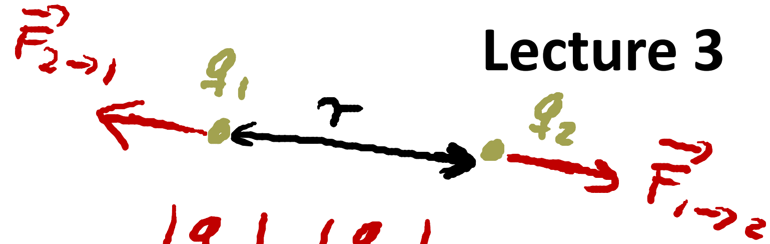
Recap

Lecture 3



- **Electrostatic Force:**

$$|F_{2\to1}| = |F_{1\to2}| = \underbrace{\frac{1}{4\pi\varepsilon_0}}_{=k} \frac{|q_1|\cdot|q_2|}{r^2}$$

  - obeys principle of superposition

$$\vec{F}_{\text{all others}\to1} = \vec{F}_{2\to1} + \vec{F}_{3\to1} + \vec{F}_{4\to1} + \ldots + \vec{F}_{n\to1}$$

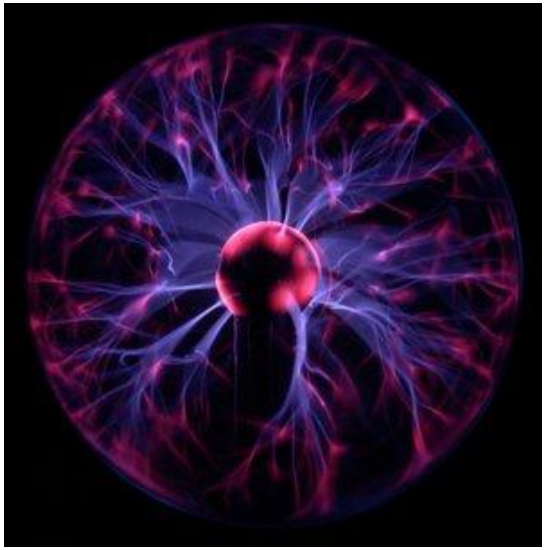
    for n charged particles

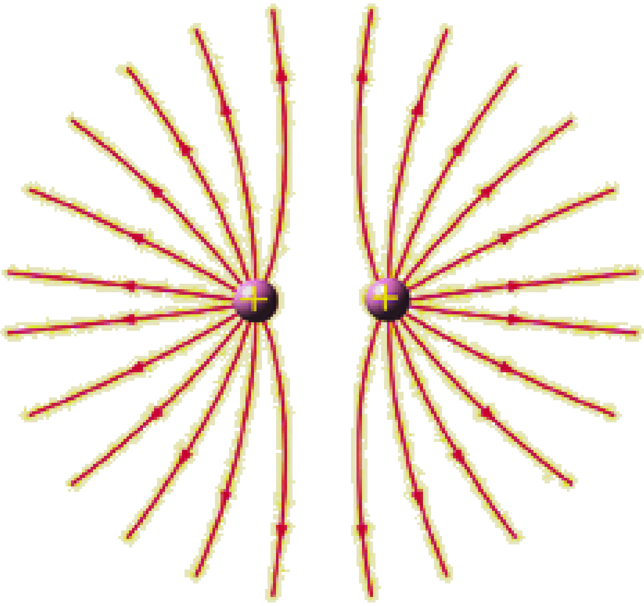
  - Shell Theorem:

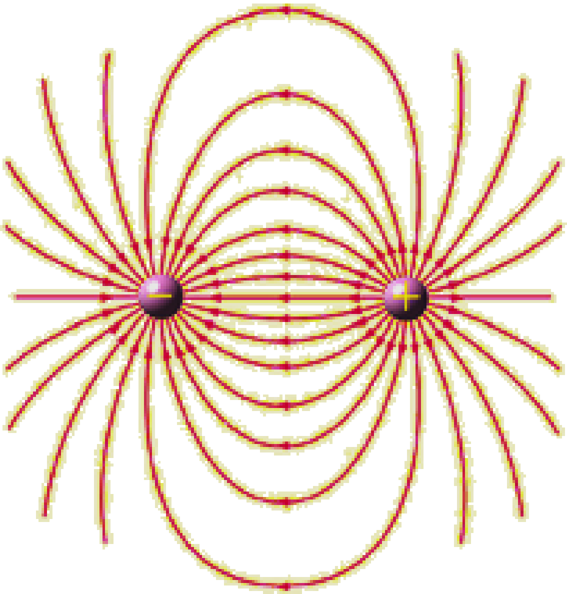
- **Conductors:** some charges move freely
- **Insulators:** no charges move freely
- **Polarization:** separation of positive and negative charges by nearby charged object

Today:

- E-paper
- Electric Fields
- Electrolocation

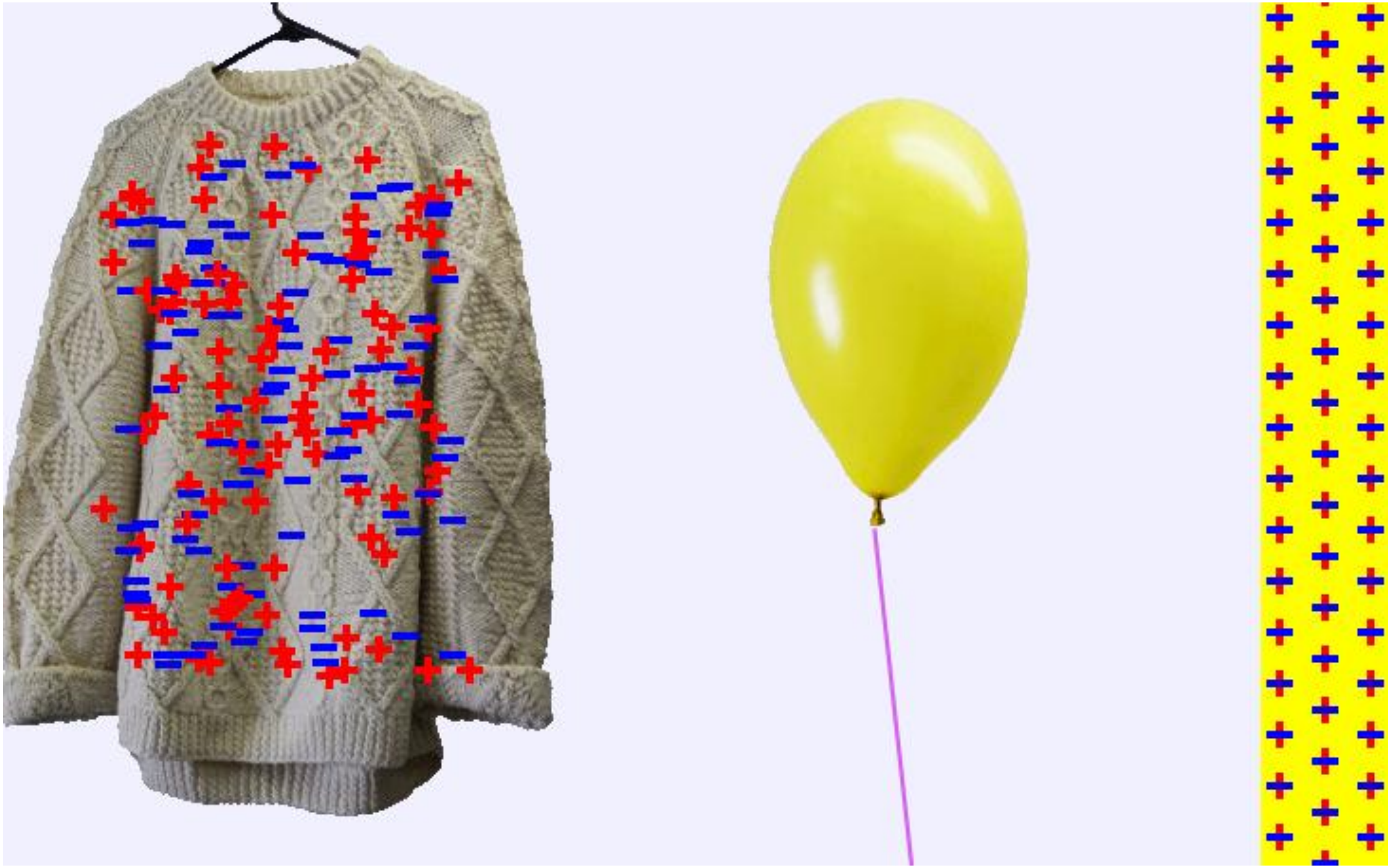


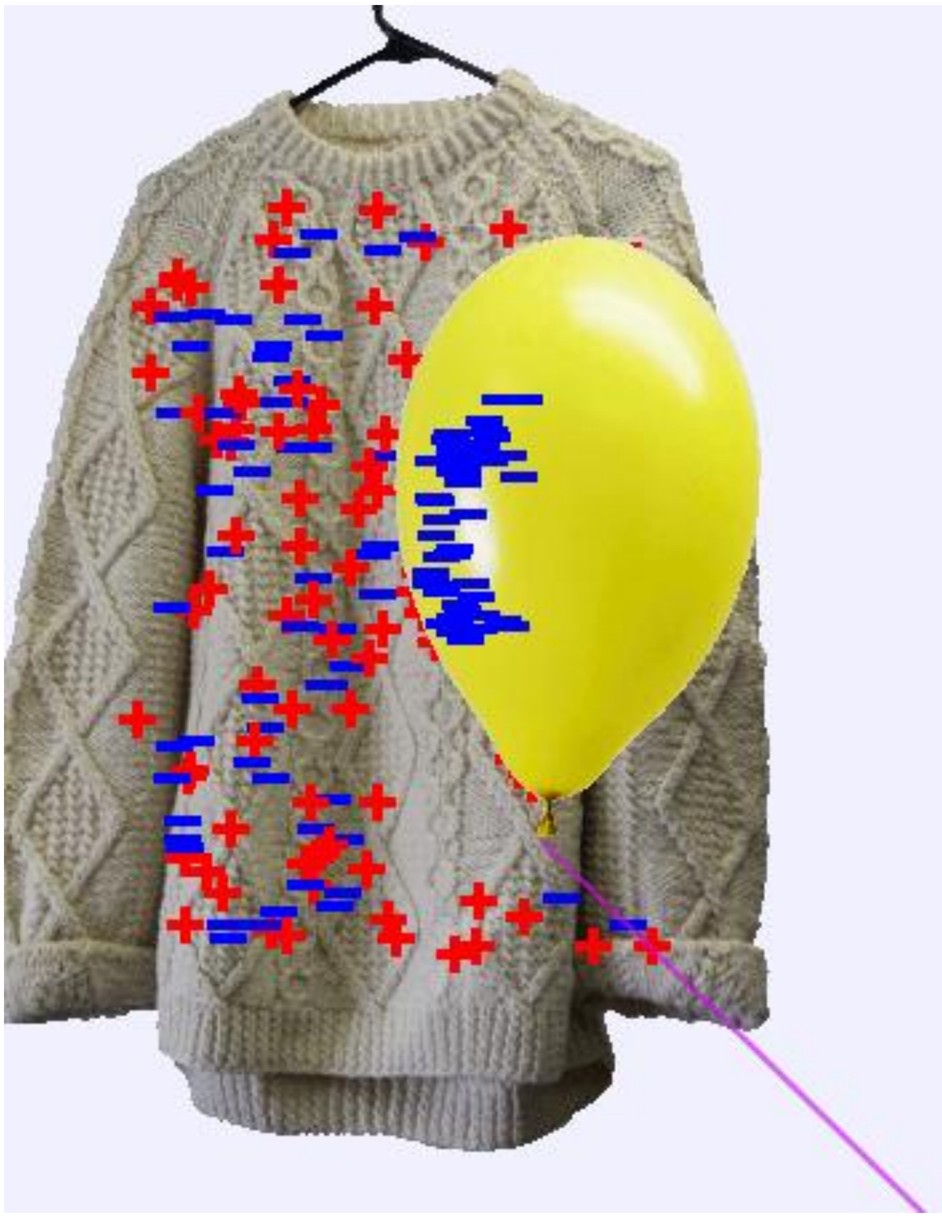


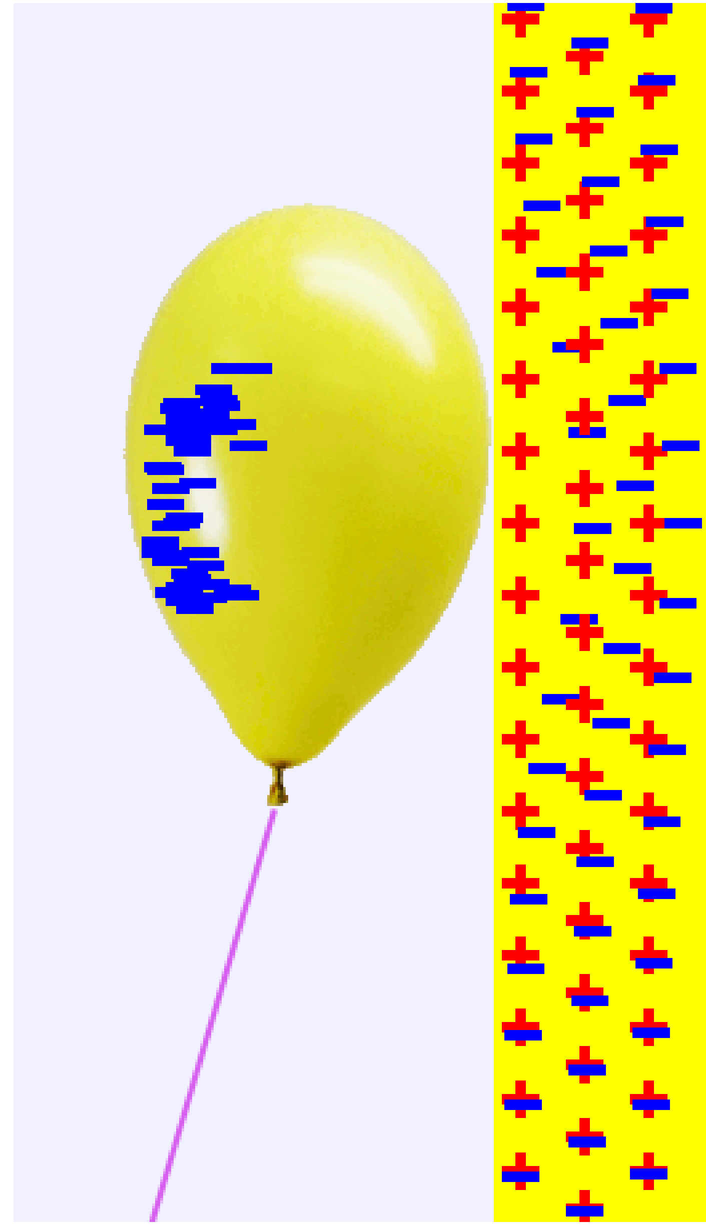


A plastic balloon is charged **negatively** and then hold to a non-conducting wall. When released, the balloon will…

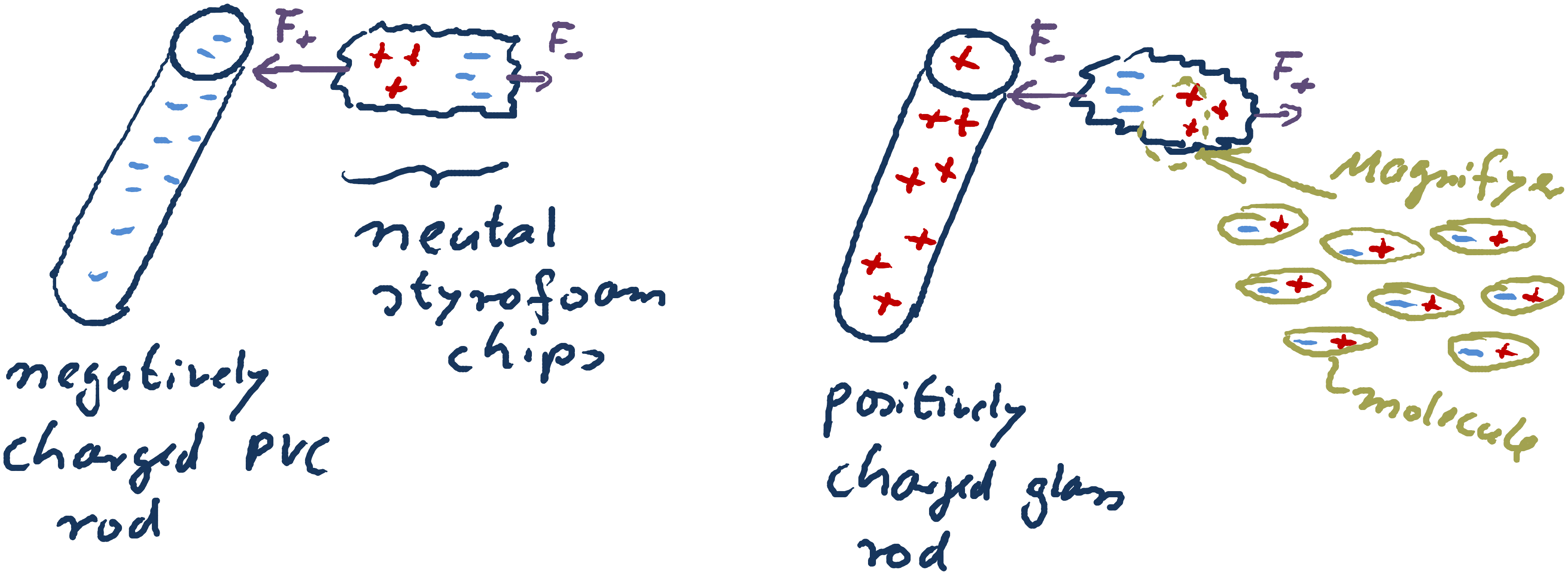
A. Drop
B. Stick to the wall
C. Can't be sure







Polarization by Induction of an Insulator

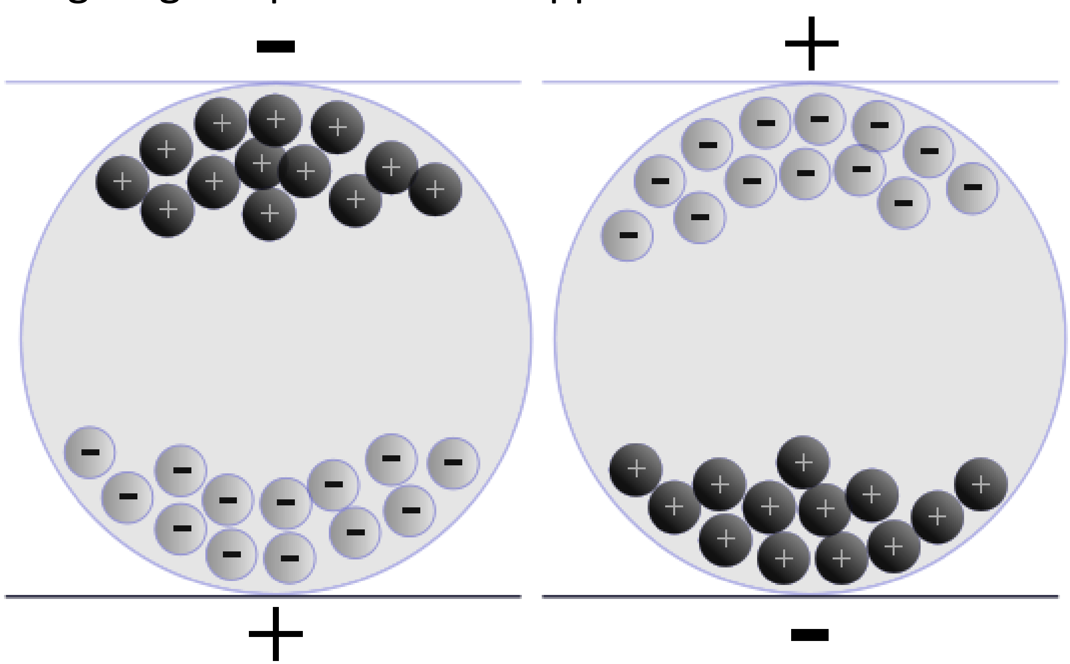


$\Rightarrow$ Molecules polarize and align

$\Rightarrow$ since $F_{el} \propto \frac{1}{r^2}$ $\Rightarrow$ attractive <u>net</u> force on styrofoam

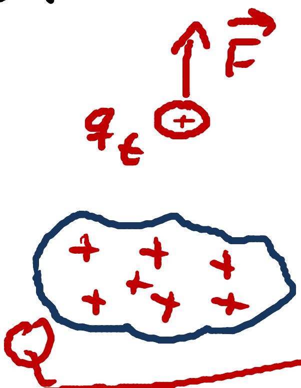
Electronic Paper

- 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.

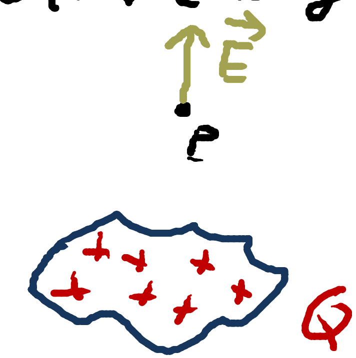


Electric Fields

Consider a small point charge q_t ("test charge") at some point P in the vicinity of other charges:



Define Electric Field $\vec{E}$ ⟺

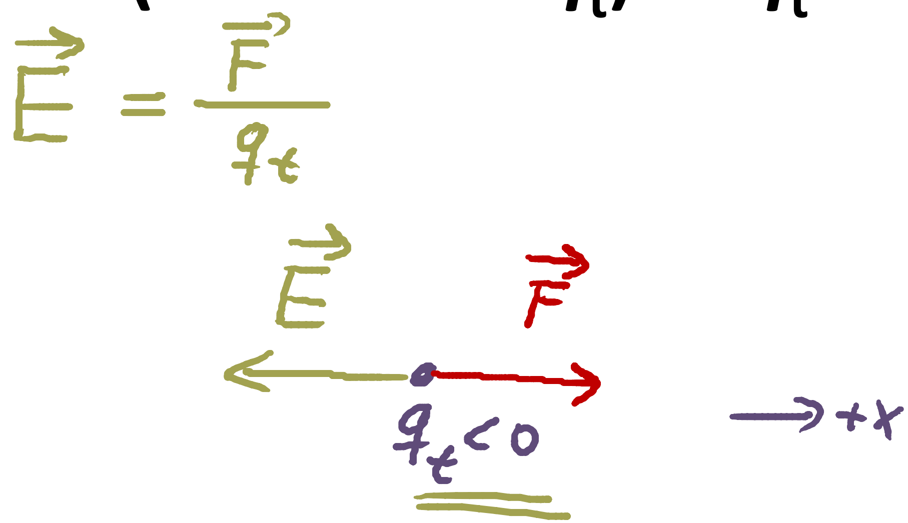


$$\vec{E}_{P \text{ by } Q} \equiv \frac{\vec{F}_{\text{on test charge } q_t}}{q_t} = \text{electric force per unit charge}$$

"The other charges Q exert a force on a test charge q_t through their electric field"

Units: $[E] = N/C \; (= V/m)$

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*

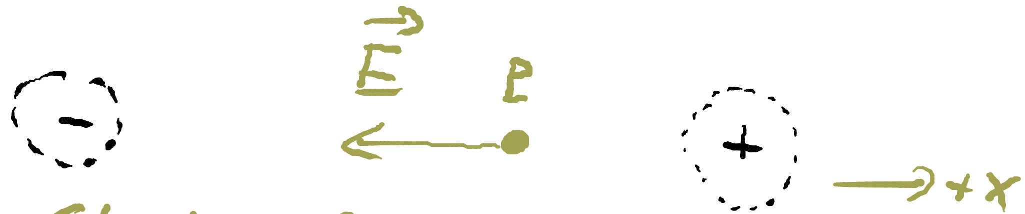
C. Can't tell for sure.

What is the electric field direction at this location if q_t is removed?

A. $+x$

B. $-x$

C. Can’t tell for sure.



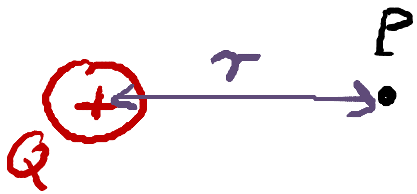
Electric field caused by other charges, not by the test charge!

⇒ Does not change if q_t is removed

Note:

1. Electric field is a vector field: has magnitude and direction
2. Usually changes with position: $\vec{E} = \vec{E}(\vec{r})$
3. Can be detected by force that it exerts on a test charge: $\vec{F} = q_{test}\,\vec{E}$ $\Rightarrow$ 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 antiparallel to field $\vec{E}$, depending on sign of test charge q_t

⑥ Electric field due to a point charge Q



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

⇒ place a test charge q_t at point P

⇒ from Coulomb's Law:

$$|\vec{F}_{Q \to q_t}| = \frac{1}{4\pi\varepsilon_0} \frac{|Q| \cdot |q_t|}{r^2} \overset{!}{=} |\vec{E}_Q| \cdot |q_t|$$

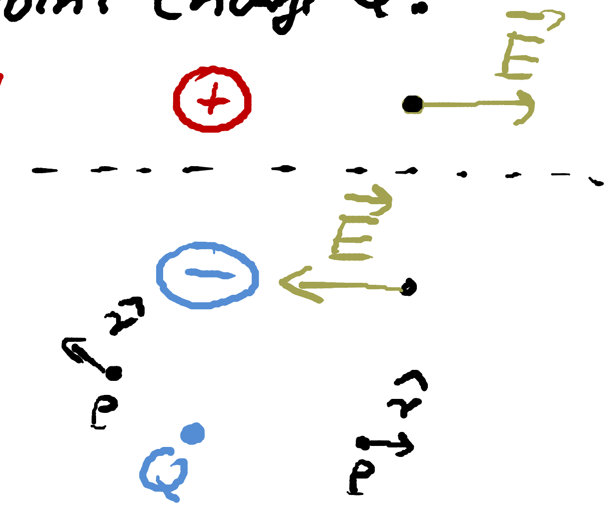
⇒ Electric field strength of point charge Q at point P

$$\boxed{|\vec{E}| = \frac{|\vec{F}|}{|q_t|} = \frac{1}{4\pi\varepsilon_0} \frac{|Q|}{r^2}} \propto \frac{1}{r^2}$$

Note: does <u>not</u> depend on q_t!

⇒ Direction of field $\vec{E}$ of point charge Q?

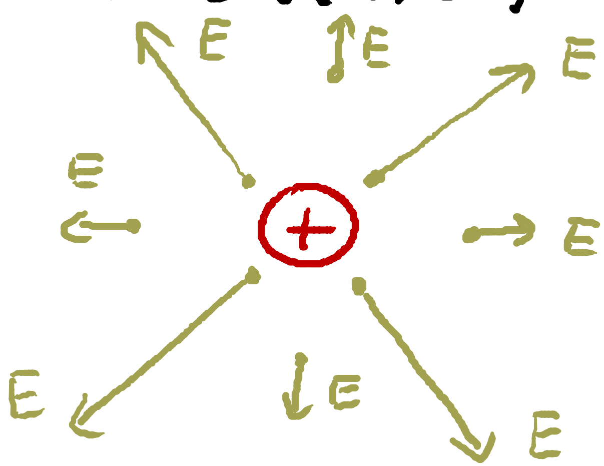
- If $Q > 0$: radially outward
- If $Q < 0$: radially inward
- In unit vector notation:



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

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

⇒ Electric field "map" of point charge:



$$|\vec{E}| \propto \frac{1}{r^2}$$

⑦ Electric fields obey the principle of superposition:

net force from n point charge acting on a test charge q_t:

$$\vec{F}_{t,net} = \vec{F}_{1\to t} + \vec{F}_{2\to t} + \dots + \vec{F}_{n\to t}$$

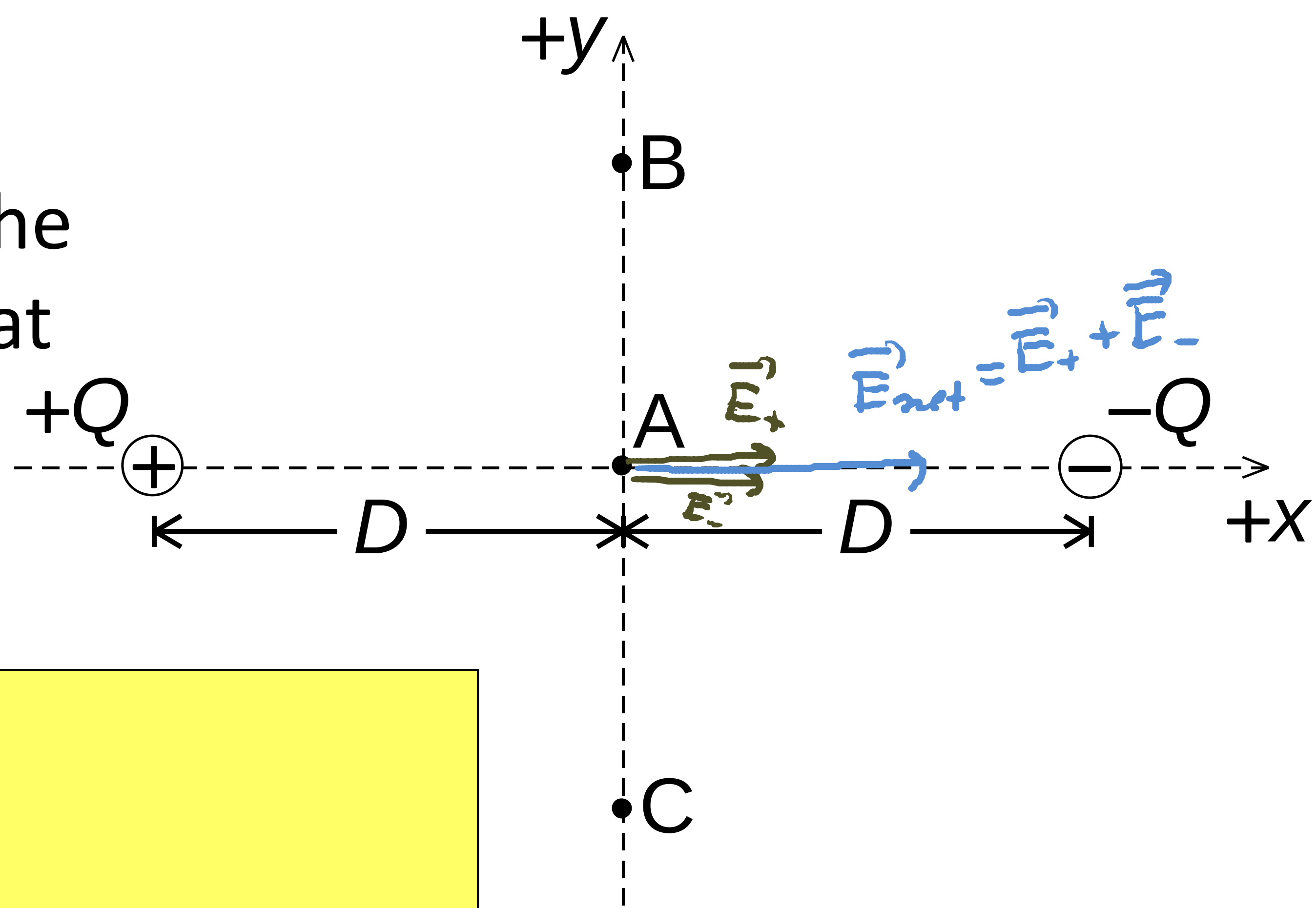
⇒ net electric field at position of test charge by n other charges:

$$\vec{E} = \frac{\vec{F}_{t,net}}{q_t} = \frac{\vec{F}_{1\to t}}{q_t} + \frac{\vec{F}_{2\to t}}{q_t} + \dots \frac{\vec{F}_{n\to t}}{q_t} = \vec{E}_1 + \vec{E}_2 + \dots + \vec{E}_n$$

$\vec{E}_1$: electric field by charge #1 at position of test charge

The electric field at any point P is the vector 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. →

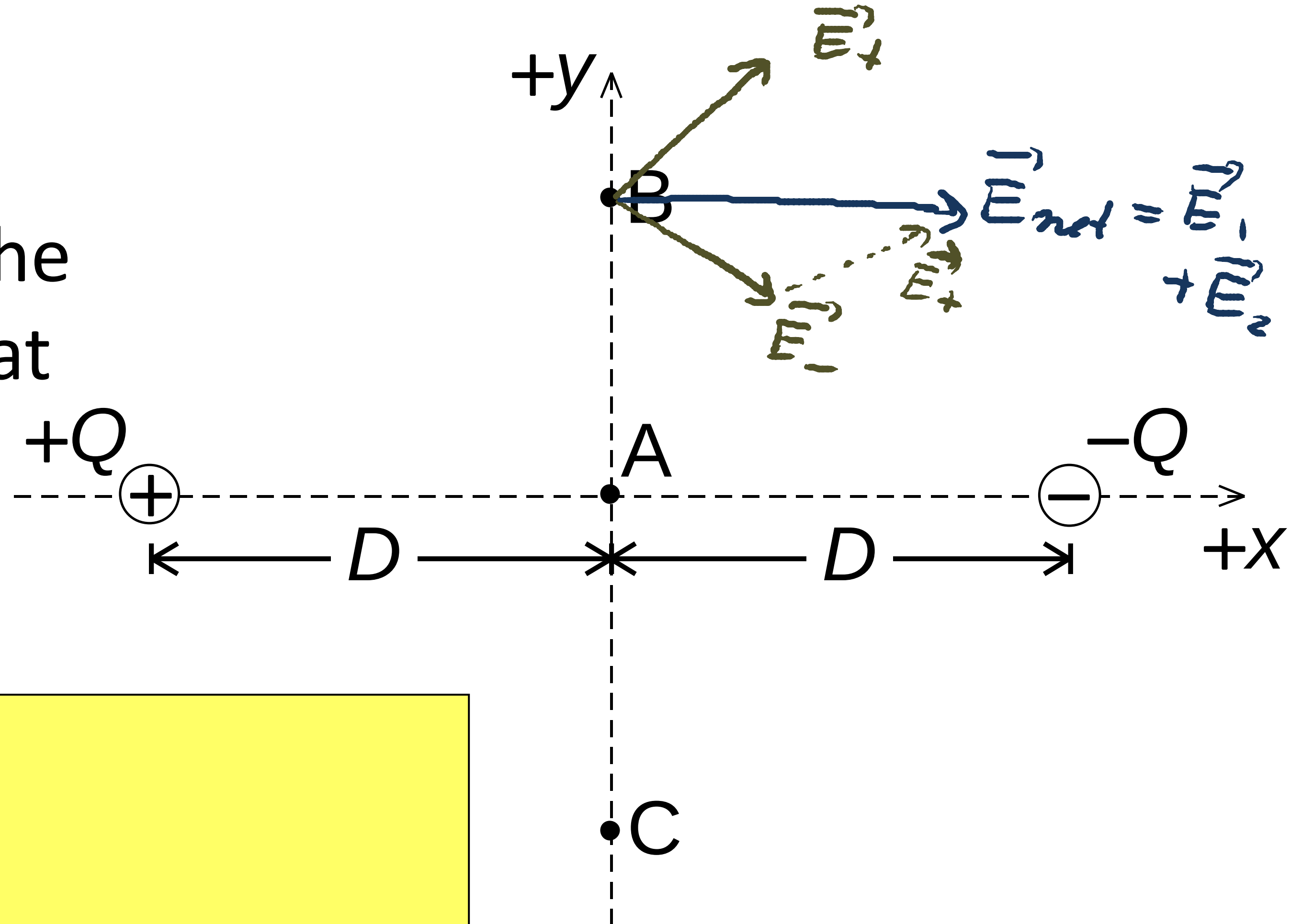
B. ←

C. ↑

D. ↓

E. None of the above

What is the direction of the electric field at **point B**?



A. →

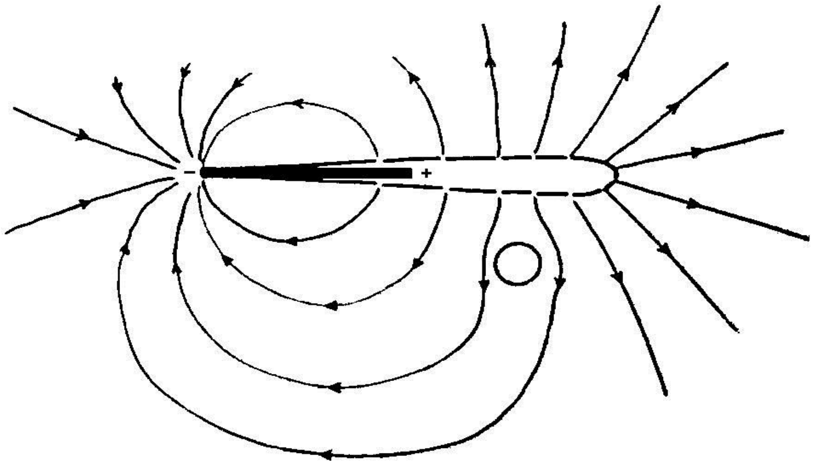
B. ←

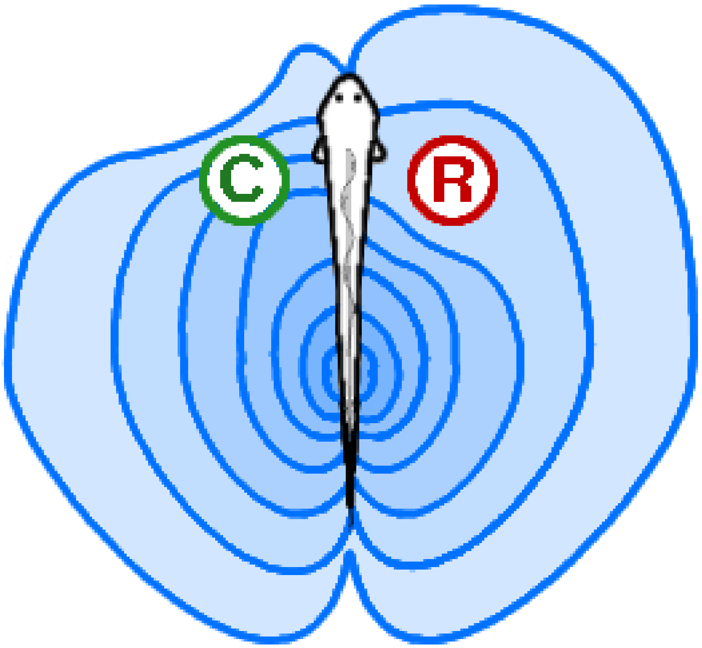
C. ↑

D. ↓

E. None of the above

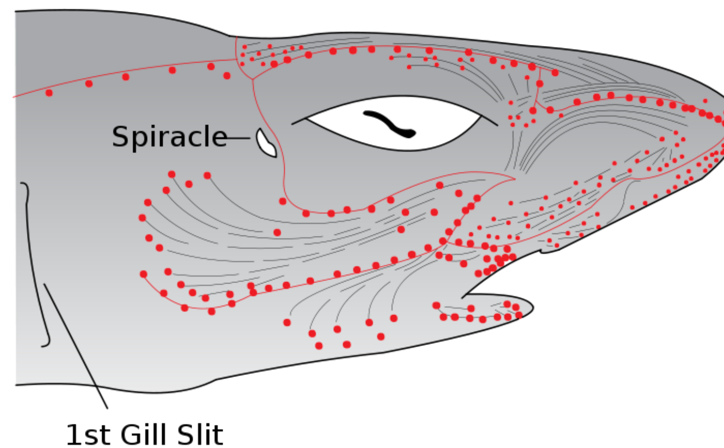
Electrolocation:





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