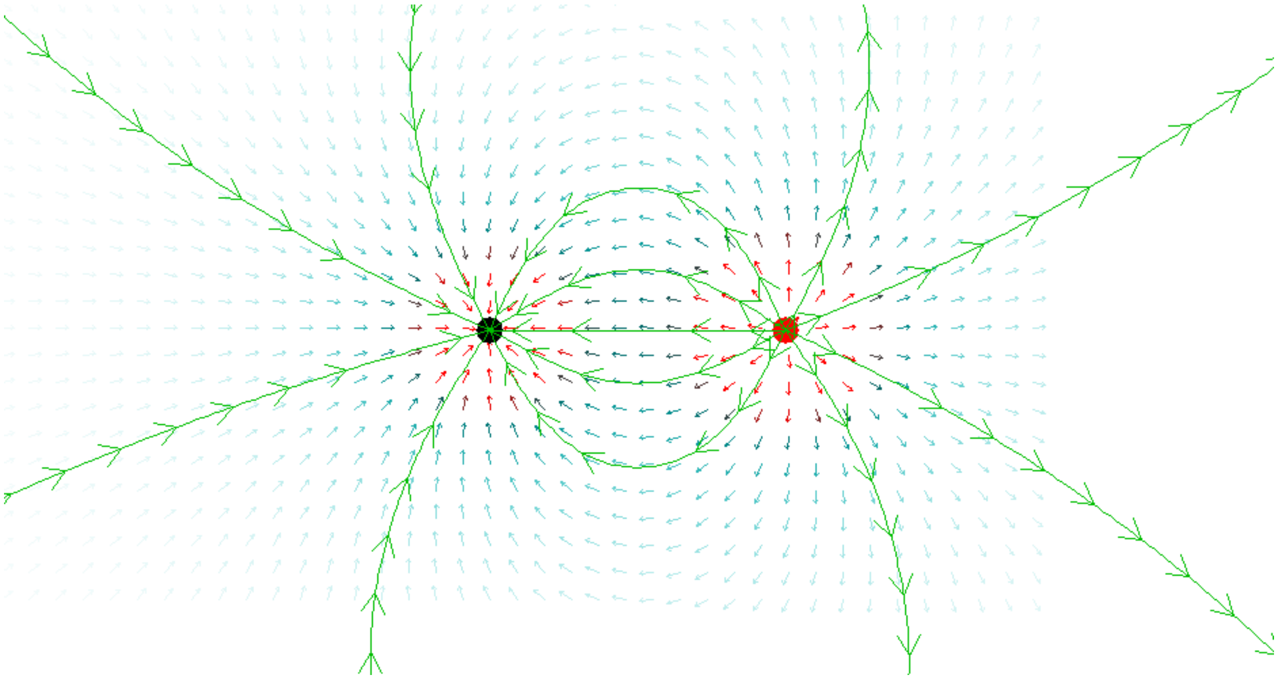
- If you have two sheets of opposite charge, then, since the electric fields are in the same direction between the sheets, but in the opposite direction outside of the sheets, the electric field is zero outside, and constant inside.





Field Lines of a Dipole

- A dipole is two charges of equal magnitude and opposite sign.



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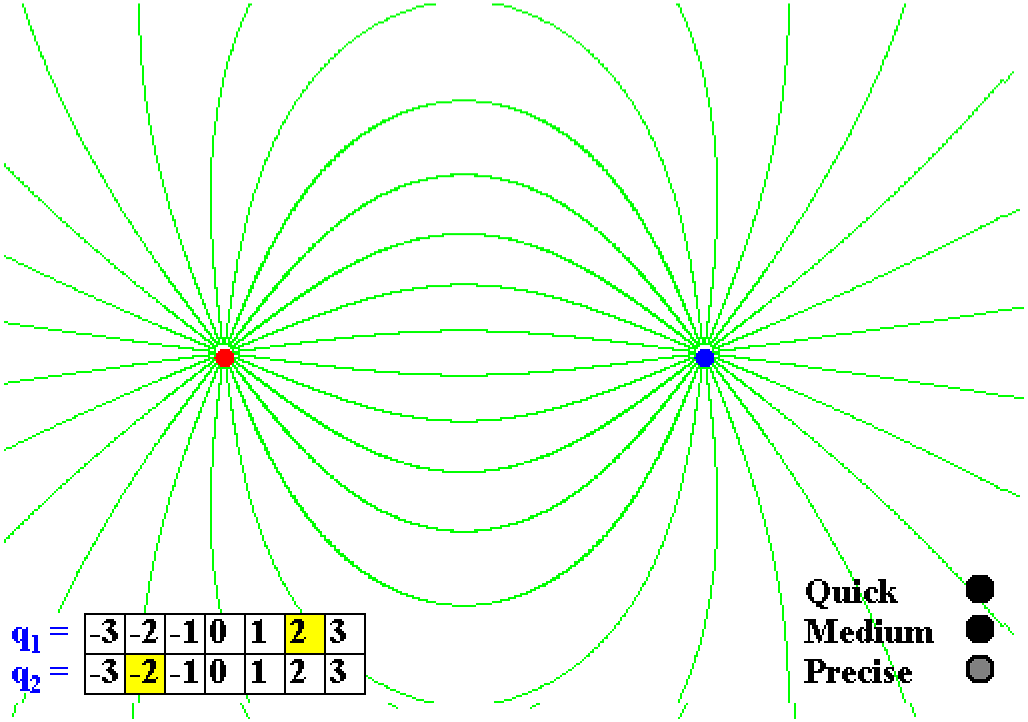
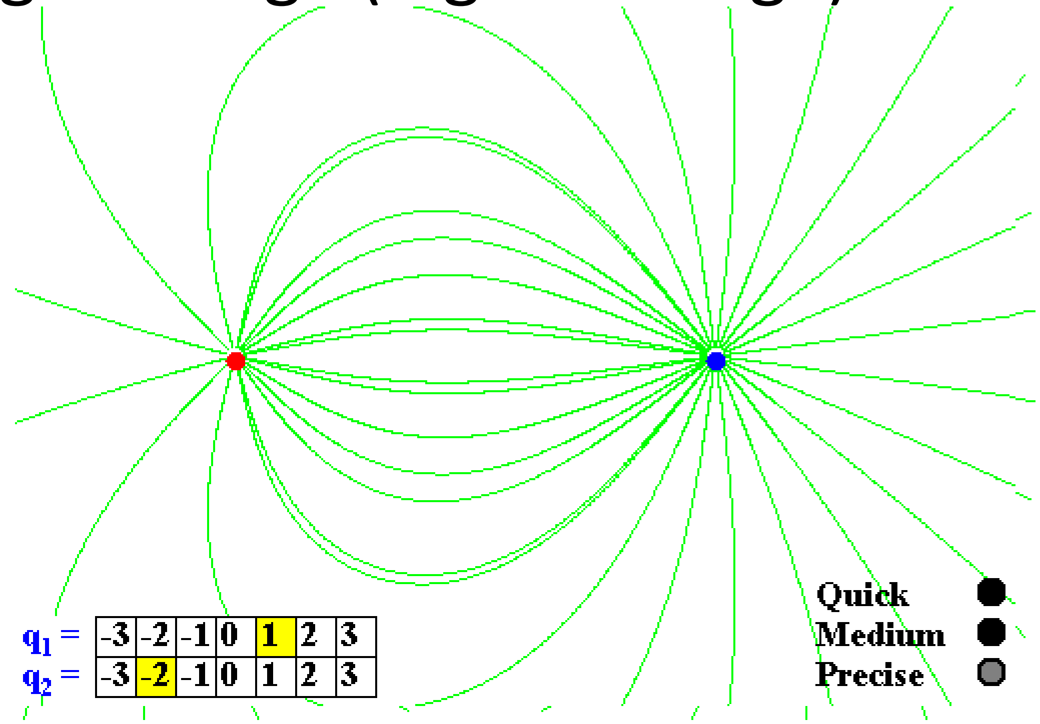


Field Lines of a Dipole

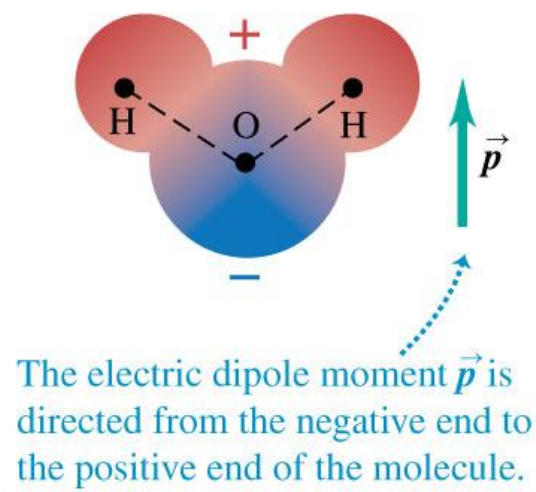
- Here are two charges of opposite sign but unequal magnitude.
- Notice that there are more field lines terminating on the right charge (higher charge)



Dipole Moment

- The dipole moment of a dipole is a vector that points in the direction from the negative charge to the positive charge, and whose magnitude is given by the product of the charge times the separation distance.

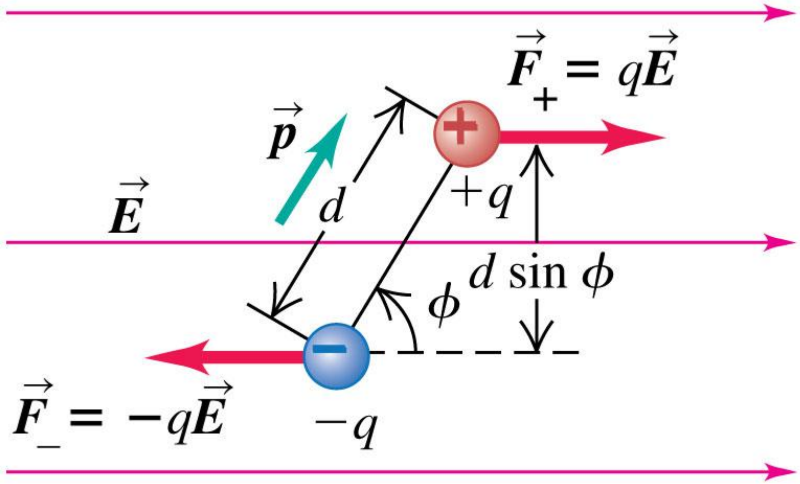
(a) A water molecule, showing positive charge as red and negative charge as blue



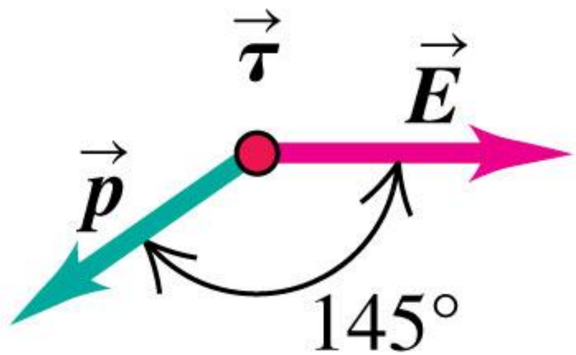
$$|\vec{p}| = |q|d$$

Torque on a Dipole

- A dipole in an electric field will feel a torque.



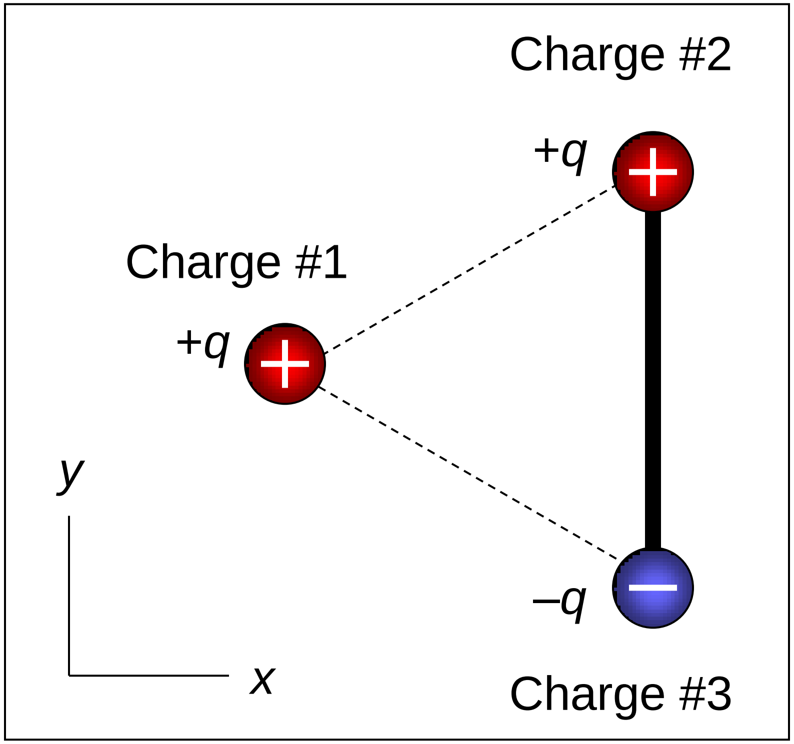
$$
\begin{aligned}
\vec{\tau} &= \vec{r} \times \vec{F} \\
&= d\sin\phi\left(qE\right) \\
&= \left(qd\right)E\sin\phi \\
&= \vec{p} \times \vec{E}
\end{aligned}
$$



CPS 12-1

Three point charges lie at the vertices of an equilateral triangle as shown. Charges #2 and #3 make up an electric dipole.

The net electric *torque* that charge #1 exerts on the dipole is



A. +x direction

B. +y direction

C. +z direction

D. –x direction

E. –z direction

CPS 12-1

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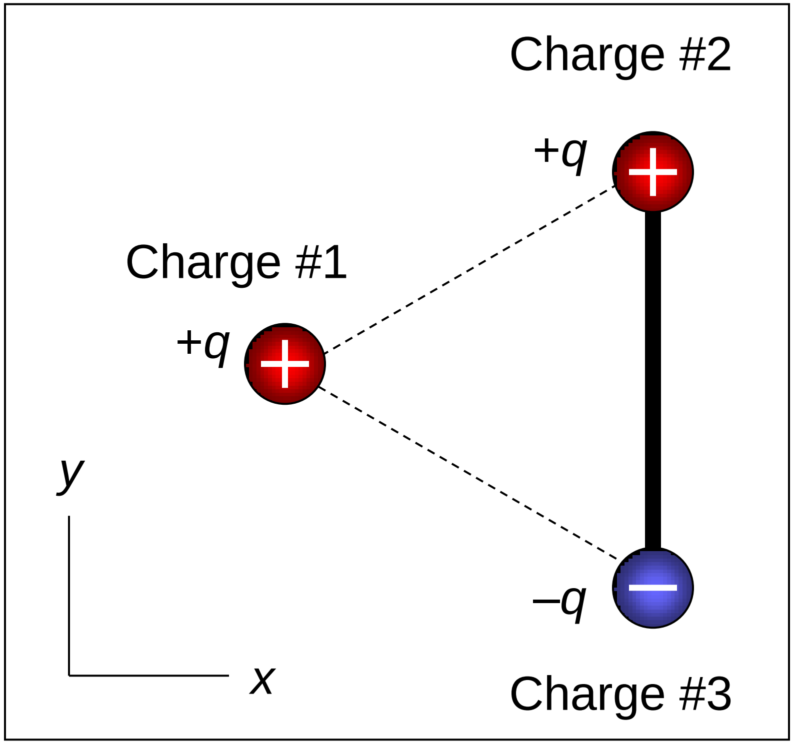

A. +x direction

B. +y direction

C. +z direction

D. –x direction

E. –z direction

Potential Energy of a Dipole in an Electric Field

- It takes work to rotate a dipole in an electric field:

$$
\begin{aligned}
dW &= \vec{F}\cdot d\vec{s} = \vec{\tau}\cdot d\vec{\phi} \\
&= -pE\sin\phi d\phi \Rightarrow \\
W &= -pE\int_{\phi_1}^{\phi_2}\sin\phi d\phi \\
&= pE\cos\phi_2 - pE\cos\phi_1 \\
&= -\Delta U = U_1 - U_2 \Rightarrow \\
U &= -pE\cos\phi = -\vec{p}\cdot\vec{E}
\end{aligned}
$$