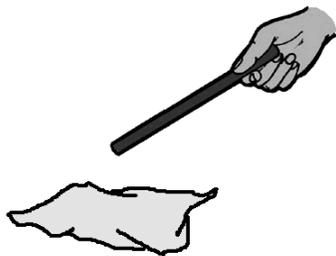
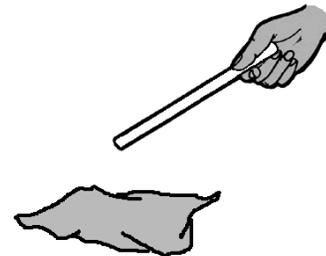


1. What happens in each case below when the two objects are rubbed together?

Rubber Rod and Fur



Plastic Strip and Fabric



2. What is the only particle that is normally transferred when an object is charged?

Why?

3. Sketch each of the following and determine the net charge.

Neutral Atom

Positive Ion

Negative Ion

Elementary charge:

	Proton	Electron	Neutron
Symbol			
Charge (e)			
Charge (C)			
Mass (kg)			

Electric charge

Symbol:

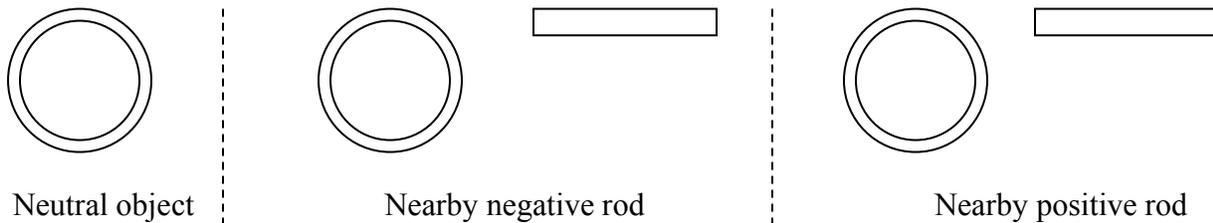
Units:

Types of materials:

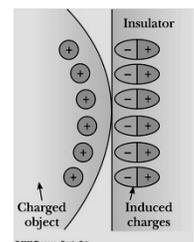
- a) **Conductors:** materials in which electric charges move freely (e.g. metals, graphite)
 b) **Insulators:** materials in which electric charges do not move freely (e.g. plastic, rubber, dry wood, glass, ceramic)
 c) **Semiconductors:** materials with electrical properties between those of conductors and insulators (e.g. silicon)
 d) **Superconductors:** materials in which electrical charges move without resistance (e.g. some
-

Charging by Friction:**Charging by Conduction:****Discharging:**a) **Grounding:**b) **Leakage:**

4. Sketch what happens when a charged rod is brought near a soda can.

**Polar:****Induction (Separation of charge):****General Conclusion**

5. Why do rubbed balloons stick to walls?

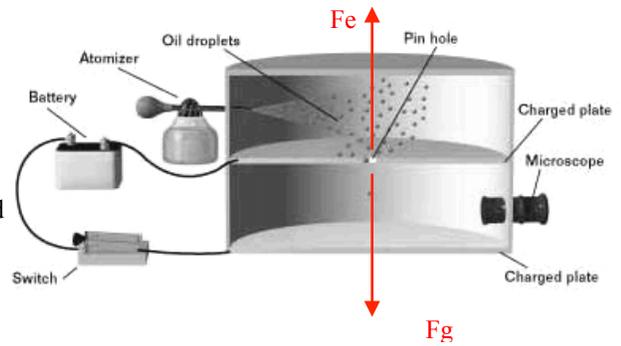


Measuring Charge

IB 11

Robert Millikan's Oil Drop Experiment

In 1909, Robert Millikan performed an experiment at the University of Chicago in which he observed the motion of tiny oil droplets between two parallel metal plates. The oil droplets were charged by friction in an atomizer and allowed to pass through a hole in the top plate. Initially the droplets fell due to their weight. The top plate was given a positive charge as the droplets fell, and the droplets with a negative charge were attracted back upward toward the positively charged plate. By turning the battery on and off, Millikan was able to watch individual oil droplets for many hours as they were suspended in mid-air and alternately rose and fell. By analyzing many measurements, he was able to make an important conclusion about electric charge.



Sample data for the charge on each oil droplet:

Conclusion:

- An object has acquired a charge of -3.2×10^{-17} C. How many excess electrons are on the object?
- A glass rod loses 2500 electrons after being rubbed with silk. What is the charge on the rod? The silk?
- How many elementary charges are in one coulomb of charge?
- Which of the following charges are possible for an object to have?
 - -8.0×10^{-19} C
 - 4.8×10^{-17} C
 - -5.6×10^{-19} C
 - 1.6×10^{-20} C
 - -5.6 C
- How can you determine if a charge is possible?

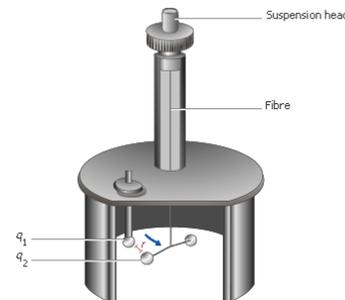
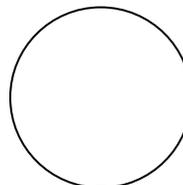
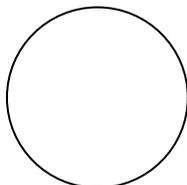
Initial State	Conduction	Final State
<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center;">+10</div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center;">-10</div> </div> <p>Total charge:</p>	<div style="display: flex; justify-content: center; align-items: center;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; margin-right: 10px;"></div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> </div> <p>Charge transfer?</p>	<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> </div> <p>Total charge:</p>
<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center;">-30</div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center;">-10</div> </div> <p>Total charge:</p>	<div style="display: flex; justify-content: center; align-items: center;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; margin-right: 10px;"></div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> </div> <p>Charge transfer?</p>	<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> </div> <p>Total charge:</p>
<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center;">+25</div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; display: flex; align-items: center; justify-content: center;">+15</div> </div> <p>Total charge:</p>	<div style="display: flex; justify-content: center; align-items: center;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px; margin-right: 10px;"></div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> </div> <p>Charge transfer?</p>	<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> <div style="border: 1px solid black; border-radius: 50%; width: 40px; height: 40px;"></div> </div> <p>Total charge:</p>

The Electrostatic Force

Coulomb's torsion balance was used to establish the relationship for the electric force between two charged spheres.



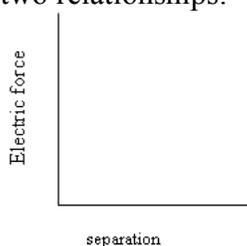
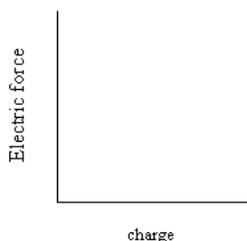
Charles Coulomb
(1736 – 1806)



The charged spheres act as if they were *point charges*.

Point charge:

Experimental data showed the following two relationships:



Relationship:

Formula:

Electrostatic Constant (Coulomb's constant):

Coulomb's Law: The electrostatic force between two charged objects is directly proportional to the product of the two charges and inversely proportional to the square of the distance between their centers and acts along a line joining their centers.

1. A proton and an electron are placed 1.0×10^{-10} meter apart.

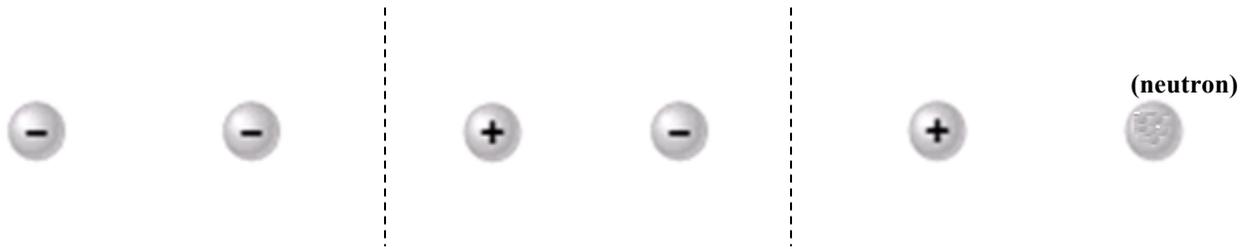


- a) Calculate the Coulomb force of attraction between them.

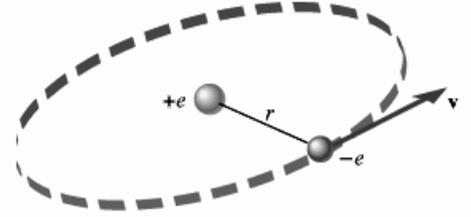
NOTE:

- b) Calculate the gravitational force of attraction between them.

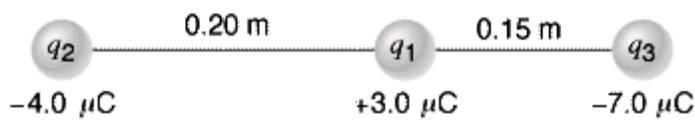
2. Sketch the directions of the electrostatic forces and the gravitational forces in each pairing below.



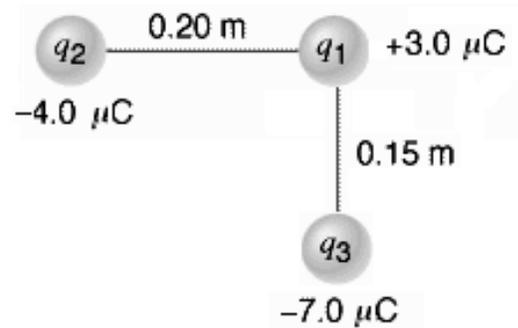
3. In the Bohr model of the hydrogen atom, the electron ($-e$) is in orbit about the nuclear proton ($+e$) at a radius of $r = 5.29 \times 10^{-11}$ m. Determine the speed of the electron, assuming the orbit to be circular.



4. Three charges are placed along a line at the positions indicated. What is the net force on charge q_1 ?

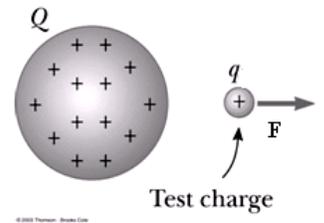


5. The three charges are now placed at right angles, as shown. What is the net force on charge q_1 ?



Electric field:

Test charge:



Electric Field Diagrams

1. Electric field around a positively charged object



2. Electric field around a negatively charged object



3. Electric field around unlike charges



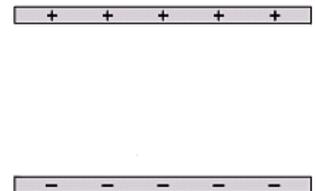
4. Electric field around two positive charges



5. Electric field around two negative charges



6. Electric field between two oppositely charged parallel plates



Properties of Electric Field Lines

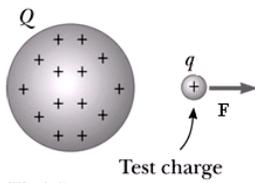
- a) They show the _____ (out of positive, into negative).
- b) They _____ since this would indicate that the resultant force is in two different directions at once.
- c) The direction of the electric field at any point is _____.
- d) The density of the field lines is proportional to the strength of the field (_____). The field is most intense where the field lines are most dense.

Electric Field Strength

IB 11

Electric Field Strength
(Intensity):

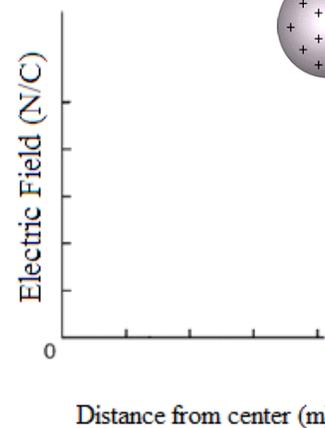
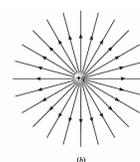
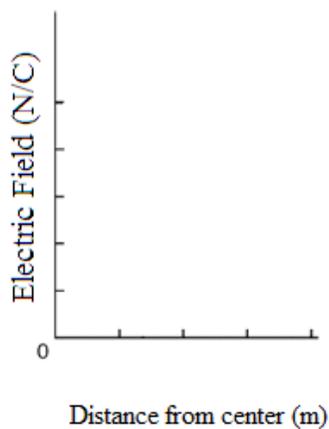
Formula:



Alternate Formula for point charges:

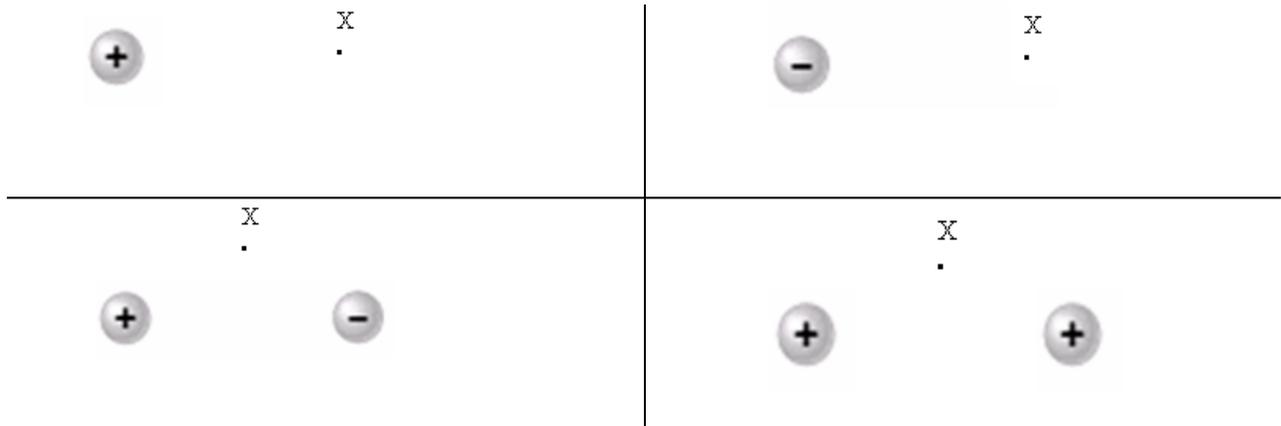
Variable:	Fe	E	Q, q
Quantity:			
Units:			
Type:			

1. What is the magnitude and direction of the electric field at a distance of 7.00 nm from a proton? Sketch a graph of the relationship between electric field strength and distance from the proton.



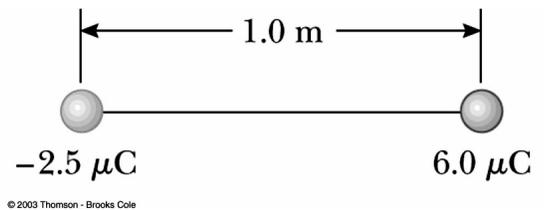
2. What is the magnitude and direction of the electric field at a point where an electron experiences a force of 3.1 pN?

1. In each case below, compare the direction of the electric field at point X produced by the charged object with the direction of the electrostatic forces exerted on a proton and on an electron placed at point X.



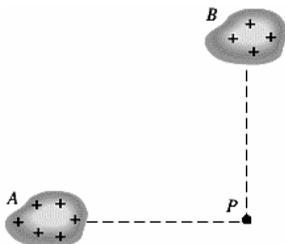
Conclusion

2. a) Find the magnitude and direction of the net electric field halfway between the two charges shown below.

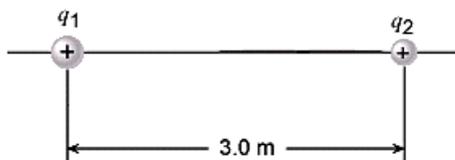


- b) Determine the electric force on a proton placed at this spot.

3. Two charged objects, *A* and *B*, each contribute as follows to the net electric field at point *P*: $E_A = 3.00$ N/C directed to the right, and $E_B = 2.00$ N/C directed downward. What is the net electric field at *P*?



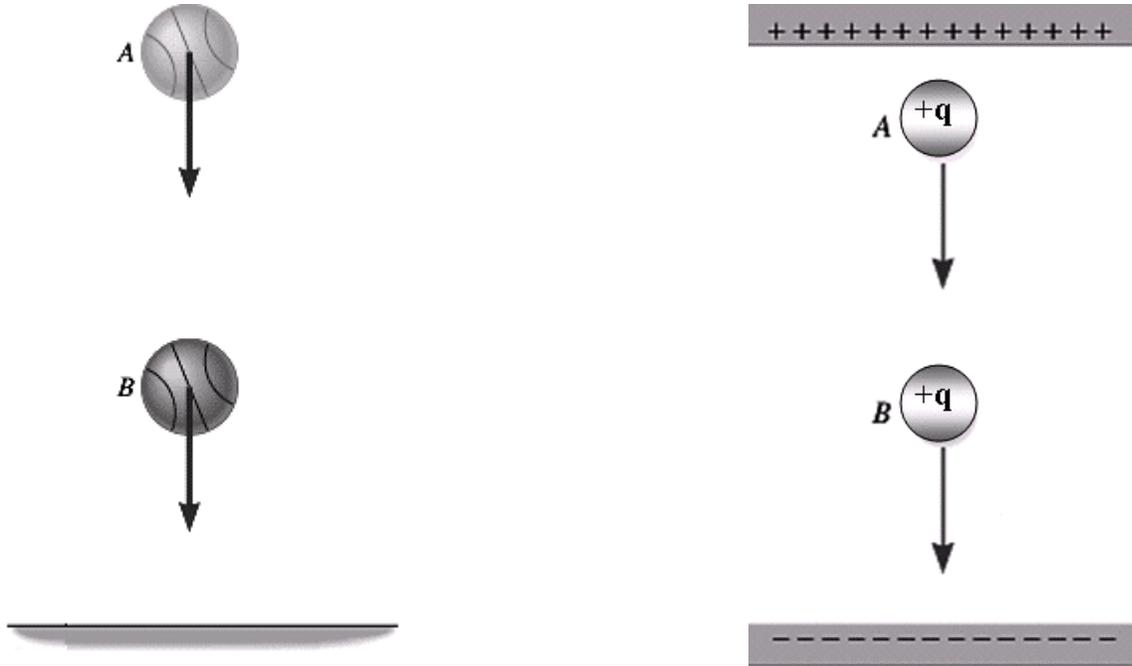
6. a) Two positive point charges, $q_1 = +16 \mu\text{C}$ and $q_2 = +4.0 \mu\text{C}$, are separated in a vacuum by a distance of 3.0 m. Find the spot on the line between the charges where the net electric field is zero.



Electric Potential Energy and Potential

IB 11

Formula:



Electric potential energy:

Symbol: Units:

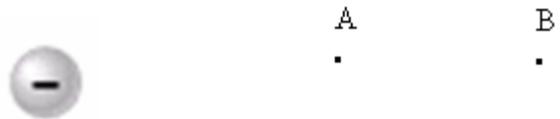
1. In the diagram above, at which spot, A or B, will the test charge have more electric potential energy?

Electric potential (voltage):

Symbol: Units:

2. In the diagram above, which spot, A or B, is at a higher electric potential?

3. Which spot, A or B, is at a higher electric potential?



4. Which spot, A or B, is at a higher electric potential?

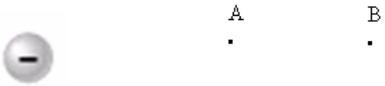


Conclusion:

Formula:

Variable:			
Quantity:			
Units:			
Type:			

1. How much work is done in moving +5.0 C of charge through a potential difference of 12 volts?



2. An electron gains 4.8×10^{-17} joule of energy moving between two points in an electric field. What is the electric potential difference between these two points?

Electronvolt:

3. Determine the conversion factor between joules and electronvolts.

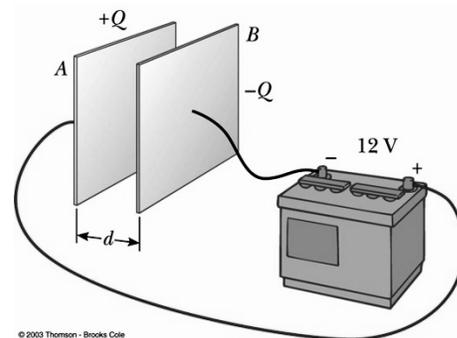
4. An external force does 4.0 eV of work moving an electron between two points in an electric field. How much energy in joules does the electron gain?

5. A proton falls through a potential difference of 30. volts. How much kinetic energy does the proton gain? Express your answer in both joules and electronvolts.

Two Parallel Plates

IB 11

Two identical metal plates, each with area A , are set a distance d apart. They are each charged by connecting them to a source of potential difference V like a battery, as shown in the diagram.



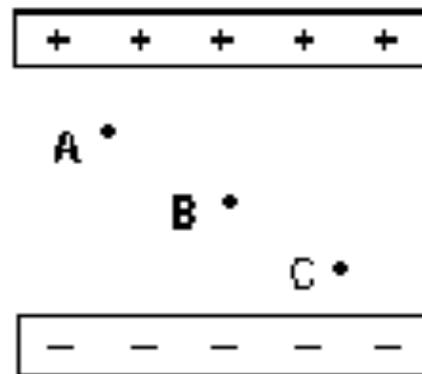
Charge on the plates =

Area of the plates =

1. a) Where is equipment like this used?

b) What is the purpose of this equipment?

2. A positive test charge is placed at each of three locations between two charged metal parallel plates: A, B, and C.



a) At which location is the electric force on the test charge greatest?

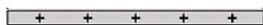
b) At what location is the electric field strongest?

c) If the charge of the test charge is doubled, what effect will this have on the:

i) electric field?

ii) electric force?

3. Draw the electric field between two charged metal parallel plates.



Uniform field:

Edge effects:

4. The electric potential difference between these plates is 100 volts.

a) Which plate is at a higher electric potential? Why?

b) What is the electric potential of each plate?

Parallel Plate Formulas:

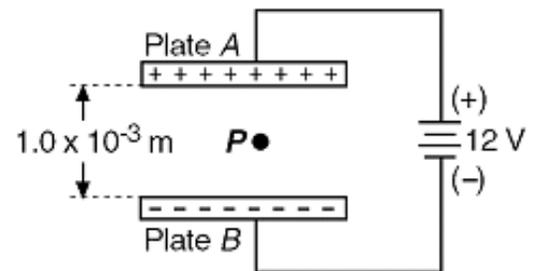
Electric Field:

Potential difference:

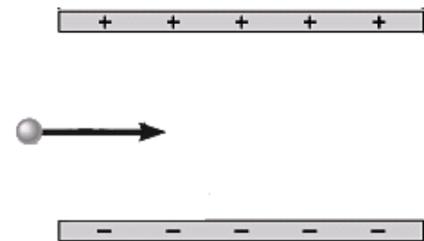
Variable:	V	E	d
Quantity:			
Units:			
Type:			

5. Two parallel plates are connected to a 12-volt battery as shown.

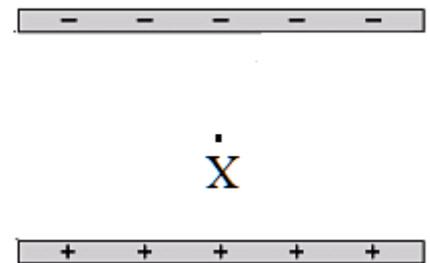
- a) What is the magnitude and direction of the electric field between the two plates?



6. Sketch the trajectory of a proton, a neutron, an electron, and an alpha particle if they are all shot with the same initial velocity into the plates.

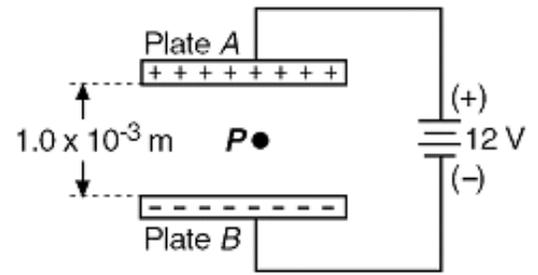


7. a) At point X, draw and label a vector to represent the electric field from the plates.
 b) At point X, draw and label a vector to represent the electric force on
 i) a proton ii) an electron
 c) Compare the electric force on the proton and electron.
 d) Compare the resulting accelerations of the proton and electron.
 e) An alpha particle is placed at point X. What is an alpha particle?
 f) Compare the alpha particle to a proton. Compare the:
 i) charge ii) mass iii) force on each iv) acceleration of each



8. A proton is released from rest at the positive plate.

a) How fast will it be traveling when it strikes the negative plate?



b) How fast will it be traveling when it strikes the negative plate?

NOTE:

Capacitor

Capacitor:

Example:

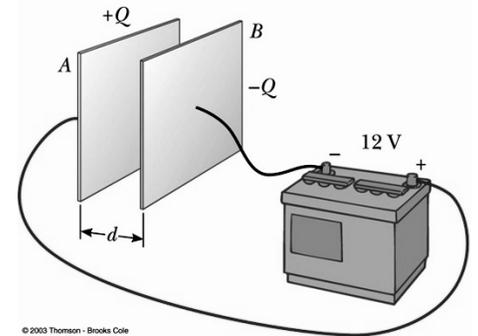
Capacitance

Meaning:

Definition:

Formula:

Units:



© 2003 Thomson - Brooks Cole

Variable:	C	Q	V
Quantity:			
Units:			
Type:			

1. The potential difference measured across a 100 pF capacitor is 25 mV. Determine the charge and number of electrons stored in the capacitor.

2. What physical properties does the capacitance of a capacitor depend on?

IB 11

Quantity	Variable	Unit

Permittivity of free space (vacuum):

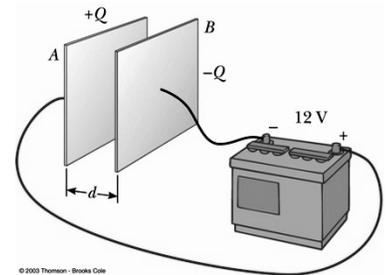
General Formula:

Formula for air:

3. The square plates in the capacitor shown above are 32 mm apart and are 5.0 cm on each side.

a) What is the capacitance?

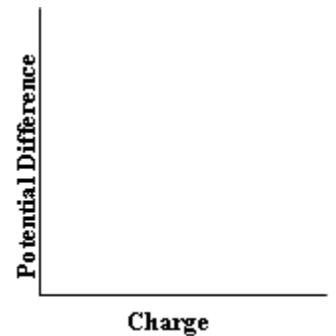
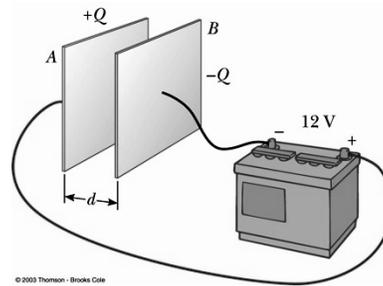
b) What is the amount of charge stored on each plate?



Energy Stored in a Capacitor

Charging a capacitor

The plates are initially uncharged and their potential difference is zero. As charge builds up on the plates, the potential difference between them increases and more work is required to move additional charge onto the plates.



1. How much work is required to charge capacitor to a final charge of Q ?

2. What do the slope and area of the graph represent?

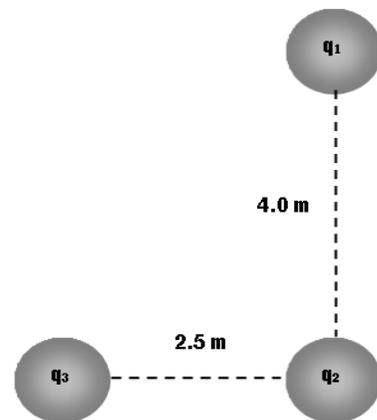
3. How much energy and charge is stored in a $5.0 \mu\text{F}$ capacitor when it is connected to a 120 V power source?

1. In the following problems, convert between elementary charges and coulombs.
 - a) What is the charge of four electrons in Coulombs?
 - b) What is the charge of four protons in Coulombs?
 - c) What is the charge of 245 electrons in Coulombs?
 - d) How many elementary charges are in $5.76 \times 10^{-16} \text{ C}$? Are they electrons or protons?
 - e) How many elementary charges are in $-4.3 \times 10^{-6} \text{ C}$? Are they electrons or protons?

2. An electron and a proton are 0.89 meter apart. They are in deep space away from all other gravitational influences.
 - a) Calculate the electrostatic force between them.
 - b) Calculate the gravitational force between them.

3. Two positive point charges, q_1 and q_2 , are a certain distance, d , apart. What happens to the magnitude of the electrostatic force between them if:
 - a) The charge on q_1 is doubled?
 - b) The charge on q_1 is doubled and the charge on q_2 is tripled?
 - c) The distance between q_1 and q_2 is doubled?
 - d) The distance between q_1 and q_2 is cut in half?

4. Three charges exist in a closed system. If $q_1 = +8.4 \text{ C}$, $q_2 = -3.8 \text{ C}$, and $q_3 = +6.1 \text{ C}$, as shown in the diagram, what is the net force (magnitude and direction) acting on charge q_2 ?



5. A positive charge of $1.50 \times 10^{-5} \text{ C}$ experiences a force of 0.26 N when located at a certain point in an electric field. What is the electric field strength at that point?
6. The electric field intensity at a point is $4.0 \times 10^5 \text{ N/C}$. What is the force that a $5.5 \times 10^{-6} \text{ C}$ charge experiences at that point?
7. What charge does a test charge have when a force of $7.90 \times 10^{-6} \text{ N}$ acts on it at a point where the electric field intensity is $1.45 \times 10^{-5} \text{ N/C}$?
8. What is the strength of the electric field at a distance of 4.8×10^{-12} meter away from an electron?
9. How much force would be exerted on a proton placed at position mentioned in #8?

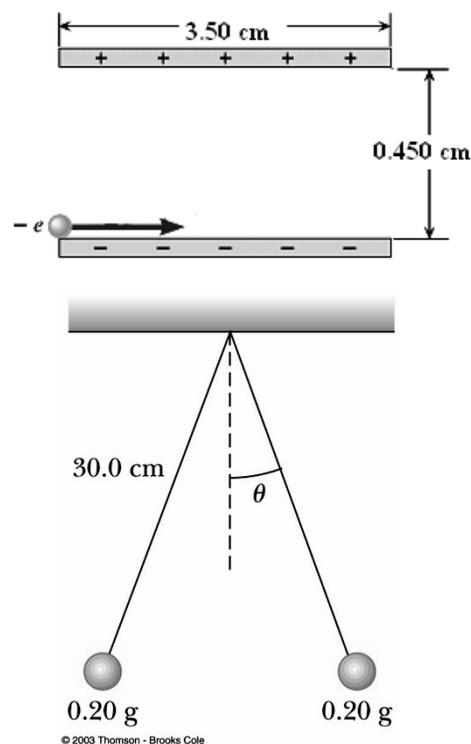
10. It takes 5.0×10^{-3} J of work to move a positive charge of 2.5×10^{-4} C from point X to point Y of an electric field. What is the difference of potential between X and Y?
11. How much work does it take to move a positive charge of 5.0×10^{-5} C from a point of lower potential to a point of higher potential when the voltage between the points is 65 Volts?
Answer in both joules and electronvolts.
12. How much work is done moving an electron between the terminals of a 12 volt battery?
Answer in both joules and electronvolts.
13. How much work is required to move a charge of 5.5×10^{-8} C between two points that have a potential difference of 92.5 V?
14. When a charge of 8.50 C is moved between two points in an electric field, 372 J of work are performed. What is the potential difference between the two points?
15. Two large, charged parallel plates are 9.5 cm apart. The magnitude of the electric field between the plates is 415 N/C.
- What is the electrical potential difference between the plates?
 - What work will you do to move a charge equal to that of one proton from the negative to the positive plate?
 - Covert your answer to b) into electronvolts.
16. Two charged plates are separated by a distance of 2.5 cm. If there is an electric potential difference of 925 V between the plates,
- What electric field exists in the middle?
 - If an electron is released from rest at the negative plate how much kinetic energy will it have when it reaches the positive plate?
 - How fast will the electron be moving when it reaches the positive plate?
17. A 12 V battery is connected across two parallel plates separated by 0.30 cm.
- Find the magnitude of the electric field between the plates.
 - Determine the force exerted on an electron placed at the negative plate.
 - Calculate the acceleration of this electron.
 - How much electric potential energy does this electron have at this location?
18. A 12.0 volt battery is connected to a 6.0 pF capacitor. What is the charge on each plate?
19. A capacitor has a capacitance of 2.00 nF. How much potential difference would be required to store 18.0 nC of charge?
20. A parallel plate capacitor has an area of 2.0 cm^2 and the plates are separated by 2.0 mm.
- What is the capacitance?
 - How much charge does this capacitor store when connected to a 6.0 volt battery?

21. A fully charged defibrillator contains 1.2 kJ of energy stored in a $110 \mu\text{F}$ capacitor. In a discharge through a patient, 600 J of electrical energy are delivered in 25 ms.

a) How much voltage is needed to store the fully charge defibrillator?

b) How much power is delivered to the patient?

22. In the figure, an electron enters the lower left side of a parallel plate capacitor and exits at the upper right side. The initial speed of the electron is $5.50 \times 10^6 \text{ m/s}$. The plates are 3.50 cm long and are separated by 0.450 cm. Assume that the electric field between the plates is uniform everywhere and find its magnitude.



23. Two small metallic spheres, each of mass 0.20 g, are suspended as pendulums by light strings from a common point as shown above. The spheres are given the same electric charge, and it is found that the two come to equilibrium when each string is at an angle of 5.0° with the vertical. If each string is 30.0 cm long, what is the magnitude of the charge on each sphere?

1.

- $-6.4 \times 10^{-19} \text{ C}$
- $+6.4 \times 10^{-19} \text{ C}$
- $-3.92 \times 10^{-17} \text{ C}$
- $3.60 \times 10^3 \text{ e}$
- $2.7 \times 10^{13} \text{ e}$

2.

- $2.9 \times 10^{-28} \text{ N}$
- $1.3 \times 10^{-67} \text{ N}$

3.

- 2F
- 6F
- $\frac{1}{4} \text{ F}$
- 4F

4. $3.8 \times 10^{10} \text{ N}$ 29° above horizontal

5. $1.7 \times 10^4 \text{ N/C}$

6. 2.2 N

7. 0.54 C

8. $6.2 \times 10^{13} \text{ N/C}$

9. $9.9 \times 10^{-6} \text{ N}$

10. 20 V

11. $2.0 \times 10^{16} \text{ eV}$

12. $1.9 \times 10^{-18} \text{ J} = 12 \text{ eV}$

13. $5.1 \times 10^{-6} \text{ J}$

14. 43.8 V

15. a) 39 V b) $6.2 \times 10^{-18} \text{ J}$ c) 39 eV

16. a) $3.7 \times 10^4 \text{ N/C}$ b) $1.5 \times 10^{-16} \text{ J}$ c) $1.8 \times 10^7 \text{ m/s}$

17. a) 4000 V/m b) $6.4 \times 10^{-16} \text{ N}$ c) $7.0 \times 10^{14} \text{ m/s}^2$

d) $1.9 \times 10^{-18} \text{ J}$ (12 eV)

18. $7.2 \times 10^{-11} \text{ C}$

19. 9.00 V

20. a) $8.9 \times 10^{-13} \text{ F}$ b) $5.3 \times 10^{-12} \text{ C}$

21. a) $V = 4.7 \times 10^3 \text{ V}$ b) $P = 2.4 \times 10^5 \text{ W}$

22. $1.21 \times 10^3 \text{ N/C}$

23. $7.2 \times 10^{-9} \text{ C}$