# Electric Field

PHY 114-01

Fall 2026

# Electric Field

- When charge distributions get more complicated, we need to use the electric field.
- This is a way to predict what the force on some unknown *test charge* will be from a known charge distribution.

$$\vec{F} = kQ \sum_i \frac{q_i}{r_i^2} \hat{r}_i = Q \left( k \sum_i \frac{q_i}{r_i^2} \hat{r}_i \right) = Q \, \vec{E}$$

- E is the electric field!
- E is a function of the position of Q

$$\vec{\mathbf{E}} \equiv \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_1^2}\hat{\mathbf{r}}_1 + \frac{q_2}{r_2^2}\hat{\mathbf{r}}_2 + \frac{q_3}{r_3^2}\hat{\mathbf{r}}_3 + \cdots + \frac{q_N}{r_N^2}\hat{\mathbf{r}}_N\right)$$

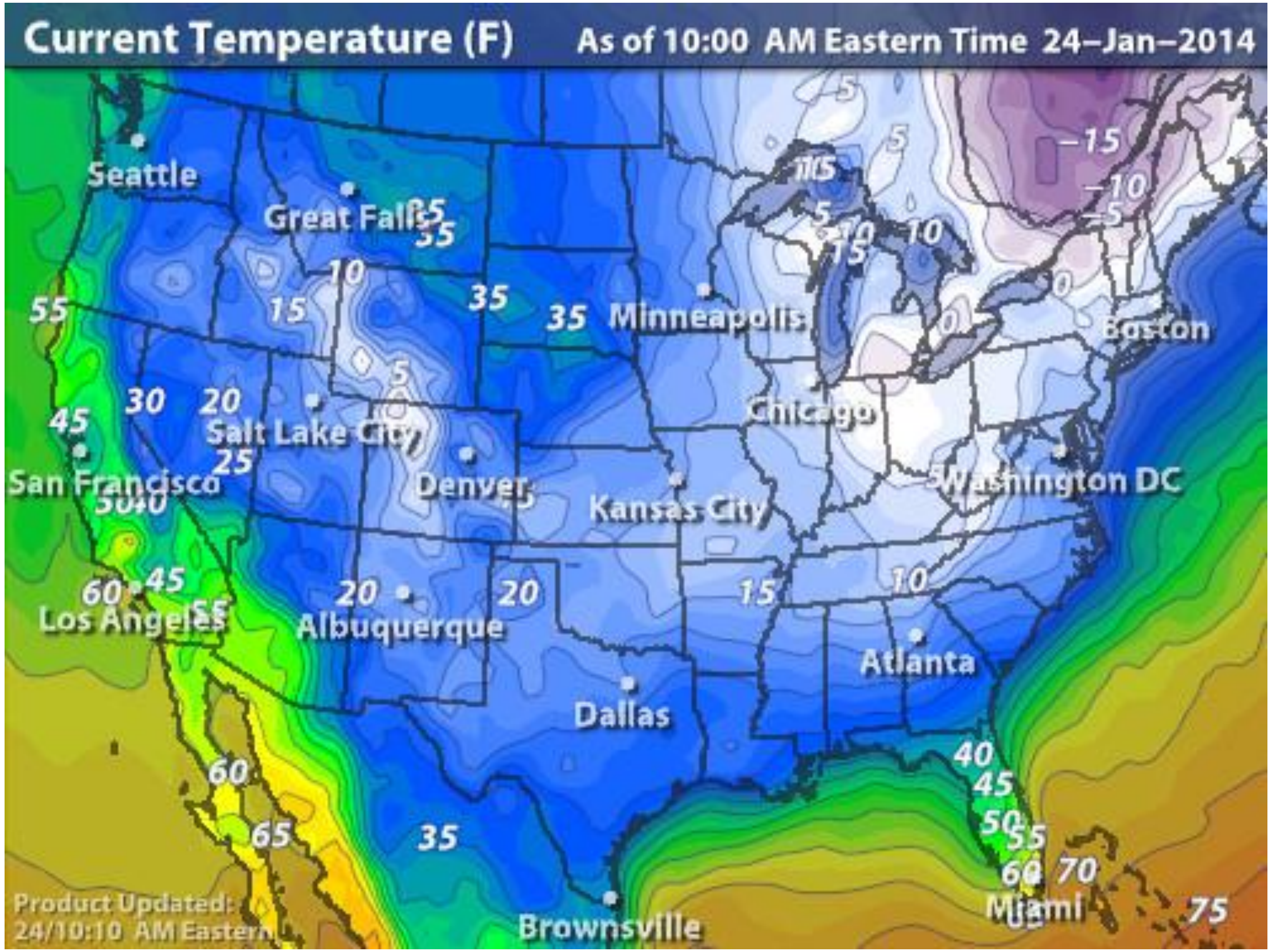
or, more compactly,

$$\vec{\mathbf{E}}(P) \equiv \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{N}\frac{q_i}{r_i^2}\hat{\mathbf{r}}_i. \tag{5.4}$$

# Fields

- A field, in physics, is a physical quantity whose value depends on (is a function of) position, relative to the source of the field.
- The electric field is a continuous, immaterial substance that surrounds the source charge, filling all of space
- $\vec{E}$ (both the magnitude and the direction) depends on where in space the point $P$ is located, with $\vec{r}_i$ measured from the locations of the source charges $q_i$

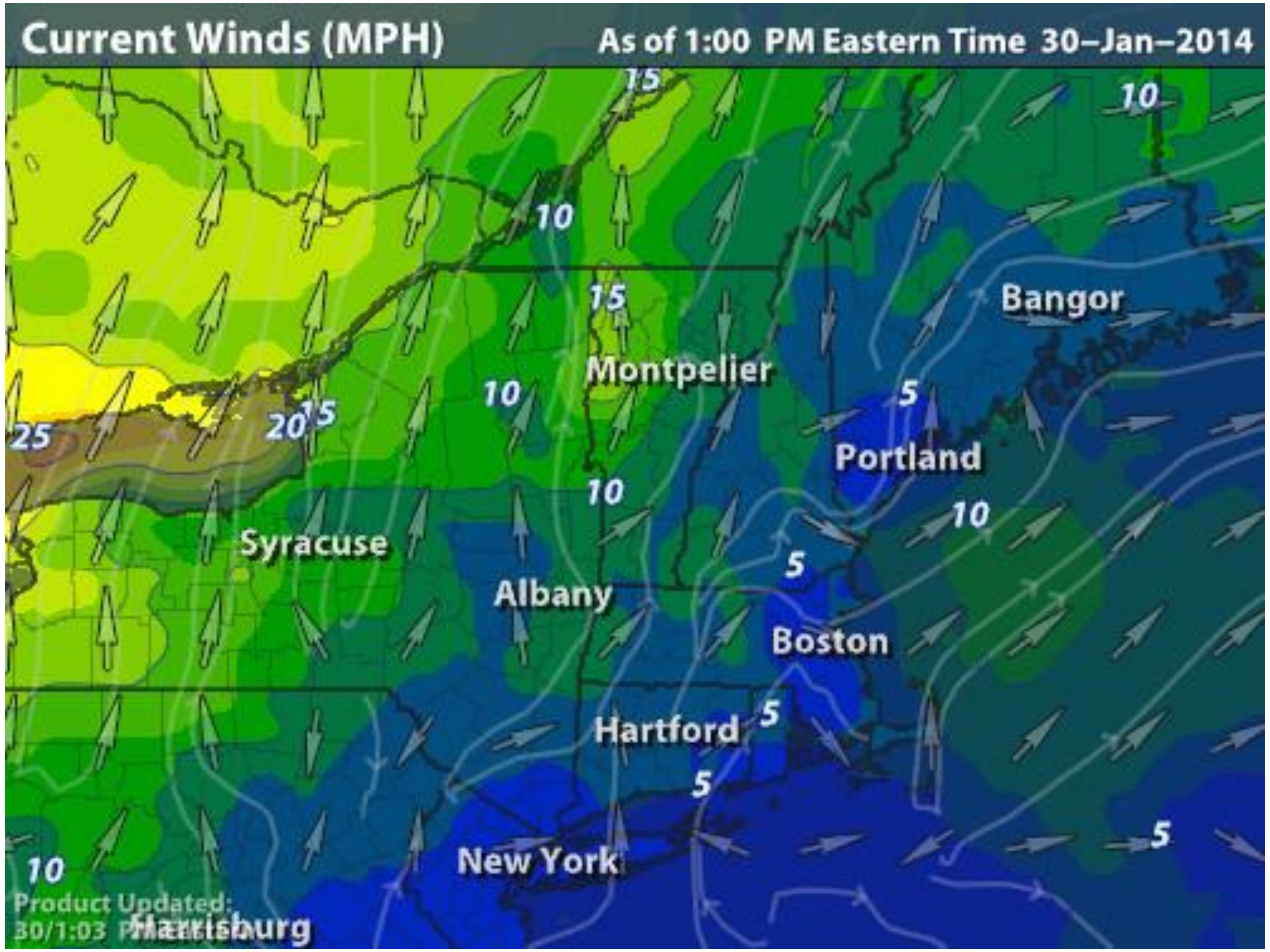
# Fields of all kinds...




**These isolated Temperatures make up a Scalar Field**

**(you learn the temperature, only a number)**

## You may prefer to know which way the wind is blowing …




That would require a **VECTOR field**.

(you learn **how fast** the wind is blowing AND in **what direction**)

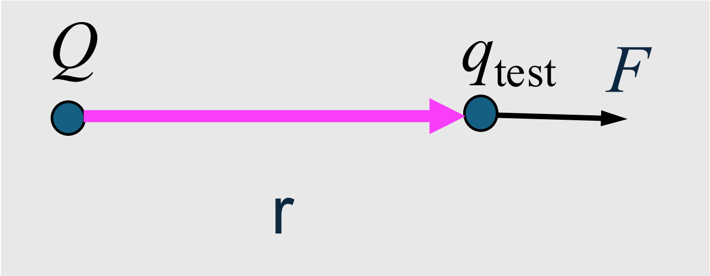
# Electric Field and Force

- **Electric fields and forces are related:**
  - **Given charge distribution, we can find the electric field $\vec{E}$, then force $\vec{F} = q\vec{E}$**
  - **Or given electric force field $\vec{F}$, we can find the electric field $\vec{E} = \vec{F}/q$**

# Electric Fields

## Definition of the Electric Field:

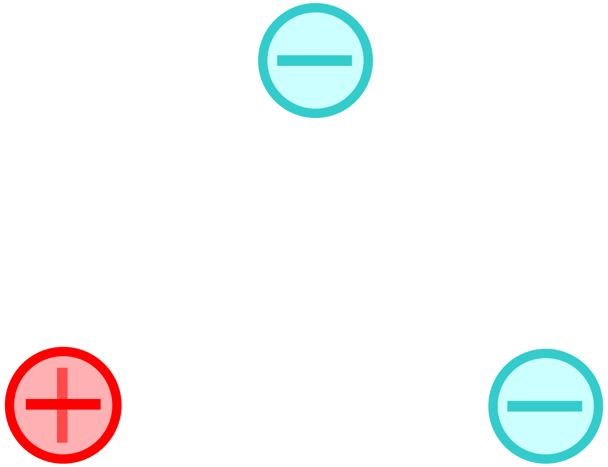
$$\vec{E} = \vec{F} / q_{test}$$




- How do we "find" the field?
  - Move around a small positive "test" charge and see what electric force it feels!

- Since F is a vector, E is a vector
  - *field direction* = direction of force on a small *positive* "test" charge

Tom places a negative charge at the top corner of an isosceles triangle to test the electric field produced by the +Q and –Q charges at the bottom of the triangle. What is the direction of the ***net force*** on the ***top*** negative charge?



A. Left.

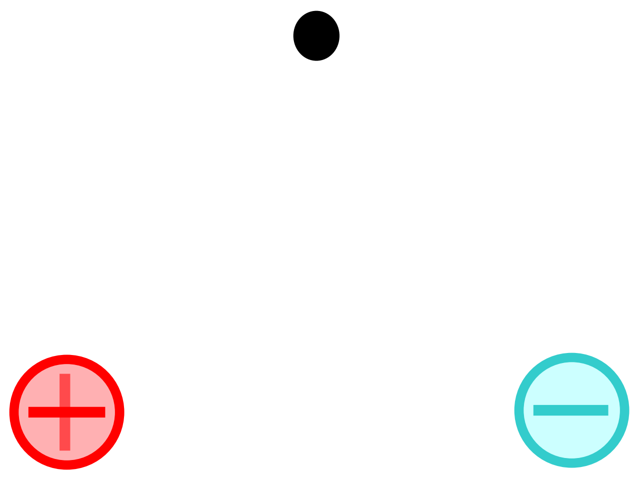
B. Down.

C. Right.

D. Up.

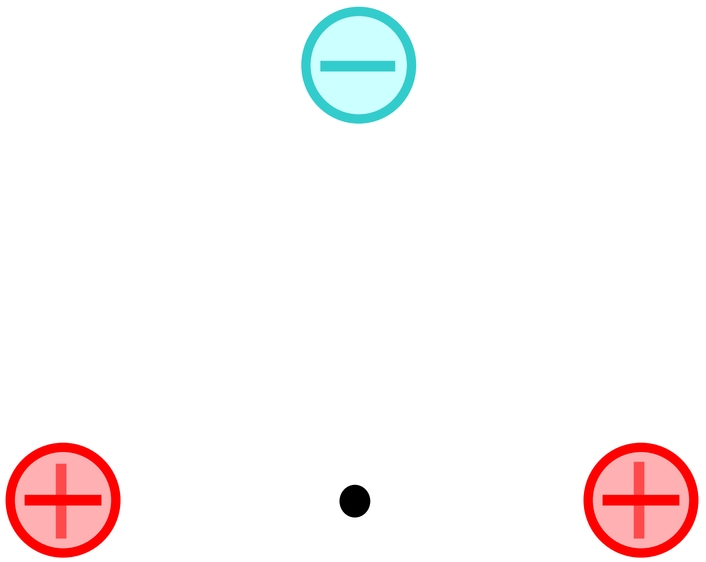
E. The net force is zero

Now, Tom removes the test charge. What is the direction of the ***electric field*** at the previous point (top of triangle)?



A. Left.
B. Down.
C. Right.
D. Up.
E. The electric field is zero

Tom never quits. He now wishes to find the direction of the electric field at the origin, as shown by the black dot.  The ***<u>electric field</u>*** at the origin points



A. Left.

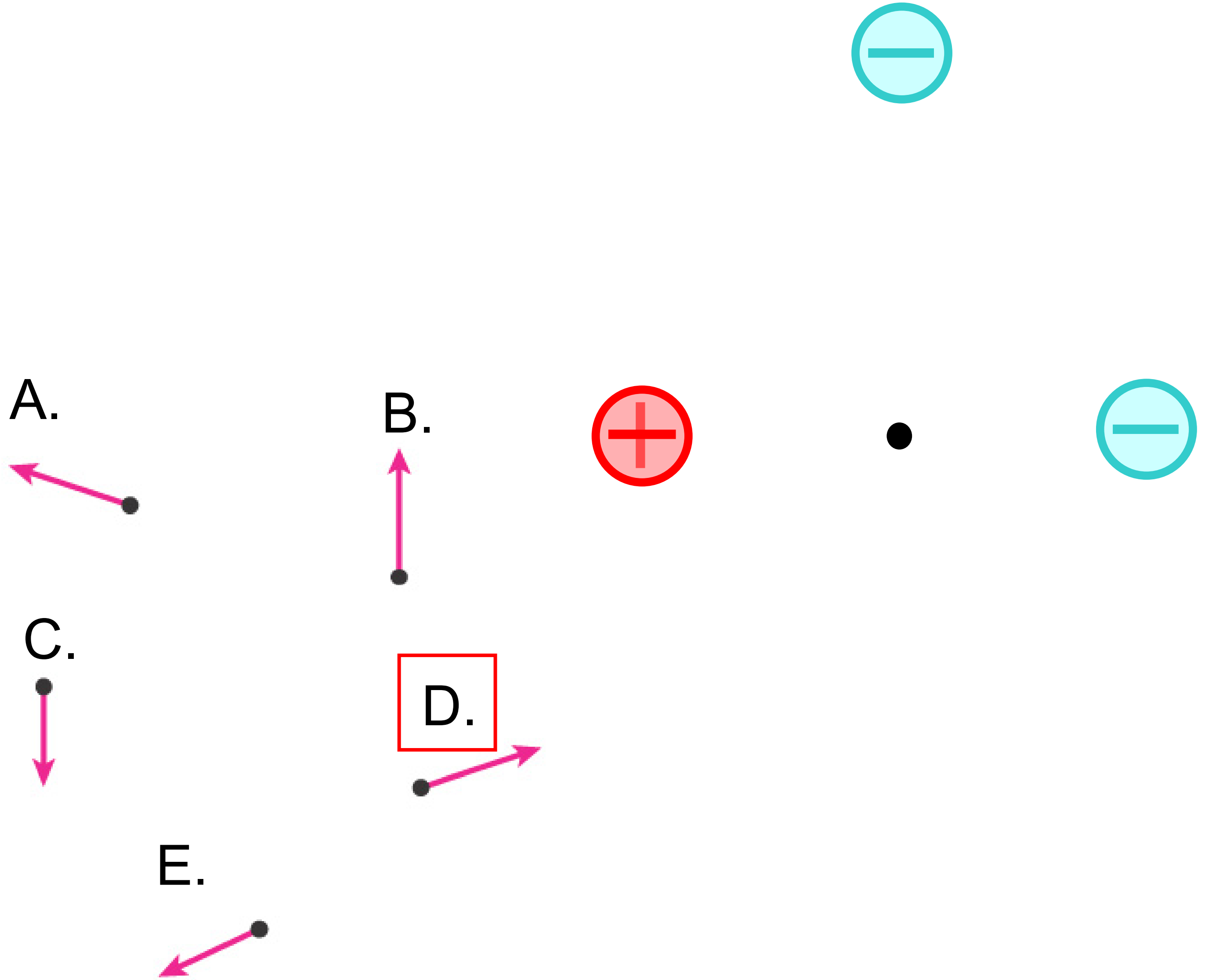
B. Down.

C. Right.

$\boxed{\text{D.}}$ Up.

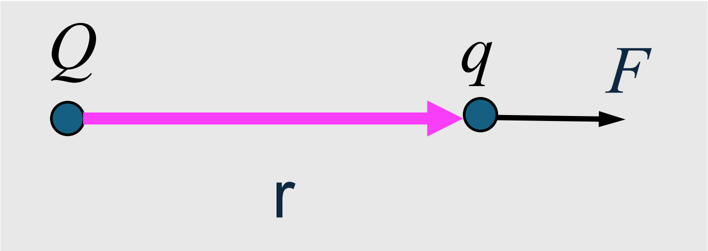
E. The net field is zero

Now, Tom changes one of the positive charges on the bottom to negative, as shown below. At the position of the dot, the ***electric field*** points approximately

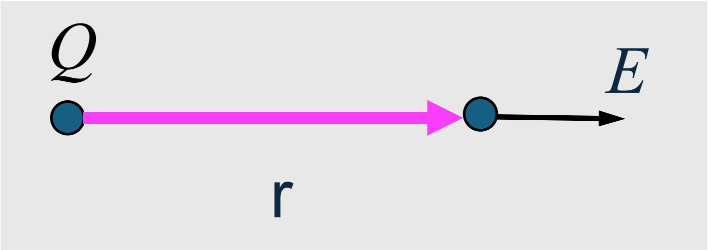


# Electric field of a point charge

Force: $$\vec{F} = k\frac{qQ}{r^2}\hat{r}$$

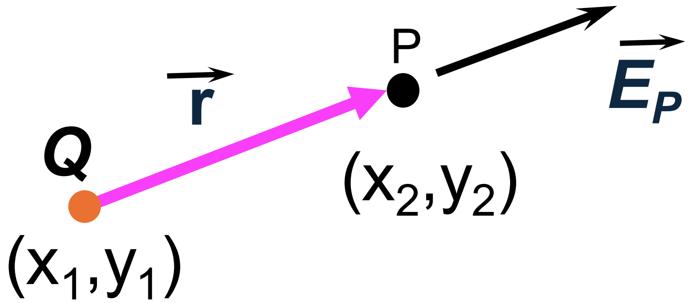



E-field: $$\vec{E} = \frac{\vec{F}}{q} = k\frac{Q}{r^2}\hat{r}$$




independent of test charge *q*

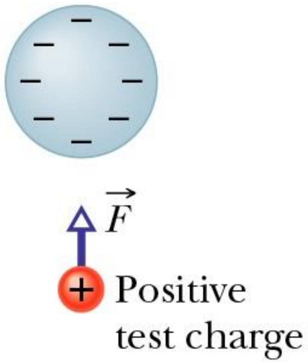
at arbitrary point P




$$\boxed{\begin{aligned}\vec{E}_P &= k\frac{Q}{r^2}\hat{r} = k\frac{Q}{r^3}\vec{r}\\ &= k\frac{Q}{r^3}[(x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j}]\end{aligned}}$$

## ConcepTest Electric Field

A test charge is placed at a certain point from a point charge, and you measure a force $F_0$ on it and an electric field of $E_0$. If the test charge is halved, the force and electric field are:




1. $F_0$, $E_0$
2. $\frac{1}{2}F_0$, $\frac{1}{2}E_0$
3. $\frac{1}{2}F_0$, $E_0$ ✓
4. $F_0$, $\frac{1}{2}E_0$
5. not enough info

**force halves, electric field is the same**

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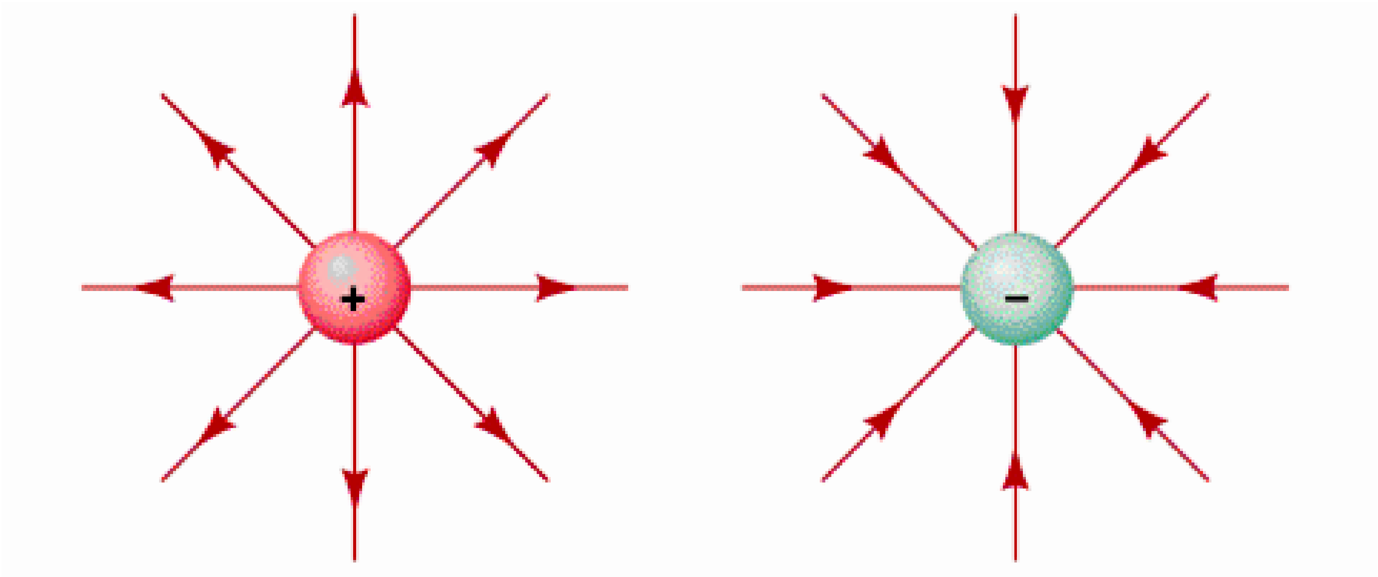
DISCUSSION TIME

# A Way to Visualize E Fields

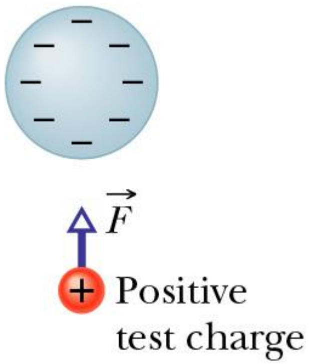



- field lines originate on positive charges
- field lines end on negative charges
  - ➢ Number of lines leaving/entering $\rightarrow$ amount of charge
  - ➢ Tangent of line $\rightarrow$ direction of E
  - ➢ Density of lines $\rightarrow$ magnitude of E

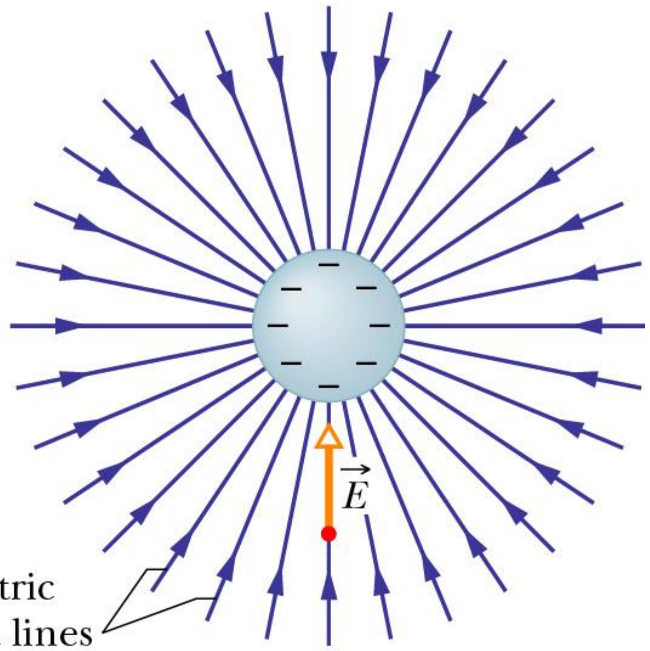
# Electric Fields

$$E = \frac{F_e}{q} = k\frac{Q}{r^2}$$

- we find the field with a small positive "test" charge
  - the field direction is the direction of the force on the positive "test" charge
  - so, for a negative charge, the field lines point inwards
- field independent of test charge

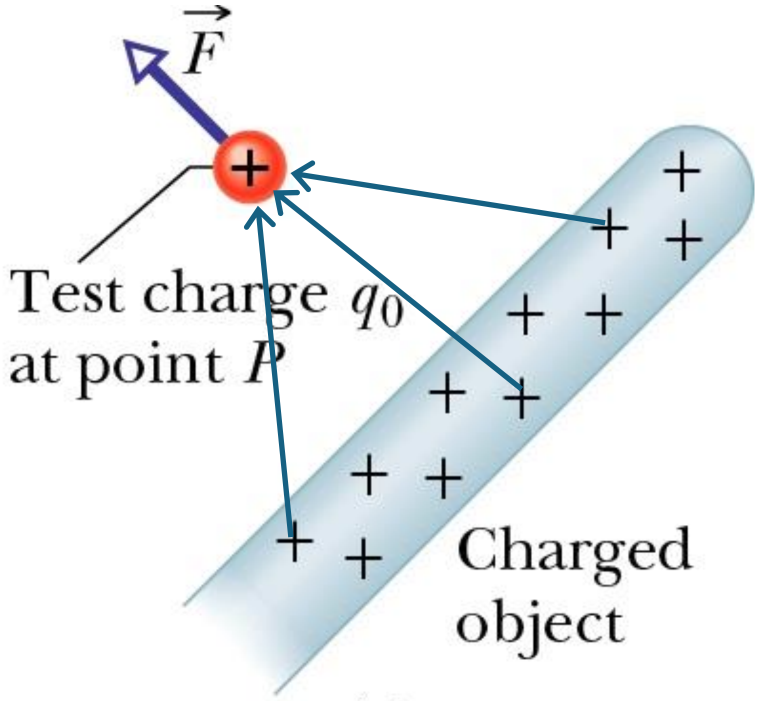



(a)

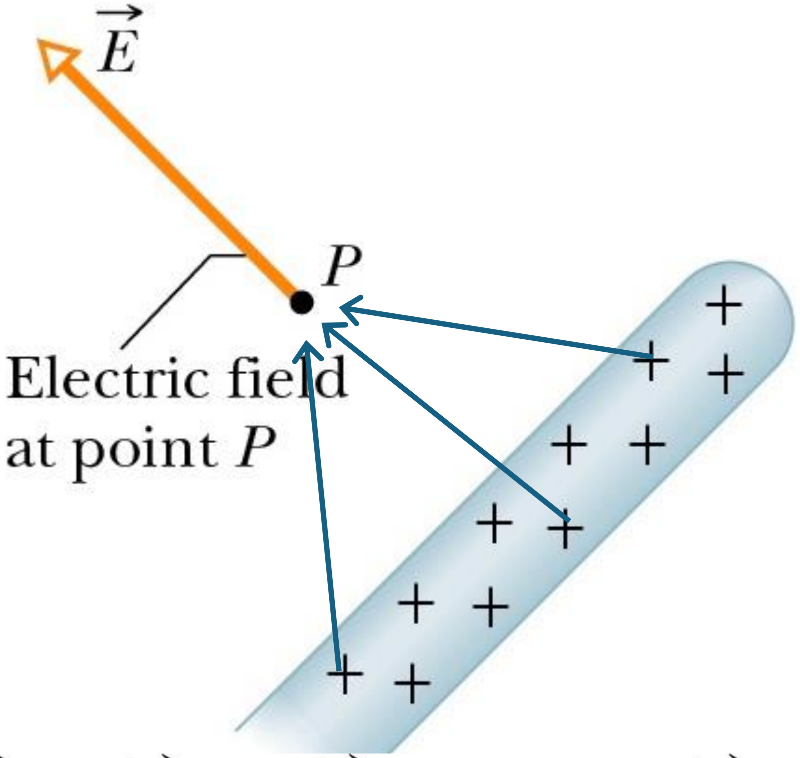



(b)

# Electric field from a system of charges




(a)




$$\vec{E} = \frac{\vec{F}_0}{q_0} = \frac{\vec{F}_{01}}{q_0} + \frac{\vec{F}_{02}}{q_0} + \cdots + \frac{\vec{F}_{0n}}{q_0}$$

$$= \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n.$$

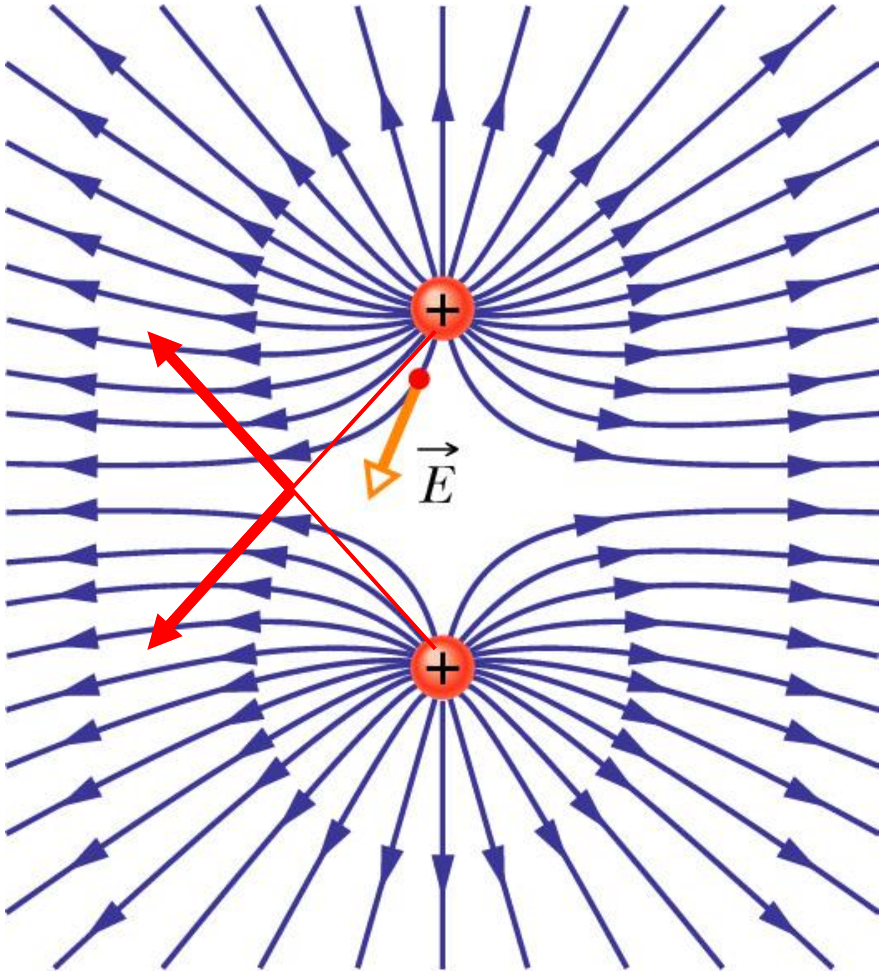
**Net electric field:**

$$\vec{\mathbf{E}} = \Sigma\, \vec{\mathbf{E}}_{\mathbf{i}}$$

**vector** sum over E fields of all charges

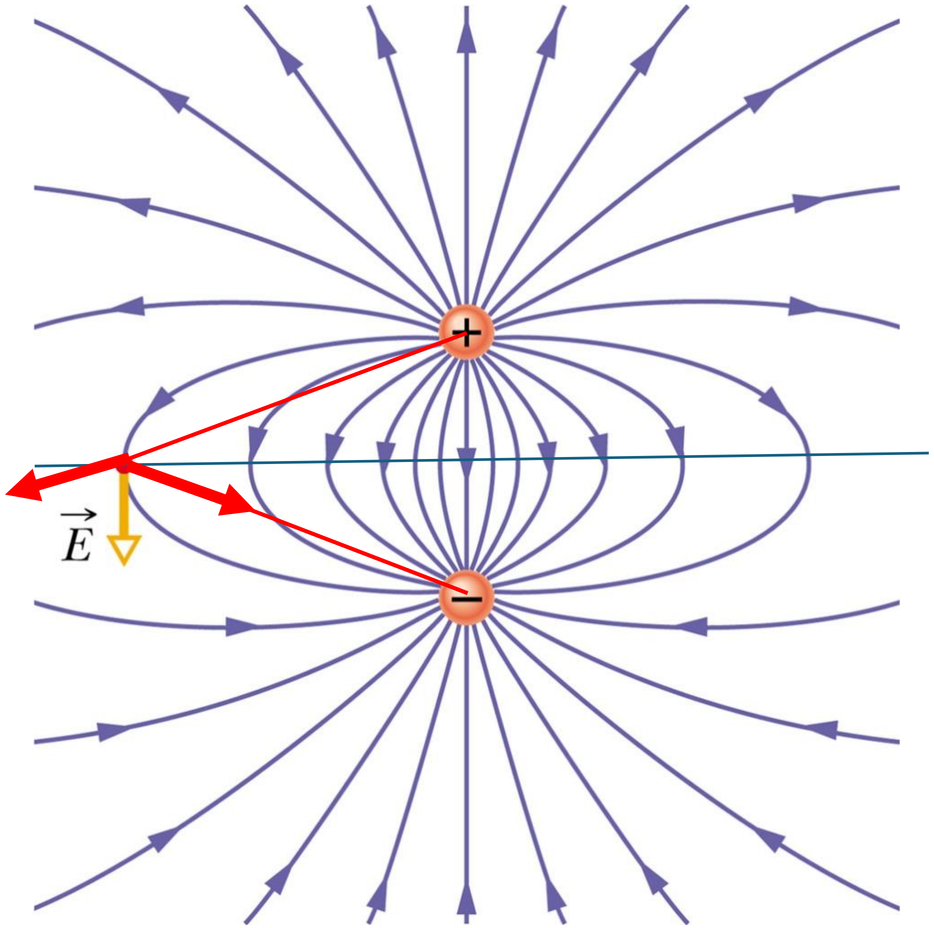
# Field Lines from Two Like Charges

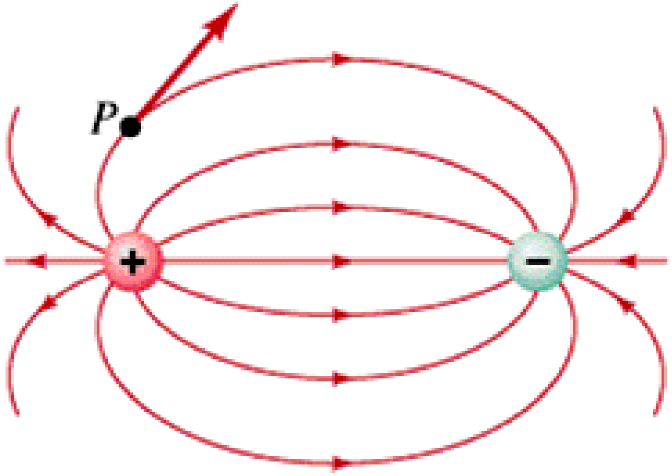
- **Note the field lines**
  - **are zero halfway between the charges**
  - ***r* >> *a* :   looks like the field of a point charge of magnitude +2*q***



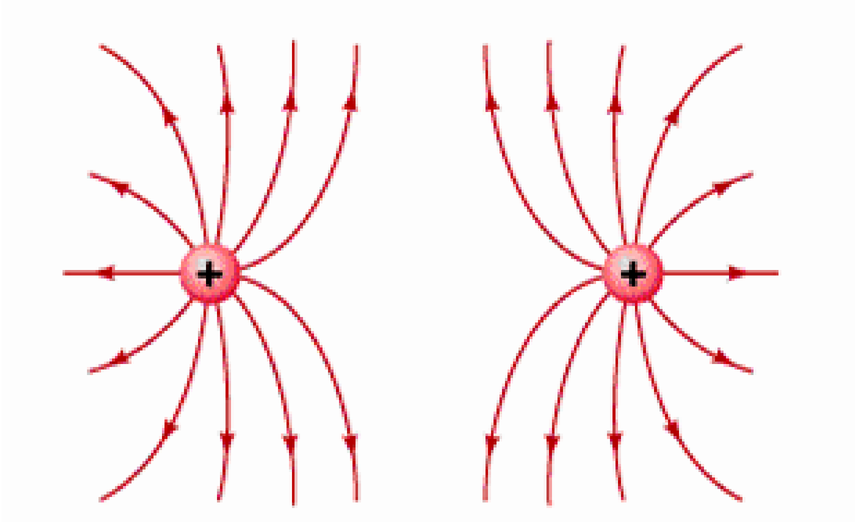
# Field Lines from Two Opposite Charges

- **Note the field lines**
  - **field is vertical in center plane between the charges**
  - ***r >> a:*** **the field of a dipole (more later)**

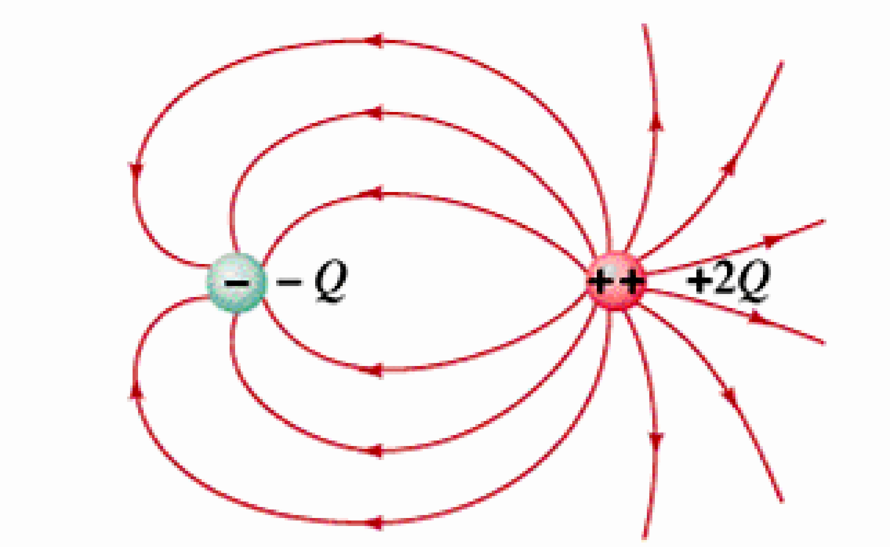





(a)

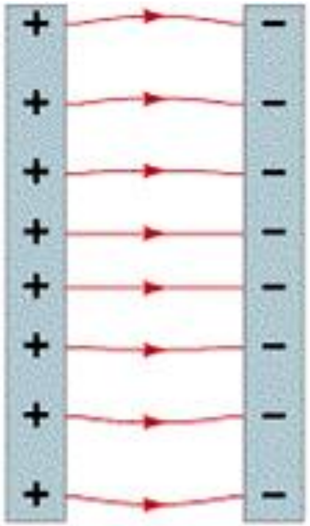



(b)




(c)

**Field lines indicate direction of the FORCE**




(d)