Physics 1B schedule Winter 2009. Instructor: D.N. Basov dbasov@ucsd.edu

Week	Mon	Wed	Friday	
1:Jan 5	Lecture: Intro, 15.1-15.3	Lecture: The Coulomb law,	Lecture: the Electric field	
2: Jan 12	Lecture: Electric Flux & Gauss's law		Lecture: Gauss law/examples	OH This week only: Fri 4-5 pm, 6-7 pm
3: Jan 19	University Holiday	Lecture: Potential	Quiz 1: chapter 15	
4: Jan 26	Lecture: capacitance	Lecture: capacitor combinations	Quiz 2: chapter 16	
5: Feb 2	Lecture: Electric current, Ohm's law	Lecture: Resistivity, Electric power	Lecture: Resistors, series parallel	
6: Feb 9	Lecture: Kirchhoff's rules	Lecture: RC circuits	Quiz 3: chapter 17	
7: Feb 16	University Holiday	Lecture: Magnetism	Lecture: torque on current loop, Ampere's law	
8: Feb 23	Lecture: current loop, solenoid	Lecture: Induced EMF	Quiz 4: chapter 18-19	
9: March 2	Lecture: Faraday's law, Lenz's law	Lecture Inductance, Inductors	Quiz 5: chapter 19-20	
10: March 9	Lecture: Energy of the magnetic field	Lecture: AC circuits	Lecture: discussion of the final exam	

HW: Ch15: 1,10,11,13,15,17,20,24,27,28,30,32,36,38,43,46,48
Ch16: 1,3,5,8,12,15,19,22,23,25,29,31,33,35,43,45,47,49,60
Ch17: 1,3,8,9,11,13,16,19,20,23,31,33,39,45,52,60
Ch18: 1,3,5,7,13,17,21,26,31,33,35,
Ch19: 1,3,8,9,11,15,19,22,24,27,29,34,37,38,41,44,47,49,57,61
Ch20: 1,5,8,11,13,16,18,23,25,27,29,31,34,37,39,

Quizzes:
HW problems, problems in class, more…
4 best out of 5
No make-up quizzes for any reason

T.A.:A: Zhoushen Huang
zhohuang@physics.ucsd.edu
B: Andreas Stergiou,
stergiou@physics.ucsd.edu

Final exam: all material in ch 15-21
no make up final for any reason

Last update: Jan 15, 2009

Potential difference and electric potential [16.1]

Recall physics 1A: $$\Delta PE_{AB} = -W_{AB} \qquad = -F\Delta x$$

Potential energy difference

Work done by a *conservative* force

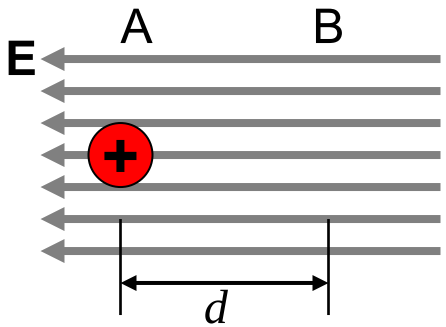
A path from A to B

Potential difference and electric potential [16.1]

Recall physics 1A: $\Delta PE_{AB} = -W_{AB} \qquad = -F\Delta x$

Potential energy difference — Work done by a *conservative* force — A path from A to B

Physics 1B: ΔPE_{AB} due to moving charged objects in an electric field



$$\Delta PE_{AB} = -W_{AB} = -Fd = -(-qEd) = qEd$$

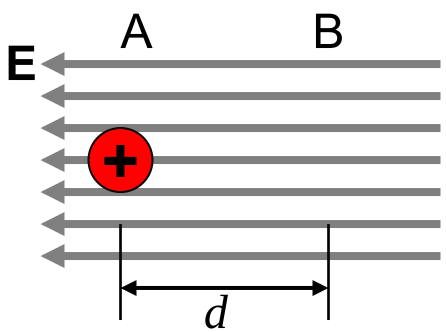
Because force is opposite to the direction of charge motion

Potential difference and electric potential [16.1]

Recall physics 1A: $\Delta PE_{AB} = -W_{AB} \qquad = -F\Delta x$

Potential energy difference — Work done by a *conservative* force — A path from A to B

Physics 1B: ΔPE_{AB} due to moving charged objects in an electric field



$$\Delta PE_{AB} = -W_{AB} = -Fd = -(-qEd) = qEd$$

Because force is opposite to the direction of charge motion

$$\Delta V \equiv V_B - V_A = \frac{\Delta PE}{q}$$

sign of charge q is important!

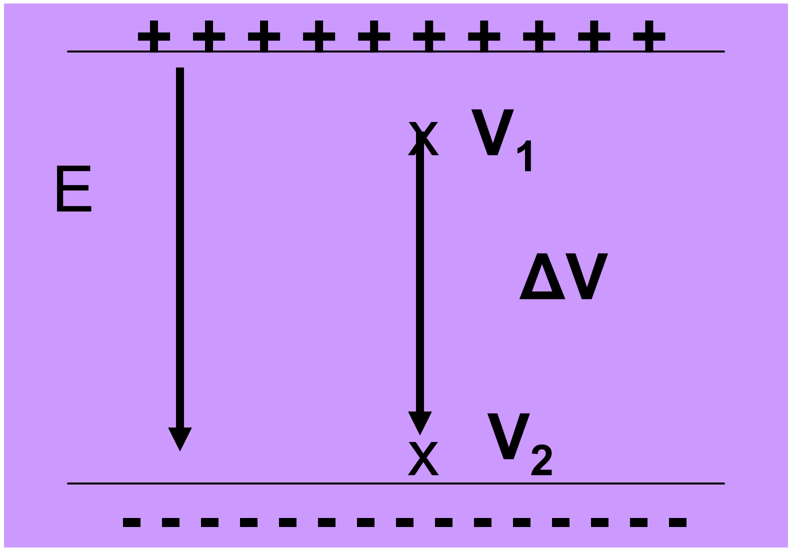
The potential difference ΔV between final point B and initial point A: V_B-V_A is defined in terms of change of PE divided by the magnitude of the charge.

Scalar quantity. Units **1V=1J/1C**

$$\frac{\Delta PE}{q} = V_B - V_A = -Ed$$

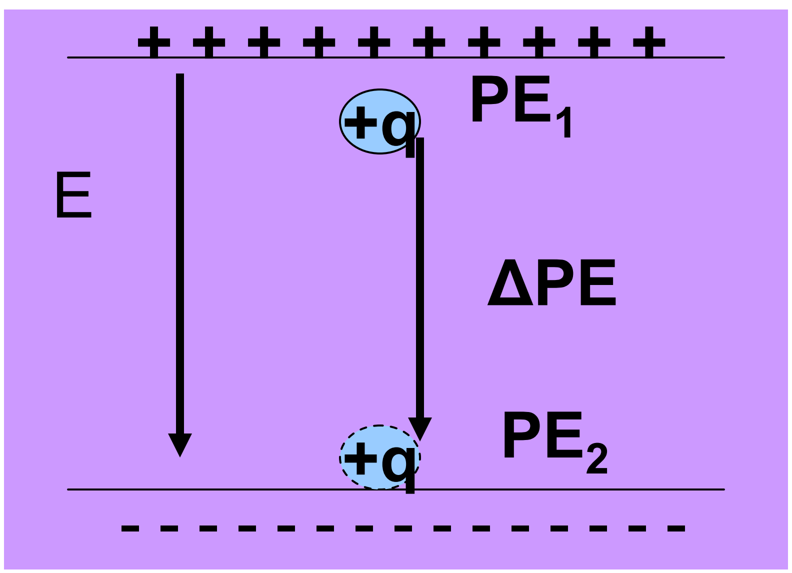
Potential difference and electric potential [16.1]

Potential: a property of the space due to charges



$$\Delta V \equiv V_B - V_A = \frac{\Delta PE}{q}$$

The potential energy is due to the charge interacting with the field.



$$\frac{\Delta PE}{q} = V_B - V_A = -Ed$$

Potential-Depends only position in the field! Units (V)

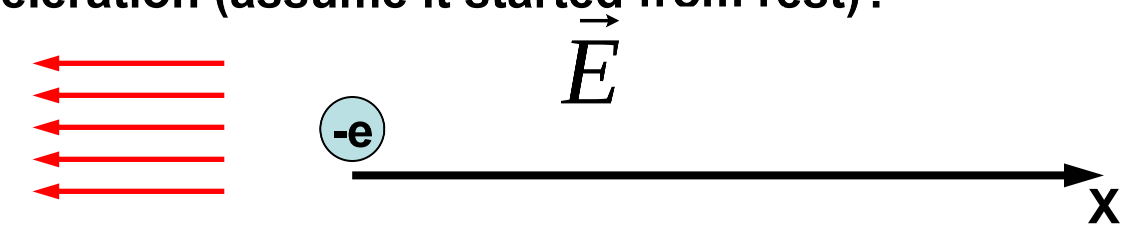
Potential Energy- Depends on the interaction of the field with a charge. Units (J)

Related by: $\Delta PE = q\Delta V$

Both PE and V are relative. Only (ΔPE and ΔV) are important!

Example

An electron in the picture tube of an older TV set is accelerated from rest through a potential difference ΔV = 5000V by a uniform electric field. What is the change in potential energy of the electron? What is the speed of the electron as a result of this acceleration (assume it started from rest)?



$$\Delta PE = q_o(\Delta V)$$ definition of electric potential

$$\Delta PE = -1.602\times10^{-19}\text{C}(+5000V) = -8.0\times10^{-16}\text{J}$$

$$\tfrac{1}{2}mv^2 = -\Delta PE \qquad v^2 = \frac{-2(\Delta PE)}{m}$$

$$v = \sqrt{\frac{-2(\Delta PE)}{m}} = \sqrt{\frac{-2(-8.0\times10^{-16}\text{J})}{9.11\times10^{-31}\text{kg}}} = 4.2\times10^{7}\,\text{m/s}$$

Potential due to a point charge [16.2]

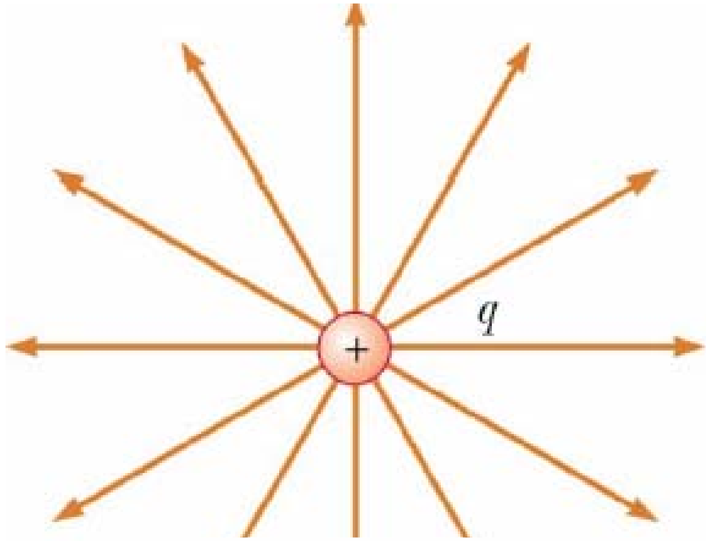
$$\frac{\Delta PE}{q} = V_B - V_A = -Ed$$

$$E = \frac{k_e q}{r^2}$$

↓

$$V = \frac{k_e q}{r} \quad \text{[Eq. 16.4]}$$

V=0 at $r = \infty$



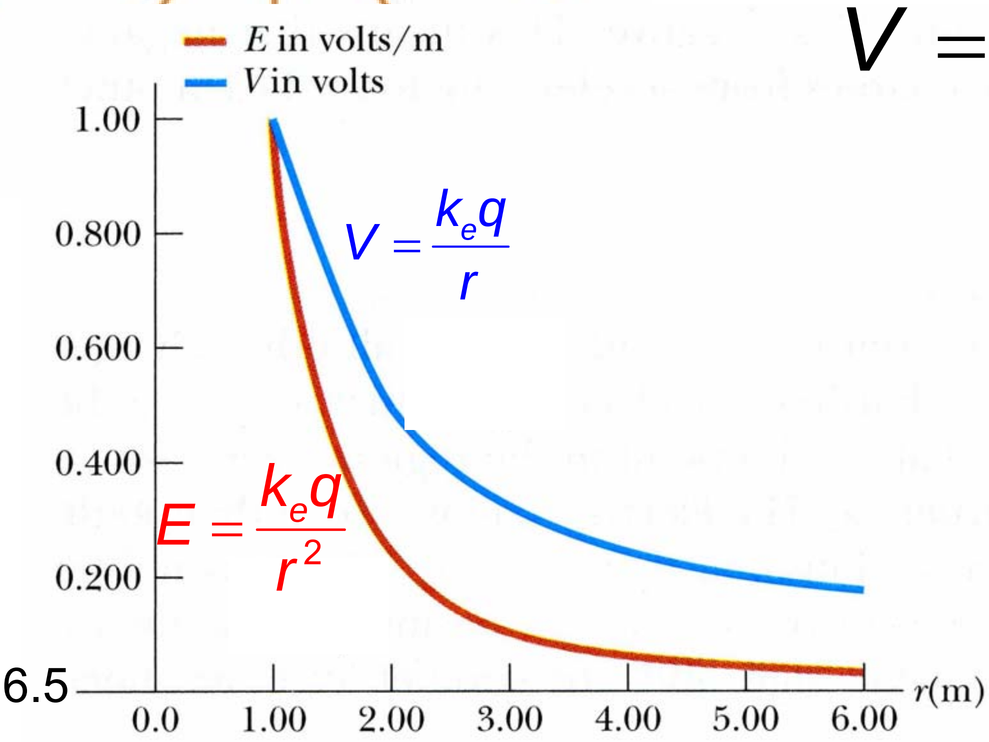


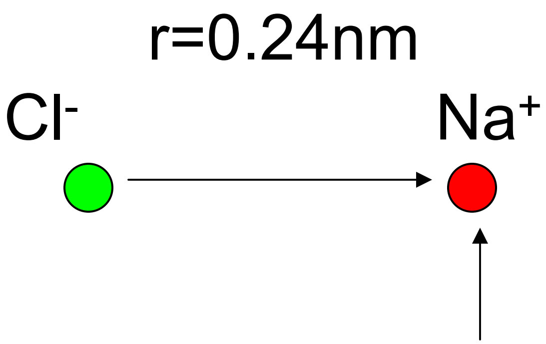
Fig.16.5

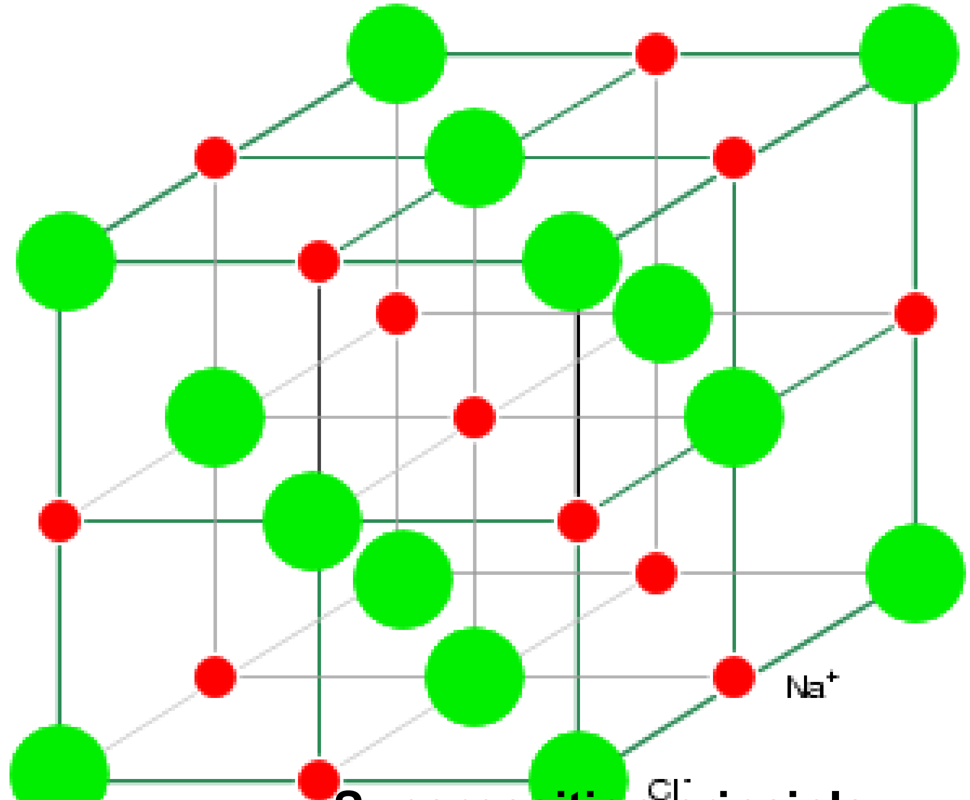
→ The electric potential or work per unit charge required to move a test charge from infinity to distance r from the positive point charge as the positive charge moves close to q.

Potential is a scalar

Potential due to a point charge [16.2]

In a crystal of Na^+ Cl^- the distance between the ions is 0.24 nm. Find the potential due to Cl^- at the position of the Na^+. Find the electrostatic energy of the Na^+ due to the interaction with Cl^-.





$$V = \frac{k_e q}{r}$$

PE=qV =1.6x10^{-19}x-6.0 = -9.6x10^{-19}J

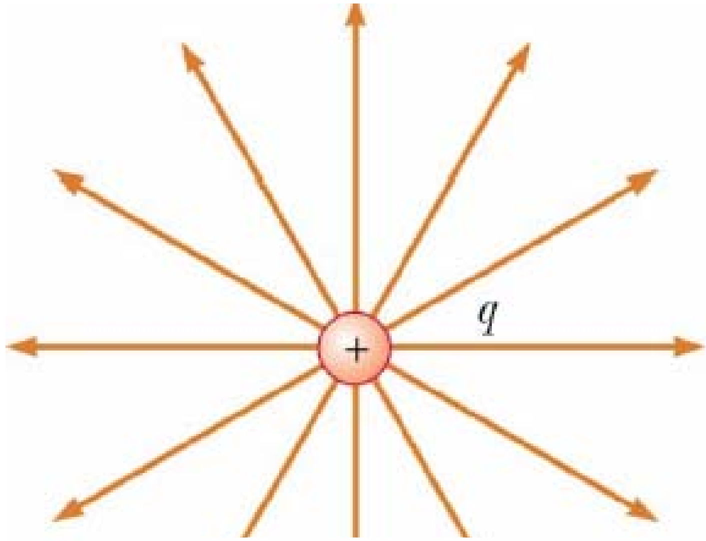
Superposition principle: the total electric potential at P due to multiple point charges is the algebraic sum of the electric potentials due to the individual charges

ELECTRON VOLT (convenient unit for atomic physics)

1eV=1.6x10^{-19} J

PE=-6.0 eV

Potential due to a point charge [16.2]



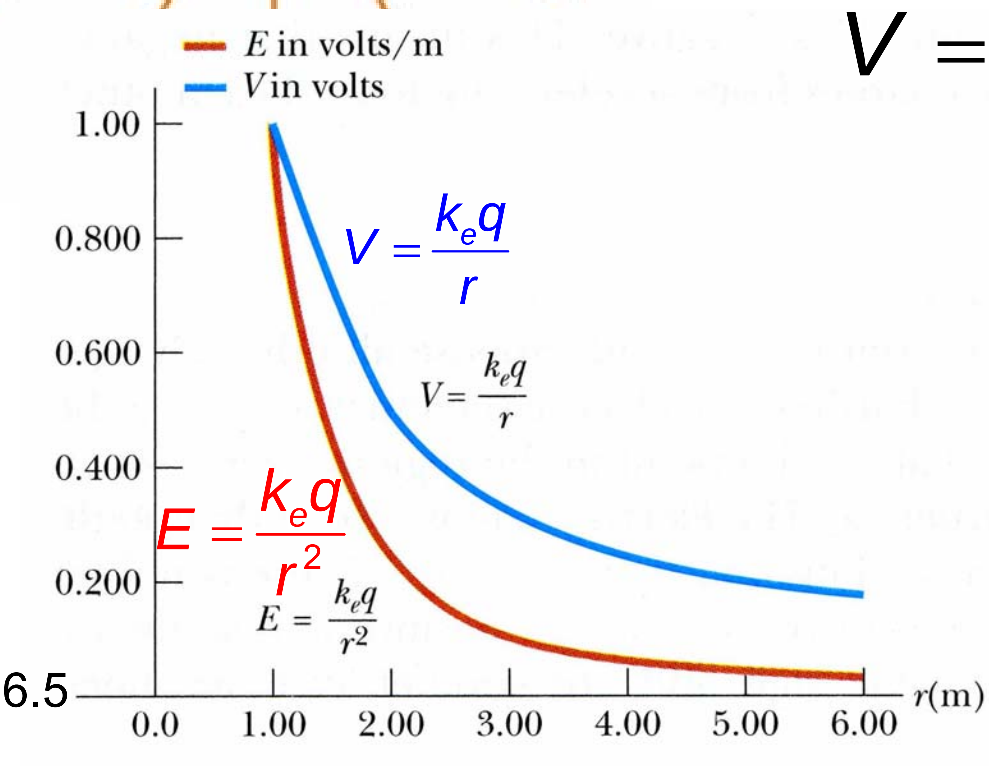


Fig.16.5

$$E = \frac{k_e q}{r^2}$$

$$\downarrow$$

$$V = \frac{k_e q}{r}$$ [Eq. 16.4]

V=0 at $r = \infty$

Superposition principle:
the total electric potential at P due to multiple point charges is the algebraic sum of the electric potentials due to the individual charges

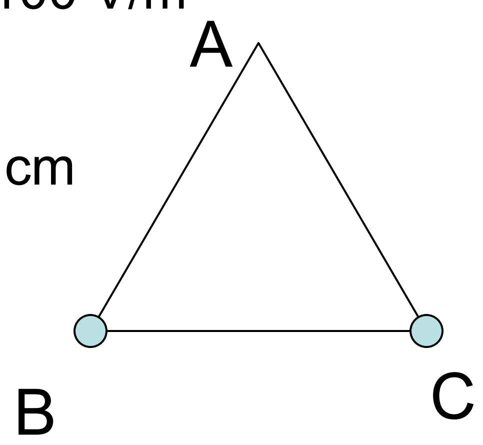
Potential is a scalar

Electric potential: superposition [16.2]

Two charges of +q each are placed at corners of an equilateral triangle, with sides of 10 cm. If the Electric field due to each charge is 100 V/m at the A find the potential at A.

E_A = 100 V/m

d=10 cm



V at A due to each charge

$$E = \frac{k_e q}{r^2}$$

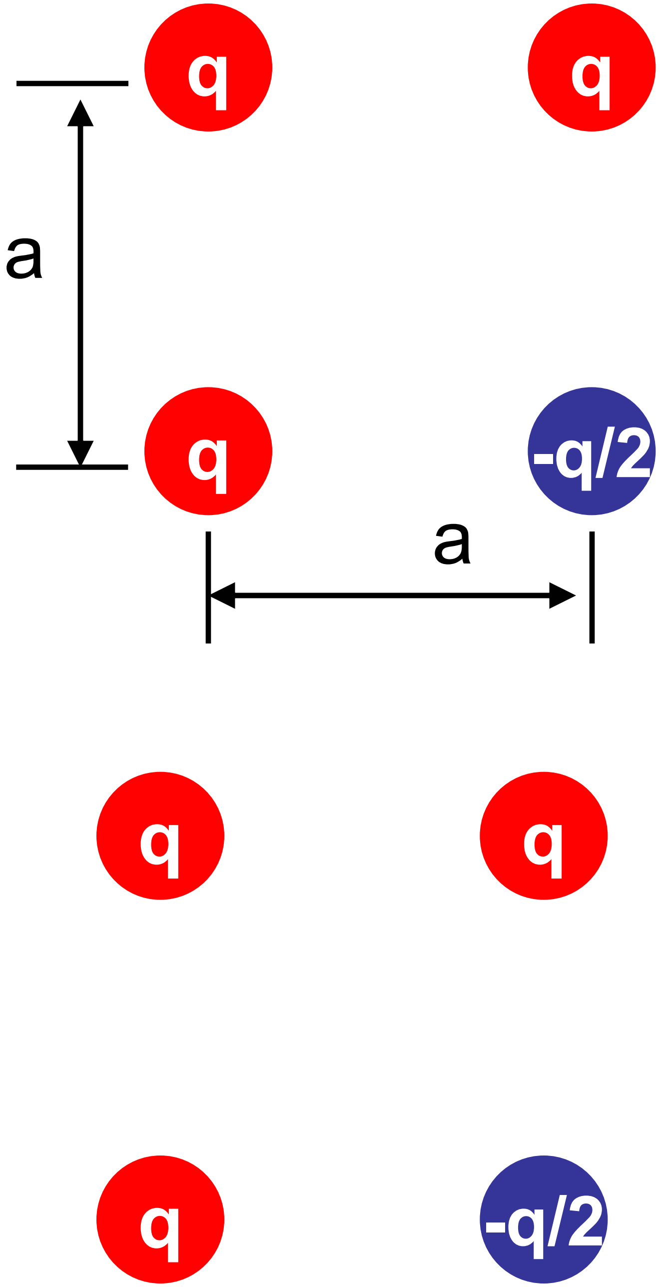
$$V = \frac{k_e q}{r}$$

$$\longrightarrow \quad \frac{E}{V} = \frac{1}{r}$$

$$V = Ed = 10V$$

$$V_{total} = V^B{}_A + V^C{}_A = 2V = 20\ V$$

ENERGY of a CHARGE DISTRIBUTION [16.2]



How much energy is stored in this square charge distribution?

$$W_1 = ? \qquad W_2 = k\frac{q^2}{a}$$

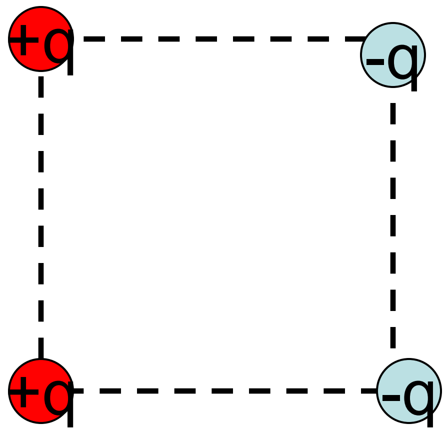
$$W_3 = k\left(\frac{q^2}{a} + \frac{q^2}{a\sqrt{2}}\right)$$

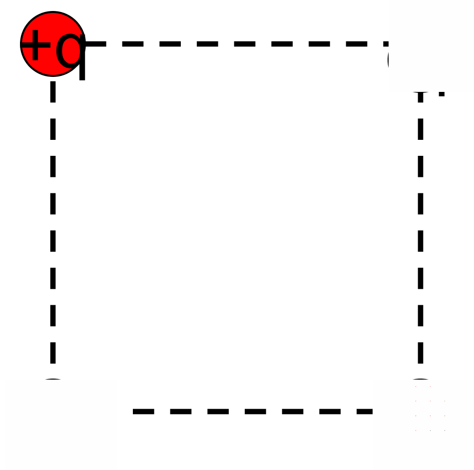
$$W_4 = k\left(-\frac{q^2}{2a} - \frac{q^2}{2a} - \frac{q^2}{2a\sqrt{2}}\right)$$

$$W = W_2 + W_3 + W_4 = \frac{kq^2\left(2\sqrt{2}+1\right)}{2a\sqrt{2}}$$

ENERGY of a CHARGE DISTRIBUTION [16.2]

Which of the charge distributions is the most stable? (has the lowest PE)





STABLE

$$PE = 0 + k\frac{q^2}{a} - k\frac{q^2}{a} - k\frac{q^2}{a\sqrt{2}} - k\frac{q^2}{a} + k\frac{q^2}{a} - k\frac{q^2}{a\sqrt{2}}$$

$$PE = -k\frac{2q^2}{a\sqrt{2}}$$

$$PE = 0 - k\frac{q^2}{a} - k\frac{q^2}{a} + k\frac{q^2}{a\sqrt{2}} - k\frac{q^2}{a} - k\frac{q^2}{a} + k\frac{q^2}{a\sqrt{2}}$$

$$PE = -k\frac{4q^2}{a} + k\frac{2q^2}{a\sqrt{2}}$$

Potentials and charge conductors [16.3]

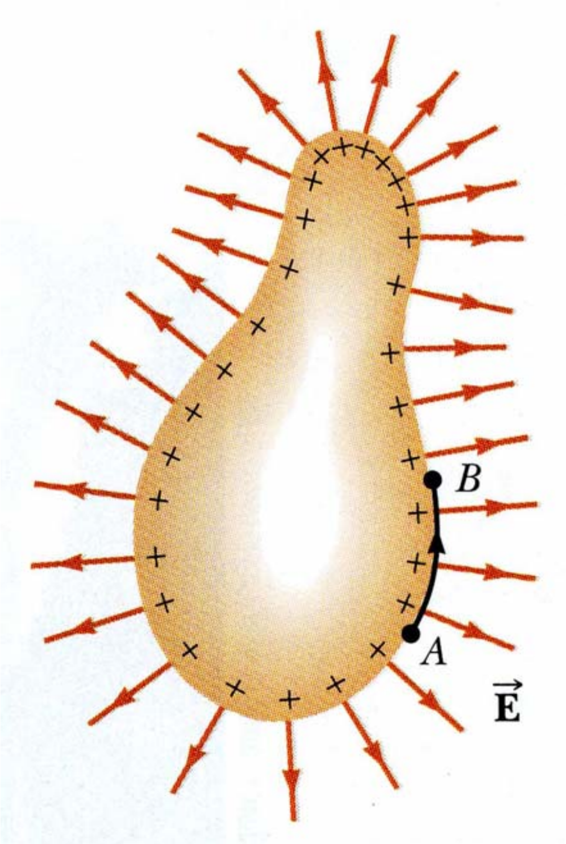


Fig. 16-9

Work on a charge done by electric force: $W=-\Delta PE$

Points A and B: $\Delta PE=q(V_B-V_A)$

$W=-q(V_B-V_A)$

No net work is required to move charges between two points at the same V!

Charged conductor: all points on the surface have the same V. Why?

At equilibrium:

E is perpendicular to a path between A&B → W=0

$V_A = V_B$

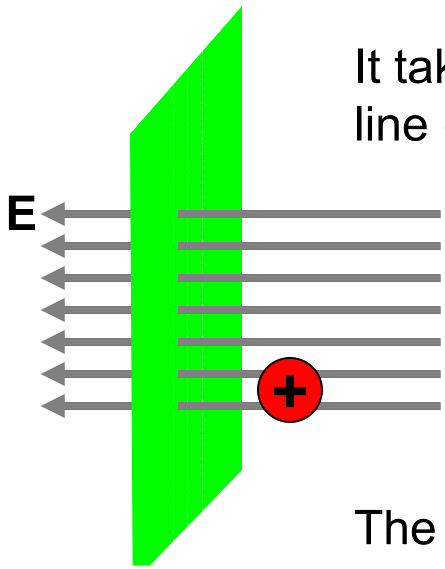
The electric potential is constant everywhere on the surface of a charge conductor in equilibrium.

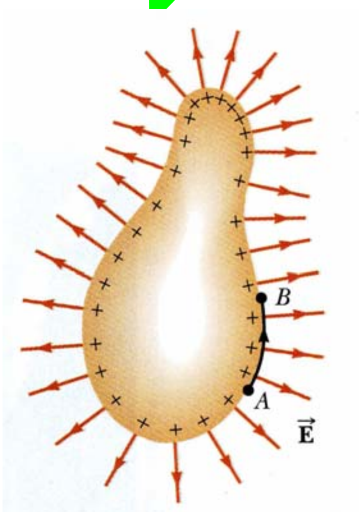
The electric potential is constant everywhere inside a conductor and is equal to the value at the surface.

Equipotential surfaces [16.4]

An equipotential surface is a surface on which all points are the same potential.

It takes no work to move a particle along an equipotential surface or line (assume speed is constant).

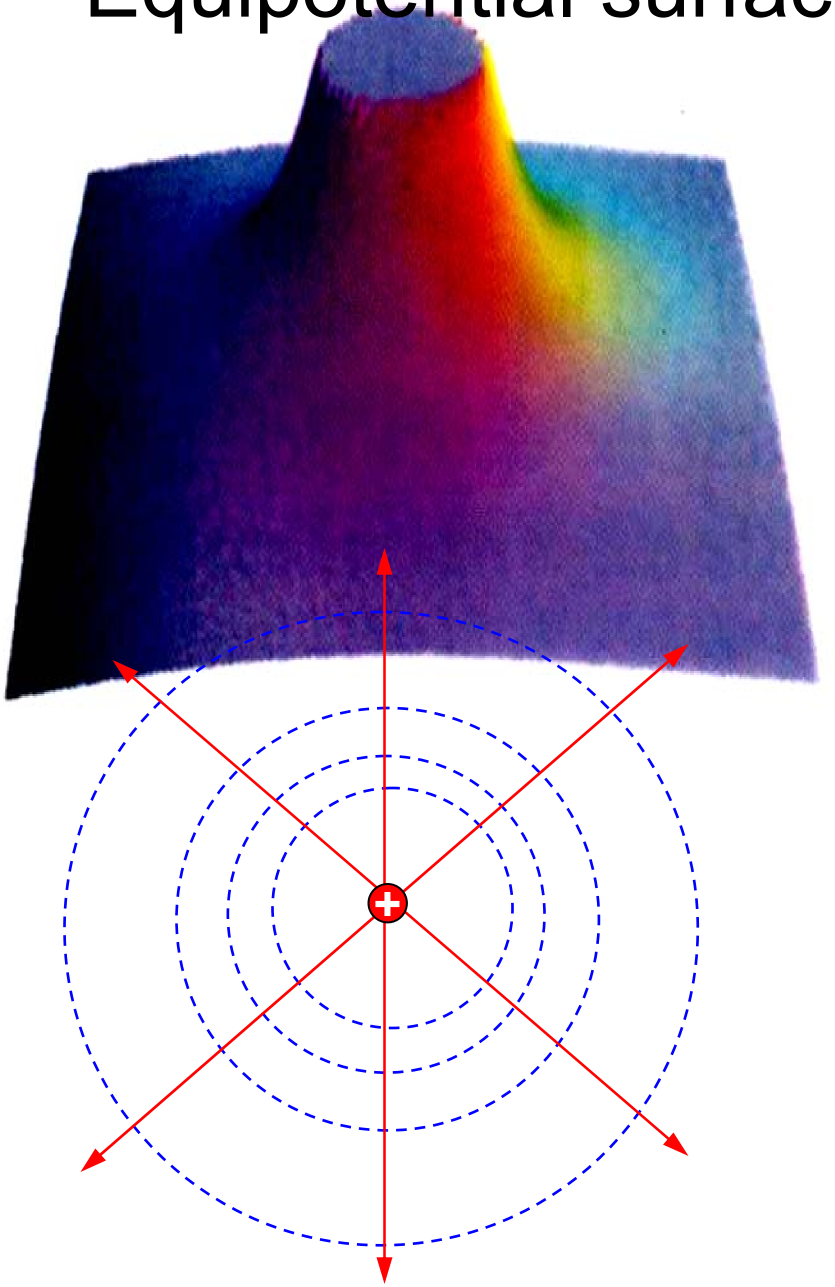


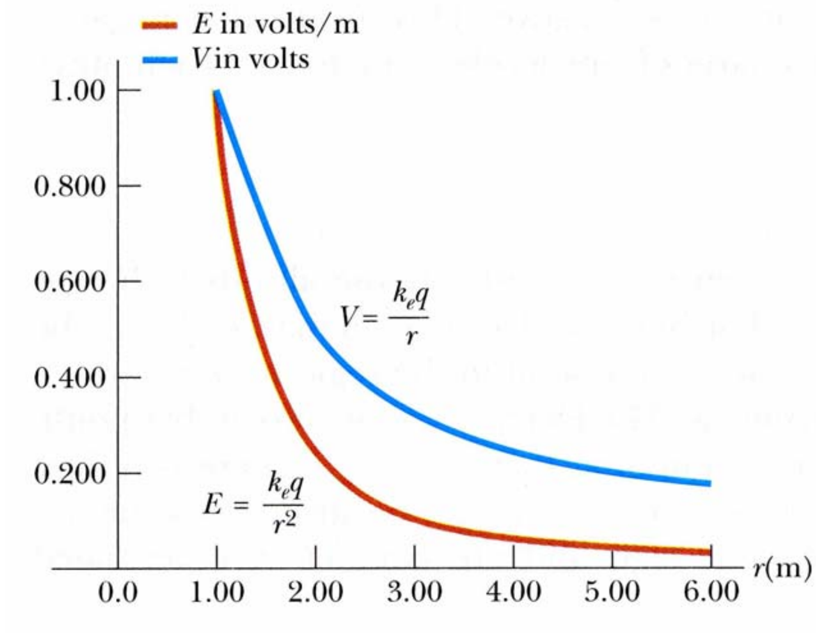


The electric field at every point on an equipotential surface is perpendicular to the surface.

Equipotential surfaces are normally thought of as being imaginary; but they may correspond to real surfaces (like the surface of a conductor).

Equipotential surfaces: point charge [16.4]



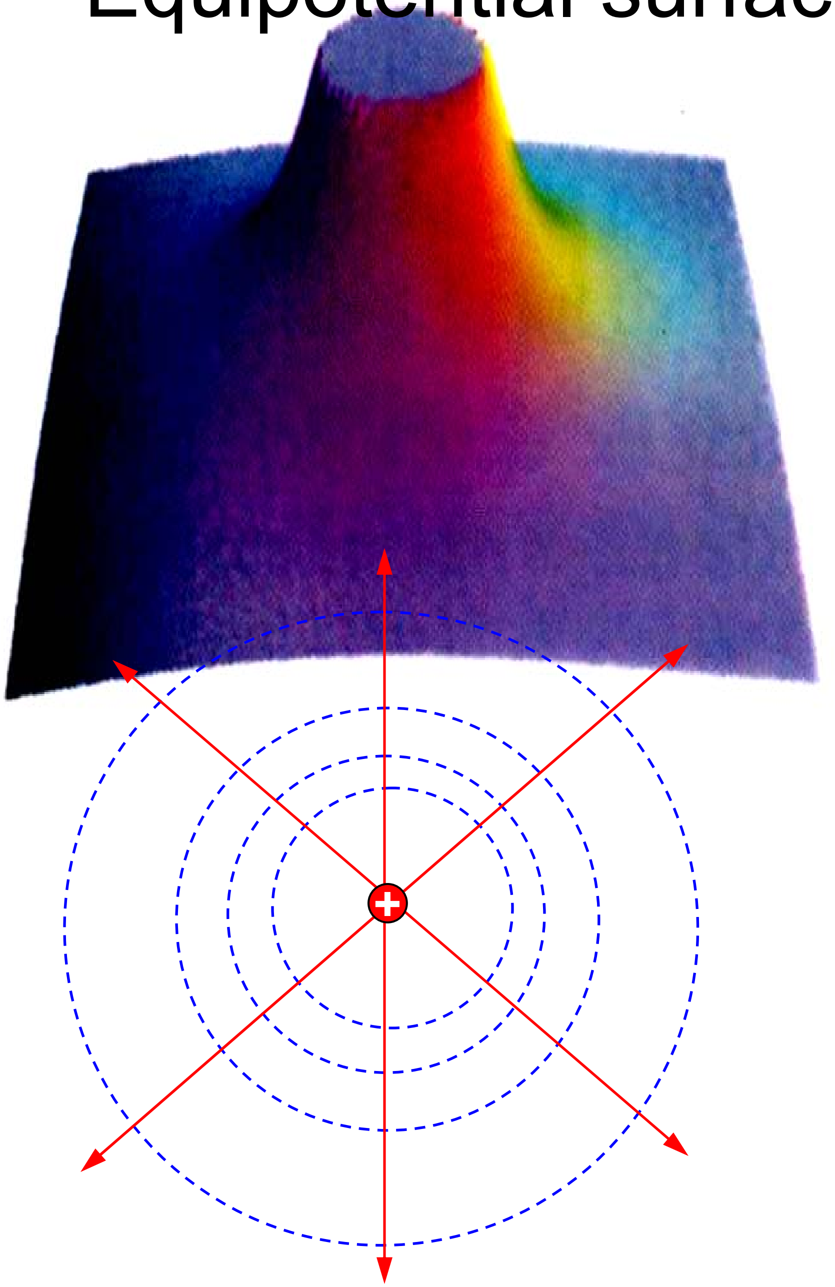


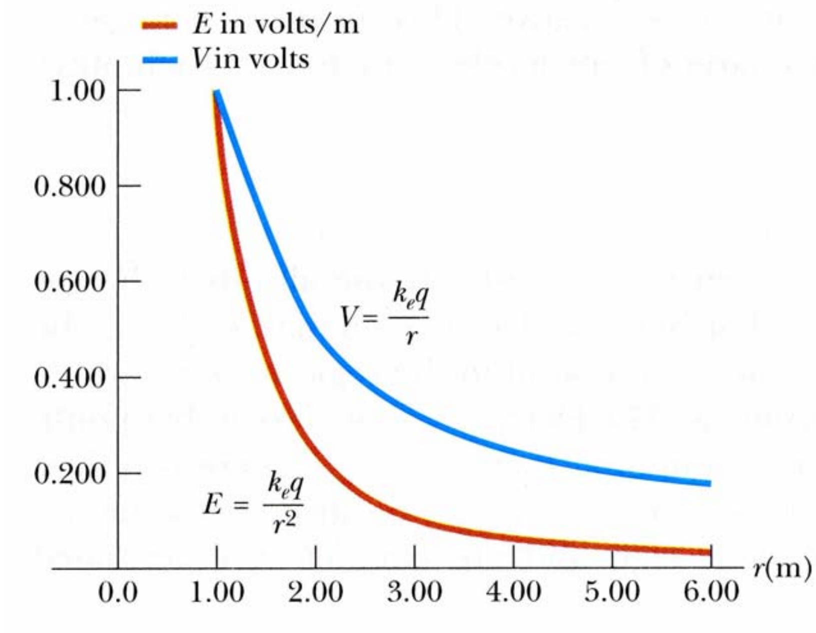
Point charge: equipotential surfaces are all spheres centered on the charge.

We represent these spheres with equipotential lines.

Note that the field lines are perpendicular to the equipotential lines at every crossing.

Equipotential surfaces: point charge [16.4]





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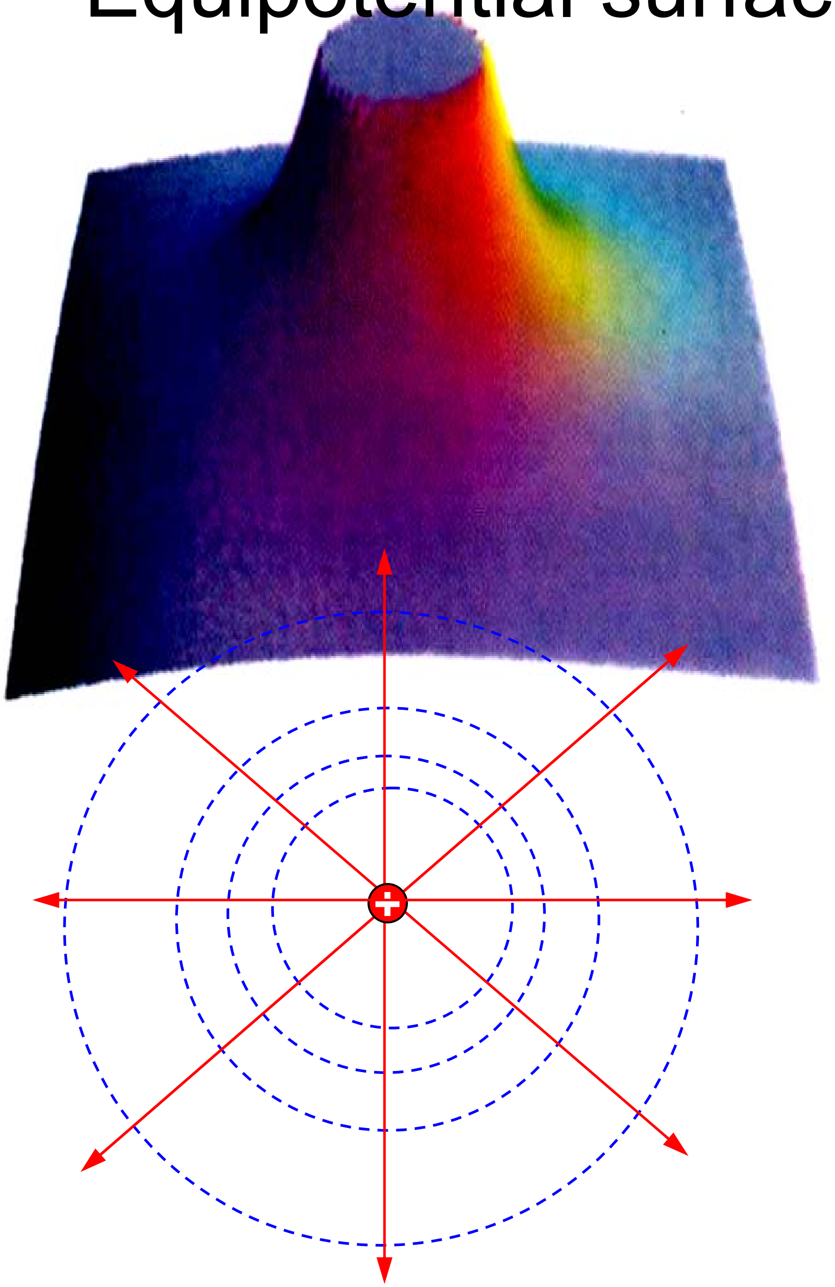
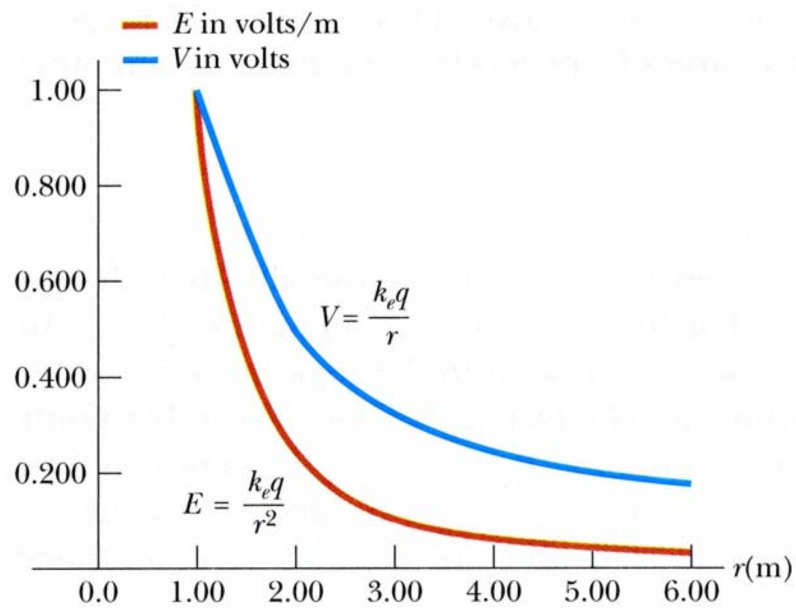
Equipotential surfaces: point charge [16.4]



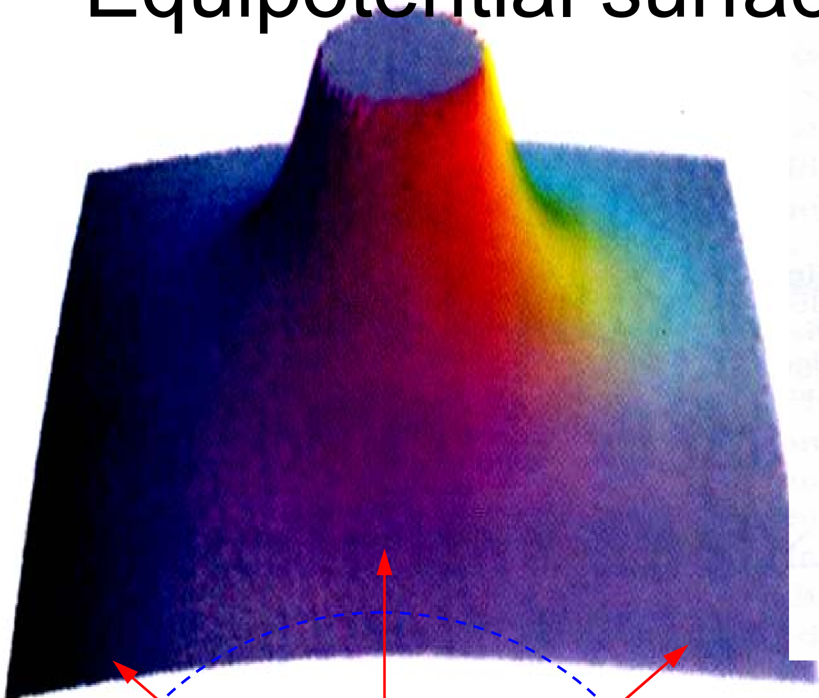


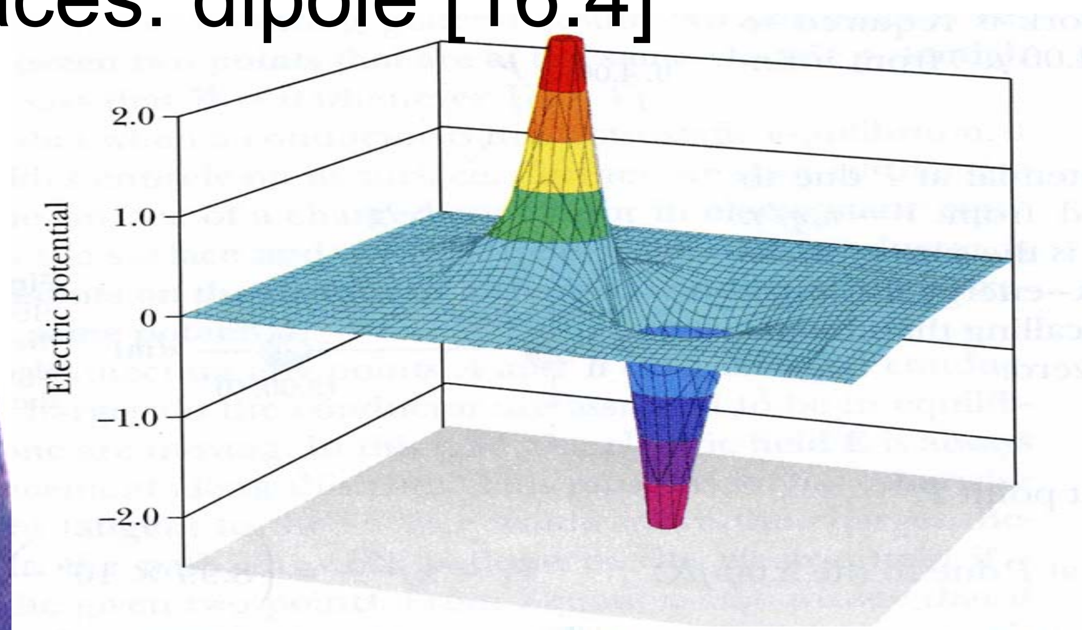
Point charge: equipotential surfaces are all spheres centered on the charge.

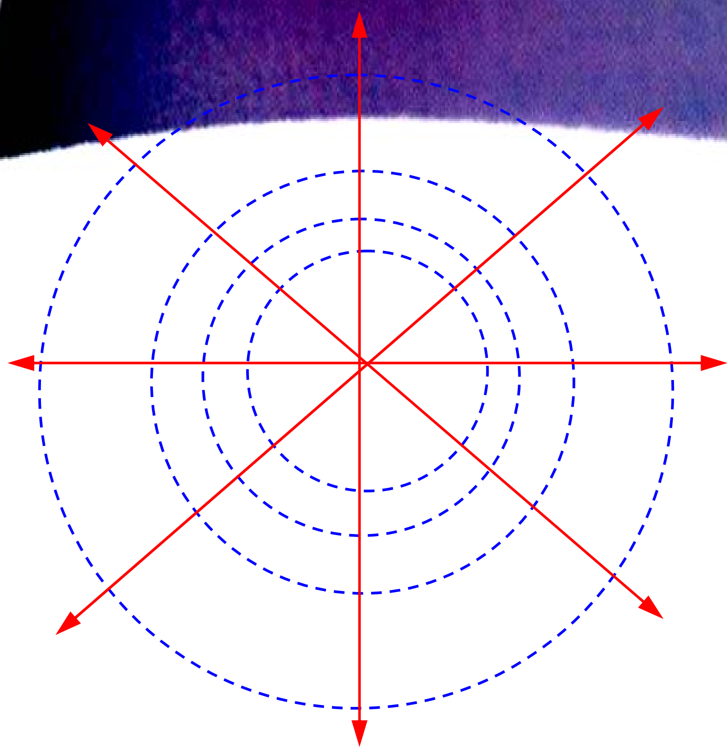
We represent these spheres with equipotential lines.

Note that the field lines are perpendicular to the equipotential lines at every crossing.

Equipotential surfaces: dipole [16.4]







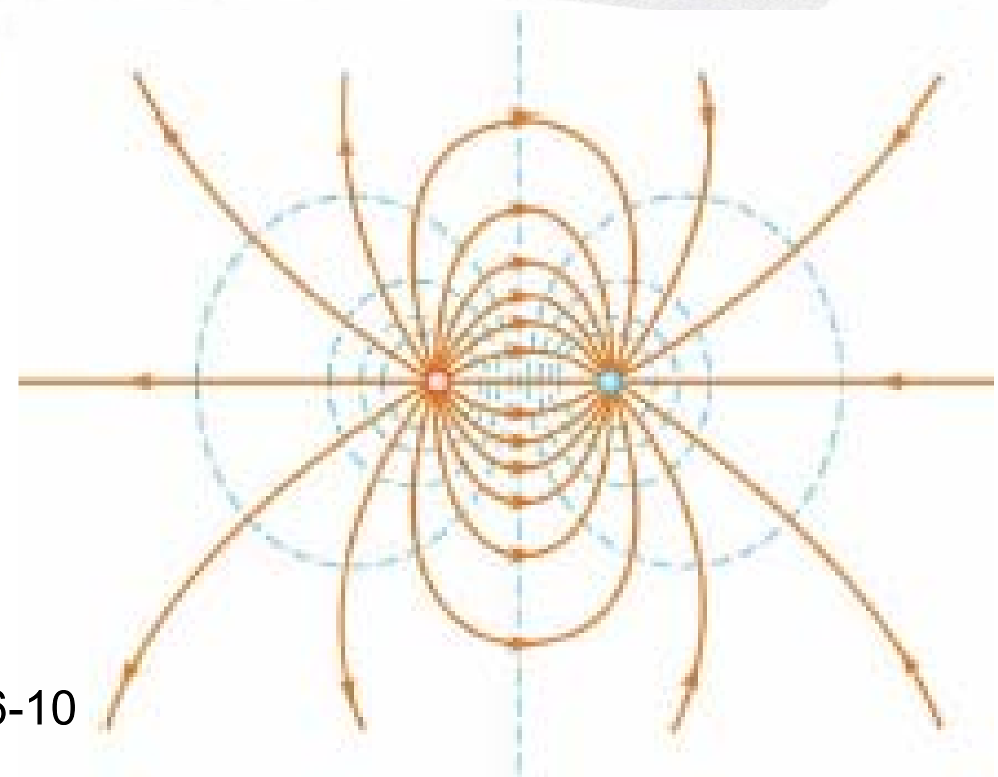
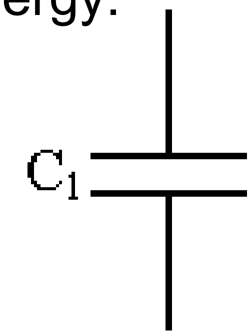


Fig.16-10

Capacitance [16.6]

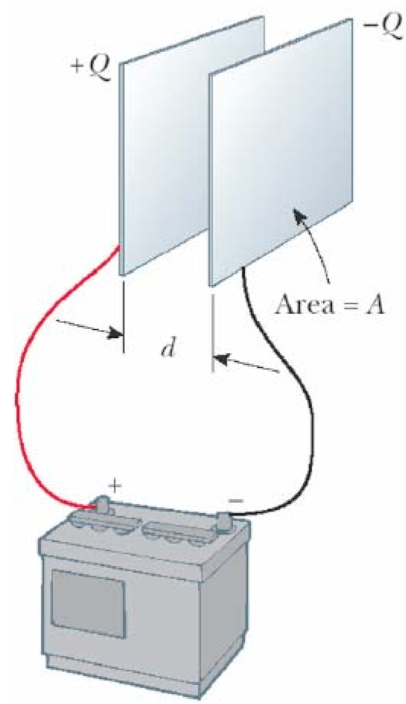
Capacitor

a device for storing charge and energy,
can be discharged rapidly to release energy.



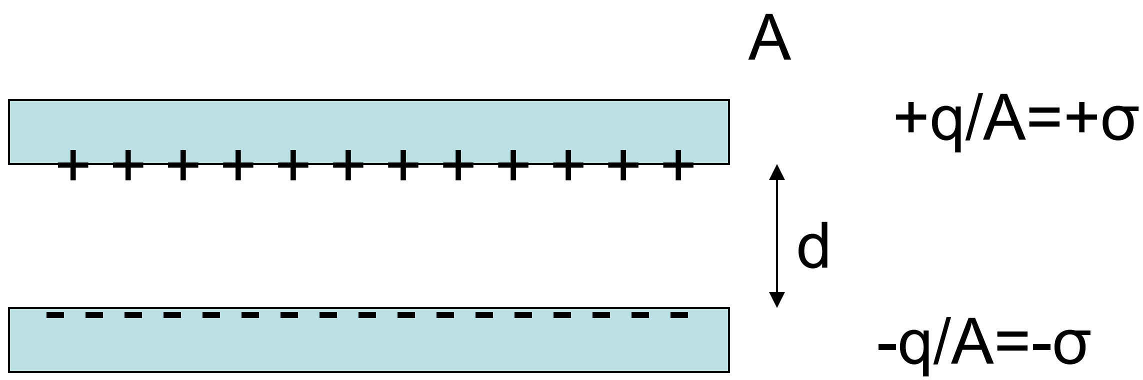
Applications

- Camera flash
- Defibrillators
- Electronic devices
- Computer memories (store information)
- Many more!



Parallel plate capacitor

two “infinite” planes of charge area A separated by distance d where d<< A, carry charge +q, -q

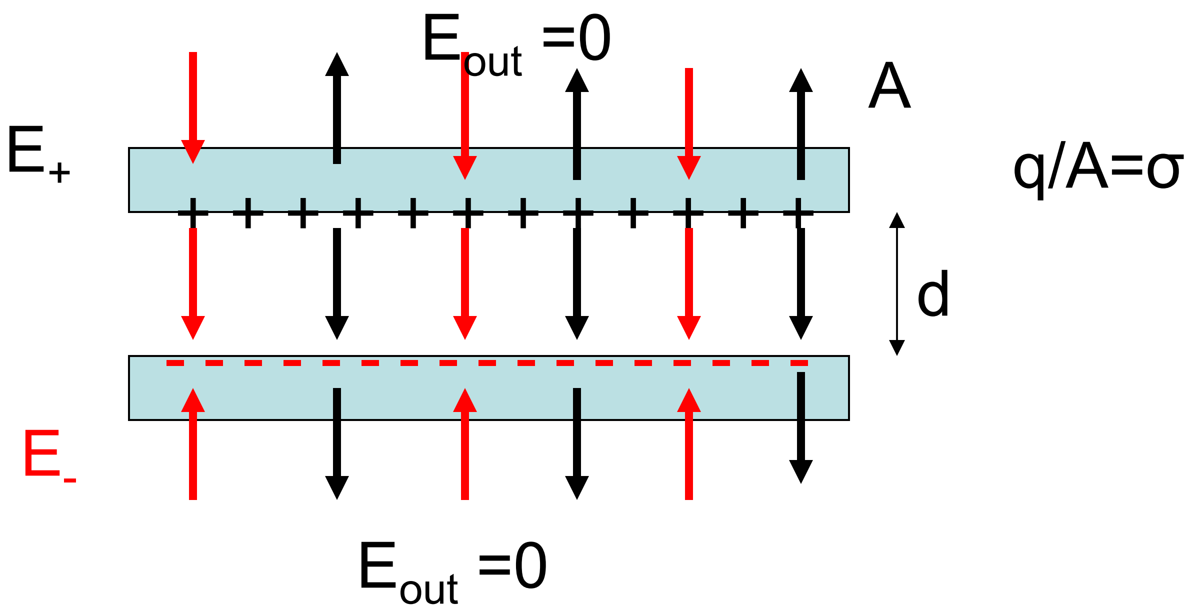


The charges are at the inner surface of the capacitor

Field inside the capacitor plates

By superposition of fields due to sheet of charge

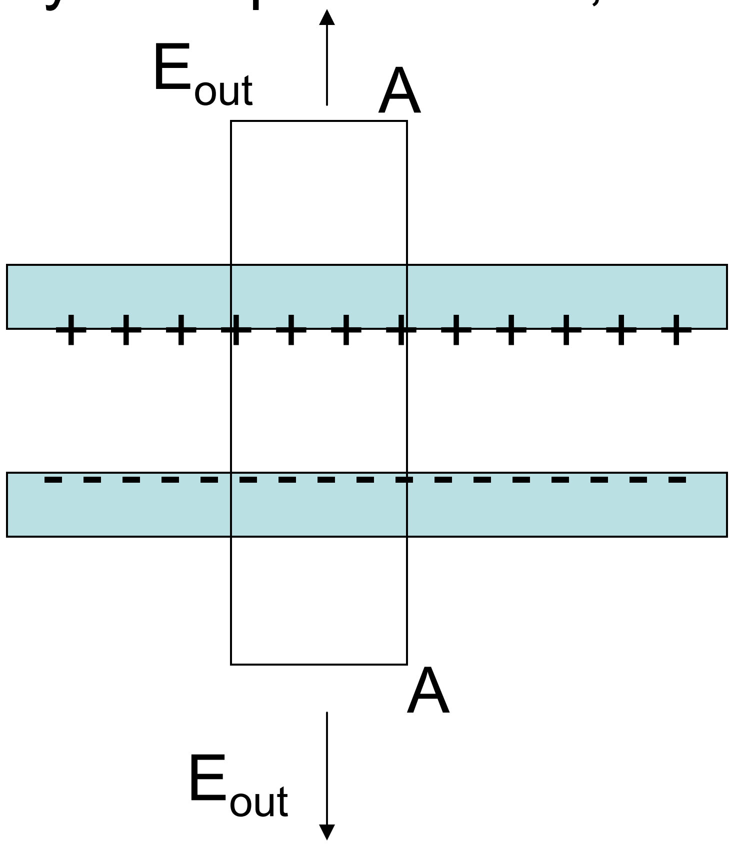
$$E_{in} = \frac{\sigma}{\varepsilon_o}$$



$$E_{in} = E_+ + E_- = 2\frac{\sigma}{2\varepsilon_o} = \frac{\sigma}{\varepsilon_0}$$

E field outside the capacitor using Gauss's Law

use a cylinder as the Gaussian surface, ends of the cylinder parallel to A, sides perpendicular to A



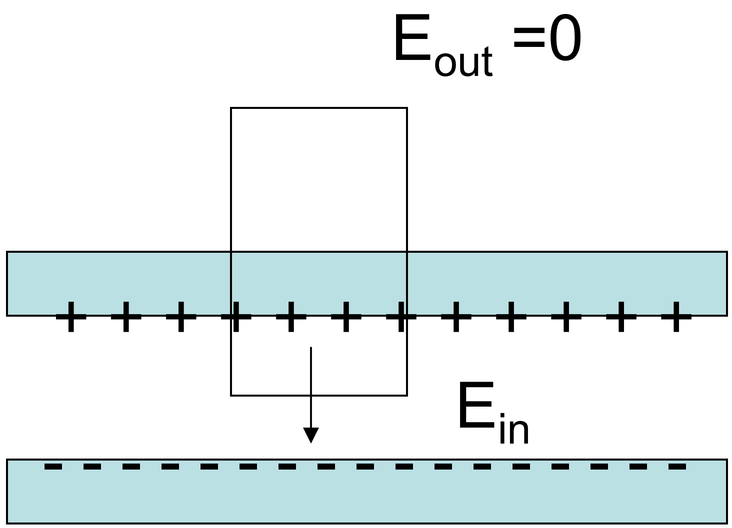
$$\Phi_E = \frac{q - q}{\varepsilon_o} = 0 = 2E_{out}A$$

$$E_{out} = 0$$

The charge in the Gaussian surface is zero.

The E field outside the capacitor is zero

E field inside the capacitor using Gauss's Law

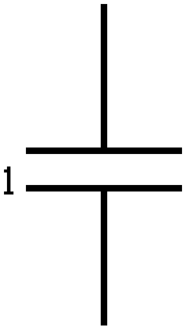


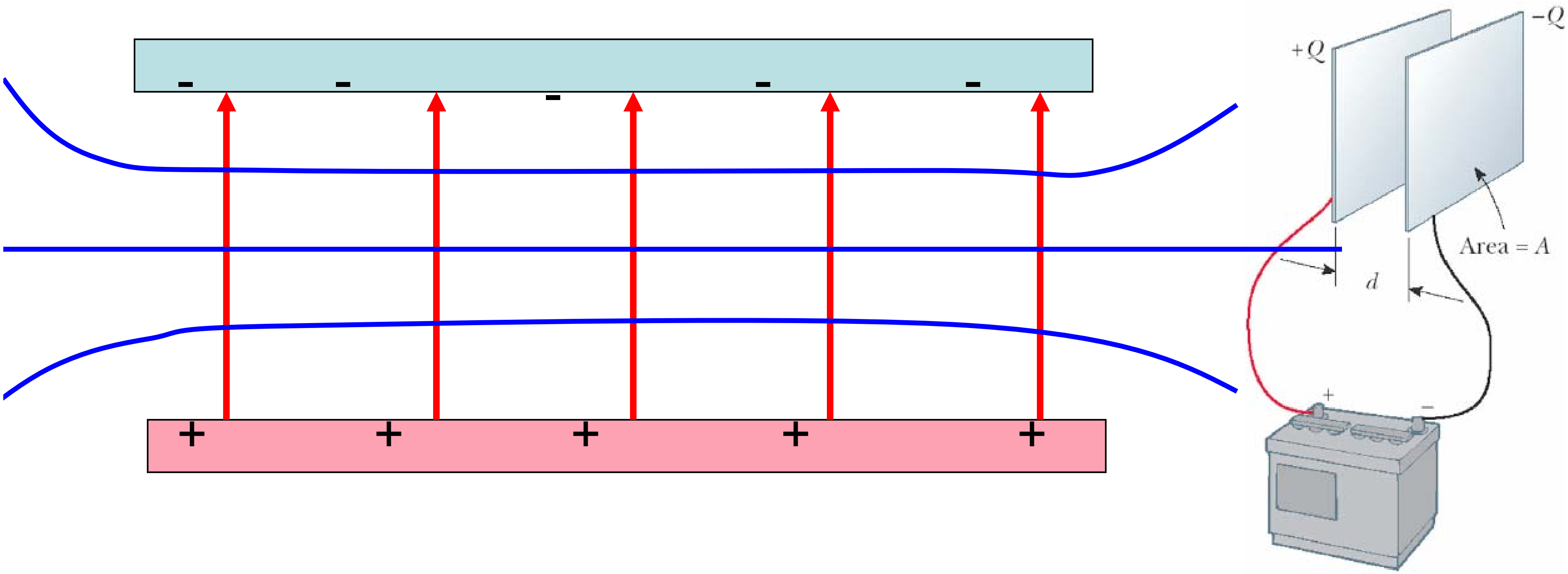
$$\Phi_E = E_{in}A = \frac{q}{\varepsilon_o}$$

$$E_{in} = \frac{q}{A\varepsilon_o} = \frac{\sigma}{\varepsilon_o}$$

Capacitance [16.6]

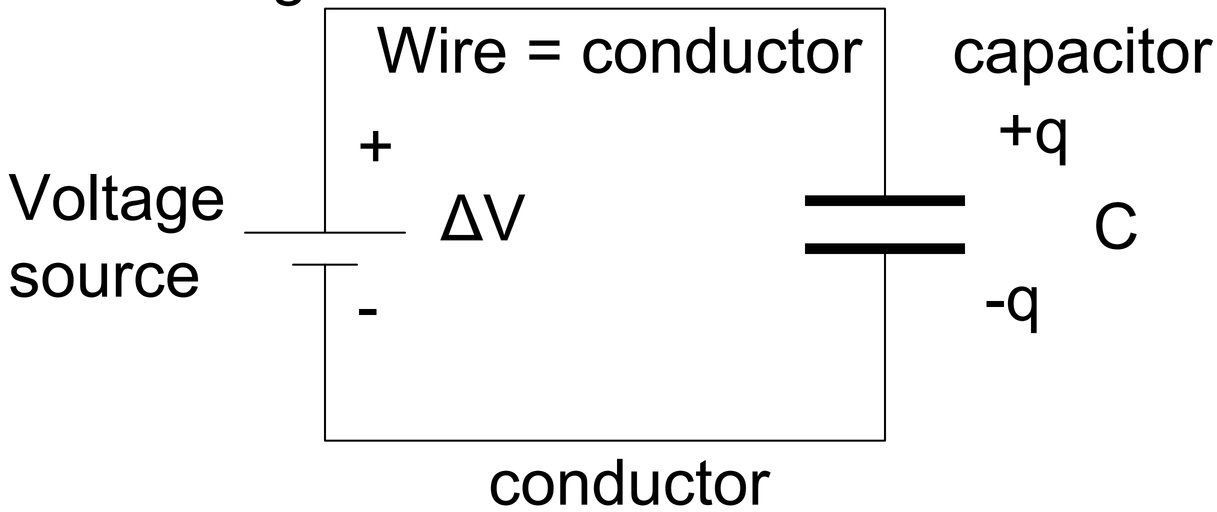
Parallel plate capacitor





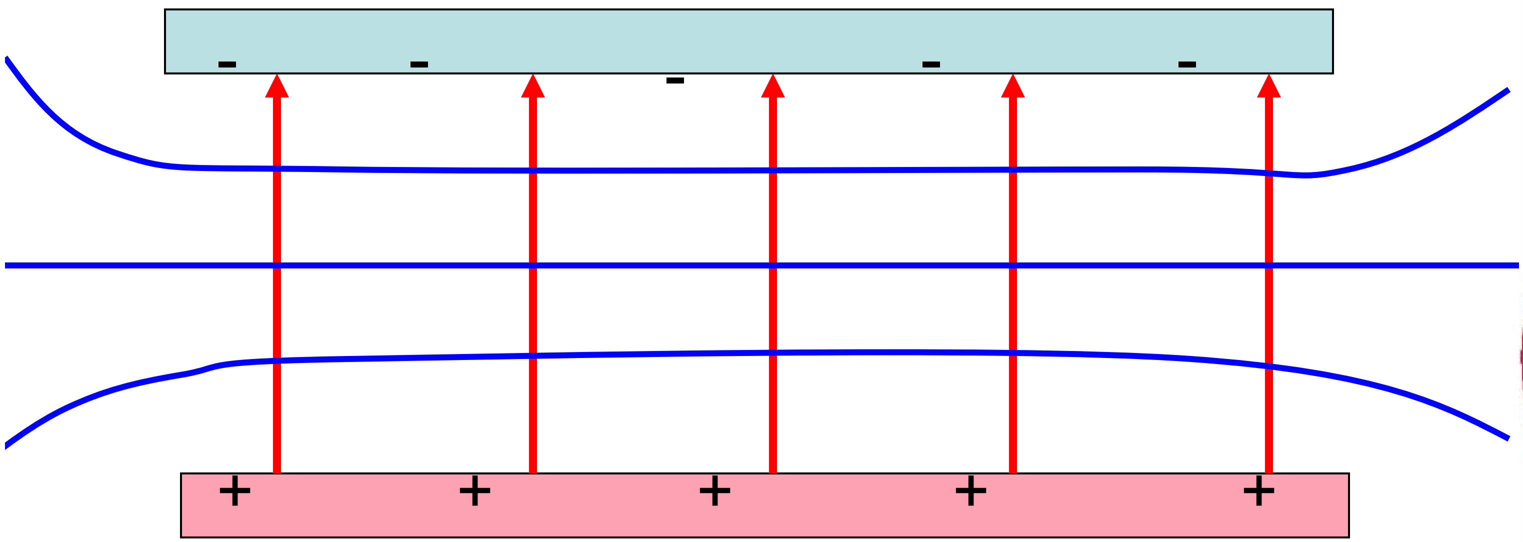
Capacitance [16.6]

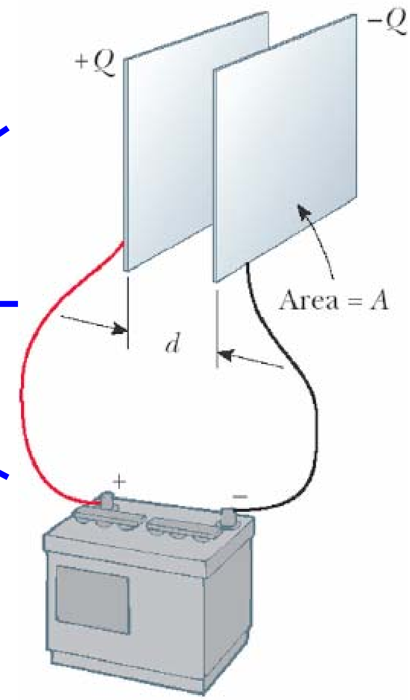
Circuit Diagram:



$$C = \frac{Q}{\Delta V}$$

$$C = \frac{[Coulomb]}{[Volt]} = 1\,\mathrm{F}$$

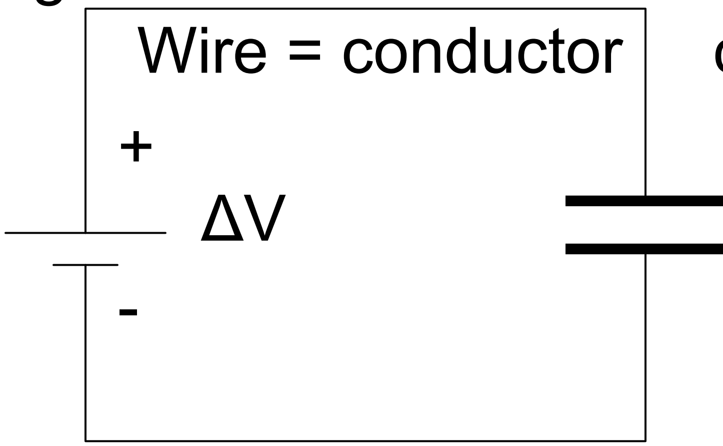




Work is done to separate charges:
Capacitors stores electrical energy

Parallel plate capacitor [16.7]

Circuit Diagram:



$$C = \frac{Q}{\Delta V}$$

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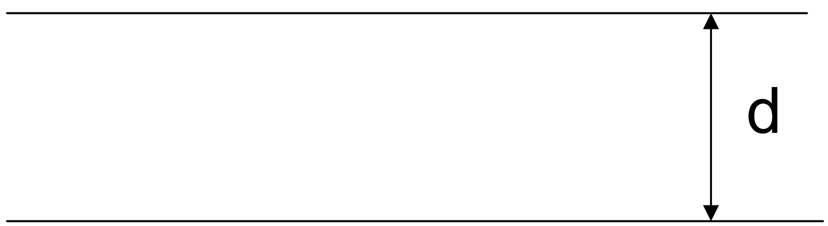


Gauss' law: $$E = \frac{\sigma}{\varepsilon_o} = \frac{q}{A\varepsilon_o} = \frac{\Delta V}{d}$$

E field increases with charge density

rearrange $$\frac{q}{\Delta V} = \frac{A\varepsilon_o}{d}$$

$$C = \frac{A\,\varepsilon_o}{d}$$

to increase C:
Increase A
Decrease d

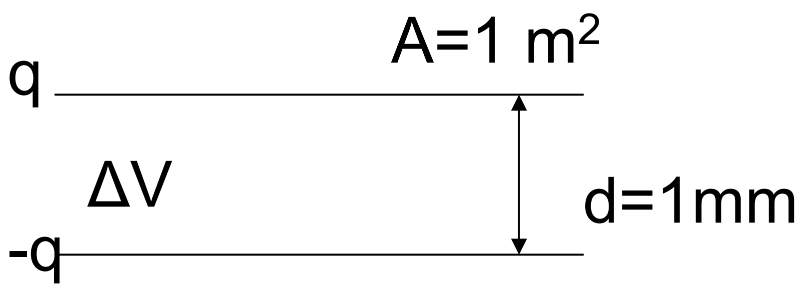
Parallel plate capacitor [16.7]

Example: A parallel plate capacitor with 2 plates each with area 1.0 m^2 separated by a distance of 1.0 mm holds +q,-q, q=10^{-6}C

a) Find the capacitance.

b) Find the E field

C) Find ΔV across the plates



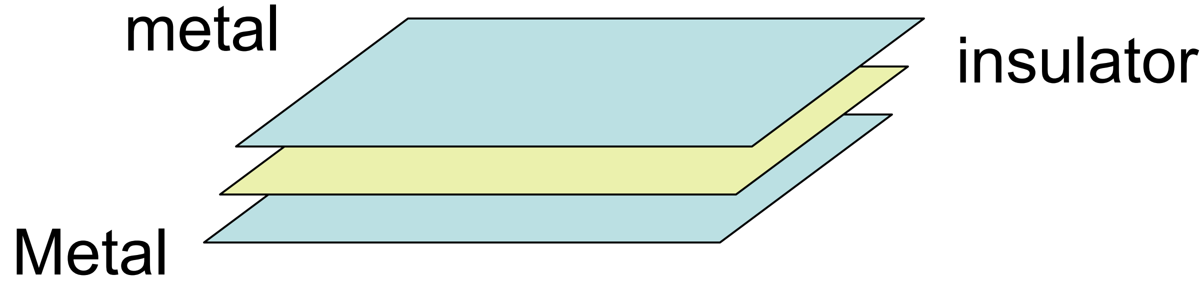
$$C = \frac{A\varepsilon_o}{d} = \frac{1(8.9x10^{-12})}{0.001} = 8.9x10^{-9}F = 8.9nF$$

$$E = \frac{q}{A\varepsilon_o} = \frac{1x10^{-6}}{(1)(8.9x10^{-12})} = 1.1x10^{5}V/m$$

$$\Delta V = Ed = 1.1x10^{5}(1x10^{-3}) = 1.1x10^{2}V$$

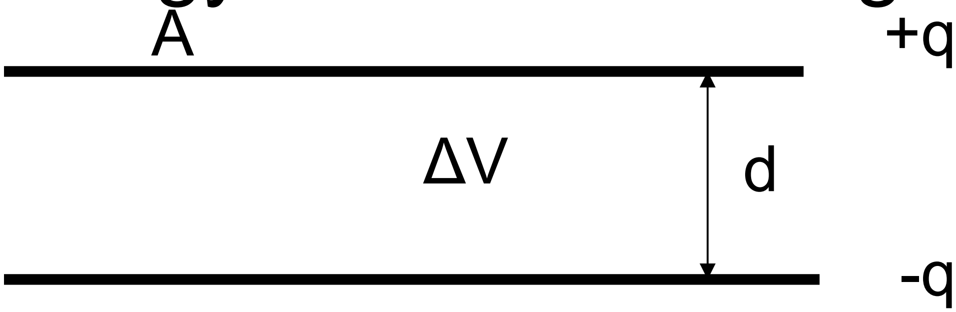
Thin film capacitors

Metal film separated by thin insulators $$C = \frac{A\,\varepsilon_o}{d}$$

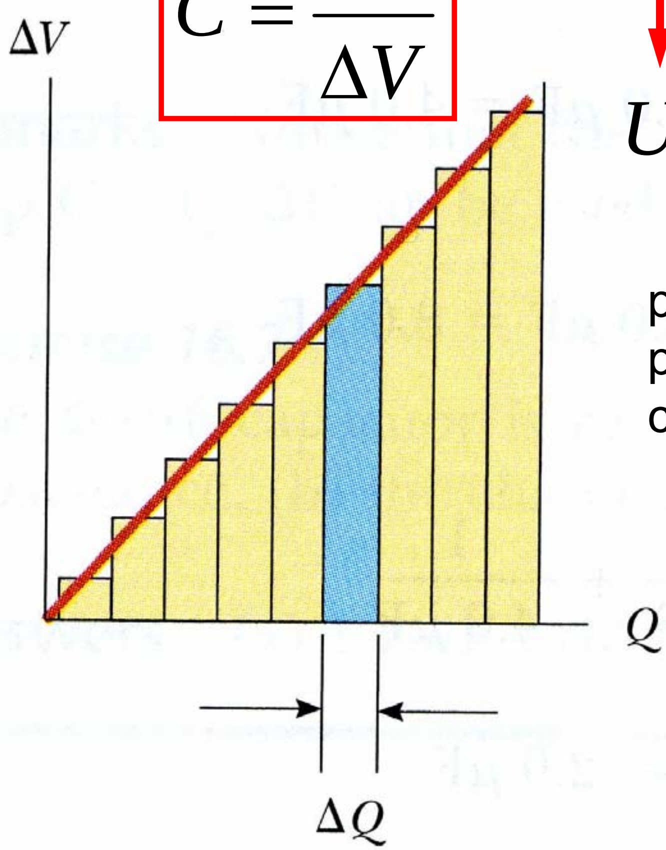


Making the area large and the insulating gap small increases C

Energy stored in a charged capacitor [16.9]



$$C = \frac{Q}{\Delta V}$$



Energy stored

$$U = \frac{1}{2} Q\Delta V = \frac{1}{2} C(\Delta V)^2 = \frac{Q^2}{2C}$$

parallel plate capacitor

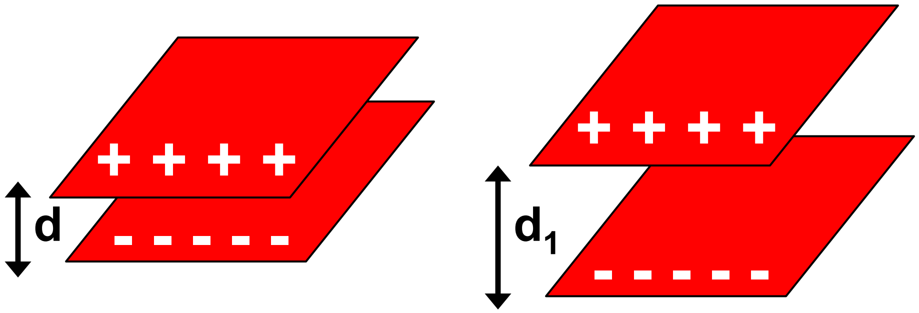
$$C = \frac{A\varepsilon_o}{d}$$

$$U = \frac{1}{2}\frac{A\varepsilon_0}{d}(Ed)^2$$

$$U = \frac{1}{2}\varepsilon_0 E^2 Ad$$

Understanding capacitors

Suppose the capacitor shown here is charged to *Q* and then the battery is *disconnected*. Now suppose I pull the plates further apart so that the final separation is *d*1.



- **How do the quantities Q, U, C, V, E change?**

$$U = \frac{1}{2} Q \Delta V$$

- Q: **= const: no way for charge to leave.**
- U: **increases.. add energy to system by separating**
- C: **decreases.. since energy ↑, but Q remains same**
- V: **increases.. since C ↓, but Q remains same**
- E: **remains the same... depends only on charge density**

$$U = \frac{Q^2}{2C}$$

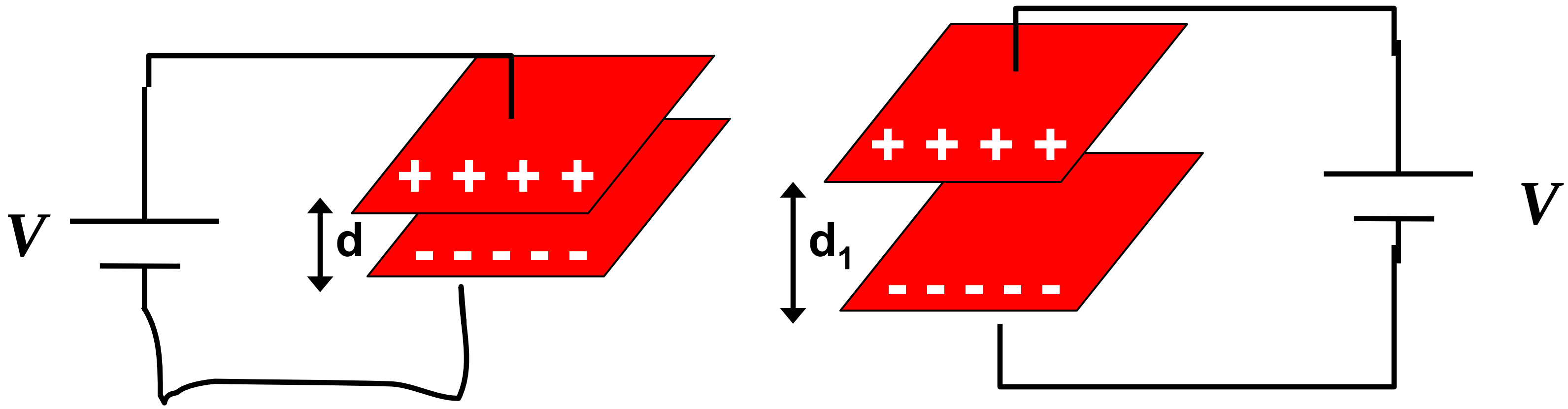
$$\Delta V = \frac{Q}{C}$$

$$C_1 = \frac{d}{d_1} C \qquad V_1 = \frac{d_1}{d} V \qquad U_1 = \frac{d_1}{d} U$$

Understanding capacitors

Suppose the battery (*V*) is kept attached to the capacitor. Again pull the plates apart from *d* to *d*1.

- **How do the quantities Q, U, C, V, E change?**



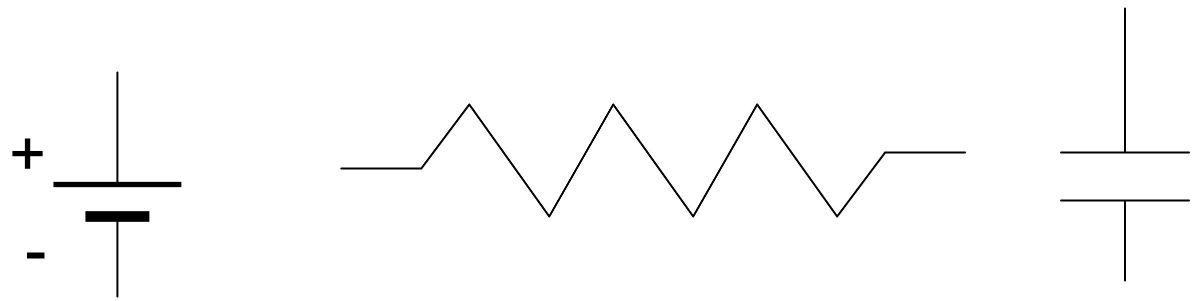
- **C: decreases (capacitance depends <u>only</u> on geometry)**
- **V: must stay the same - the battery forces it to be V**
- **Q: must decrease, $Q=CV$ charge flows off the plate**
- **E: must decrease ($E=\frac{V}{D}$, $E=\frac{\sigma}{E_0}$)**
- **U: must decrease ($U=\frac{1}{2}CV^2$)**

$$C=\frac{Q}{V}=\frac{\varepsilon_0 A}{d}$$

$$C_1=\frac{d}{d_1}C \qquad E_1=\frac{d}{d_1}E \qquad U_1=\frac{d}{d_1}U$$

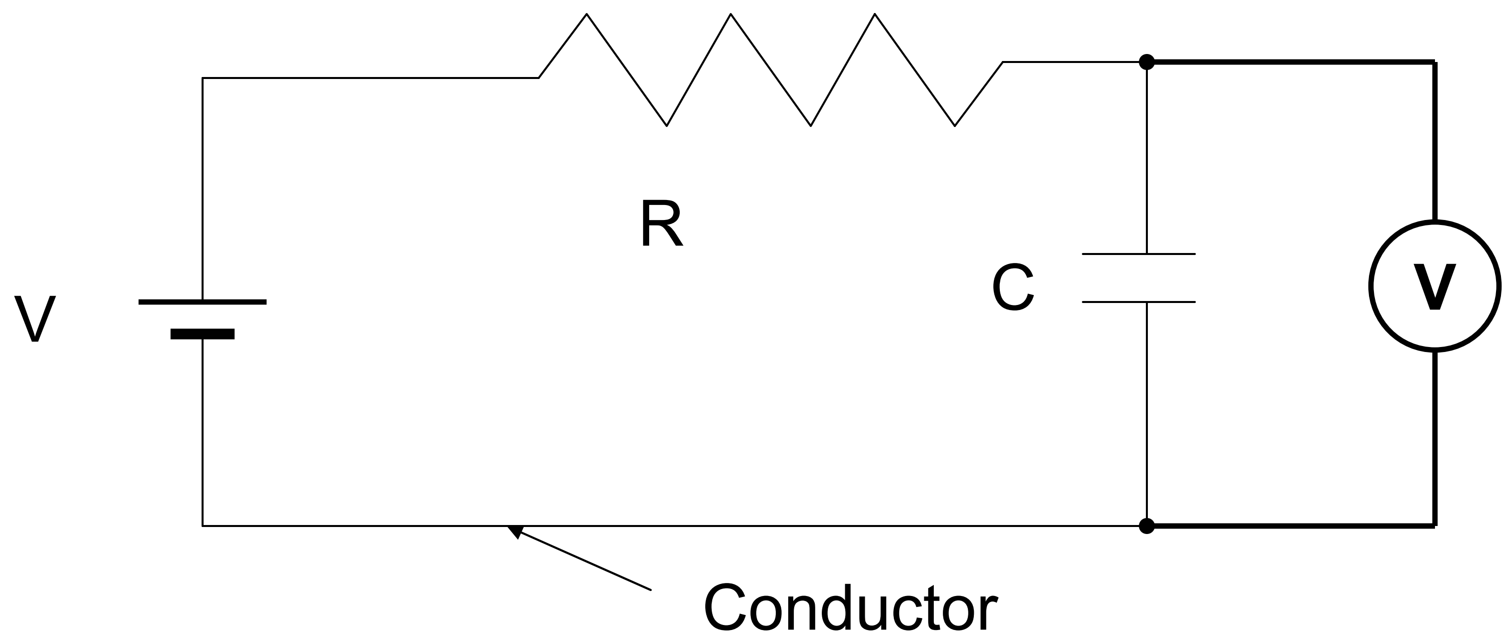
Combinations of capacitors [16.8]

Capacitors connected in series and parallel

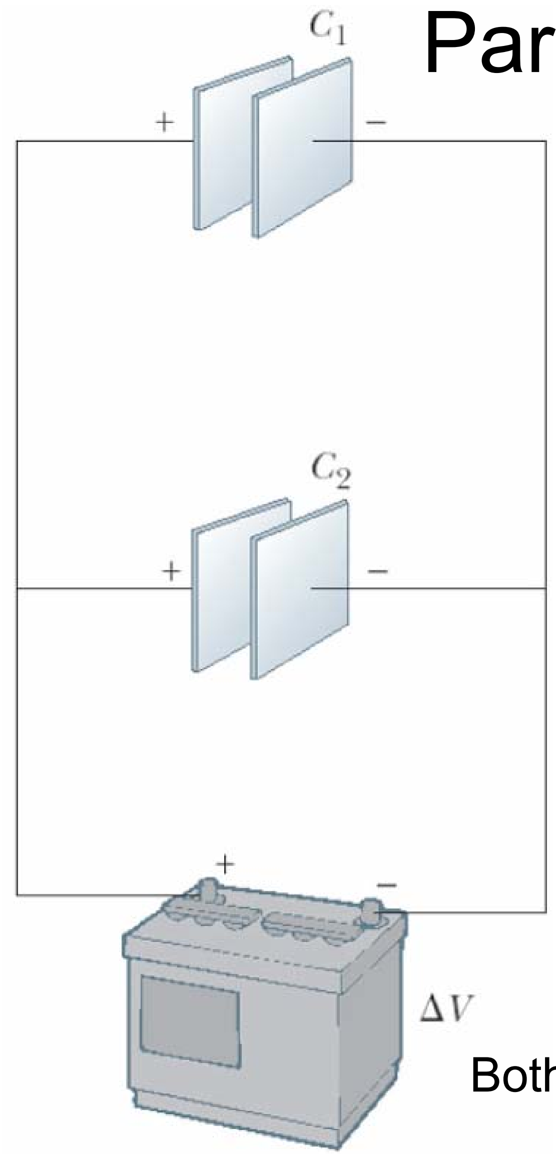


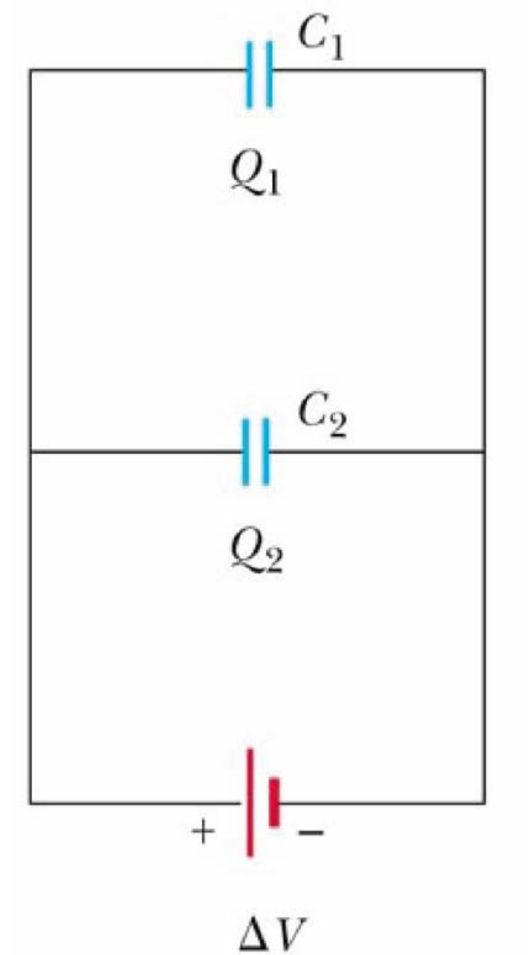
Voltage source resistor capacitor

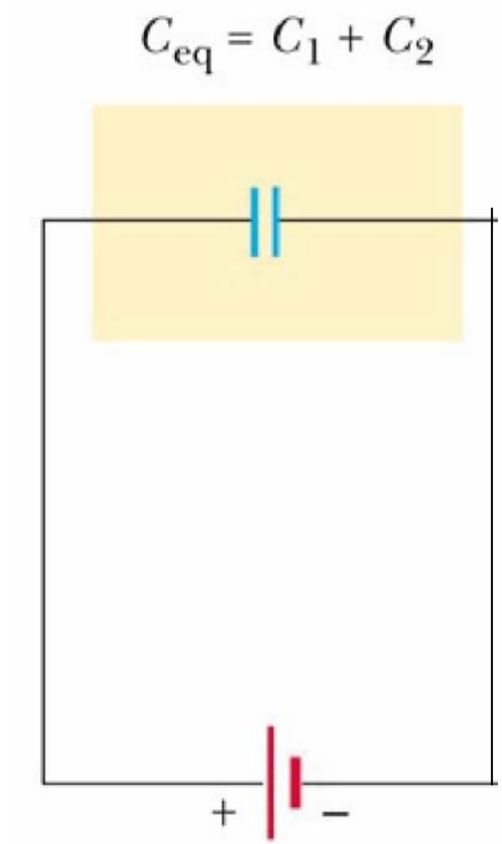
Circuit diagram



Parallel capacitors [16.8]







Both capacitors are at same potential: $\Delta V = \Delta V_1 = \Delta V_2$

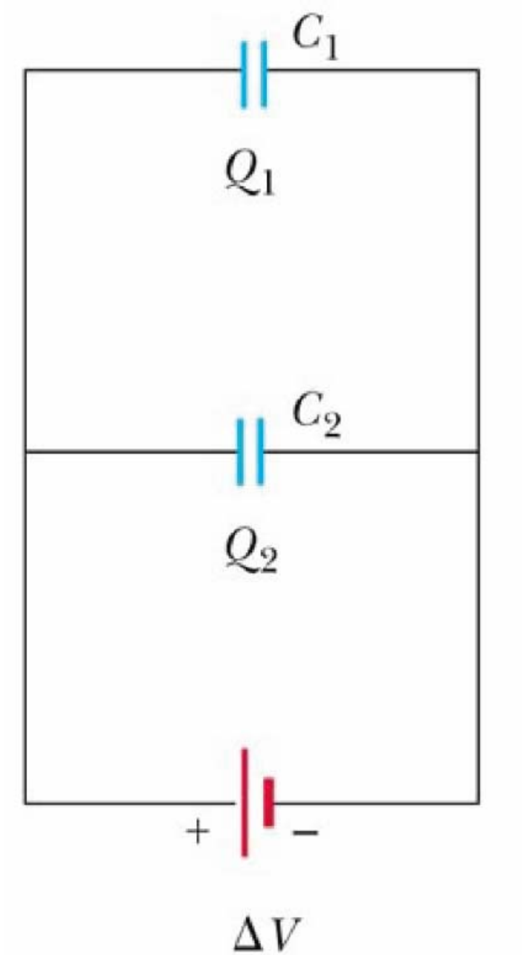
Total charge: $q = q_1 + q_2 = C_1\Delta V + C_2\Delta V$

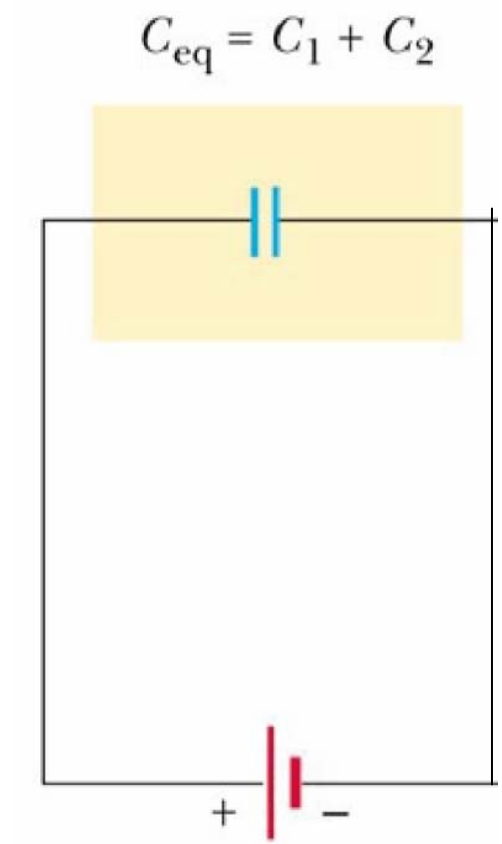
Fig. 16-17

$$C_{eq} = \frac{q}{\Delta V} = \frac{C_1\Delta V + C_2\Delta V}{\Delta V}$$

$$C_{eq} = C_1 + C_2$$

Parallel capacitors [16.8]





For N capacitors in parallel:

$$C_{eq} = C_1 + C_2 + \ldots\ldots.. C_N$$

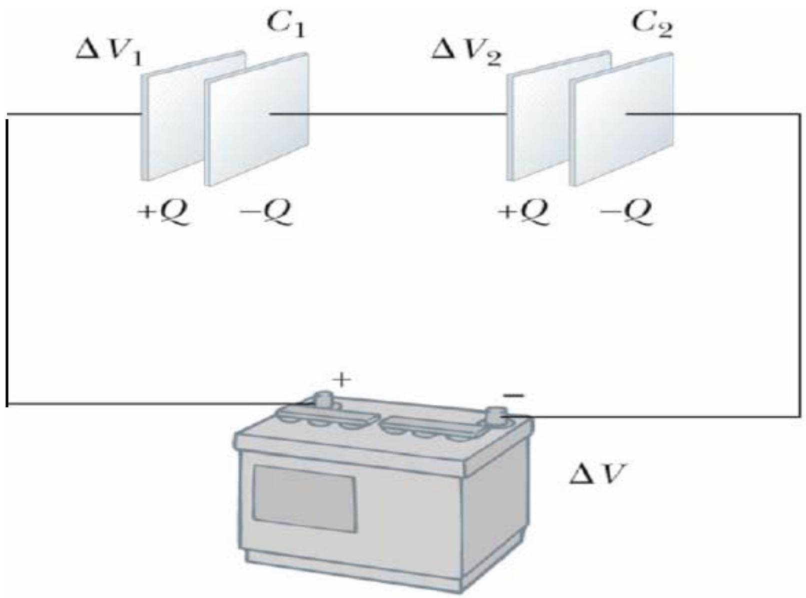
Both capacitors are at same potential: $\Delta V = \Delta V_1 = \Delta V_2$

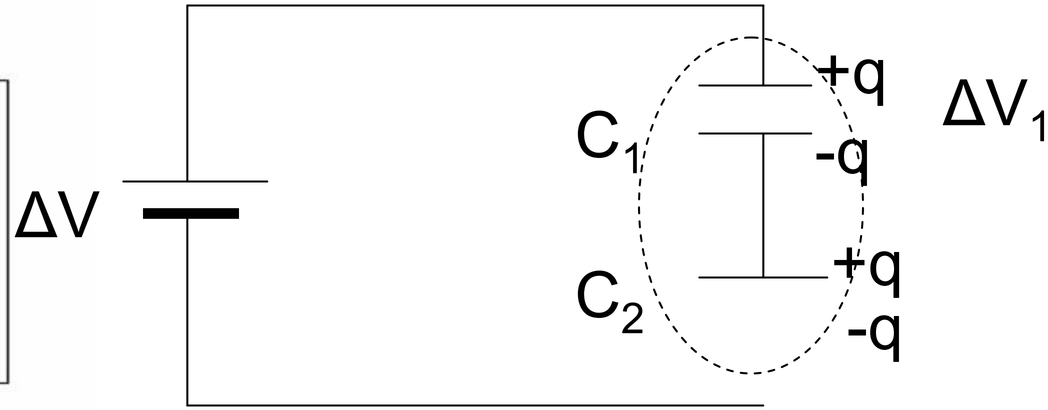
Total charge: $q = q_1 + q_2 = C_1 \Delta V + C_2 \Delta V$

$$C_{eq} = \frac{q}{\Delta V} = \frac{C_1 \Delta V + C_2 \Delta V}{\Delta V}$$

$$C_{eq} = C_1 + C_2$$

Capacitors in series [16.8]





the charge on both capacitors in series is q

$$C_{eq} = \frac{q}{\Delta V}$$

$q = q_1 = q_2$

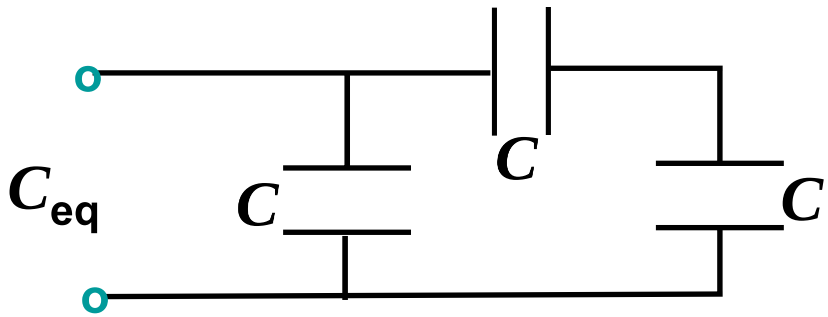
$$\Delta V = \Delta V_1 + \Delta V_2 = \frac{q}{C_1} + \frac{q}{C_2}$$

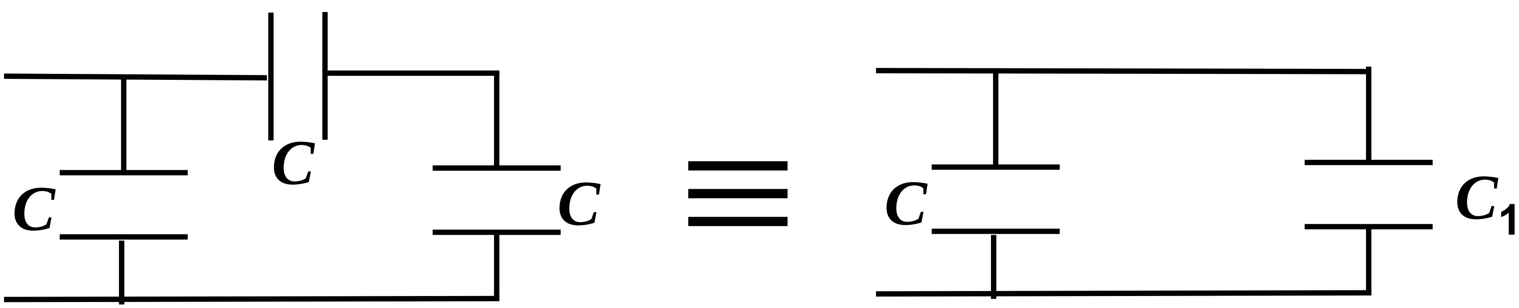
$$\frac{1}{C_{eq}} = \frac{\Delta V}{q} = \frac{1}{q}\left(\frac{q}{C_1} + \frac{q}{C_2}\right) \quad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\boxed{\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots\ldots\ldots \frac{1}{C_N}}$$

Combinations of capacitors [16.8]

- **What is the equivalent capacitance, C_{eq}, of the combination shown?**





$$\frac{1}{C_1} = \frac{1}{C} + \frac{1}{C} \Rightarrow C_1 = \frac{C}{2} \Rightarrow C_{eq} = C + \frac{C}{2} = \frac{3}{2}C$$

34. Find the equivalent capacitance.

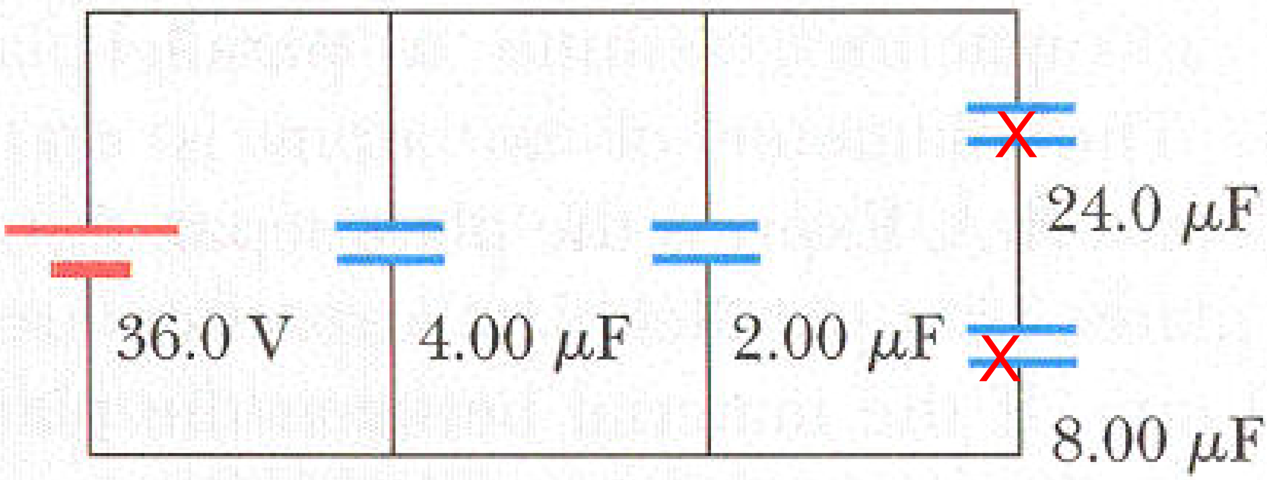


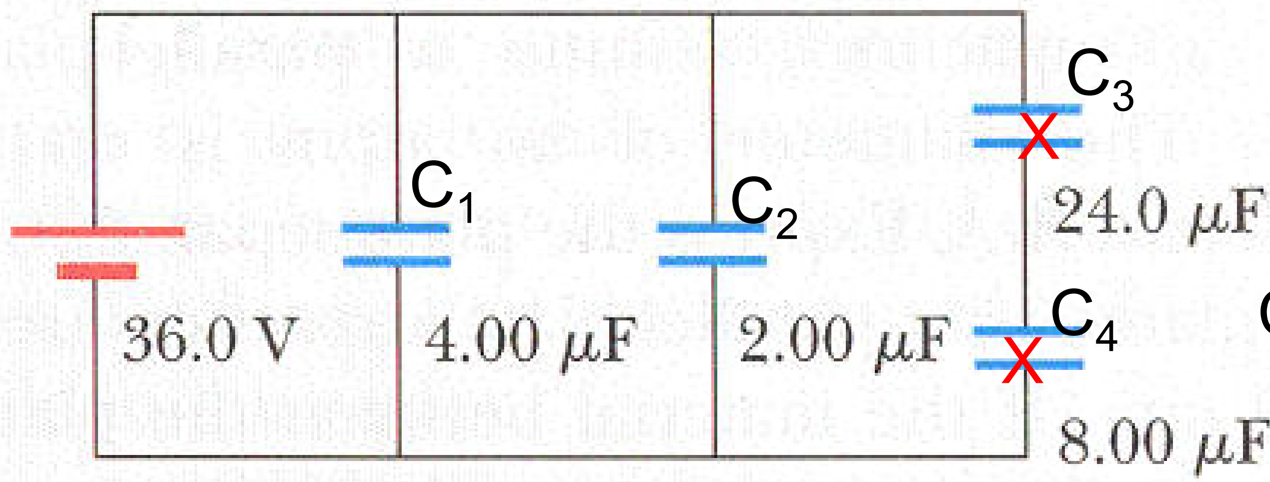
FIGURE P16.34

C_{series}=6μF

$$\frac{1}{C_{series}} = \frac{1}{24} + \frac{1}{8} = \frac{4}{24} = \frac{1}{6}$$

C_{eq}= 4.00+2.00+6.00=12.00 μF

34. Find the charge on each capacitor.



C_{series} =6μF

FIGURE P16.34

$$q = C\Delta V$$

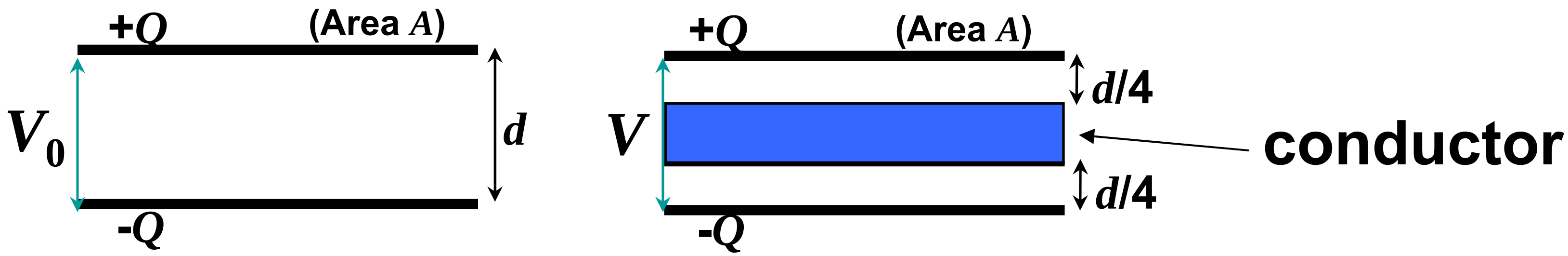
$q_1 = C_1\Delta V = 4\times10^{-6}(36) = 1.44\times10^{-4}$ C

$q_2 = C_2\Delta V = 2\times10^{-6}(36) = 0.72\times10^{-4}$ C

$q_3 = q_4 = C_{series}\Delta V = 6\times10^{-6}(36) = 2.16\times10^{-4}$ C

Combinations of capacitors [16.8]

- **What is the relationship between V_0 and V in the systems shown below?**



- **The electric field in the conductor = 0.**
- **The electric field everywhere else is:** $E = Q/(A\varepsilon_0)$
- **To find the potential difference, integrate the electric field:**

$$V_0 = Ed$$

$$V = E\frac{d}{4} + 0 + E\frac{d}{4}$$

$$V = \frac{1}{2}Ed$$

Combinations of capacitors [16.8]

Problem 16-42. Find the equivalent capacitance between a and b.

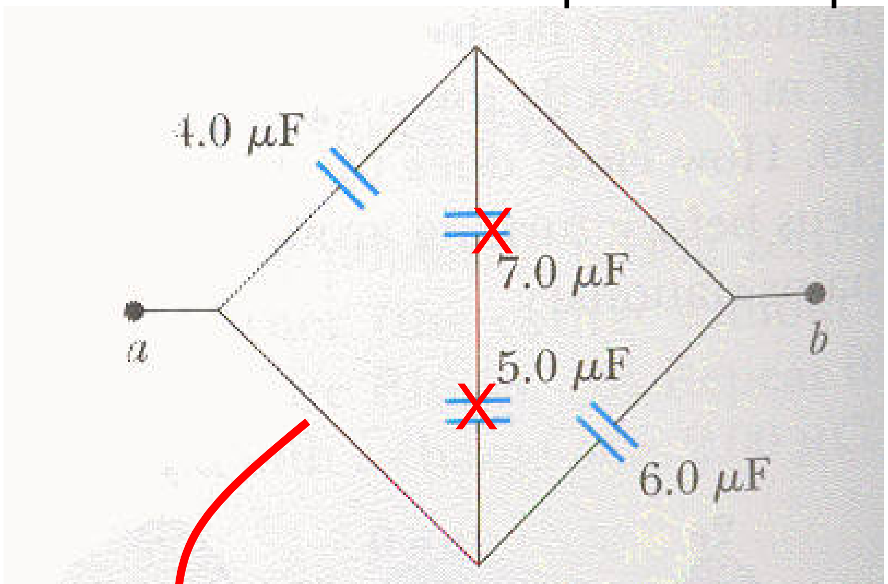
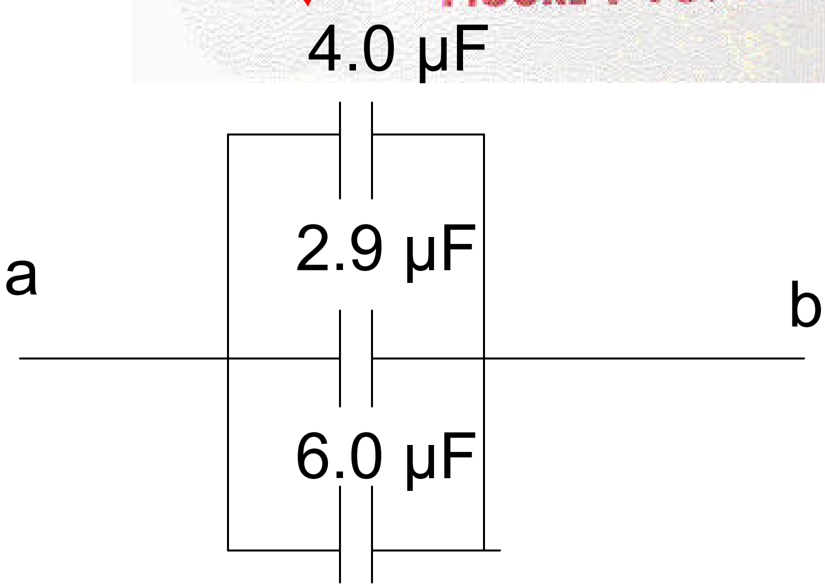


FIGURE P16.42



$$\frac{1}{C_{ser}} = \frac{1}{7} + \frac{1}{5} = \frac{1}{35/12}$$

$$C_{ser} = 2.9\,\mu F$$

$$C_{eq} = 4.0 + 2.9 + 6.0$$

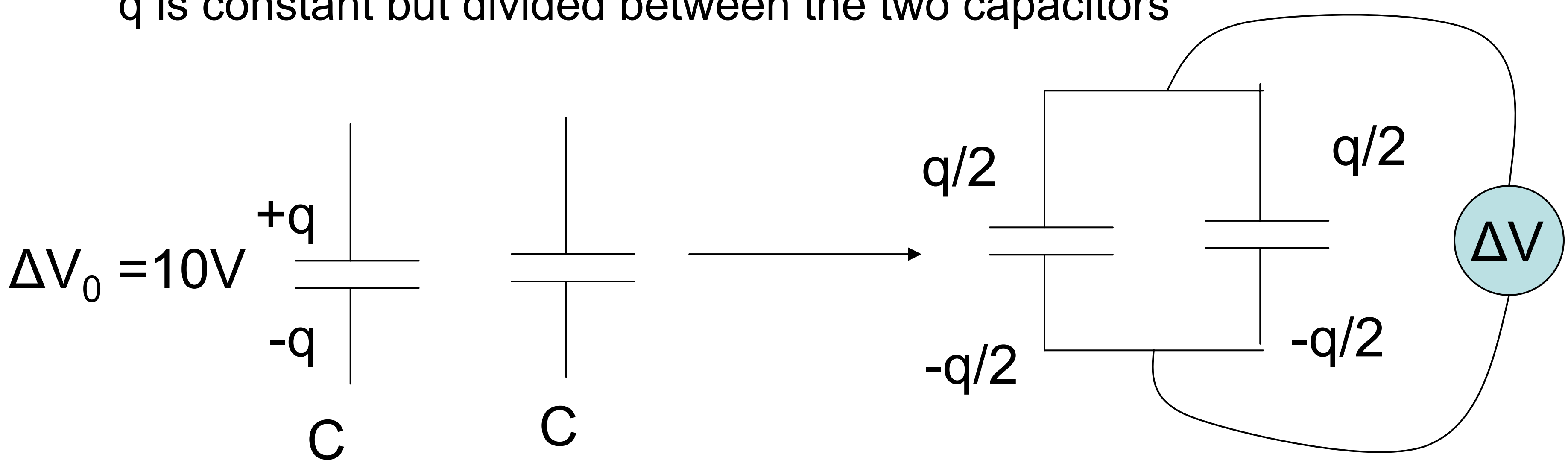
$$= 12.9\ \mu F$$

Combinations of capacitors [16.8]

Two identical capacitors. charge one capacitor at 10 V , disconnect, connect the charged capacitor to the uncharged capacitor. What is the voltage drop across the each capacitor?

One way to do this problem:

q is constant but divided between the two capacitors



the charge on each capacitor is reduced by 2 fold
thus the voltage across each capacitor is reduced by 2fold

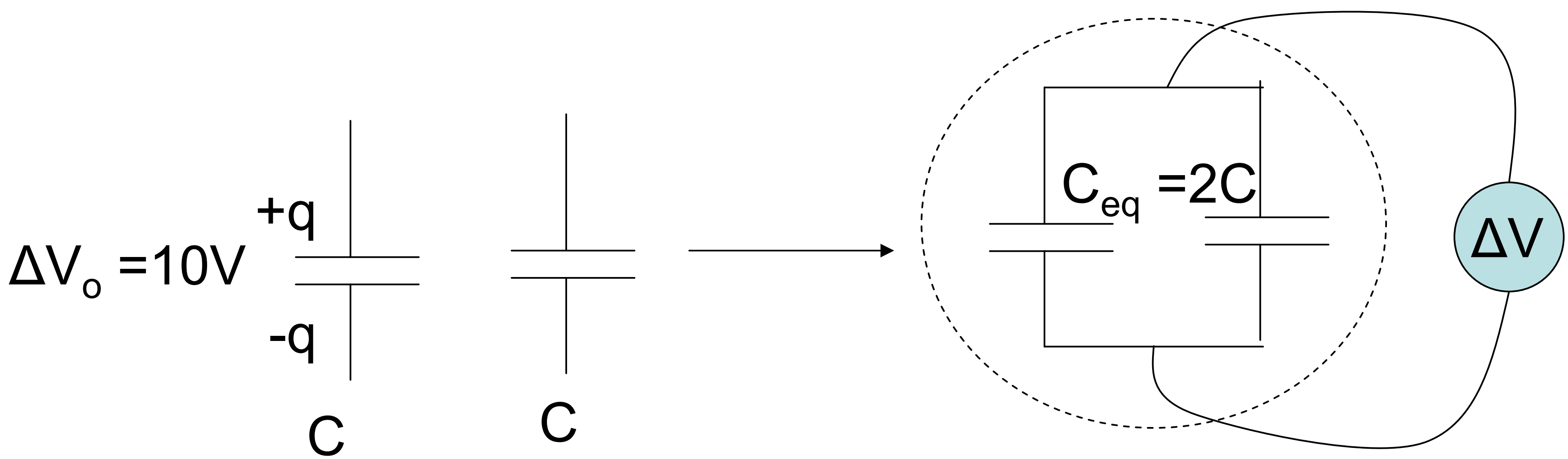
$$\Delta V = \frac{\Delta V_o}{2}$$

Combinations of capacitors [16.8]

Two identical capacitors. charge one capacitor at 10 V , disconnect, connect the charged capacitor to the uncharged capacitor. What is the voltage drop across the each capacitor?

Another way to do this problem

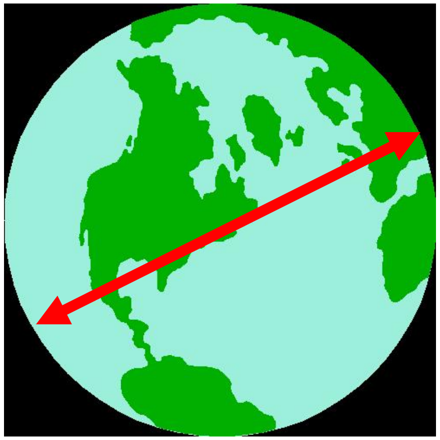
q is constant but is placed on an equivalent capacitor



The voltage is reduced by 2 fold $$\Delta V = \frac{q}{C_{eq}} = \frac{q}{2C} = \frac{\Delta V_o}{2}$$

Capacitors with dielectrics [16.8]

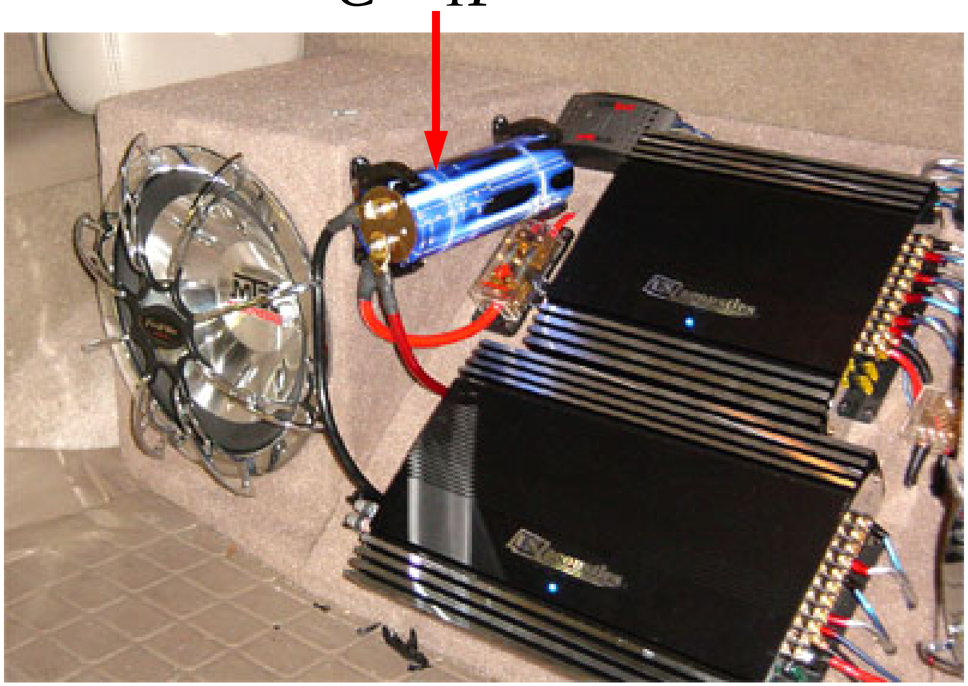
$C = 600\,\mu F$

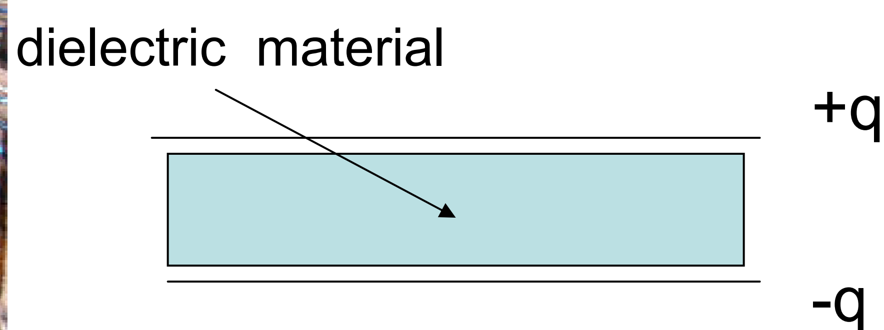


Dielectric material – insulators such as paper, glass plastic, ceramic.

"Dielectric Strength" - is the electric field at which conduction occurs through the material

$C = 1F$





Capacitors with dielectrics [16.8]

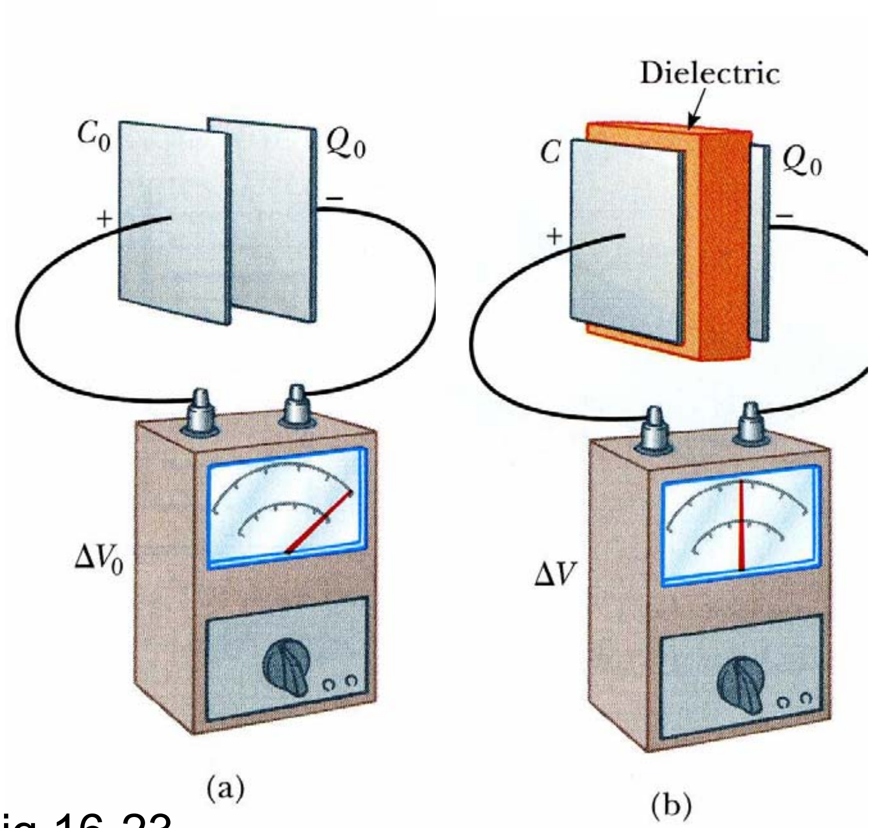
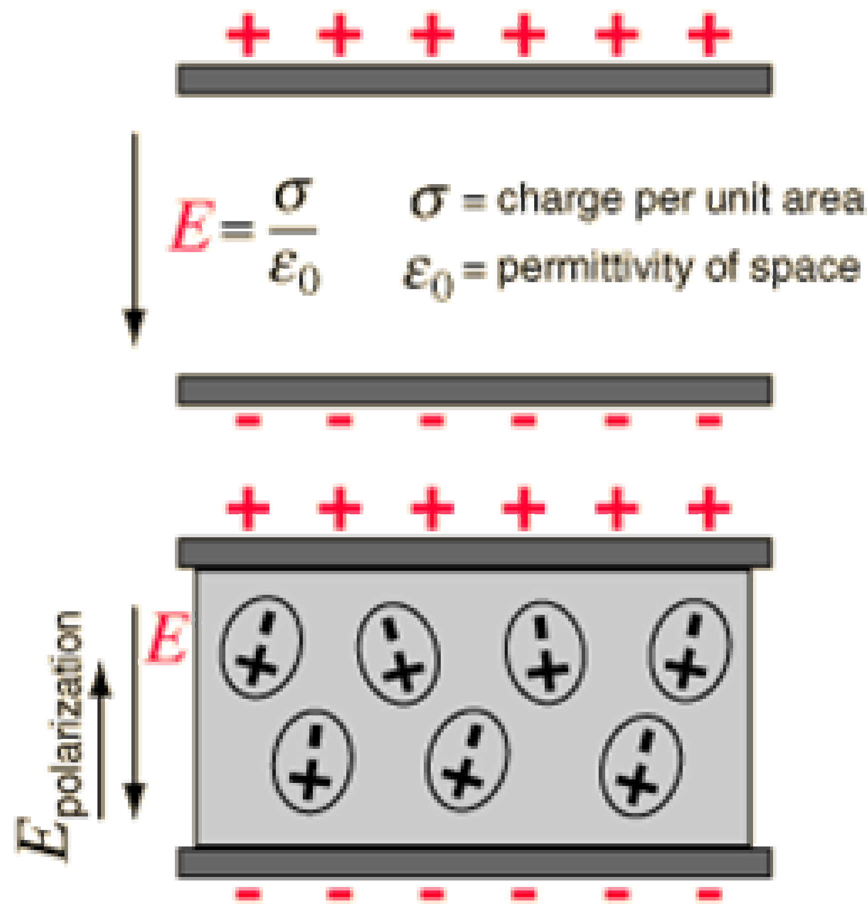


Fig.16-23

$$\Delta V = \frac{\Delta V_o}{\kappa}$$

Potential due to charge q decreases by κ

κ= dielectric constant (dimensionless)



$$E_{effective} = E - E_{polarization} = \frac{\sigma}{k\varepsilon_0}$$

Capacitors with dielectrics [16.8]

Originally

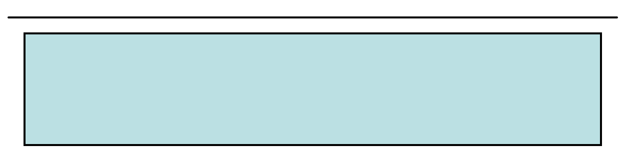
+q

ΔV_o

C_o

-q

Add dielectric



+q

ΔV

-q

$$C = \frac{q}{\Delta V} = \frac{\kappa q}{\Delta V_o}$$

$$C = \kappa C_o$$

Capacitance increases

Capacitors with dielectrics [16.8]

Originally

+q

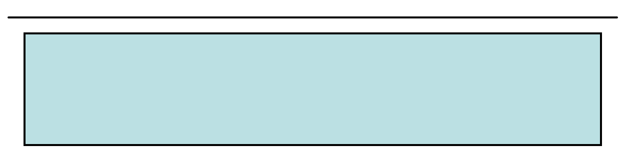
ΔV_o

C_o

-q

Add dielectric

$$C = \kappa C_o$$



+q

ΔV

-q

$$E = \frac{\Delta V}{d} = \frac{\Delta V_o}{\kappa d}$$

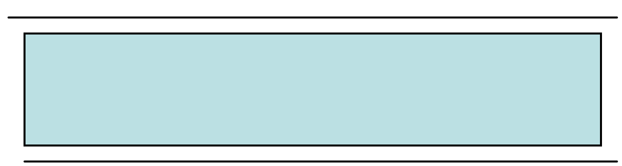
$$E = \frac{E_o}{\kappa}$$

Electric field decreases (when not connected to a battery)

Capacitors with dielectrics [16.8]

Originally

Add dielectric



$$C = \kappa C_o \qquad E = \frac{E_o}{\kappa}$$

$$E = \frac{q}{\kappa \varepsilon_o A} = \frac{q}{\varepsilon A}$$

$$\varepsilon = \kappa \varepsilon_o$$

Permittivity is increased (Compared to vacuum)

Capacitors with dielectrics [16.8]

Example: A parallel plate capacitor consists of metal sheets ($A = 1.0 m^2$) separated by a Teflon sheet ($\kappa=2.1$) with a thickness of 0.005 mm. (a) find the capacitance. (b) Find the maximum voltage. The maximum electric field across Teflon is $60x10^6$ V/m. – this is its *dielectric strength*.

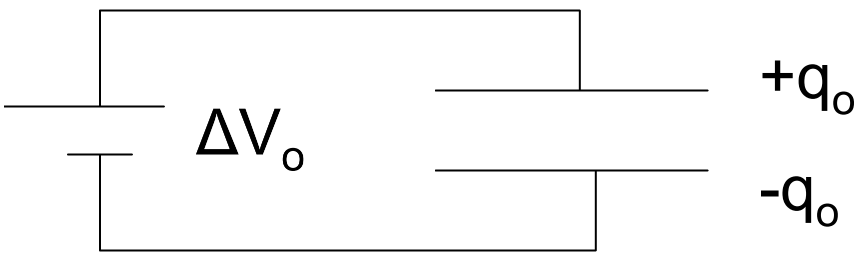
(a)

$$C = \frac{\kappa \varepsilon_o A}{d} = \frac{2.1(8.8x10^{-12})(1.0)}{0.005x10^{-3}}$$

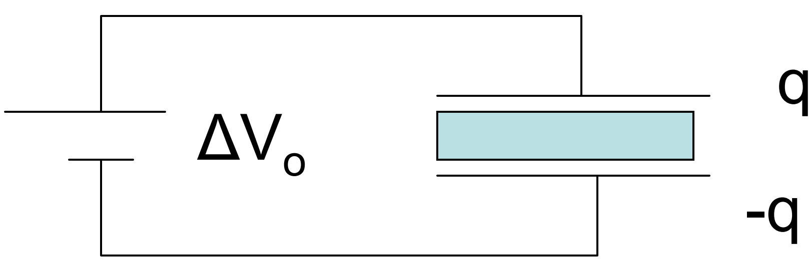
$$C = 3.7x10^{-6} F$$

(b) $$\Delta V_{\max} = E_{ds} d = 60x10^{6}(0.005x10^{-3}) = 300V$$

Capacitors with dielectrics summary [16.8]



C_o



C= κC_o

q= $CV = \kappa C_o V_o = \kappa q$

E= $\frac{\Delta V}{d} = \frac{\Delta V_o}{d} = E_o$

PE= $\frac{1}{2} C \Delta V^2 = \frac{1}{2} \kappa C \Delta V_o^{\,2} = \kappa PE_o$