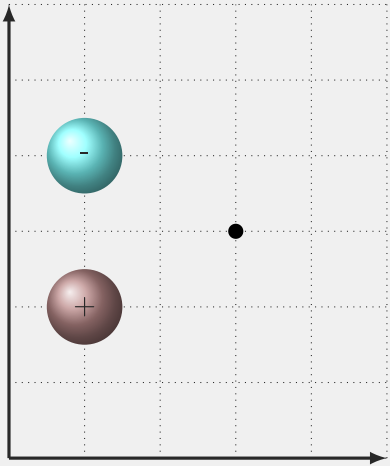
Announcements

- Homework
  - Online HW2 due tonight!
  - Online HW3 will be due on Friday
- Video HW's graded and comments emailed back to you
- We will almost finish Chapter 13 today
- Polling: `rembold-class.ddns.net`

Review Question

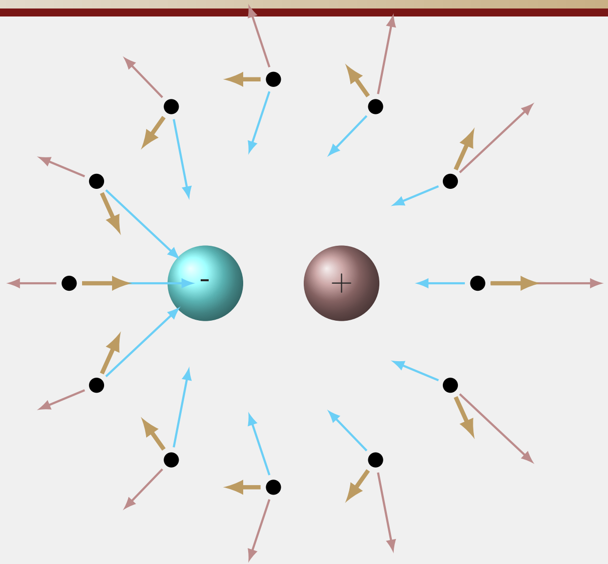


Given the dipole to the left, in what direction would a negative charge placed at the black dot feel a force?

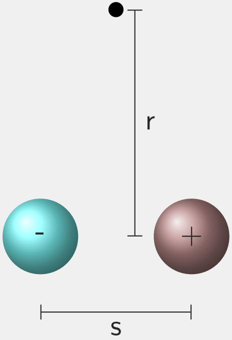
A) Up
B) Down
C) Left
D) Right

Solution: Down

Dipole Refresher



Perpendicular to the Axis: More Numbers



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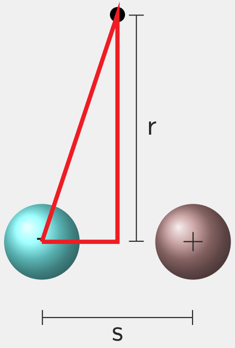

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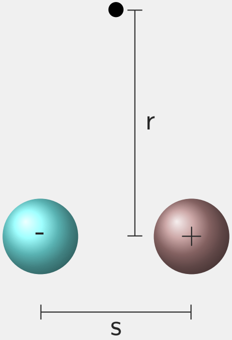


$$\hat{\mathbf{r}}_+ = \frac{\left\langle -\frac{s}{2}, r, 0 \right\rangle}{\sqrt{\left(\frac{s}{2}\right)^2 + r^2}}$$

$$\hat{\mathbf{r}}_- = \frac{\left\langle \frac{s}{2}, r, 0 \right\rangle}{\sqrt{\left(\frac{s}{2}\right)^2 + r^2}}$$

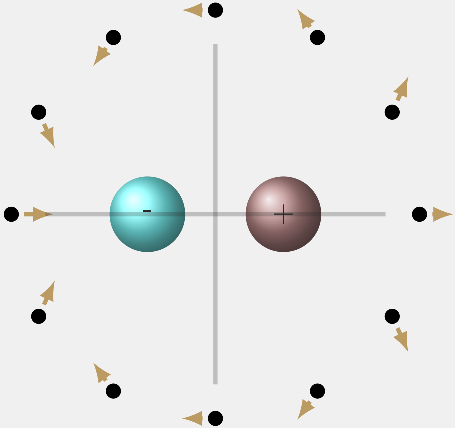
$$\vec{\mathbf{E}}_+ = \frac{1}{4\pi\epsilon_0} \frac{q}{\left(\frac{s}{2}\right)^2 + r^2} \cdot \frac{\left\langle -\frac{s}{2}, r, 0 \right\rangle}{\sqrt{\left(\frac{s}{2}\right)^2 + r^2}}$$

$$\vec{\mathbf{E}}_- = \frac{1}{4\pi\epsilon_0} \frac{-q}{\left(\frac{s}{2}\right)^2 + r^2} \cdot \frac{\left\langle \frac{s}{2}, r, 0 \right\rangle}{\sqrt{\left(\frac{s}{2}\right)^2 + r^2}}$$

Simplifying the Perpendicular

- Y-components equal and opposite $\Rightarrow$ cancel
- X-components equal and the same direction $\Rightarrow$ double
- Results in
$$\vec{\mathbf{E}}_{net,\perp} = \frac{1}{4\pi\epsilon_0}\frac{-qs}{[(\frac{s}{2})^2 + r^2]^{3/2}}\langle 1, 0, 0\rangle$$
- Again, if $r \gg s$, then this simplifies to become:
$$\left|\vec{\mathbf{E}}_{net,\perp}\right| = \frac{1}{4\pi\epsilon_0}\frac{qs}{r^3}$$

Dipole Summary



$$\left|\vec{\mathbf{E}}_{axis}\right| \approx \frac{1}{4\pi\epsilon_0}\frac{2qs}{r^3}$$
$$\left|\vec{\mathbf{E}}_{\perp}\right| \approx \frac{1}{4\pi\epsilon_0}\frac{qs}{r^3}$$

- E-field along axis points from - $\rightarrow +$
- E-field along perpendicular points from $+ \rightarrow$ -

From this Moment on...

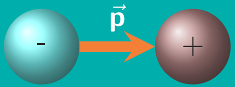
- Notice that qs shows up in both expressions
- Given some distance away, qs is what dictates the strength of the field
- Give it a fancy name!

The Electric Dipole Moment

The electric dipole moment is defined as

$$p = qs$$

where q is the charge, s the separation and p the dipole moment. It can also be defined as a vector that points from the negative charge to the positive charge.



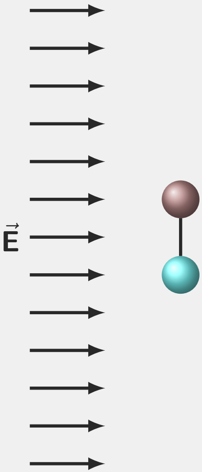
Dipole Example

Suppose a dipole located at the origin has a dipole moment of $\langle 0.01, 0, 0\rangle\,\mathrm{C\,m}$. What force does a $10\,\mathrm{mC}$ particle at $\vec{\mathbf{r}} = \langle 0, 6, 2\rangle$ experience?

Solution: $3.56\,\mathrm{kN}$

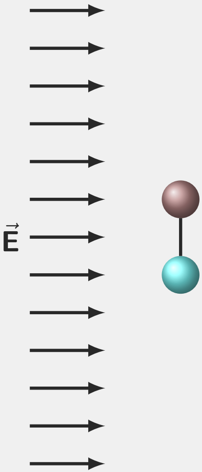
Dipole Swimming

- Let's consider the behavior of a dipole in a constant electric field



Dipole Swimming

- Let's consider the behavior of a dipole in a constant electric field
    - System should have net force zero: zero movement



Dipole Swimming

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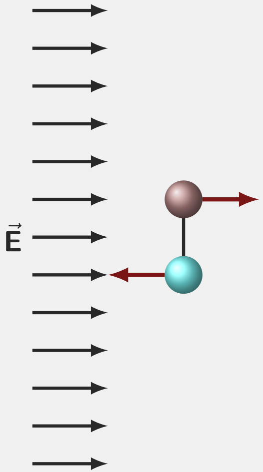

Dipole Swimming

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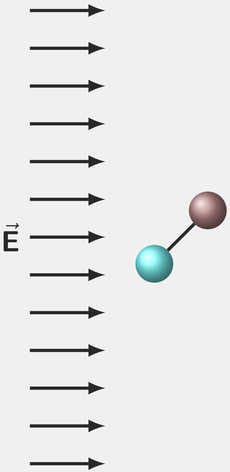
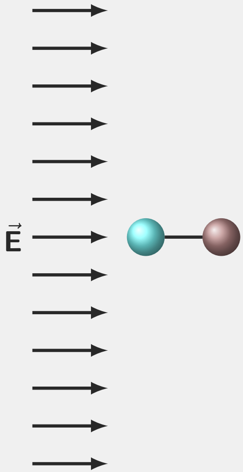
  - System should have net force zero: zero movement
  - Individual charges will feel a force
  - Results in torque that spins the dipole around



Dipole Swimming

- Let's consider the behavior of a dipole in a constant electric field
  - System should have net force zero: zero movement
  - Individual charges will feel a force
  - Results in torque that spins the dipole around
  - End result? $\vec{\mathbf{p}}$ aligned with $\vec{\mathbf{E}}$



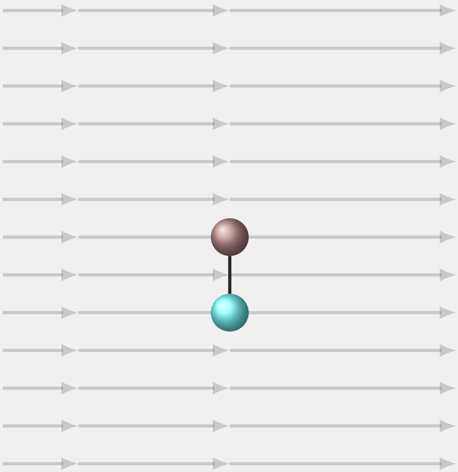
Understanding Check!

Consider our previous dipole instead is in an electric field that increased to the right.

$$\vec{\mathbf{E}} = \langle 2x, 0, 0 \rangle$$

What will the net motion of the dipole be over a prolonged amount of time?

A) It should move to the right
B) It should move to the left
C) It should not move left or right
D) It should move out of the board



Solution: Move to the right

Computationally Making the Magic

At this point we have everything we need to computationally draw electric fields:

1. Define your source charges
2. Choose the points you want to investigate the E-field at
3. Looping through those points:
    i. Calculate your displacement
    ii. Calculate your electric field
    iii. Draw your E-field vector
4. Behold the splendor of what you have drawn!

Some Example Code

```
ball = sphere(pos=vec(0,0,0), radius=1, color=color.red)
ball.q = 10E-6

oofpez=9E9
scf=0.0001
```

Defining constants and sources

```
for i in arange(-10,10,1):
    for j in arange(-10,10,1):
        r = vec(i,j,0) - ball.pos
        Efield = oofpez*ball.q*r.hat/mag(r)**2
        arrow(pos=vec(i,j,0), axis=Efield*scf, shaftwidth=0.1)
```

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Grid of vectors

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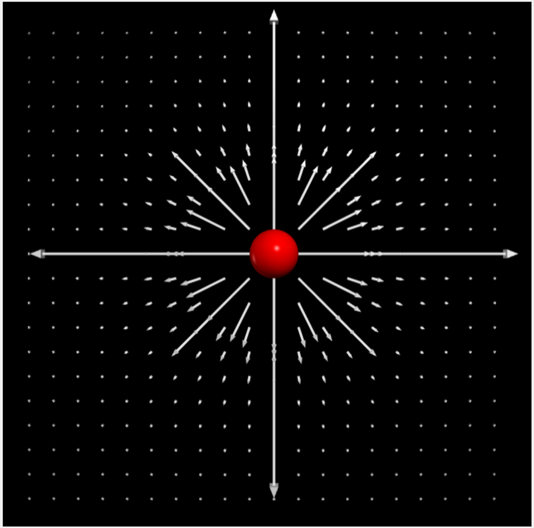
Calculating E-field and drawing

Pictures!



Fancier Pictures!