Recap

- **Electrostatic Force**:
  \[ |F_{2\to1}| = |F_{1\to2}| = \frac{1}{4\pi \varepsilon_0} \frac{|q_1| \cdot |q_2|}{r^2} \]
  - obey principle of superposition
  \[ F_{\text{all other } \to 1} = F_{2\to1} + F_{3\to1} + F_{4\to1} + \ldots + F_{n\to1} \]
  for \( n \) charged particles
  - *Shell Theorem*

- **Conductor**: some charges move freely
- **Insulator**: no charges move freely
- **Polarization**: separation of positive and negative charge by nearby charged object
Today:

• E-paper
• Electric Fields
• Electrolocation
A plastic balloon is charged negatively and then hold to a non-conducting wall. When released, the balloon will...

A. Drop  
B. Stick to the wall  
C. Can’t be sure
Polarization by Induction of an Insulator

- Negatively charged PVC rod
- Neutral styrofoam chips
- Positively charged glass rod

\[ \Rightarrow \text{Molecule polarize and align} \]
\[ \Rightarrow \text{since } F_{\text{el}} \propto \frac{1}{r^2} \Rightarrow \text{attractive net force on styrofoam} \]
Electronic Paper

- Paper consists of a sheet of very small transparent capsules, each about 40 micrometers across.
- Each capsule contains an oily solution containing black dye (the electronic ink), with numerous white titanium dioxide particles suspended within.
- The white particles are slightly negatively charged.
- Applying a negative charge to the surface electrode repels the particles to the bottom of local capsules, forcing the black dye to the surface and giving the pixel a black appearance.
- Reversing the voltage has the opposite effect - the particles are forced to the surface, giving the pixel a white appearance.
Electric Fields

Consider a small point charge $q_\text{t}$ ("test charge") at some point $P$ in the vicinity of other charges.

Define Electric Field $\vec{E}$

$$\vec{E}_P \text{ by } Q \equiv \frac{\vec{F}_{\text{on test charge } q_\text{t}}}{q_\text{t}} = \text{electric force per unit charge}$$

"The other charge, $Q$ exert a force on a test charge $q_\text{t}$ through their electric field."

Units: $[E] = \text{N/C} = \text{V/m}$
A very small stationary negative test charge \( q_t \) \((q_t < 0)\) at a certain location experiences a net electric force in the +x direction. What is the direction of the electric field (not due to \( q_t \)) at \( q_t \)'s location?

- **A.** +x
- **B.** −x
- **C.** Can't tell for sure.
What is the electric field direction at this location if \( q_t \) is removed?

A. \( +x \)
B. \( -x \)
C. Can’t tell for sure.

Electric field caused by other charges, not by the test charge:

\[ E \text{ does not change if } q_t \text{ is removed} \]
Note:

1. Electric field is a vector field: has magnitude and direction.
2. Usually changes with position: \( \vec{E} = \vec{E}(r) \).
3. Can be detected by force that it exerts on a test charge: \( \vec{F} = q_{\text{test}} \vec{E} \Rightarrow \) can probe/ map out electric field by given charge distribution by placing test charge at various points.
4. "Test charge" does not disturb the original charge distribution causing the electric field we are probing.
5. Electric force \( \vec{F} \) caused by field \( \vec{E} \) can be parallel or anti-parallel to field \( \vec{E} \), depending on sign of test charge \( q_{\text{test}} \):
   - \( q_{\text{test}} > 0 \)
   - \( q_{\text{test}} < 0 \)
Electric field due to a point charge $Q$

What is the electric field $\vec{E}$ at point $P$?

$\Rightarrow$ place a test charge $q_\text{test}$ at point $P$

$\Rightarrow$ from Coulomb's Law:

$$|\vec{E}_{Q\to q_\text{test}}| = \frac{1}{4\pi \varepsilon_0} \frac{|Q| \cdot |q_\text{test}|}{r^2} = |\vec{E}_Q| \cdot |q_\text{test}|$$

$\Rightarrow$ Electric field strength of point charge $Q$ at point $P$

$$|\vec{E}| = \frac{|\vec{E}_{Q\to q_\text{test}}|}{|q_\text{test}|} = \frac{1}{4\pi \varepsilon_0} \frac{|Q|}{r^2} \propto \frac{1}{r^2}$$

Note: does not depend on $q_\text{test}$.
Direction of field $\mathbf{E}$ of point charge $Q$:

- If $Q > 0$: radially outward
- If $Q < 0$: radially inward

In unit vector notation:

$$\mathbf{E} = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2} \mathbf{\hat{r}}$$

with $\mathbf{\hat{r}} = $ unit vector, that points radially away from the point charge, with magnitude $1|\mathbf{\hat{r}}| = 1$

Electric field "map" of point charge:

$$|\mathbf{E}| \propto \frac{1}{r^2}$$
Electric fields obey the principle of superposition:

Net force from \( n \) point charge acting on a test charge \( q_0 \):

\[
\vec{F}_{\text{net}, \text{test}} = \vec{F}_{1 \to q_0} + \vec{F}_{2 \to q_0} + \cdots + \vec{F}_{n \to q_0}
\]

\[\Rightarrow \]

Net electric field at position of test charge by \( n \) other charges:

\[
\vec{E} = \frac{q_0}{\vec{F}_{\text{net}, \text{test}}}
\]

\[
\vec{E} = \frac{q_0}{q_0} \cdot \frac{q_0}{q_0} \frac{q_0}{q_0} \frac{q_0}{q_0}
\]

\[
= \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n
\]

The electric field at any point \( P \) is the sum of the fields at that point \( P \) by each of the charges separately.
What is the direction of the electric field at point A?

A. \( \rightarrow \)
B. \( \leftarrow \)
C. \( \uparrow \)
D. \( \downarrow \)
E. None of the above
What is the direction of the electric field at point B?

A. →
B. ←
C. ↑
D. ↓
E. None of the above
Electrolocation:

- In **active electrolocation**, the animal senses its surrounding environment by generating electric fields and detecting distortions in these fields using electoreceptor organs.

- This is important in ecological niches where the animal cannot depend on vision: for example in caves, in murky water and at night.

- Examples: electric eel, ...
• In **passive electrolocation**, the animal senses the weak bioelectric fields generated by other animals and uses it to locate them.

• These electric fields are generated by all animals due to the activity of their nerves and muscles. A second source of electric fields in fish is the ion pumps associated with osmoregulation at the gill membrane.

• Examples: shark (can detect 0.5 μV/m!), platypus, Guiana dolphin…

Electroreceptors in the head of a shark.