
Electric Fields and Forces

AP Physics B

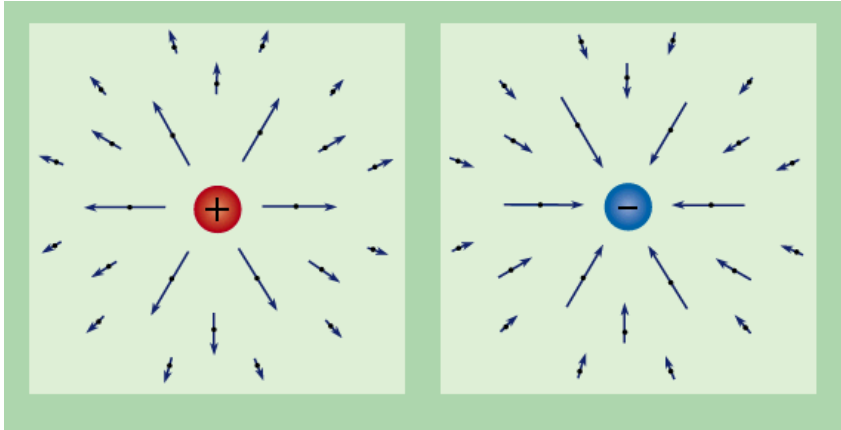
Electric Charge

“Charge” is a property of subatomic particles.

Facts about charge:

- There are 2 types basically, positive (protons) and negative (electrons)
 - LIKE charges REPEL and OPPOSITE charges ATTRACT
 - Charges are symbolic of fluids in that they can be in 2 states, STATIC or DYNAMIC.
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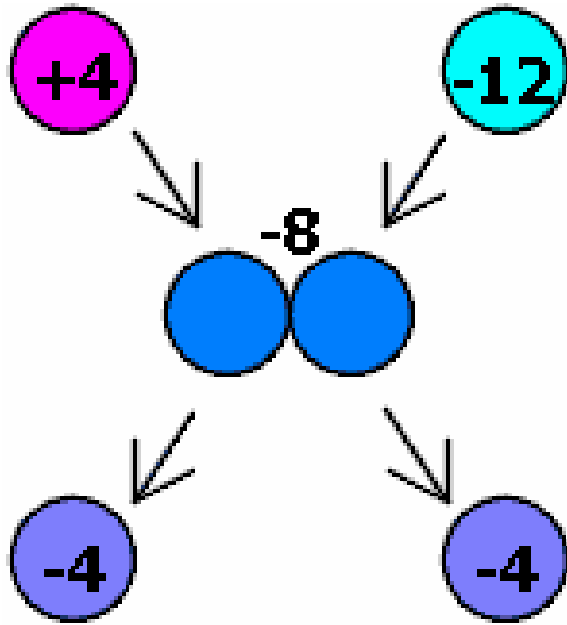
Electric Charge – The specifics



- The symbol for CHARGE is “q”
- The unit is the COULOMB(C), named after Charles Coulomb
- If we are talking about a SINGLE charged particle such as 1 electron or 1 proton we are referring to an ELEMENTARY charge and often use, e , to symbolize this.

Particle	Charge	Mass
Proton	1.6×10^{-19} C	1.67×10^{-27} kg
Electron	1.6×10^{-19} C	9.11×10^{-31} kg
Neutron	0	1.67×10^{-27} kg

Charge is “CONSERVED”



Charge cannot be created or destroyed only transferred from one object to another. Even though these 2 charges attract initially, they repel after touching. Notice the NET charge stays the same.

Conductors and Insulators

The movement of charge is limited by the substance the charge is trying to pass through. There are generally 2 types of substances.

Conductors: Allow charge to move readily through it.

Insulators: Restrict the movement of the charge



Conductor = Copper Wire
Insulator = Plastic sheath

Charging and Discharging

There are basically 2 ways you can charge something.

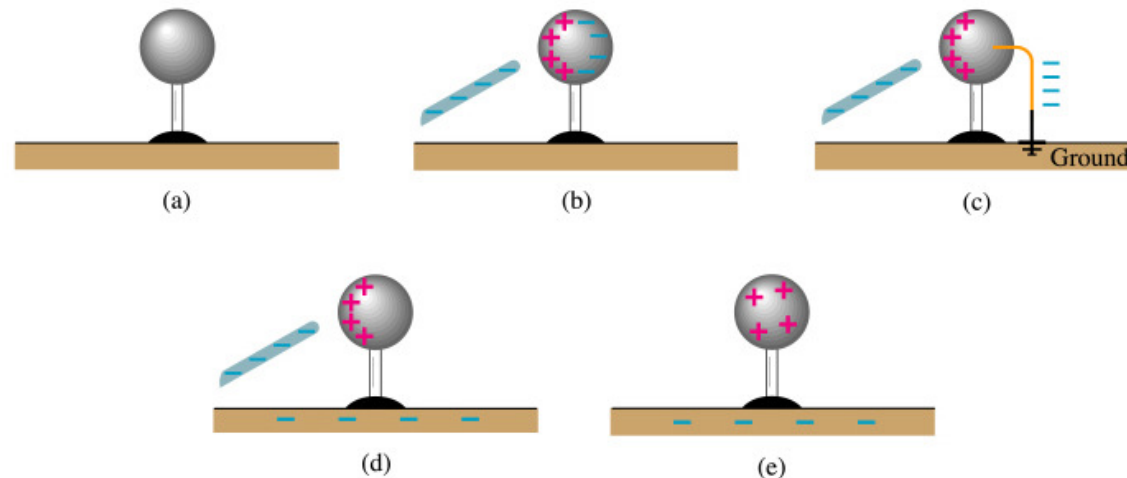
1. **Charge by friction**
2. Induction



“BIONIC is the first-ever ionic formula mascara. The primary ingredient in BIONIC is a chain molecule with a positive charge. The friction caused by sweeping the mascara brush across lashes causes a negative charge. Since opposites attract, the positively charged formula adheres to the negatively charged lashes for a dramatic effect that lasts all day.”

Induction and Grounding

The second way to charge something is via **INDUCTION**, which requires **NO PHYSICAL CONTACT**.



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We bring a negatively charged rod near a neutral sphere. The protons in the sphere localize near the rod, while the electrons are repelled to the other side of the sphere. A wire can then be brought in contact with the negative side and allowed to touch the **GROUND**. The electrons will always move towards a more massive objects to increase separation from other electrons, leaving a **NET** positive sphere behind.

Electric Force

The electric force between 2 objects is symbolic of the gravitational force between 2 objects. RECALL:

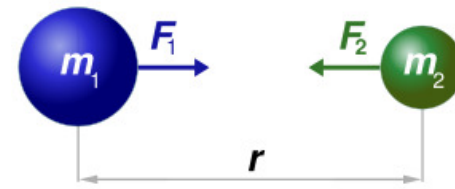
$$F_g \propto Mm \quad F_g \propto \frac{1}{r^2}$$

$$F_E \propto q_1q_2 \quad F_E \propto \frac{1}{r^2} \quad F_E \propto \frac{q_1q_2}{r^2}$$

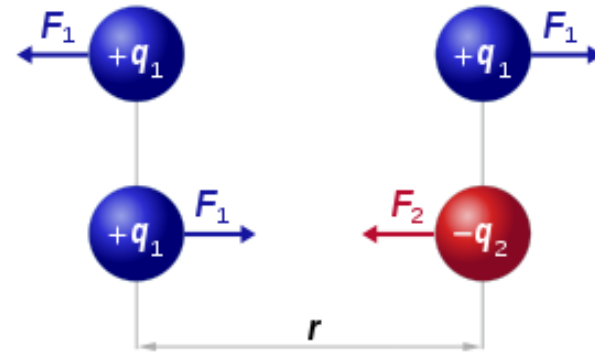
k = constant of proportionality

$$k = \text{Coulomb constant} = 8.99 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}$$

$$F_E = k \left| \frac{q_1q_2}{r^2} \right| \rightarrow \text{Coulomb's Law}$$



$$F_1 = F_2 = G \frac{m_1 \times m_2}{r^2}$$



$$F_1 = F_2 = k_c \frac{q_1 \times q_2}{r^2}$$

Electric Forces and Newton's Laws

Electric Forces and Fields obey Newton's Laws.

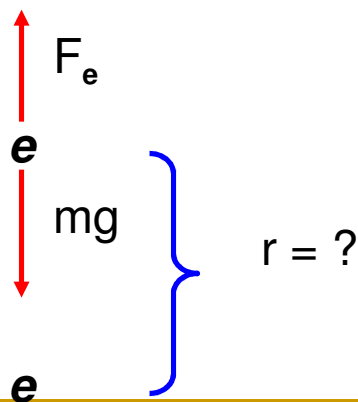
$$F_{Net} = F_e = F_g$$
$$mg = k \frac{qQ}{r^2} = ma$$

Example: An electron is released above the surface of the Earth. A second electron directly below it exerts an **electrostatic force** on the first electron just great enough to cancel out the **gravitational force** on it. How far below the first electron is the second?

$$F_E = mg$$

$$k \frac{q_1 q_2}{r^2} = mg \rightarrow r = \sqrt{k \frac{q_1 q_2}{mg}}$$

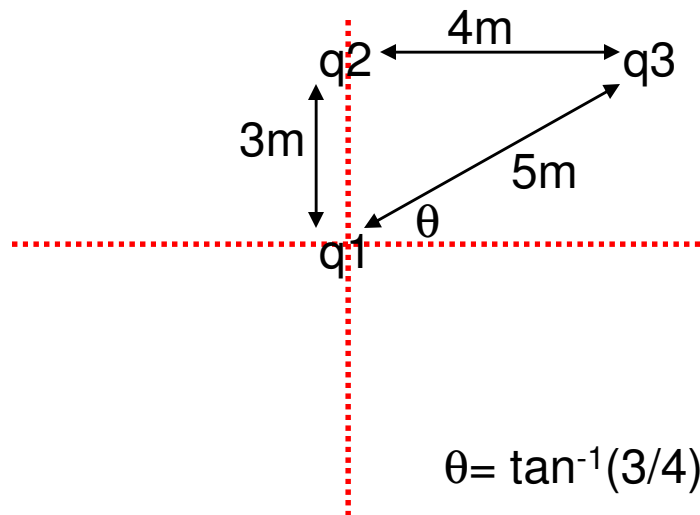
$$\sqrt{(8.99^9) \frac{(1.6 \times 10^{-19})^2}{(9.11 \times 10^{-31})(9.8)}} = 5.1 \text{ m}$$



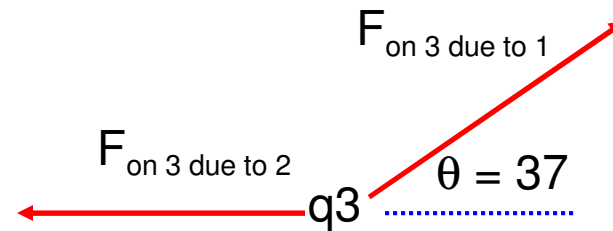
Electric Forces and Vectors

Electric Fields and Forces are ALL vectors, thus all rules applying to vectors must be followed.

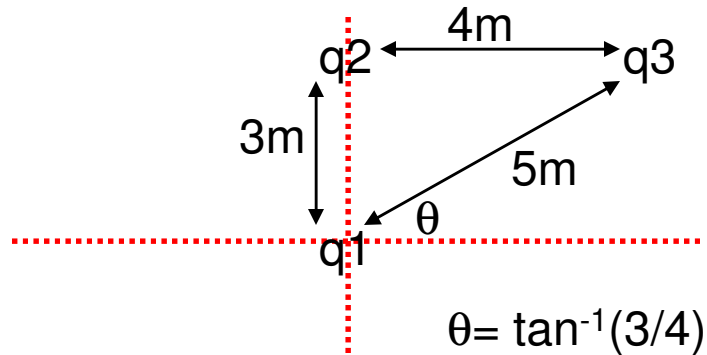
Consider three point charges, $q_1 = 6.00 \times 10^{-9} \text{ C}$ (located at the origin), $q_3 = 5.00 \times 10^{-9} \text{ C}$, and $q_2 = -2.00 \times 10^{-9} \text{ C}$, located at the corners of a RIGHT triangle. q_2 is located at $y = 3 \text{ m}$ while q_3 is located 4 m to the right of q_2 . Find the **resultant** force on q_3 .



Which way does q_2 push q_3 ?
Which way does q_1 push q_3 ?



Example Cont'

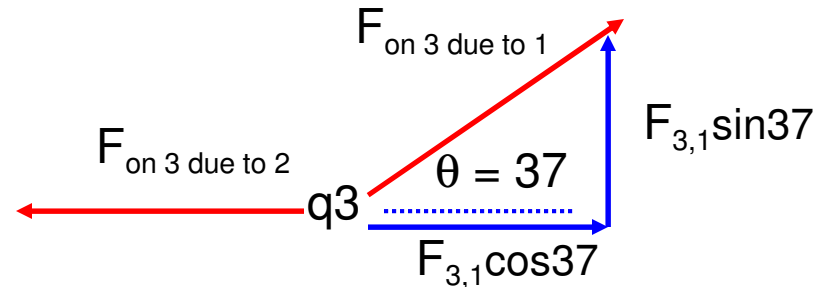


$$F_{3,2} = (8.99 \times 10^9) \frac{(5.0 \times 10^{-9})(2 \times 10^{-9})}{4^2}$$

$$F_{3,2} = \mathbf{5.6 \times 10^{-9} \text{ N}}$$

$$F_{3,1} = (8.99 \times 10^9) \frac{(6 \times 10^{-9})(5 \times 10^{-9})}{5^2}$$

$$F_{3,1} = \mathbf{1.1 \times 10^{-8} \text{ N}}$$



$$\sum F_x = F_{3,1} \cos(37) - F_{3,2}$$

$$\sum F_x = 3.18 \times 10^{-9} \text{ N}$$

$$\sum F_y = F_{3,1} \sin(37) = 6.62 \times 10^{-9} \text{ N}$$

$$F_{\text{resultant}} = \sqrt{(\sum F_x)^2 + (\sum F_y)^2}$$

$$F_{\text{res}} = \mathbf{7.34 \times 10^{-9} \text{ N}}$$

$$\text{Direction} = \theta = \tan^{-1}\left(\frac{\sum F_y}{\sum F_x}\right) =$$

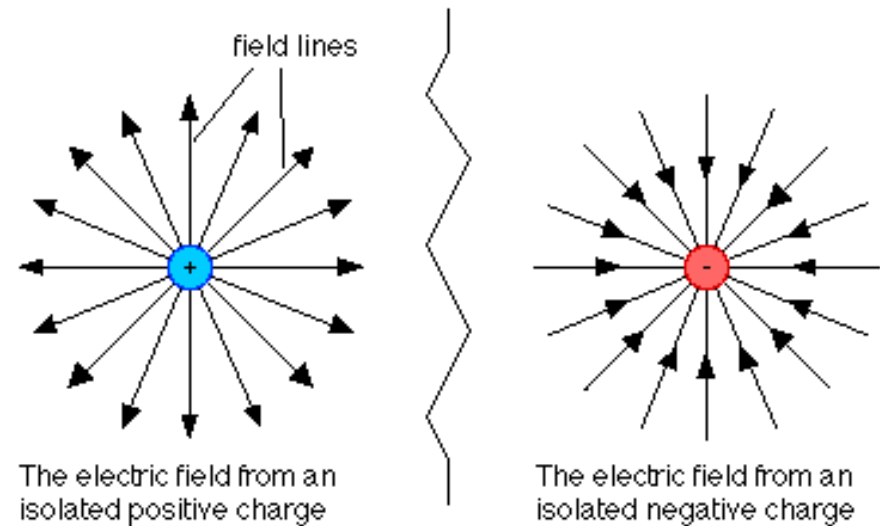
64.3 degrees above the +x

Electric Fields

By definition, they are
“LINES OF FORCE”

Some important facts:

- An electric field is a vector
- Always is in the direction that a POSITIVE “test” charge would move
- The amount of force PER “test” charge



If you placed a 2nd positive charge (test charge), near the positive charge shown above, it would move **AWAY**.

If you placed that same charge near the negative charge shown above it would move **TOWARDS**.

Electric Fields and Newton's Laws

$$F_g = G \frac{mM}{r^2}, F_e = k \frac{qQ}{r^2}$$

$$\frac{F_g}{m} = g, \quad \frac{F_e}{q} = E$$

Once again, the equation for **ELECTRIC FIELD** is symbolic of the equation for **WEIGHT** just like coulomb's law is symbolic of Newton's Law of Gravitation.

The symbol for Electric Field is, "E". And since it is defined as a force per unit charge the unit is Newtons per Coulomb, N/C.

NOTE: the equations above will ONLY help you determine the MAGNITUDE of the field or force. Conceptual understanding will help you determine the direction.

The "q" in the equation is that of a "test charge".

Example

An electron and proton are each placed at rest in an external field of 520 N/C. Calculate the speed of each particle after 48 ns

What do we know
$m_e = 9.11 \times 10^{-31} \text{ kg}$
$m_p = 1.67 \times 10^{-27} \text{ kg}$
$q_{\text{both}} = 1.6 \times 10^{-19} \text{ C}$
$v_o = 0 \text{ m/s}$
$E = 520 \text{ N/C}$
$t = 48 \times 10^{-9} \text{ s}$

$$\vec{E} = \frac{\vec{F}_E}{q} \quad 520 = \frac{\vec{F}_E}{1.6 \times 10^{-19}}$$

$$F_E = \mathbf{8.32 \times 10^{-17} \text{ N}}$$

$$F_{Net} = ma \quad F_E = F_{Net}$$

$$F_E = m_e a \rightarrow (9.11 \times 10^{-31})a = \mathbf{9.13 \times 10^{13} \text{ m/s/s}}$$

$$F_E = m_p a \rightarrow (1.67 \times 10^{-27})a = \mathbf{4.98 \times 10^{10} \text{ m/s/s}}$$

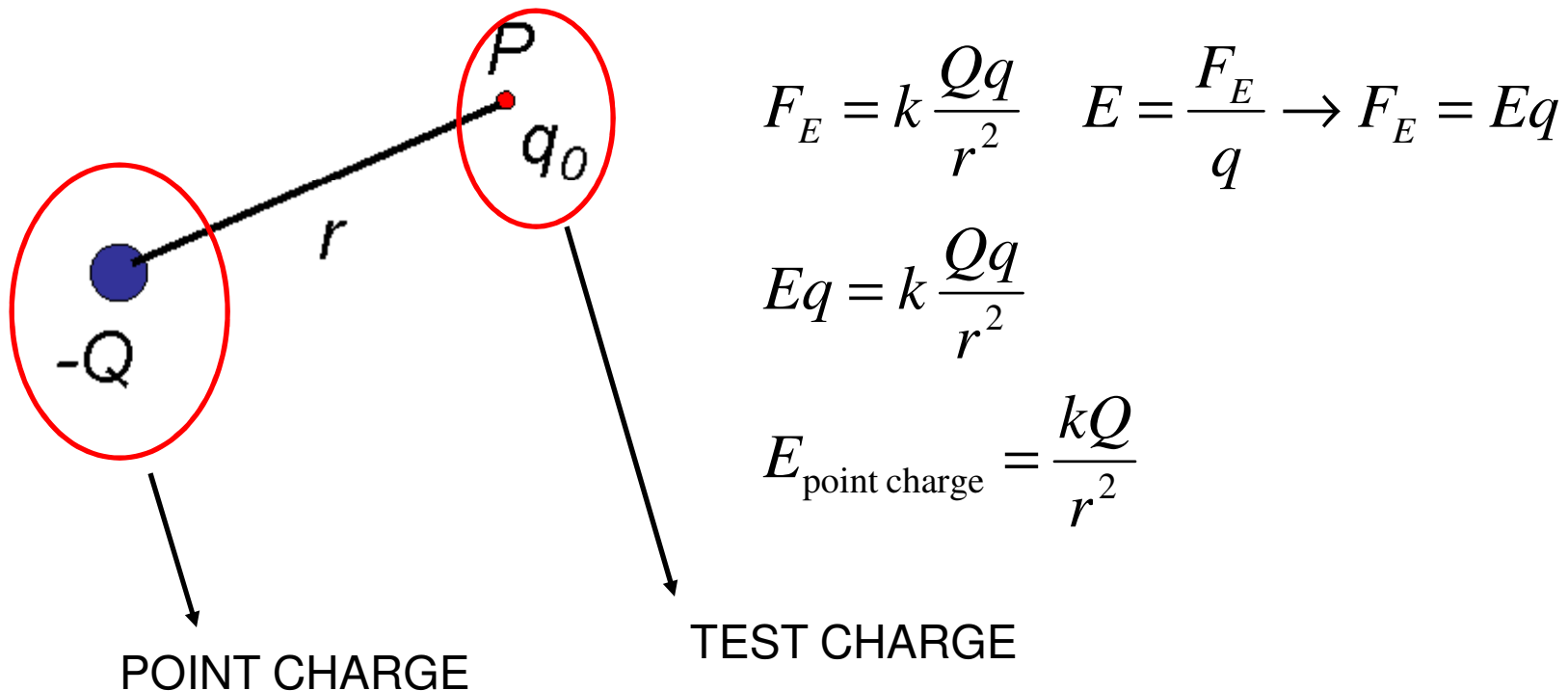
$$v = v_o + at$$

$$v_e = a_e (48 \times 10^{-9}) = \mathbf{4.38 \times 10^6 \text{ m/s}}$$

$$v_p = a_p (48 \times 10^{-9}) = \mathbf{2.39 \times 10^3 \text{ m/s}}$$

An Electric Point Charge

As we have discussed, all charges exert forces on other charges due to a field around them. Suppose we want to know how strong the field is at a specific point in space near this charge the calculate the effects this charge will have on other charges should they be placed at that point.



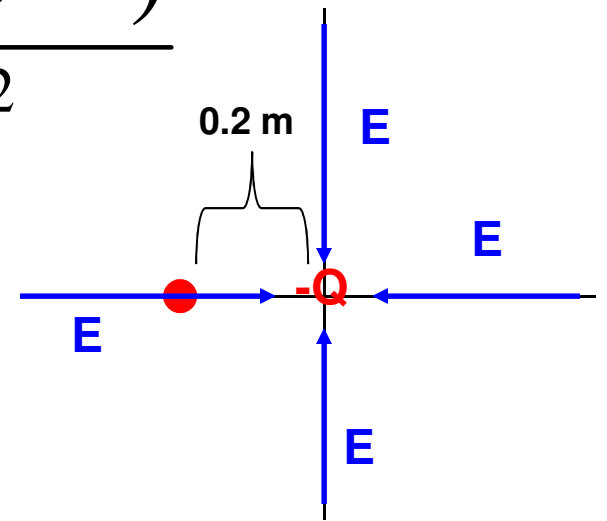
Example

A $-4 \times 10^{-12} \text{C}$ charge Q is placed at the origin. What is the magnitude and direction of the electric field produced by Q if a test charge were placed at $x = -0.2 \text{ m}$?

$$E = \frac{kQ}{r^2} = 8.99 \times 10^9 \frac{(4 \times 10^{-12})}{.2^2}$$

$$E_{mag} = 0.899 \text{ N/C}$$

$$E_{dir} = \text{Towards } Q \text{ to the right}$$

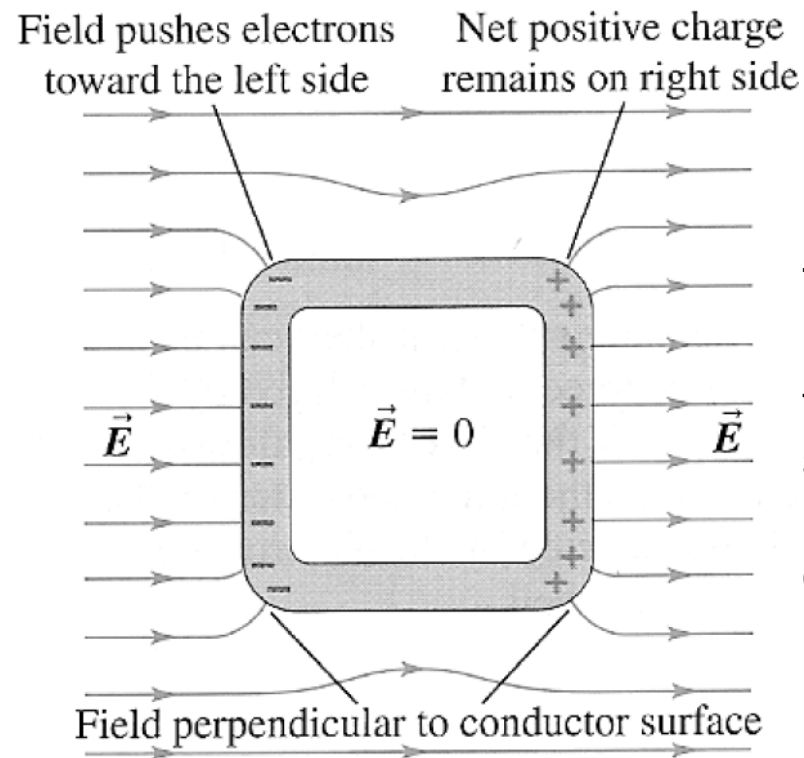


Remember, our equations will only give us MAGNITUDE. And the electric field LEAVES POSITIVE and ENTERS NEGATIVE.

Electric Field of a Conductor

A few more things about electric fields, suppose you bring a conductor NEAR a charged object. The side closest to which ever charge will be INDUCED the opposite charge. However, the charge will ONLY exist on the surface. There will never be an electric field inside a conductor. Insulators, however, can store the charge inside.

There must be a positive charge on this side



There must be a negative charge on this side OR this side was induced positive due to the other side being negative.