Physics 112

Introduction and Chapter 15

Formalities

* My name is Dr. Jared Workman
* Before you leave try and make a friend and get contact info
* What's this course about? Let's go to the webpage

Review

* What I expect you to know
  * Vectors
  * Newton's Laws
  * Algebra
    * I will not be covering every step of every problem

Assistance

* Me
* Friends
    * I encourage you to work together
* Tutoring Center
* Links on my site

One important Caveat

* If you hand in a homework problem with no work done it will be graded a zero

Why do you care?

* This stuff forms the basis for
  * Power
  * Medicine
  * Optics
  * All modern electronics

Let's start with Chapter 15

* We will not cover Gauss's Law or the Van Der Graaff Generator. In general your study guide is essentially what I tell you not to cover

Forces

* You've seen many, normal, gravitational, frictional, tension, bouyant, etc
* There are really only 4
  * Strong
  * Weak
  * Electromagnetic
  * Gravitational

* All phenomenon are manifestations of these four fundamental forces
* Let's start with the electromagnetic force
* The electromagnetic force is 10^{36} times more powerful between two particles than the gravitational force
* Why don't we see it in everyday life?
* Why does so much energy go into generating electricity?

EM force

* There are two types of charges, positive and negative
* Like charges repel and unlike charges repel
  * protons, electron, neutrons
* The SI unit of force is the coulomb and is given by $e = 1.6 \times 10^{-19}$ C
  * Protons = +e, electrons = -e, neutrons=0e
* Charge is a conserved quantity
* Charge is a quantized quantity, it always comes in units of +-ne, where n is an integer

Let's stop for a moment

* How do nuclei stay together?

Demo

* Rub a glass rod with silk
* Electrons are transferred to the silk, leaves an equivalent number of protons on the rod
* There is a force clearly operating here

2 basic types of materials

Conductors

- Conductors are materials in which the electric charges move freely in response to an electric force.
  - Copper, aluminum and silver are good conductors.
  - When a conductor is charged in a small region, the charge readily distributes itself over the entire surface of the material.

Conductors in Electrostatic Equilibrium

- When no net motion of charge occurs within a conductor, the conductor is said to be in **electrostatic equilibrium.**
- An isolated conductor has the following properties:
  - The electric field is zero everywhere inside the conducting material.
  - Any excess charge on an isolated conductor resides entirely on its surface.

Properties, Cont.

- The electric field just outside a charged conductor is perpendicular to the conductor's surface.
- On an irregularly shaped conductor, the charge accumulates at locations where the radius of curvature of the surface is smallest (that is, at sharp points).

Insulators

- Insulators are materials in which electric charges do not move freely.
  - Glass and rubber are examples of insulators.
  - When insulators are charged by rubbing, only the rubbed area becomes charged.
    - There is no tendency for the charge to move into other regions of the material.

Also

Semiconductors

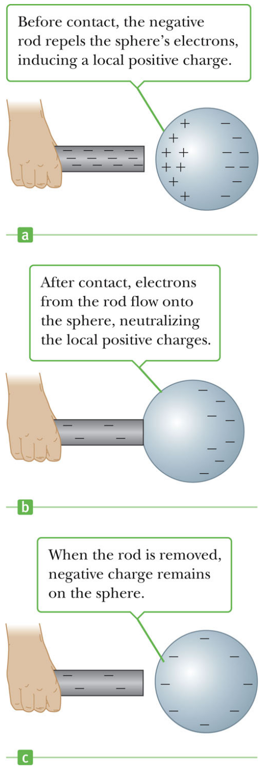
- The characteristics of semiconductors are between those of insulators and conductors.
- Silicon and germanium are examples of semiconductors.

How to impart a net charge to an object

* Conduction - touch
* Induction - no touch

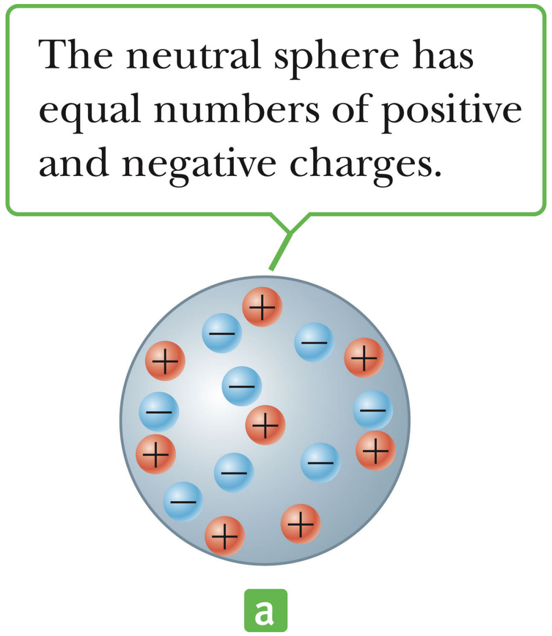
Charging by Conduction

- A charged object (the rod) is placed in contact with another object (the sphere).
- Some electrons on the rod can move to the sphere.
- When the rod is removed, the sphere is left with a net negative charge.
- The object being charged is always left with a charge having the same sign as the object doing the charging.



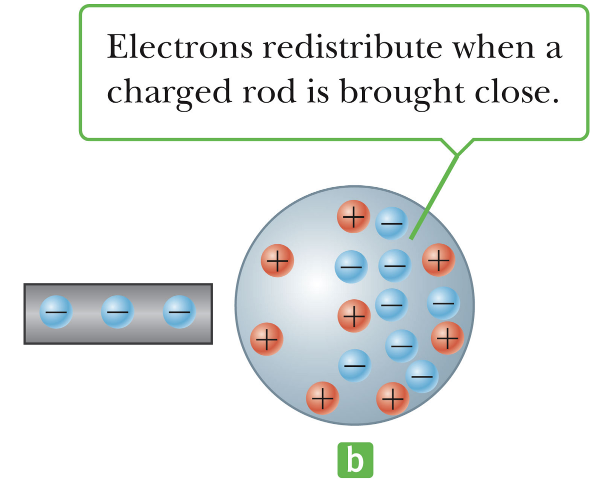
Charging by Induction

- When an object is connected to a conducting wire or pipe buried in the earth, it is said to be grounded.
- A neutral sphere has equal number of electrons and protons.



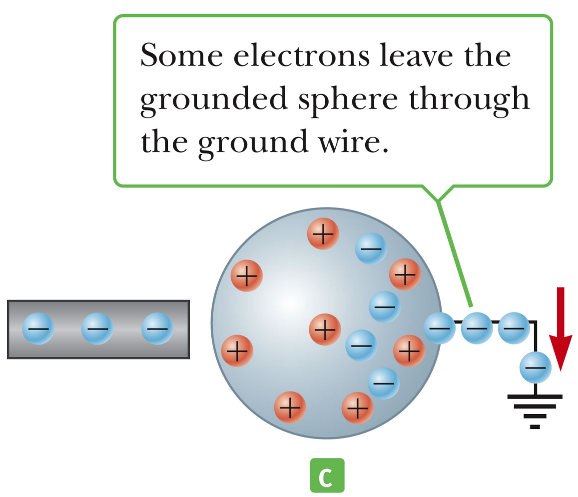
Charging by Induction, 2

- A negatively charged rubber rod is brought near an uncharged sphere.
- The charges in the sphere are redistributed.
  - Some of the electrons in the sphere are repelled from the electrons in the rod.



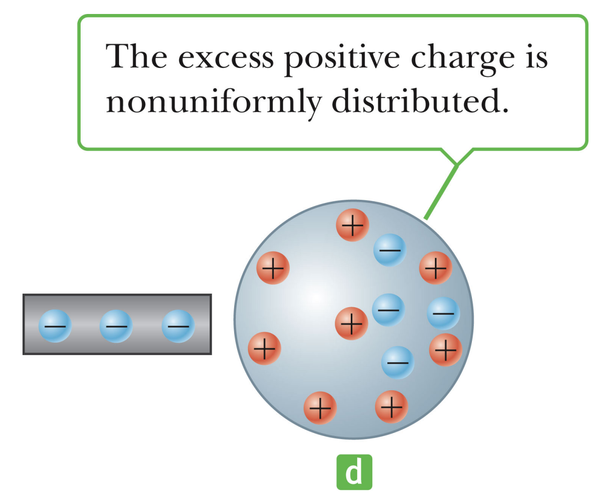
Charging by Induction, 3

- The region of the sphere nearest the negatively charged rod has an excess of positive charge because of the migration of electrons away from this location.
- A grounded conducting wire is connected to the sphere.
  - Allows some of the electrons to move from the sphere to the ground



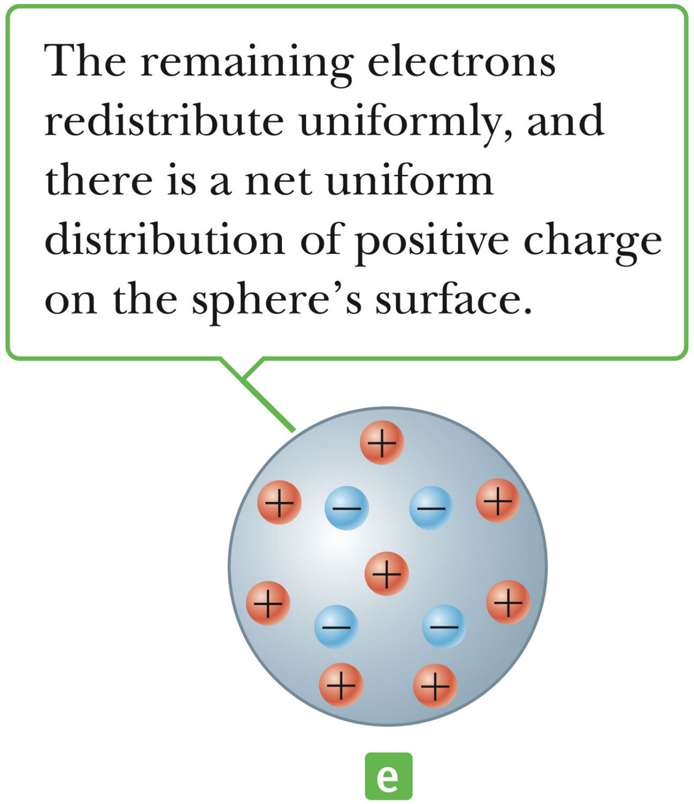
Charging by Induction, 4

- The wire to ground is removed, the sphere is left with an excess of induced positive charge
- Initially, the positive charge on the sphere is nonuniformly distributed.



Charging by Induction, Final

- Eventually, the excess positive charge becomes evenly distributed due to the repulsion between the positive charges.
- *Charging by induction requires no contact with the object inducing the charge.*



Charging results in polarization

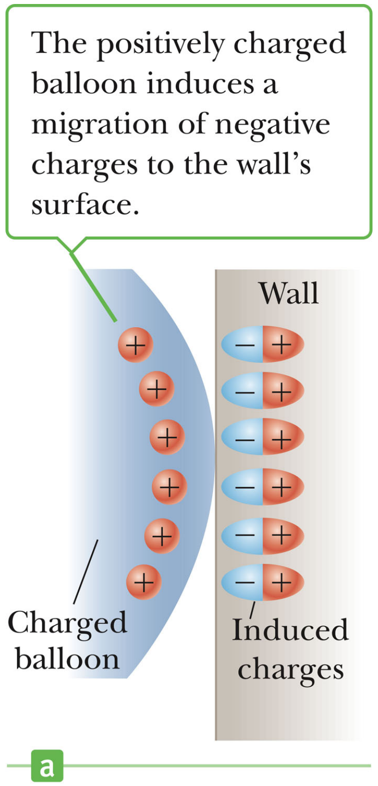
Polarization

- In most neutral atoms or molecules, the center of positive charge coincides with the center of negative charge.
- In the presence of a charged object, these centers may separate slightly.
  - This results in more positive charge on one side of the molecule than on the other side
- This realignment of charge on the surface of an insulator is known as *polarization.*

Polarization

Examples of Polarization

- The charged object (on the left) induces charge on the surface of the insulator.
- A charged comb attracts bits of paper due to polarization of the paper.



Question

1. Doug rubs a piece of fur on a hard rubber rod, giving the rod a negative charge. What happens?

a. Protons are removed from the rod.
b. Electrons are added to the rod.
c. The fur is also charged negatively.
d. The fur is left neutral.

Question

A repelling force must occur between two charged objects under which conditions?

a. Charges are of unlike signs.
b. Charges are of like signs.
c. Charges are of equal magnitude.
d. Charges are of unequal magnitude.

Question

4. A metallic object holds a charge of -3.8×10^6 C. What total number of electrons does this represent? ($e = 1.6 \times 10^{-19}$ C is the magnitude of the electronic charge.)

a. 4.2×10^{24}

b. 6.1×10^{25}

c. 2.4×10^{25}

d. 1.6×10^{24}

Let's start getting quantitative

* Coulomb's law
* How charges attract or repel
* Remember, this is somewhat contrived, the forces change as soon as motion starts

Coulomb's Law

- Coulomb shows that an electric force has the following properties:
  - It is directed along the line joining the two particles and inversely proportional to the square of the separation distance, r, between them
  - It is proportional to the product of the magnitudes of the charges, $|q_1|$ and $|q_2|$ on the two particles
  - It is attractive if the charges are of opposite signs and repulsive if the charges have the same signs

Coulomb's Law, Cont.

- Mathematically,

$$F = k_e \frac{|q_1||q_2|}{r^2}$$

- k_e is called the *Coulomb Constant*
  - $k_e = 8.987\,5 \times 10^9$ N m²/C²
- Typical charges can be in the µC range
  - Remember, Coulombs must be used in the equation
- Remember that force is a *vector* quantity
- Applies only to point charges and spherical distributions of charges
  - r is the distance between the two centers of charge

Characteristics of Particles

Table 15.1 Charge and Mass of the Electron, Proton, and Neutron

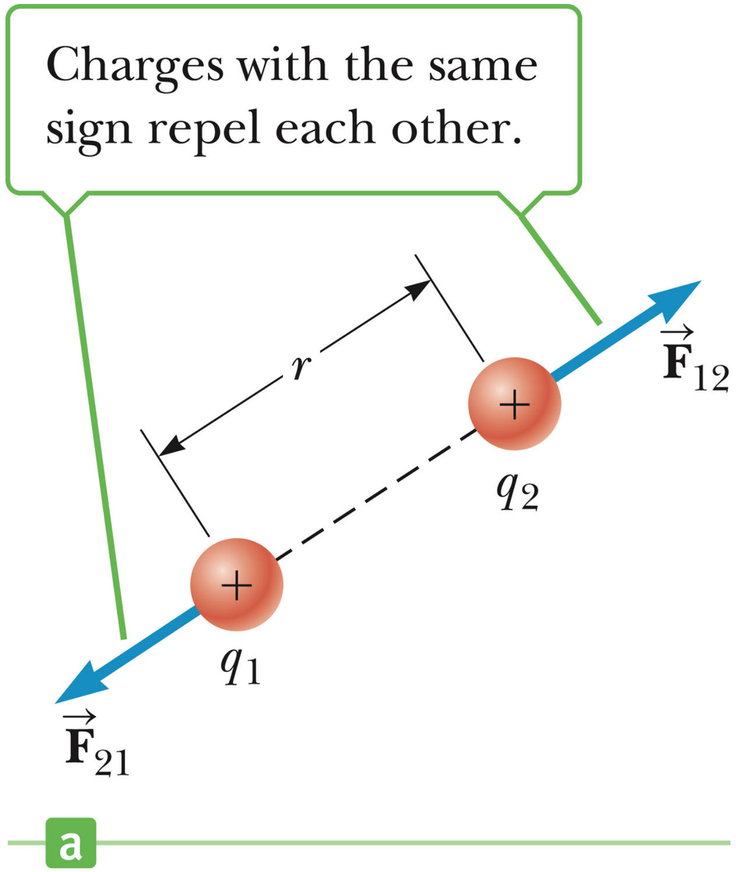
Particle	Charge (C)	Mass (kg)
Electron	-1.60×10^{-19}	9.11×10^{-31}
Proton	$+1.60 \times 10^{-19}$	1.67×10^{-27}
Neutron	0	1.67×10^{-27}

Caveat

* Coulomb's law as we apply it is somewhat fictitious. In reality a force means an acceleration which means movement.
* For our problems assume they mean all particles are held in place by a thumbtack.

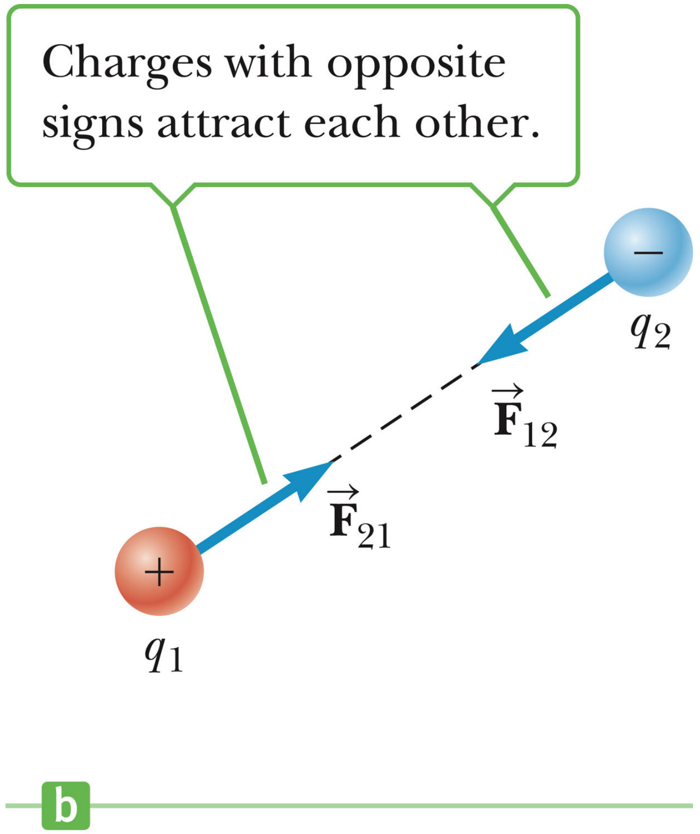
Vector Nature of Electric Forces

- Two point charges are separated by a distance *r*
- The like charges produce a repulsive force between them
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2



Vector Nature of Forces, Cont.

- Two point charges are separated by a distance *r*
- The unlike charges produce an attractive force between them
- The force on q_1 is equal in magnitude and opposite in direction to the force on q_2



Important

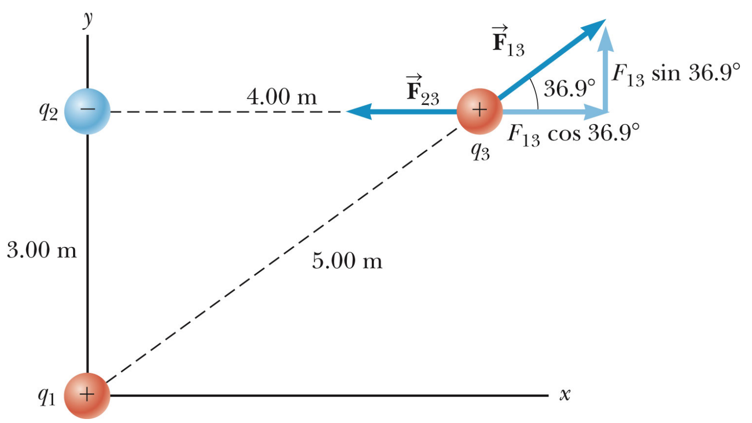
* Calculate only the magnitude. Put the directions in by hand.

The Superposition Principle

- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present.
  - Find the electrical forces between pairs of charges separately
  - Then add the vectors
    - Remember to add the forces as *vectors*

Superposition Principle Example

- The force exerted by q_1 on q_3 is $\vec{F}_{13}$
- The force exerted by q_2 on q_3 is $\vec{F}_{23}$
- The *total force* exerted on q_3 is the vector sum of $\vec{F}_{13}$ and $\vec{F}_{23}$



Let's do a couple examples

The electric Field

* Ok, a field is going to be a new concept for you guys
* Here's how I like to think of a field (sort of)

A field

* Is a convenient way of defining how a test particle would move placed in a region containing other particles that are exerting forces

Electric Fields

* Fields are represented by field lines
* Protons act as sources for the field
* Electrons as sinks. The directions of the arrows on the field line indicate which way a positive charge would move (reverse this for a negative charge).

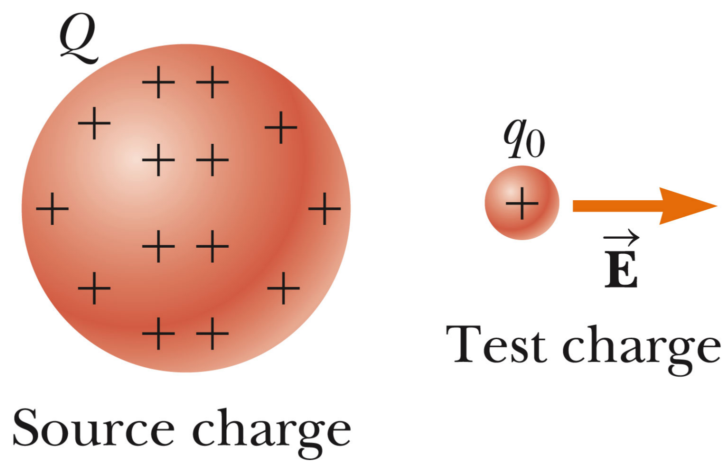
The Electric Field

Electrical Field

- Faraday developed an approach to discussing fields.
- An **electric field** is said to exist in the region of space around a charged object.
  – When another charged object enters this electric field, the field exerts a *force* on the second charged object.

Electric Field, Cont.

- A charged particle, with charge Q, produces an electric field in the region of space around it.
- A small *test charge*, q_o, placed in the field, will experience a force.

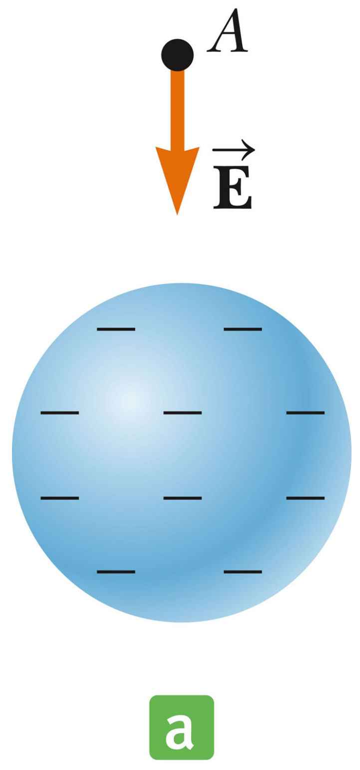


Electric Field

- Mathematically, $\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q_o} = \frac{k_e Q}{r^2}$
- SI unit: N / C
- Use this for the magnitude of the field
- The electric field is a vector quantity
- The direction of the field is defined to be the direction of the electric force that would be exerted on a small *positive* test charge placed at that point.

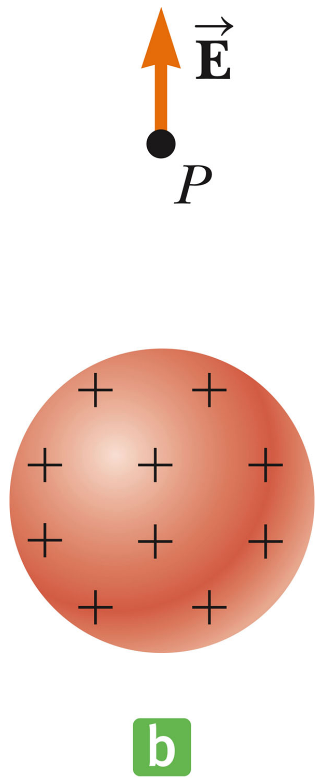
Direction of Electric Field

- The electric field produced by a negative charge is directed toward the charge.
  - A positive test charge would be attracted to the negative source charge.



Direction of Electric Field, Cont.

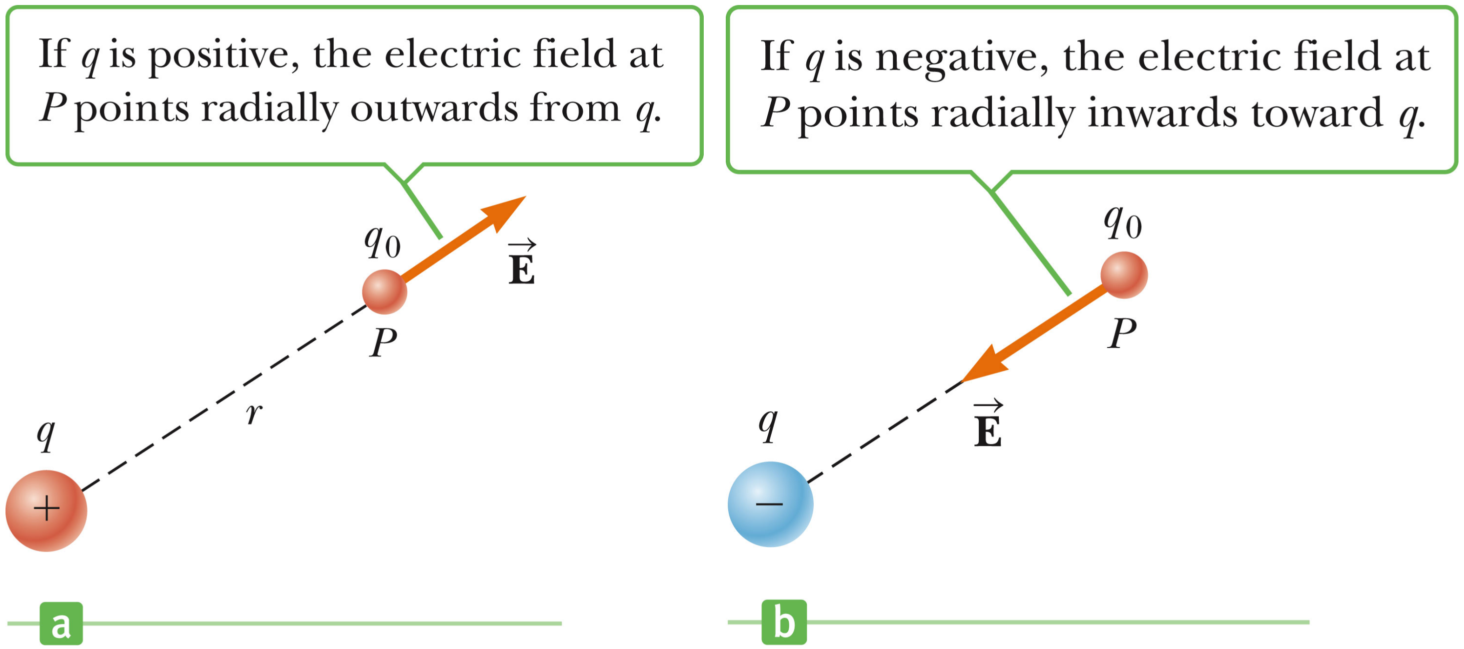
- The electric field produced by a positive charge is directed away from the charge.
  - A positive test charge would be repelled from the positive source charge.



More About a Test Charge and The Electric Field

- The test charge is required to be a small charge.
  - It can cause no rearrangement of the charges on the source charge.
  - Mathematically, the size of the test charge makes no difference.
    - Using q_o = 1 C is convenient
- The electric field exists whether or not there is a test charge present.

Electric Field, Direction Summary



Electric Fields and Superposition Principle

- The superposition principle holds when calculating the electric field due to a group of charges.
  - Find the fields due to the individual charges.
  - Add them as vectors.
  - Use symmetry whenever possible to simplify the problem.

Problem Solving Strategy

- **Draw** a diagram of the charges in the problem.
- **Identify** the charge of interest.
  - You may want to circle it
- **Units** – Convert all units to SI.
  - Need to be consistent with k_e

Problem Solving Strategy, Cont.

- **Apply Coulomb's Law.**
  - For each charge, find the force on the charge of interest.
  - Determine the direction of the force.
  - The direction is always along the line of the two charges.
- **Sum all the x- and y- components.**
  - This gives the x- and y-components of the resultant force
- **Find the resultant force** by using the Pythagorean theorem and trigonometry.

Problem Solving Strategy, Electric Fields

- Calculate Electric Fields of point charges.
  - Use the equation to find the electric field due to the individual charges.
  - The direction is given by the direction of the force on a positive test charge.
  - The Superposition Principle can be applied if more than one charge is present.

Electric Field Lines

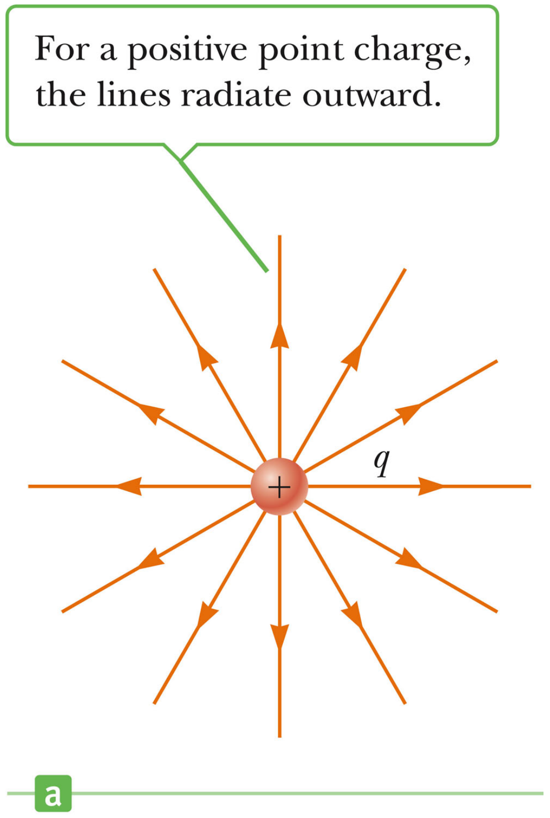
- A convenient aid for visualizing electric field patterns is to draw lines pointing in the direction of the field vector at any point.
- These lines are called **electric field lines** and were introduced by Michael Faraday.

Electric Field Lines, Cont.

- The field lines are related to the field in the following manners:
  - The electric field vector, $\vec{\mathbf{E}}$, is tangent to the electric field lines at each point.
  - The number of lines per unit area through a surface perpendicular to the lines is proportional to the strength of the electric field in a given region.

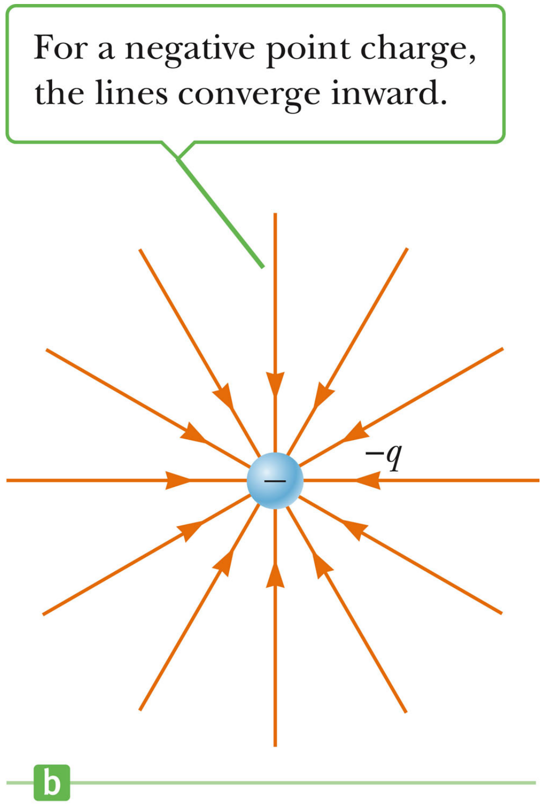
Electric Field Line Patterns

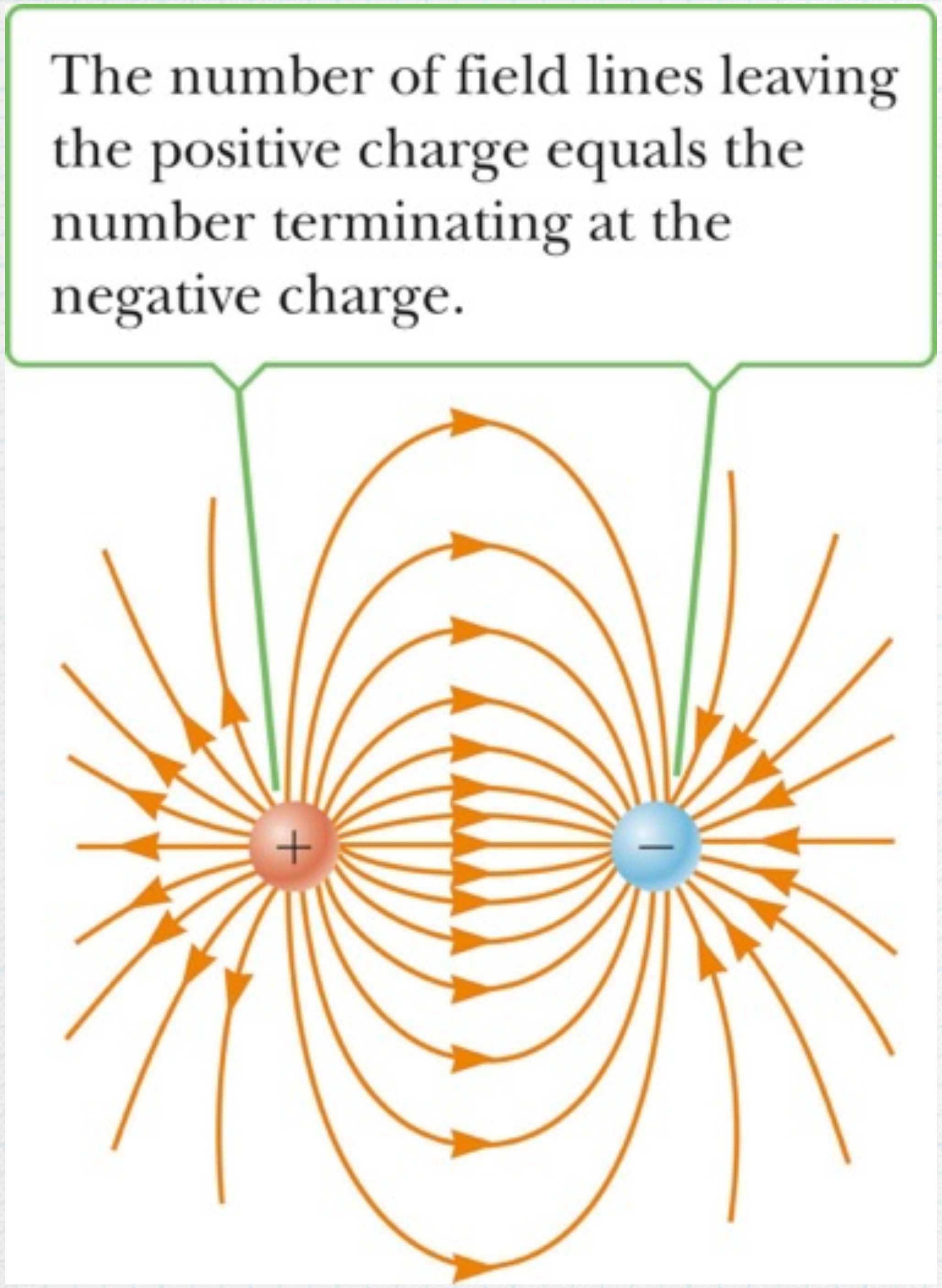
- Point charge
- The lines radiate equally in all directions.
- For a positive source charge, the lines will radiate outward.

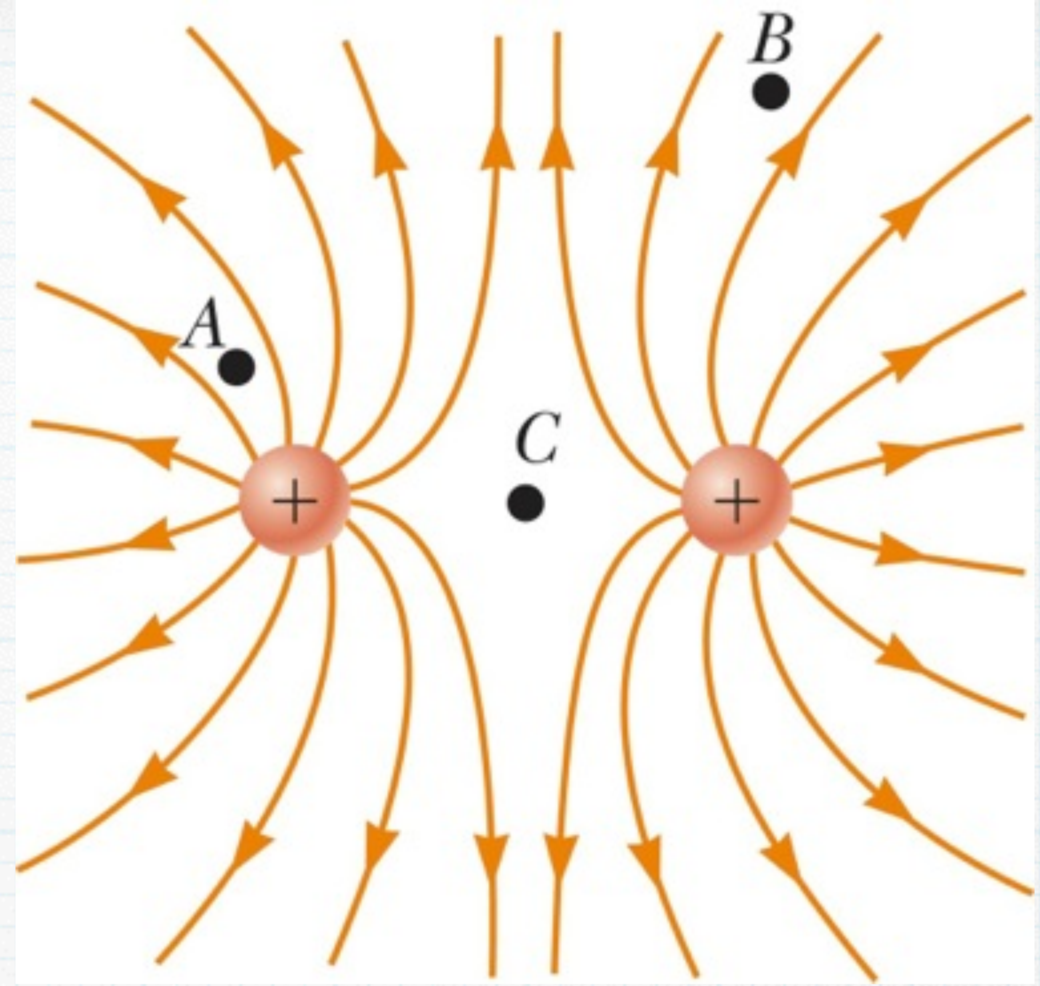


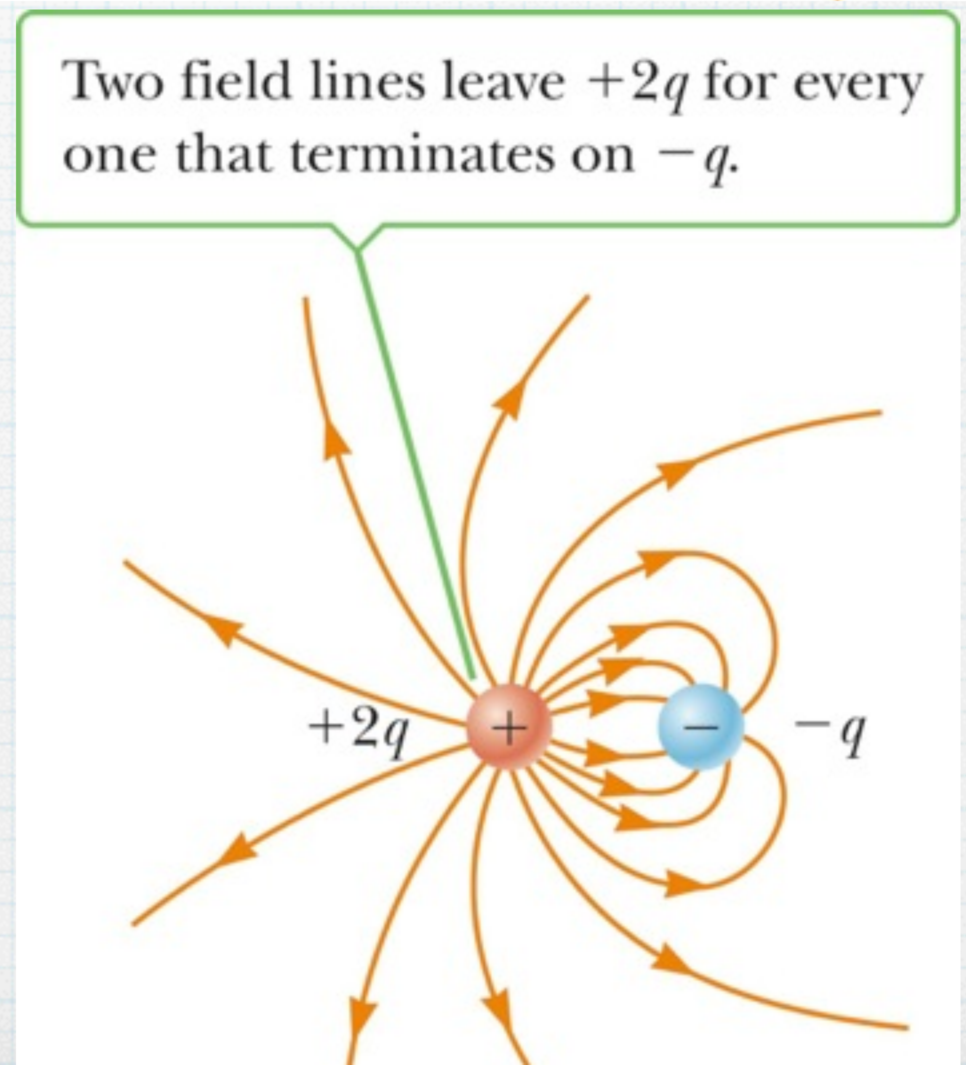
Electric Field Line Patterns

- For a negative source charge, the lines will point inward.

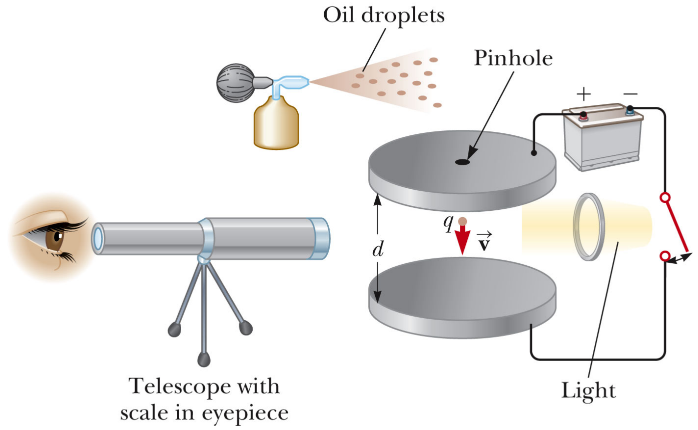



The number of field lines leaving the positive charge equals the number terminating at the negative charge.
+
−

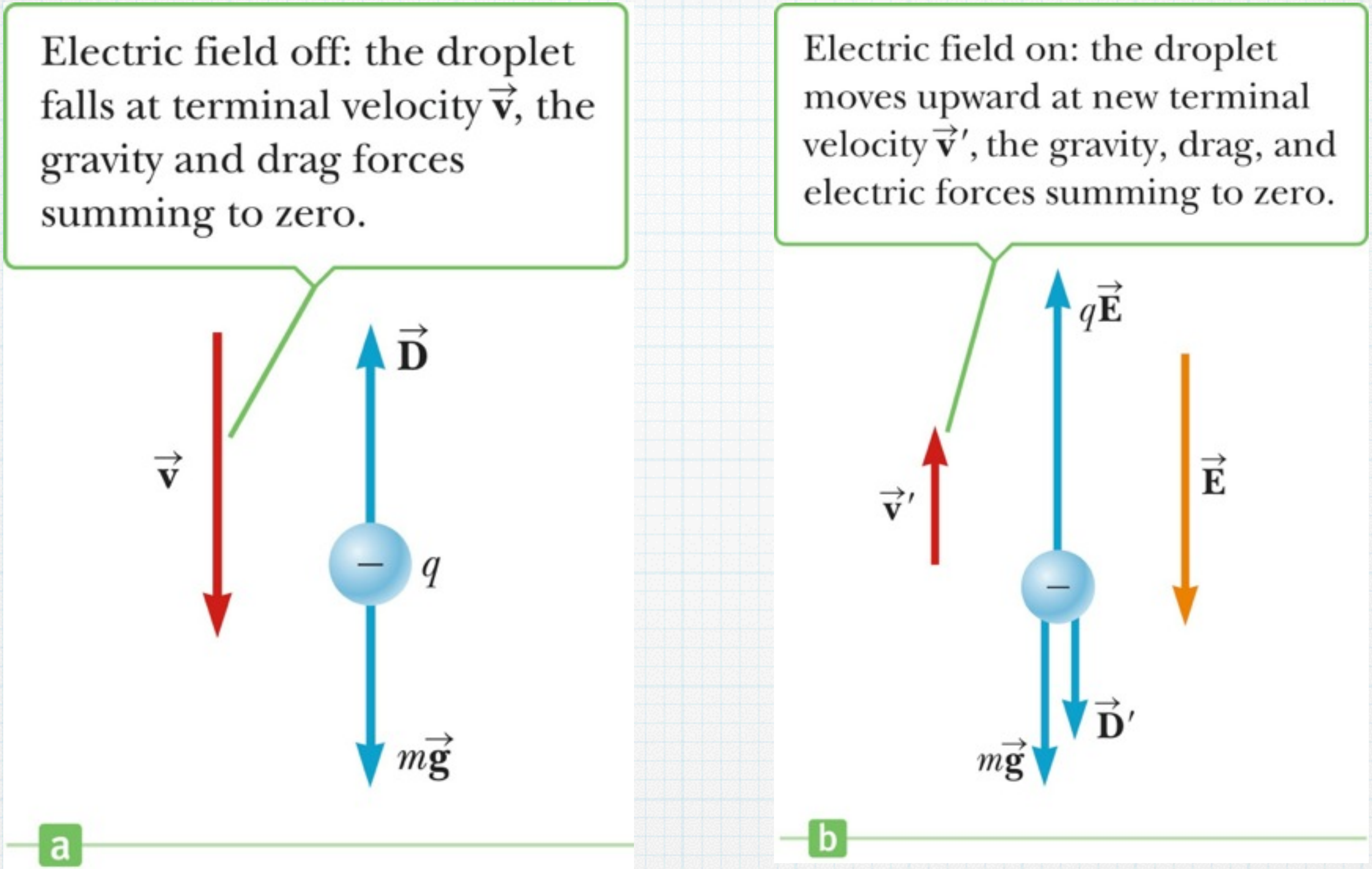

B
A
C
+
+


Two field lines leave +2q for every one that terminates on −q.
+2q
+
−
−q

Millikan Oil-Drop Experiment



- Measured the elementary charge, e
- Found every charge had an integral multiple of e
  - q = n e


Electric field off: the droplet falls at terminal velocity $\vec{v}$, the gravity and drag forces summing to zero.
$\vec{D}$
$\vec{v}$
q
$m\vec{g}$
a
Electric field on: the droplet moves upward at new terminal velocity $\vec{v}'$, the gravity, drag, and electric forces summing to zero.
$q\vec{E}$
$\vec{E}$
$\vec{v}'$
$\vec{D}'$
$m\vec{g}$
b

Question

If the distance between two point charges is tripled, the mutual force between them will be changed by what factor?

a.9.0
b.3.0
c.0.33
d.1/9

Question

An electron with a charge value of 1.6×10^{-19} C is moving in the presence of an electric field of 400 N/C. What force does the electron experience?

a. 2.3×10^{-22} N

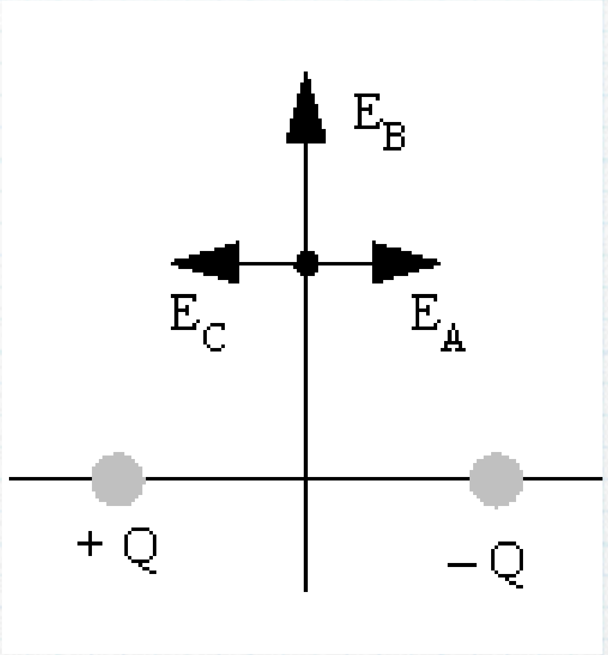
b. 1.9×10^{-21} N

c. 6.4×10^{-17} N

d. 4.9×10^{-17} N

Question

Two charges, $+Q$ and $-Q$, are located two meters apart and there is a point along the line that is equidistant from the two charges as indicated. Which vector best represents the direction of the electric field at that point?



a. Vector E_A
b. Vector E_B
c. Vector E_C
d. The electric field at that point is zero.

Let's do some examples

Key Concepts

* Charge is conserved
* Charge is quantized e = 1.6 x 10-19 C
* Only NET charge matters
* Charging may be through conduction or induction
* Opposites attract, likes repel
* Electric forces and fields are VECTOR quantities
* Electric forces and fields obey the superposition principle

Key Equations

$$\vec{F}_e = k\frac{q_1 q_2}{r^2}\hat{r}$$

$$\vec{E} = k\frac{q}{r^2}\hat{r} = \frac{\vec{F}_e}{q_0}$$