PHYSICS 1B – Fall 2009

Electricity
&
Magnetism

Professor Brian Keating

SERF Building. Room 333

Wednesday October 14, 2009

UCSD UCSD

16.1 PART 2 & 16.2 ELECTRIC POTENTIAL (CONTINUED)

Quiz grades: on the web by last 5 digits of your PID number

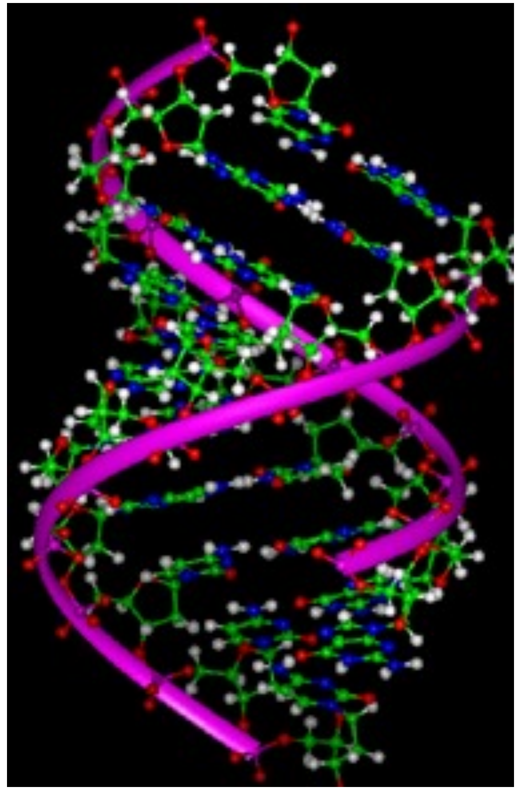
Average was an 7 with a standard deviation of 2.

Hydrogen Bond

N—H   O—C ⟶ N—H O—C

The hydrogen bond energy can be estimated by partial charges

-0.3e	+0.3e	-0.4e	+0.4e	
N	H	O	C	
0.1	0.2	0.25		nm



DNA

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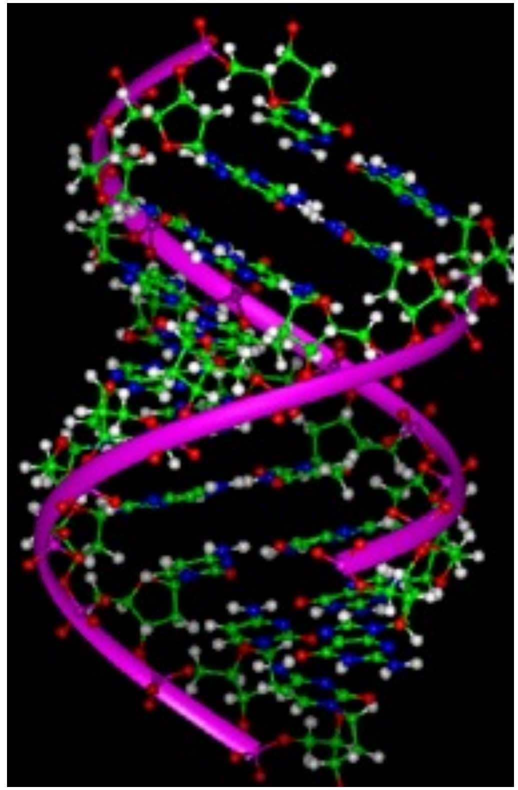
-0.3e	+0.3e	-0.4e	+0.4e
N	H	O	C

N—H: 0.1, H···O: 0.2, O—C: 0.25 nm

bond energy =sum $\frac{kq_iq_j}{r_{ij}}$ (scalar sum)



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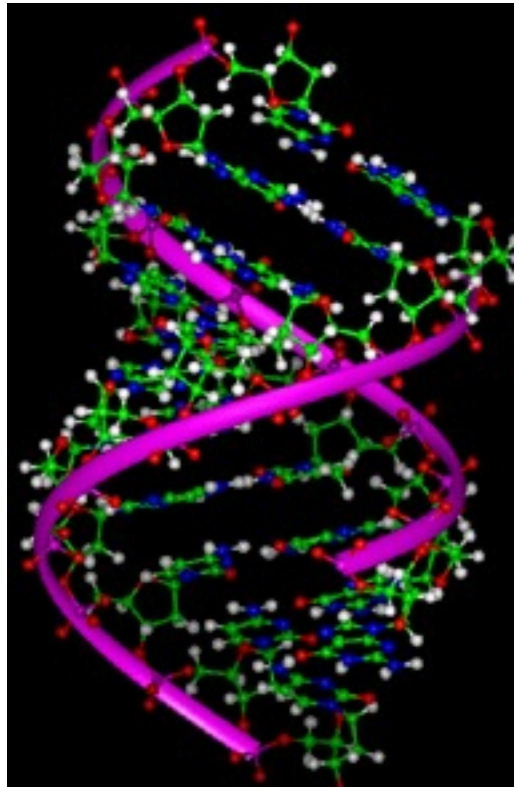
N—H O—C

0.1 0.2 0.25 nm

bond energy =sum $\frac{kq_iq_j}{r_{ij}}$ (scalar sum)

$$\Delta PE = \frac{ke^2}{10^{-9}}\left(\frac{(-.3)(-.4)}{.1+.2} + \frac{-.3(.4)}{.1+.2+.25} + \frac{+.3(-.4)}{.2} + \frac{.3(.4)}{.2+.25}\right)$$



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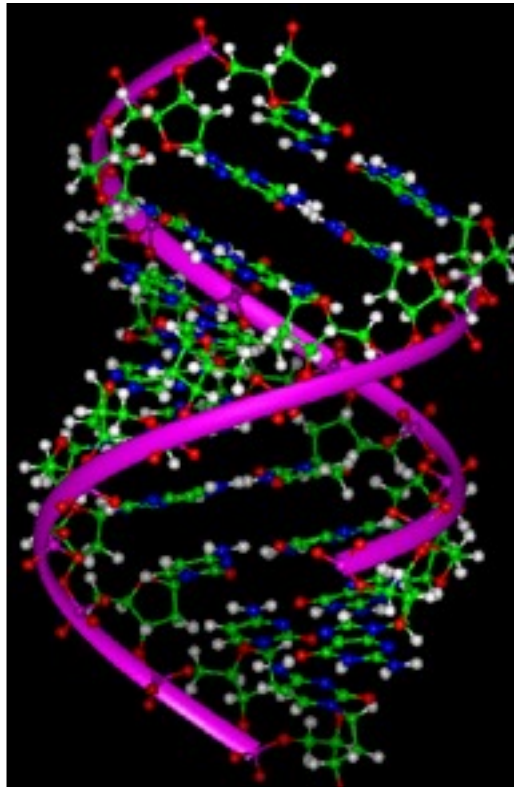

DNA

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Hydrogen Bond

N—H   O—C ⟶ N—H O—C

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-0.3e	+0.3e	-0.4e	+0.4e
N	H	O	C

N—H (0.1) H···O (0.2) O—C (0.25) nm

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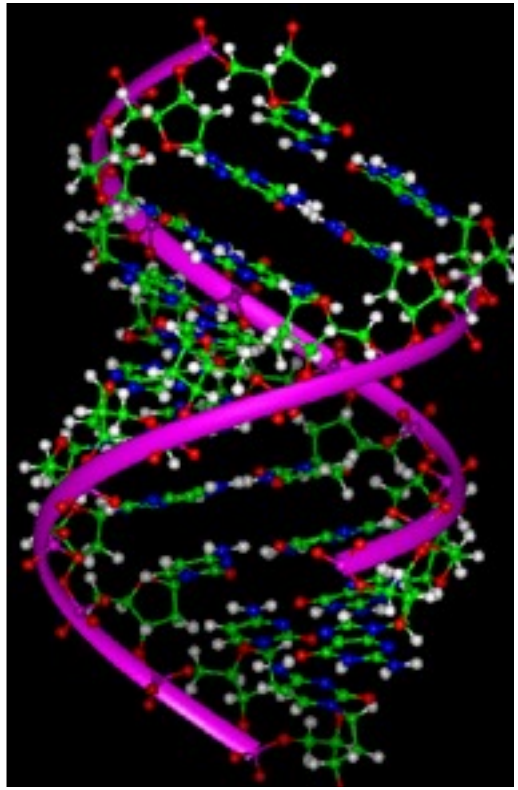

DNA

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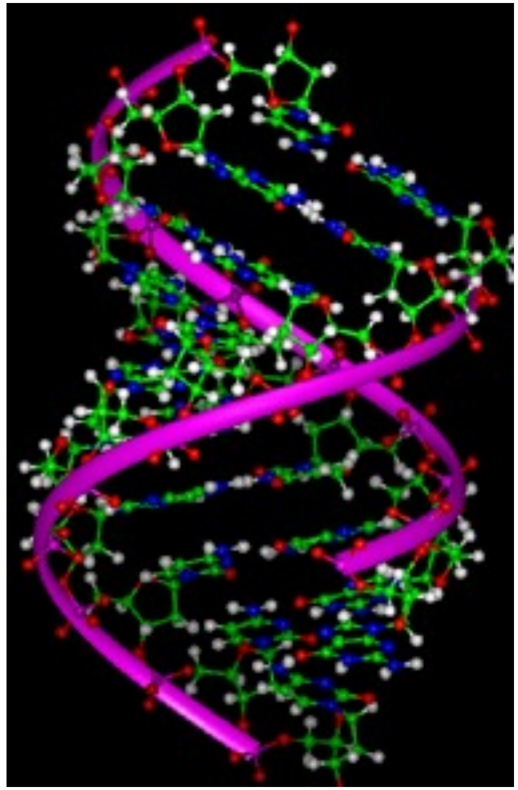
ΔPE=-0.22 eV

Hydrogen Bond

N—H O—C ⟶ N—H O—C



DNA

The hydrogen bond energy can be estimated by partial charges

-0.3e +0.3e -0.4e +0.4e

N—H O—C

0.1 0.2 0.25 nm

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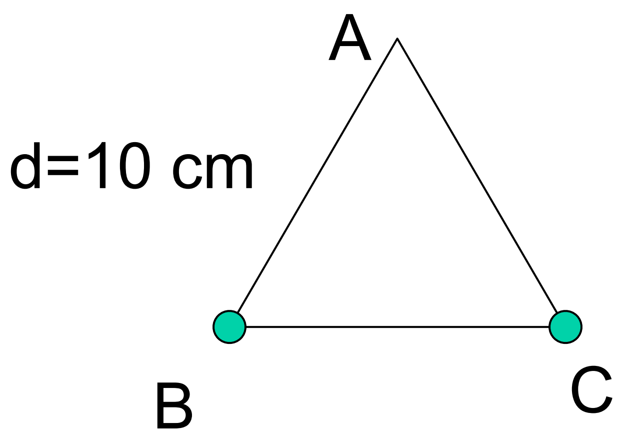
ΔPE=-0.22 eV

Weaker than a ionic bond but still significant.

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



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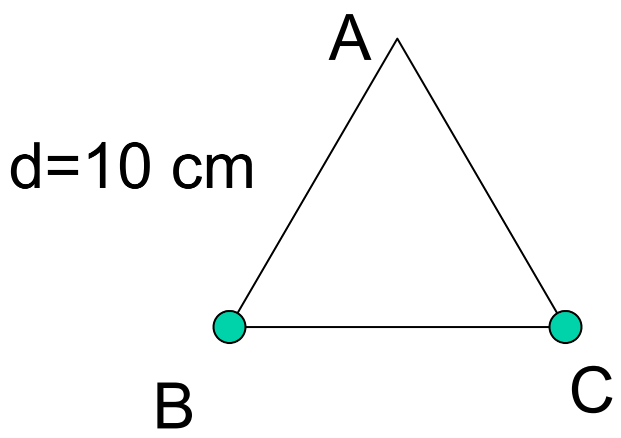
V at A due to each charge



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

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

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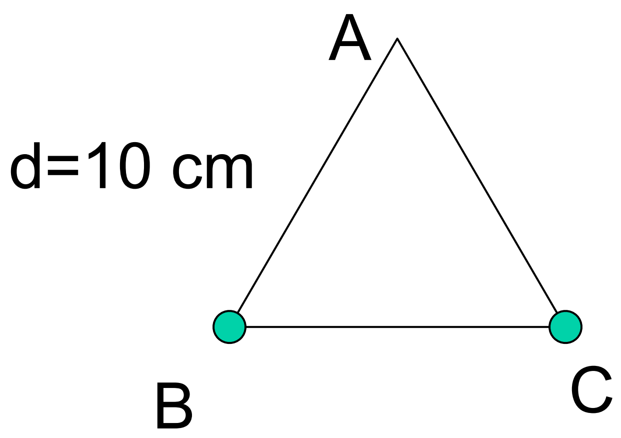

V at A due to each charge

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

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

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

$$V = Er = 100(0.1) = 10V$$

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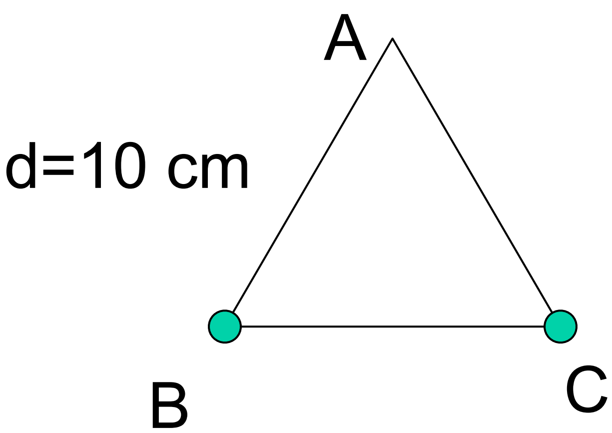

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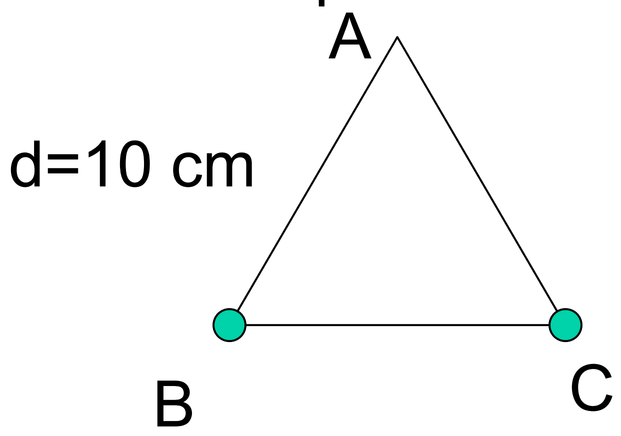
$$V = Er = 100(0.1) = 10V$$

$V_{total}=V_{BA} + V_{CA}=2V = 20\ V$

Potential is a scalar

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

What is the potential at A?



A. 10V

B. 100V

C. 1000V

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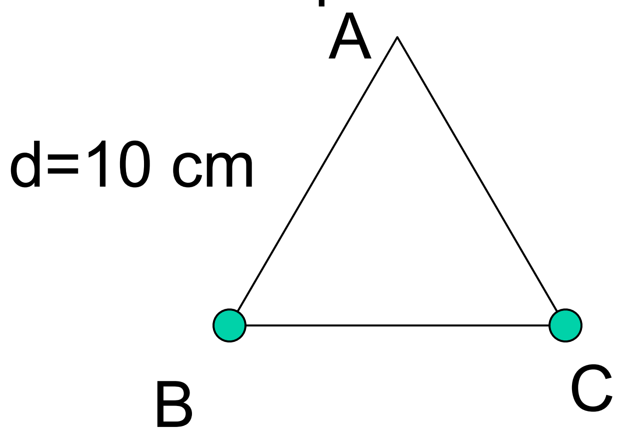

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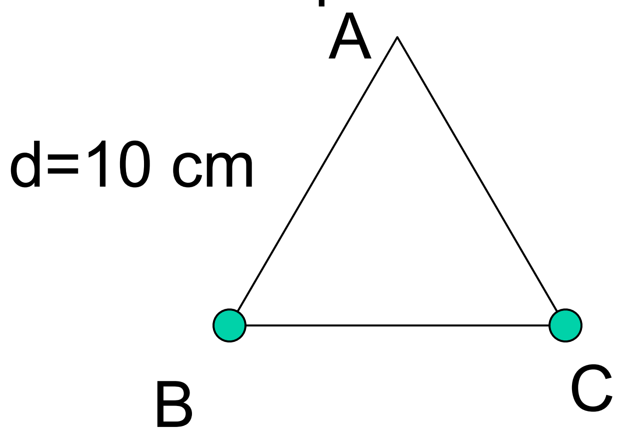

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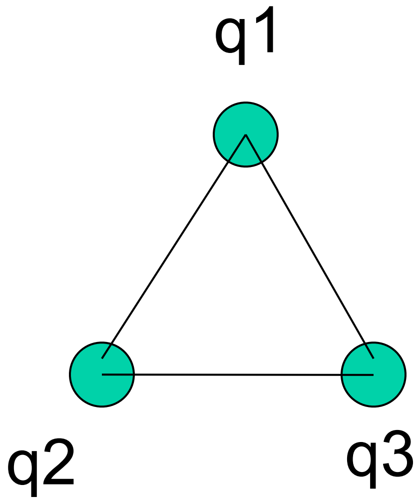
$$V = Er = 100(0.1) = 10V$$

$V_{total} = V_{BA} + V_{CA} = 2V = 20$ V

Potential is a scalar

3 charges of $1x10^{-9}$ C are placed at the corners of a equilateral triangle Each side of the triangle has a length of 1.0 cm. Find the work needed to bring the charges together from a long distance away.



PE due to Coulomb interaction

How many interactions?

PE =

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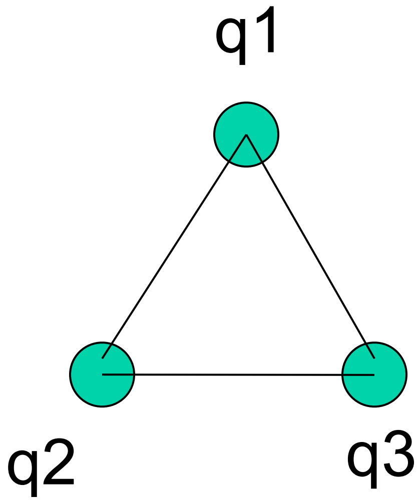

PE due to Coulomb interaction

How many interactions? 3

PE =

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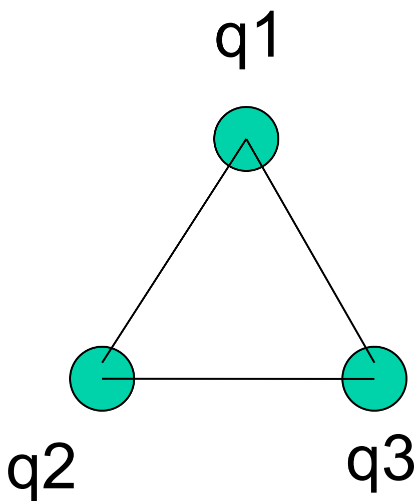

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$PE = PE_{12}+PE_{13}+PE_{23}$

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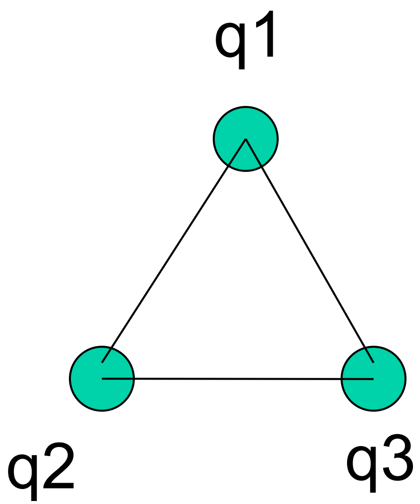

PE due to Coulomb interaction

How many interactions? 3

$PE = PE_{12}+PE_{13}+PE_{23}$

$$PE = 3\frac{k_e q^2}{r}$$

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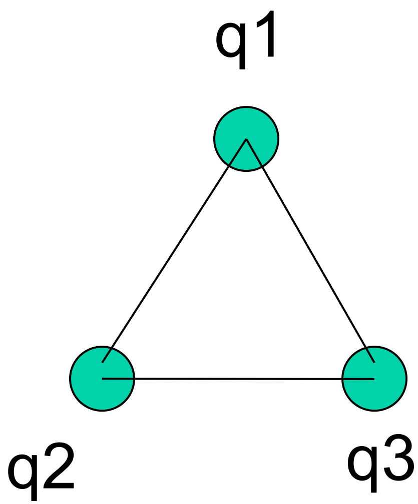


PE due to Coulomb interaction

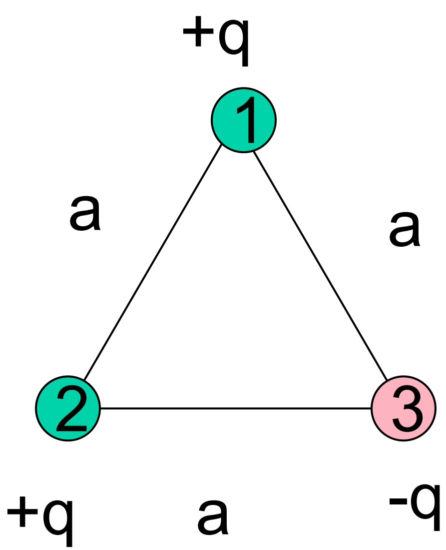
How many interactions? 3

$PE = PE_{12}+PE_{13}+PE_{23}$

$$PE = 3\frac{k_e q^2}{r}$$

$$PE = 3\frac{9x10^{9}(1x10^{-9})^2}{(0.01)^2} = 2.7x10^{-4} J$$

The following charges are brought together from a large distance away. What is the change in PE? Is the charge distribution stable? (i.e. does it have a negative PE)



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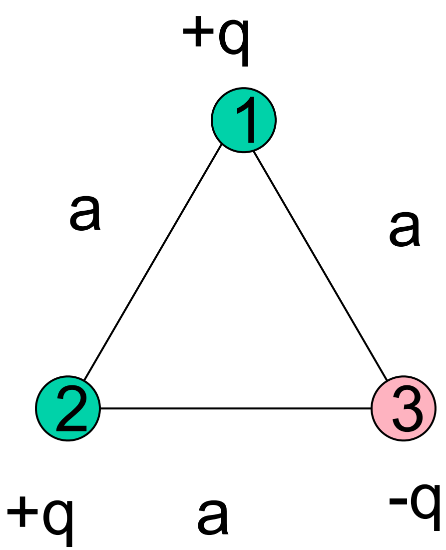

How many interactions?

How many positive?

How many negative?

What is the total change in PE?

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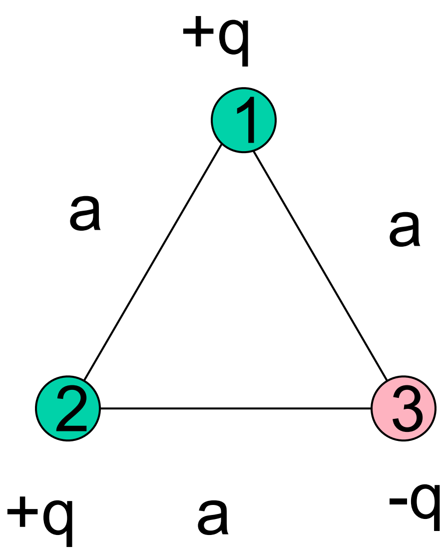

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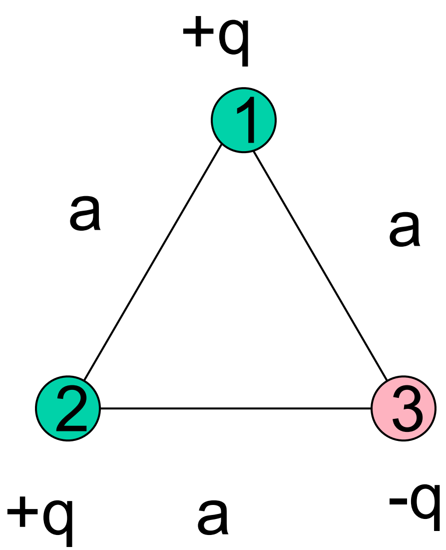

How many interactions? 3

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How many negative?

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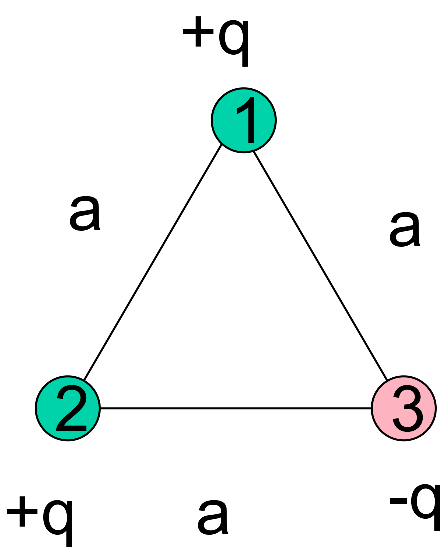


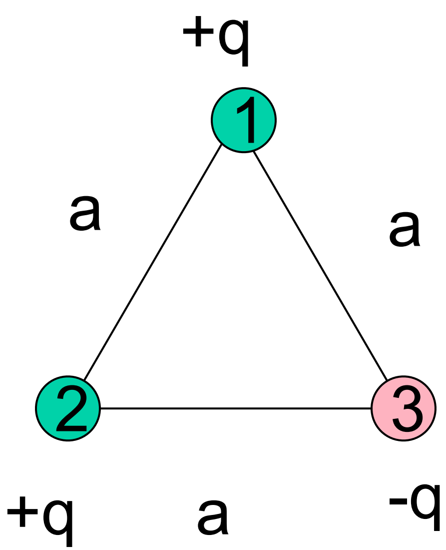
How many interactions? 3

How many positive? 1

How many negative? 2

What is the total change in PE?

The following charges are brought together from a large distance away. What is the change in PE? Is the charge distribution stable? (i.e. does it have a negative PE)



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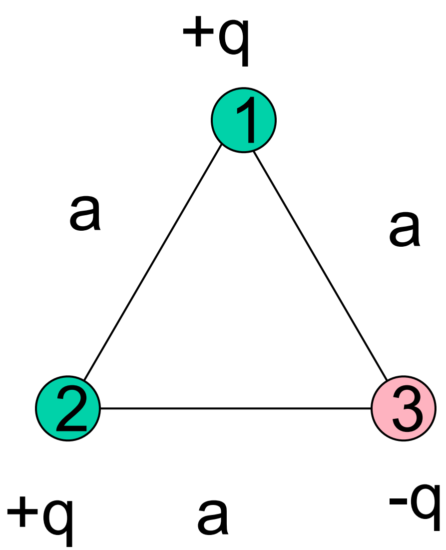

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What is the total change in PE?

$$PE = PE_{12} + PE_{13} + PE_{23}$$

$$PE = PE_0 - 2PE_0 = -PE_0 = -\frac{k_e q^2}{a}$$

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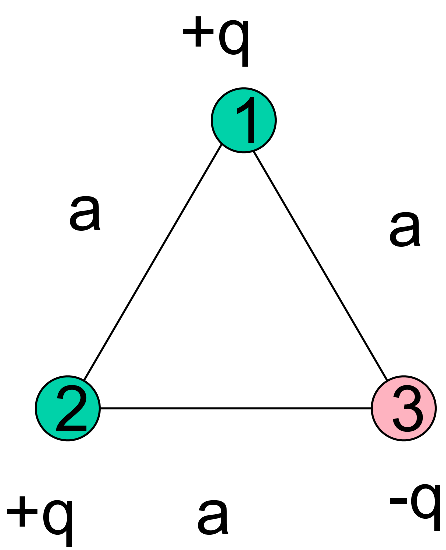

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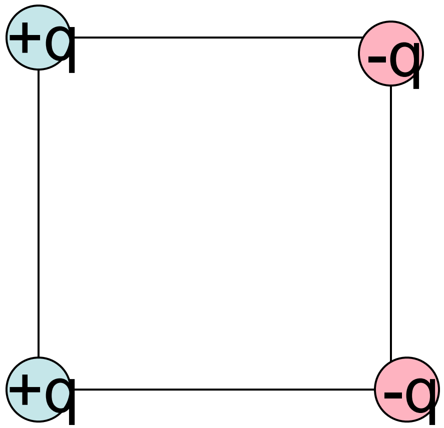
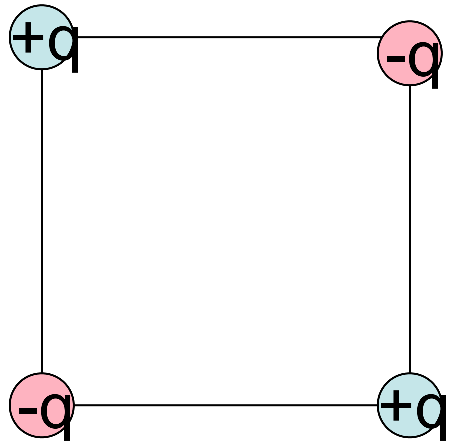
STABLE

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



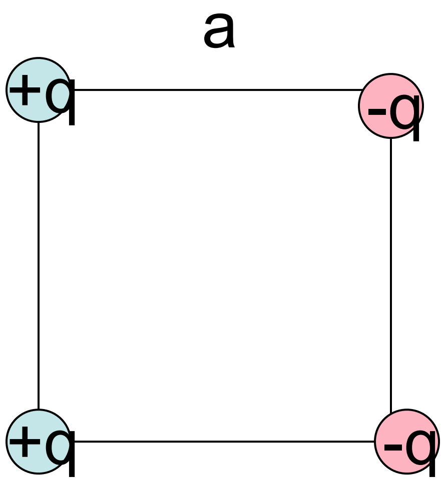
A. This one



B. This one

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

$$PE_0 = \frac{k_e q^2}{a}$$



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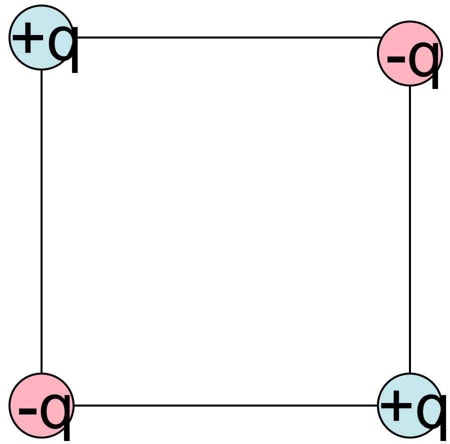

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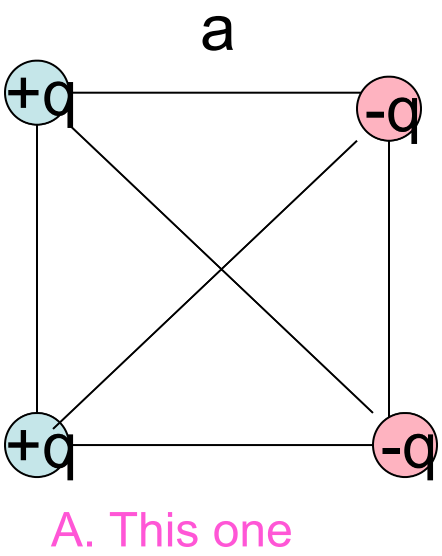

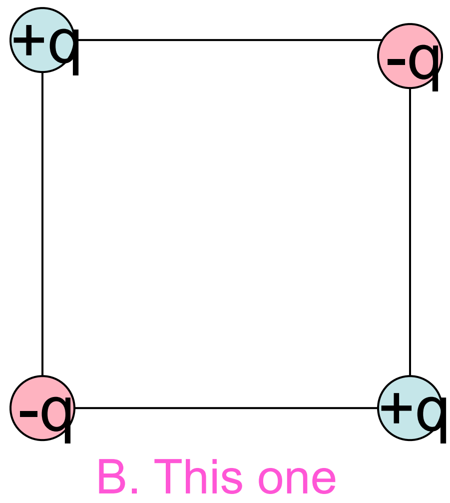

PE_0

$PE_0/\sqrt{2}$

Total PE

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

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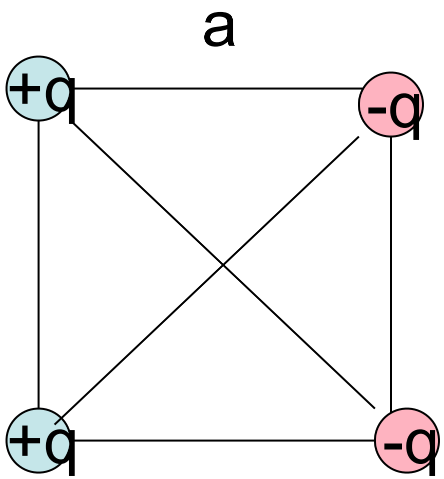

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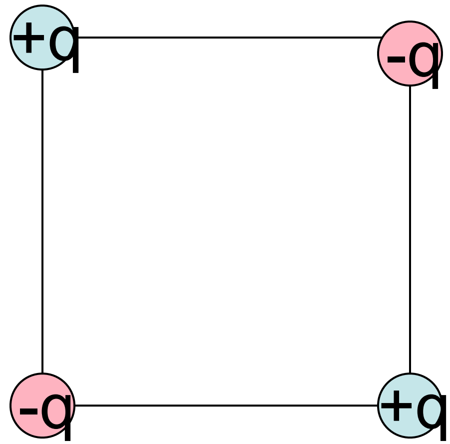

B. This one

PE_0	+2	-2
$PE_0/\sqrt{2}$		
Total PE		

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

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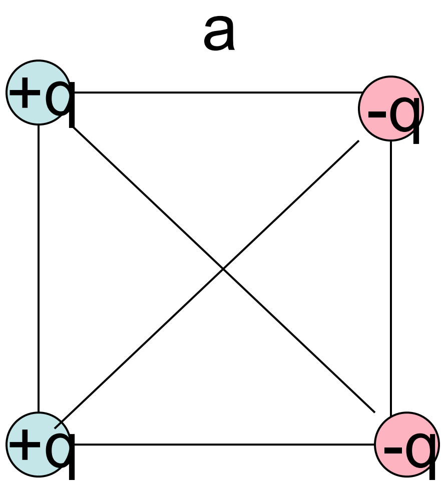

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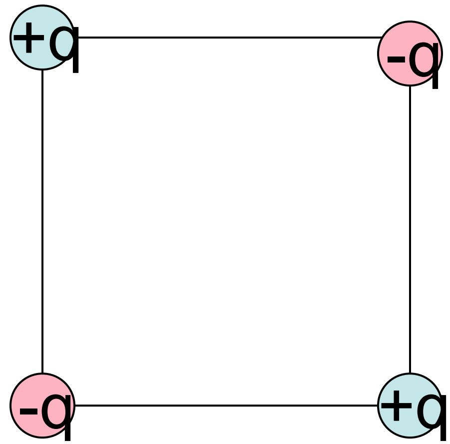

B. This one

PE_0	+2	-2	
$PE_0/\sqrt{2}$		-2	
Total PE			

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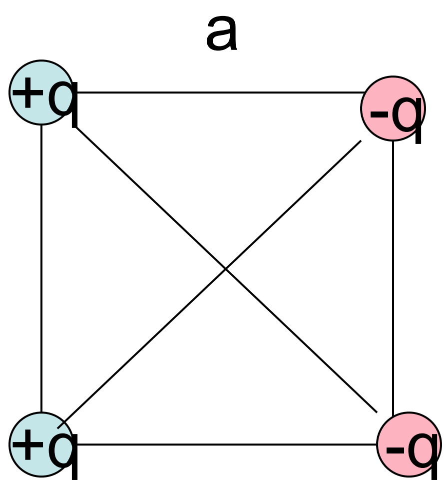

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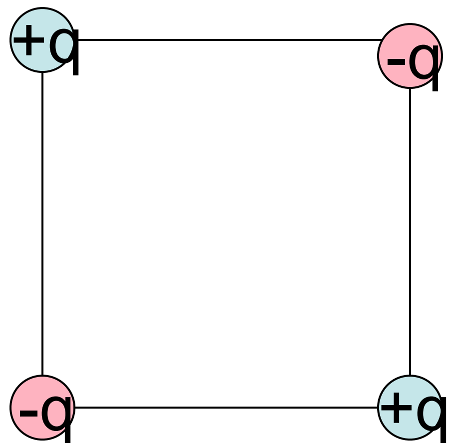


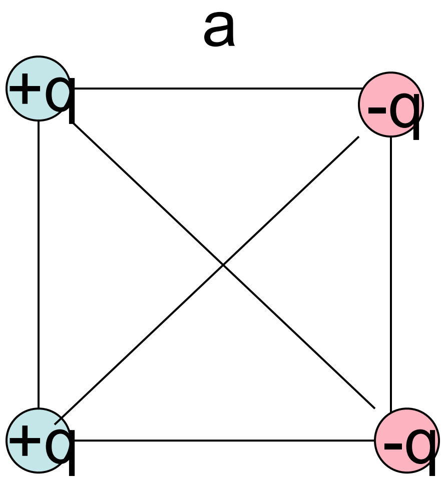
B. This one

PE_0	+2	-2
$PE_0/\sqrt{2}$		-2

Total PE $\quad -\frac{2}{\sqrt{2}} PE_0 = -1.4 PE_0$

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

$$PE_0 = \frac{k_e q^2}{a}$$



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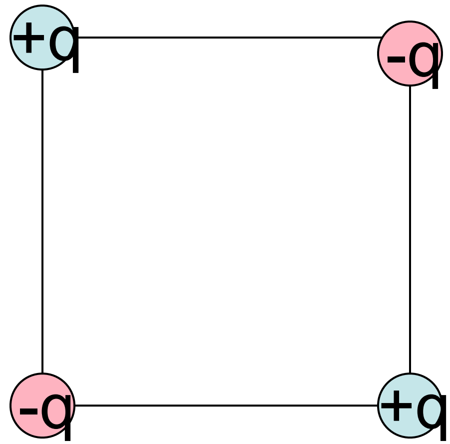
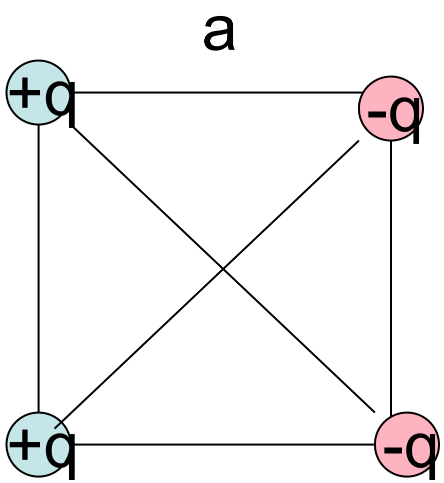


B. This one

	A		B
PE_0	+2	-2	-4
$PE_0/\sqrt{2}$		-2	
Total PE	$-\frac{2}{\sqrt{2}} PE_0 = -1.4 PE_0$		

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

$$PE_0 = \frac{k_e q^2}{a}$$



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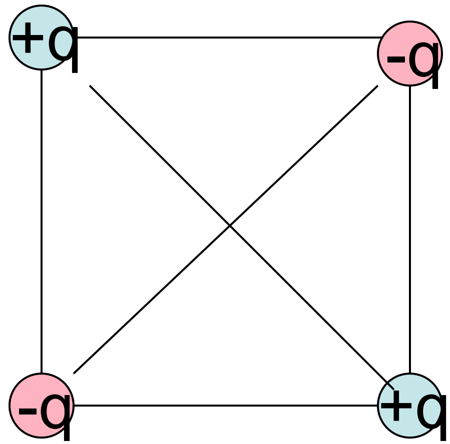

B. This one

	A		B	
PE_0	+2	-2		-4
$PE_0/\sqrt{2}$		-2	+2	
Total PE	$-\frac{2}{\sqrt{2}} PE_0 = -1.4 PE_0$			

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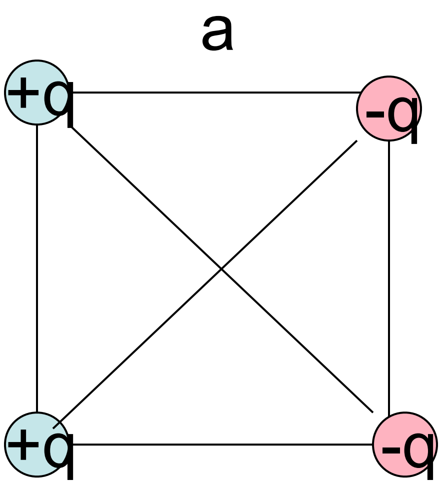
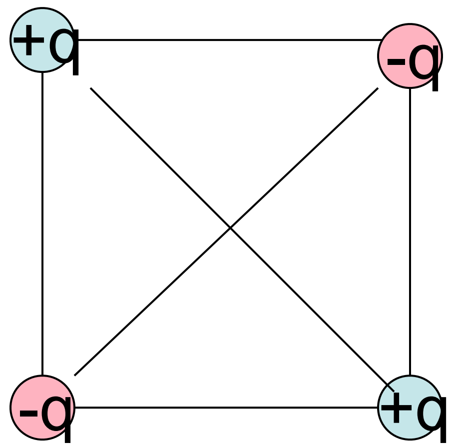


A. This one

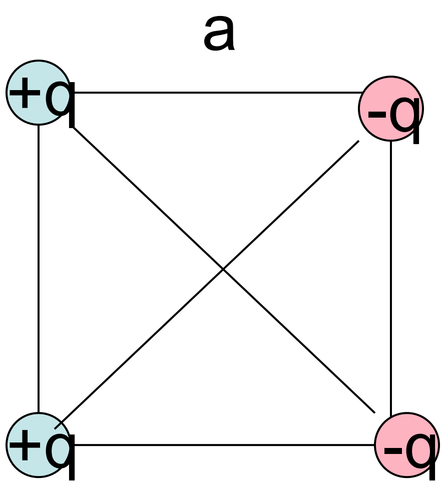


B. This one

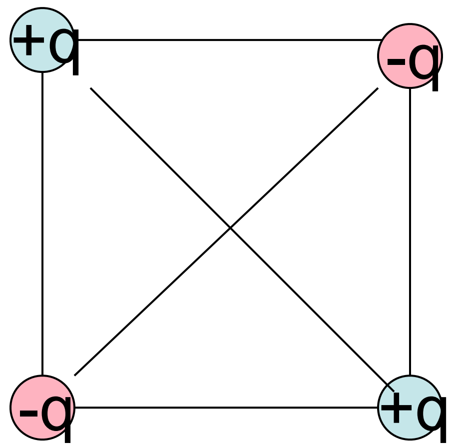
	A	B
PE_0	+2 -2	-4
$PE_0/\sqrt{2}$	-2	+2
Total PE	$-\frac{2}{\sqrt{2}}PE_0 = -1.4PE_0$	$(-4+\frac{2}{\sqrt{2}})PE_o = -2.6PE_0$

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

$$PE_0 = \frac{k_e q^2}{a}$$



A. This one



B. This one

STABLE

	A		B
PE_0	+2	-2	-4
$PE_0/\sqrt{2}$		-2	+2
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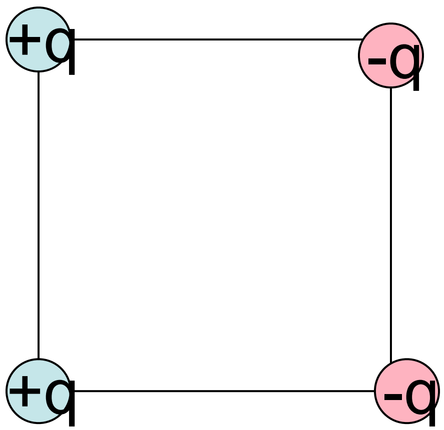

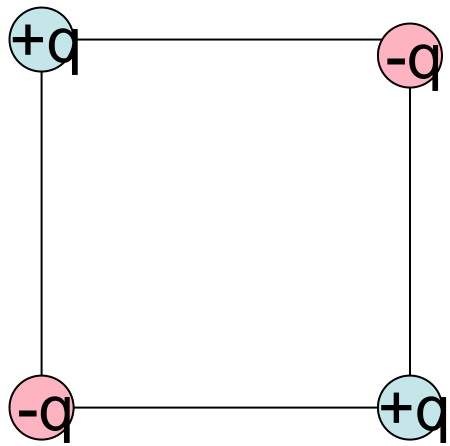

#+V?	#-V?

#+V?	#-V?

Which of the charge distributions is the most stable?
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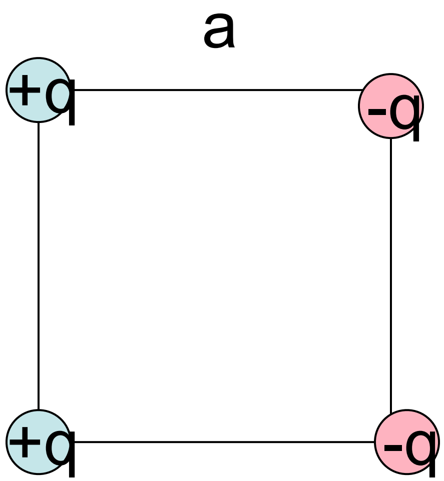

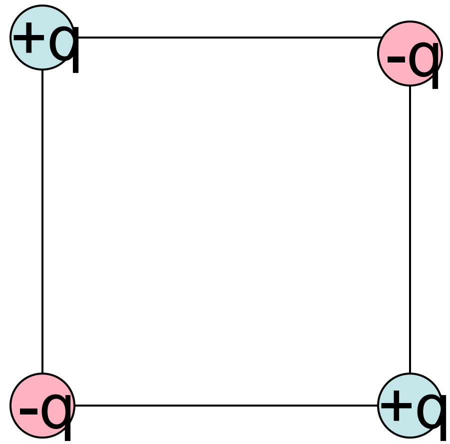

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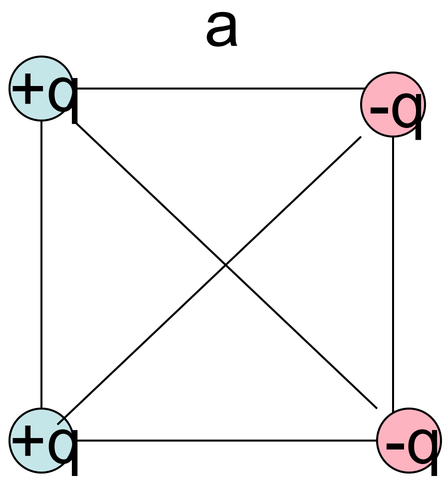
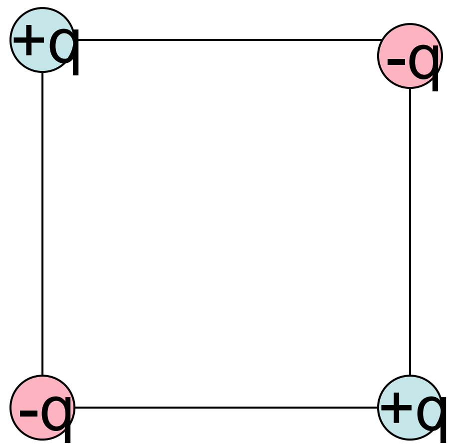
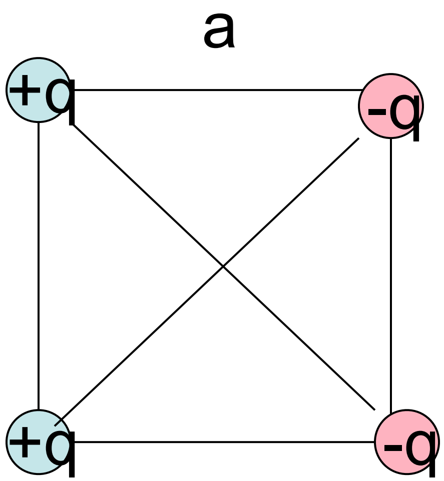


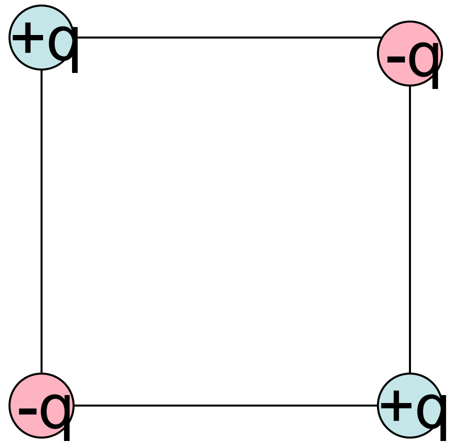


	#+V?	#-V?	#+V?	#-V?
PE_0				
$PE_0/\sqrt{2}$				
Total PE				

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

$$PE_0 = \frac{k_e q^2}{a}$$





	#+V?	#-V?	#+V?	#-V?
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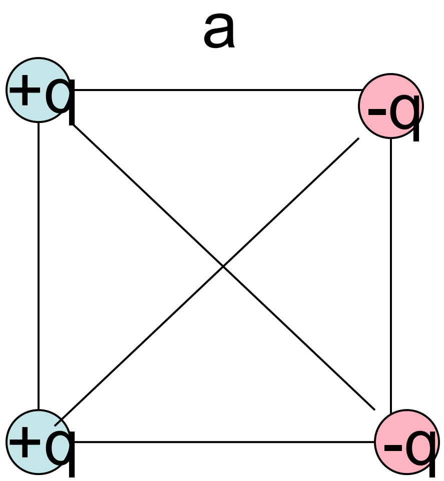

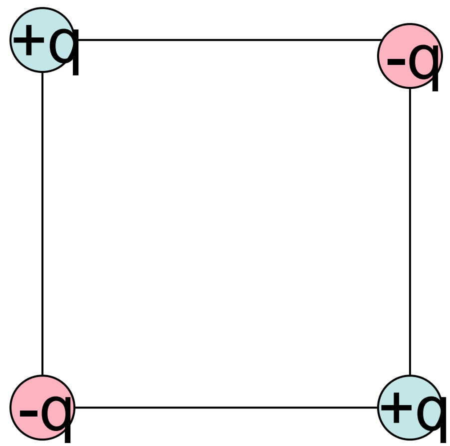

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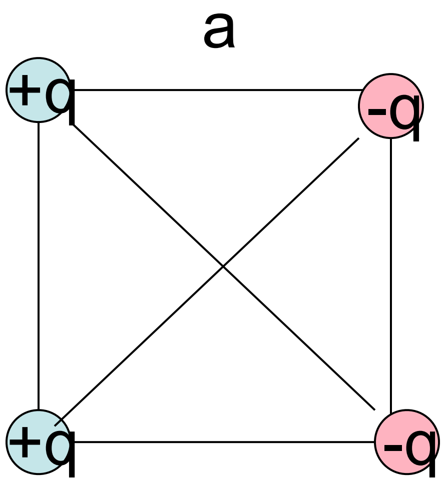

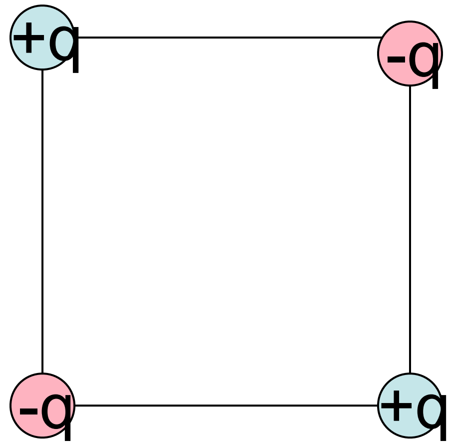

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	#+V?	#-V?	#+V?	#-V?
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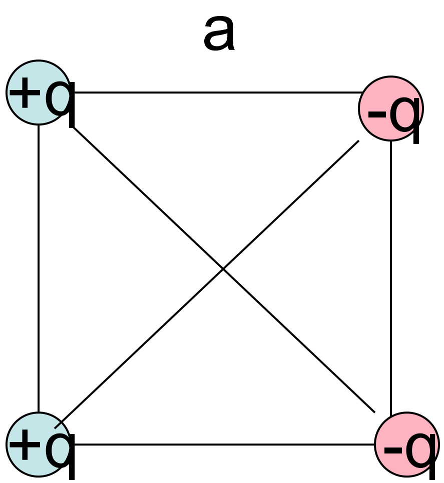

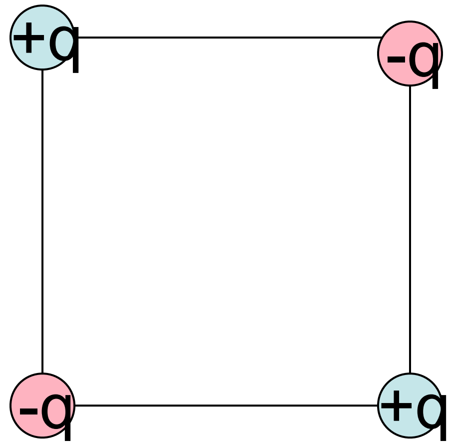

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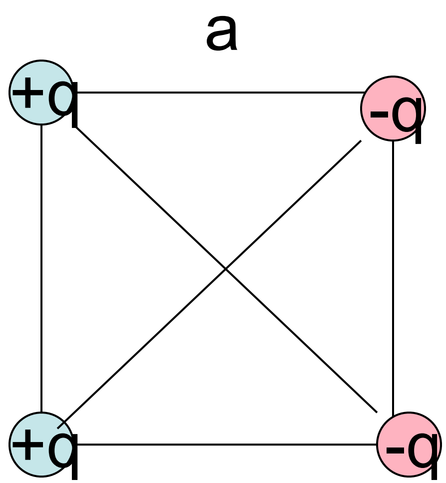

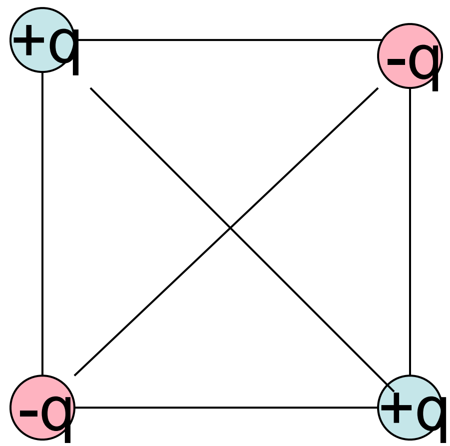

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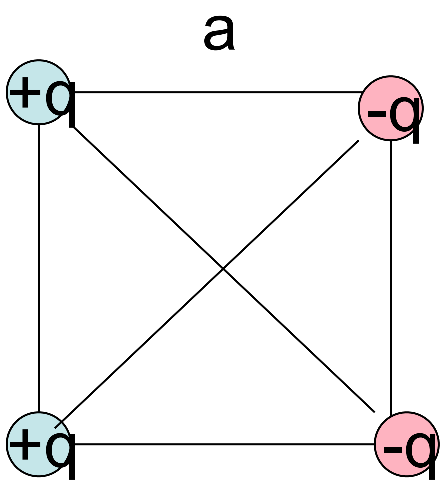

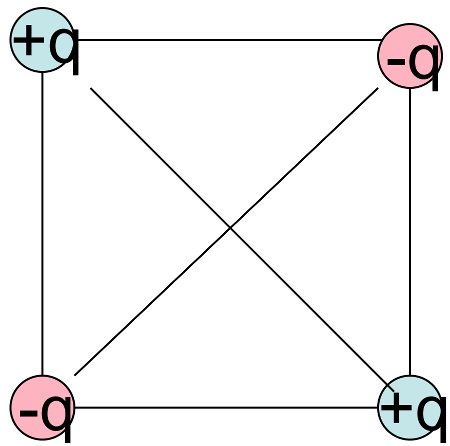

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Which of the charge distributions is the most stable?
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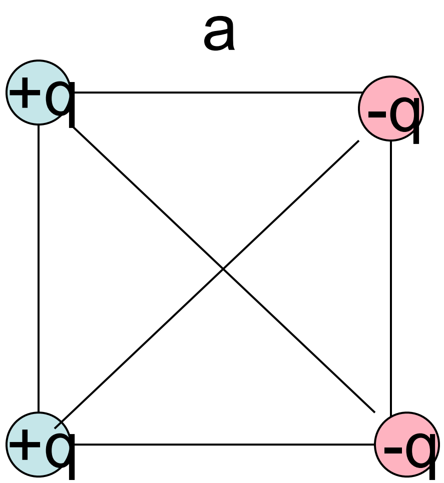

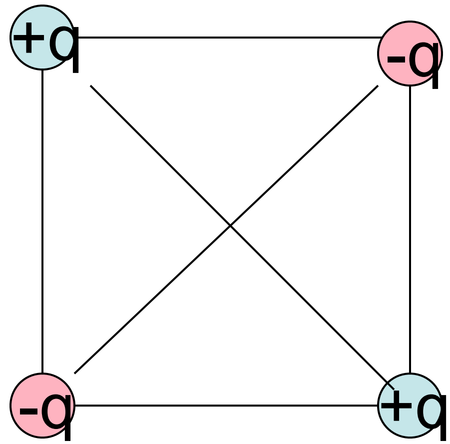

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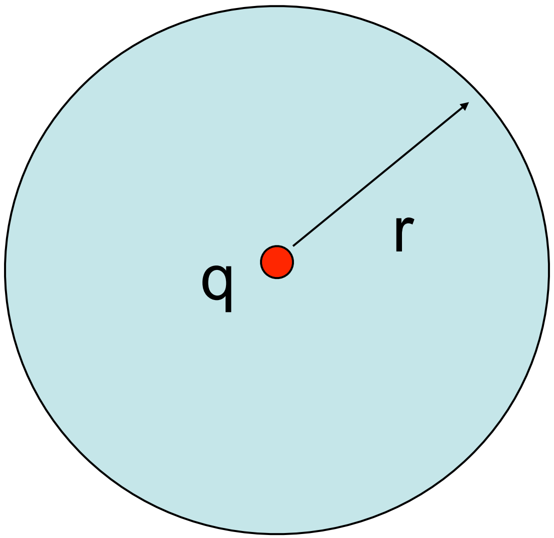
more stable

16.2 Equipotentials

Equipotential surfaces

Equipotential Surface - positions in space at which the electrical potentials are equal

Example 1- A sphere centered around a point charge



Every point on the surface of the sphere of radius r has the same potential

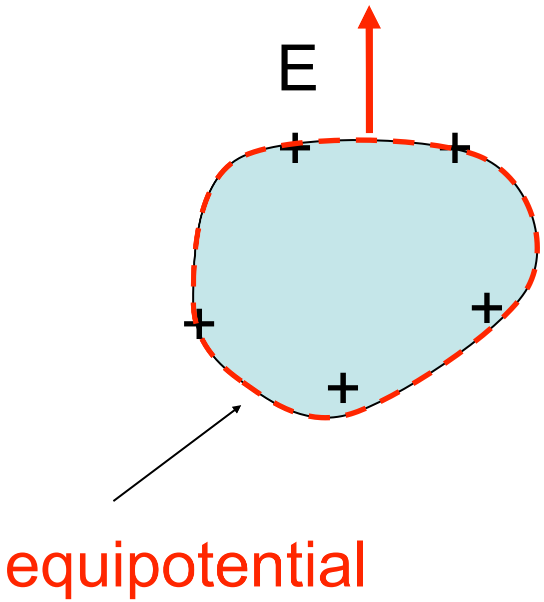
$$V = \frac{k_e q}{r}$$

The surface of the sphere is an equipotential surface

Equipotential surface-

Example 2: a charged conductor

The surface of a conductor is an equipotential surface.



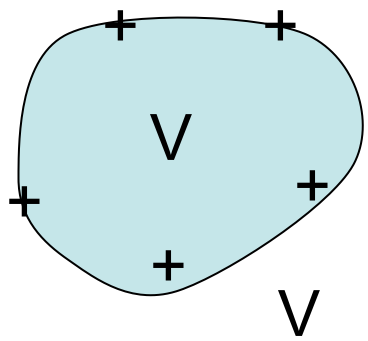
E field is perpendicular to the surface.

Component of E =0 parallel to the surface

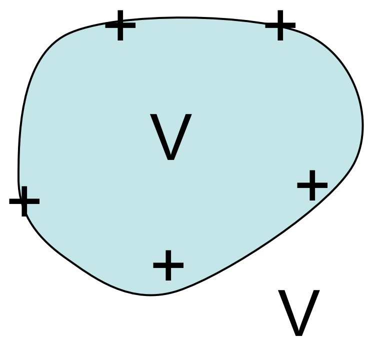
$\Delta V = Ed = 0$

Thus, No change in potential along the surface

The interior of the conductor is an equipotential and at the same potential as the surface.



The interior of the conductor is an equipotential and at the same potential as the surface.



E=0 in the conductor

Thus, the potential doesn't change from the surface potential

PHYSICS 1B – Fall 2009

Electricity
&
Magnetism

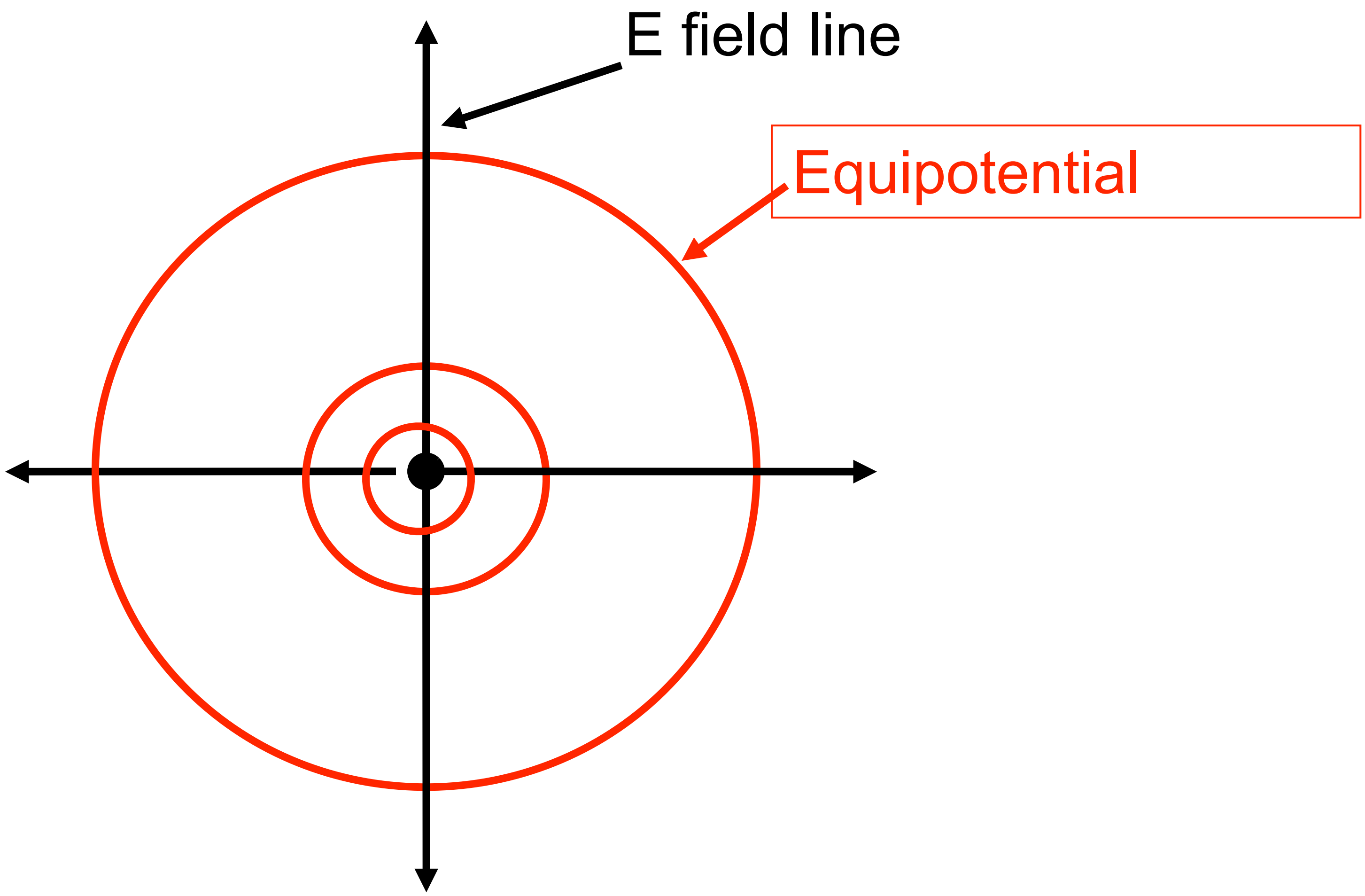
Professor Brian Keating

SERF Building. Room 333

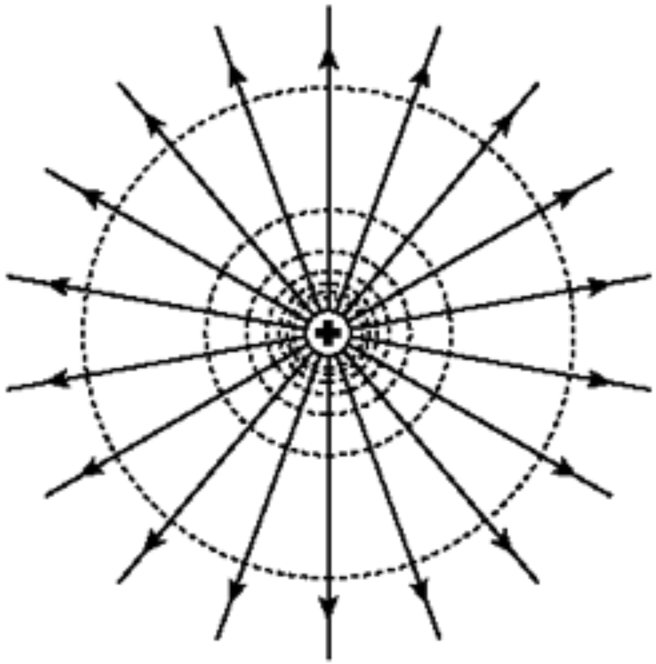
Friday October 16, 2009

UCSD UCSD

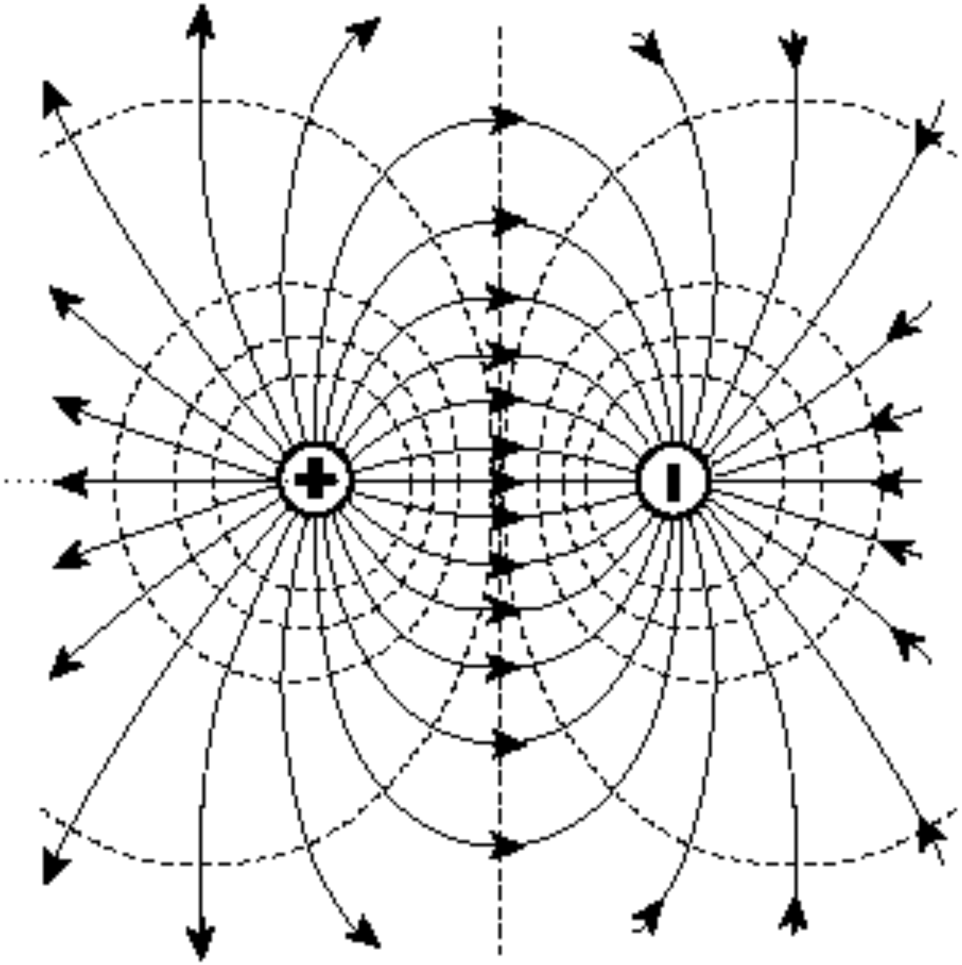
The equipotential surfaces are perpendicular to E field lines.



Equipotential lines: point charge



Equipotential lines: dipole



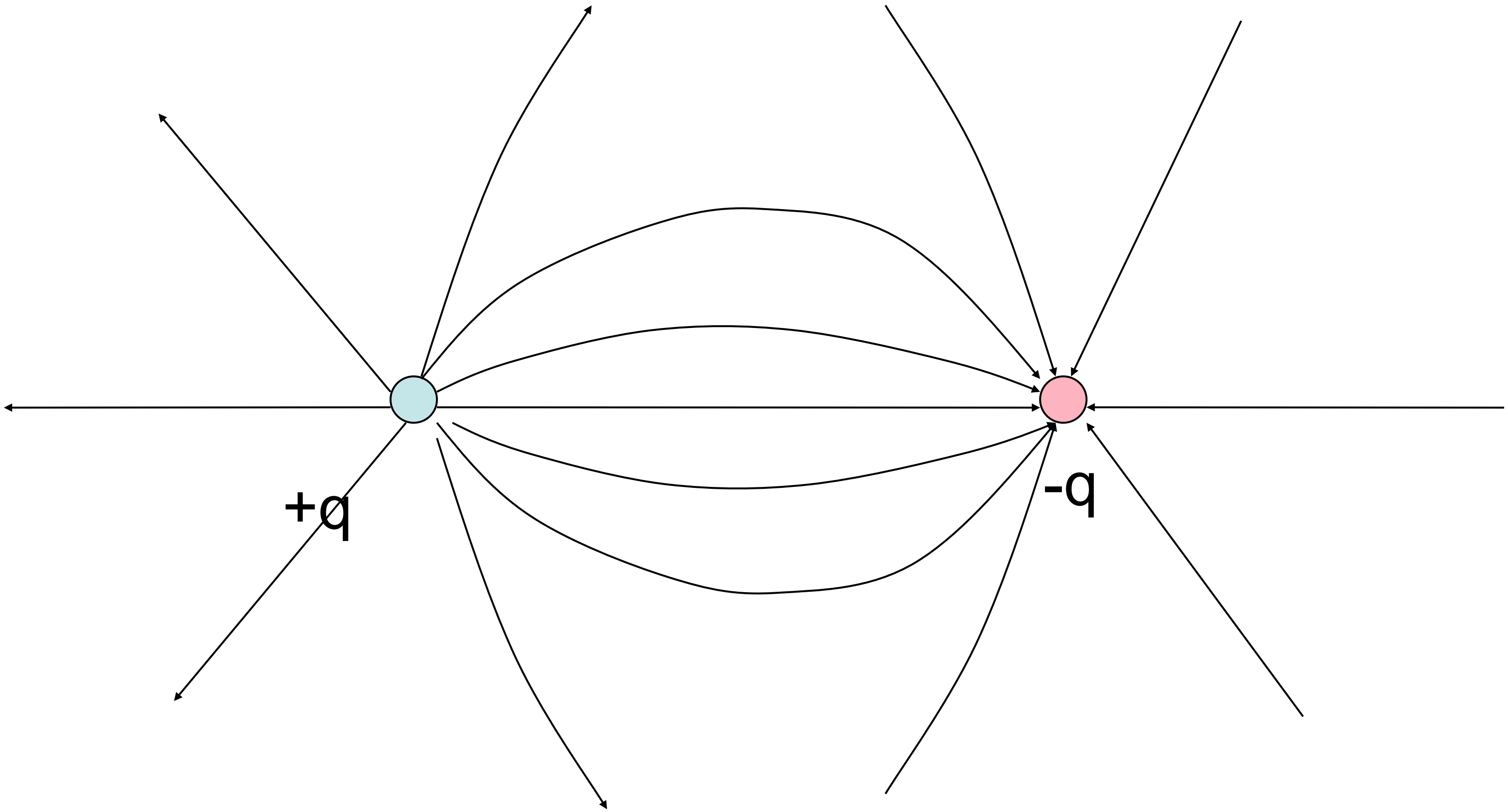
Which line type/style represents the electric field?

A. solid

B. dashed

Draw a sketch of the equipotential surfaces for a electric dipole (+q, –q) in a plane through both charges

Draw a sketch of the equipotential surfaces for a electric dipole (+q, –q) in a plane through both charges



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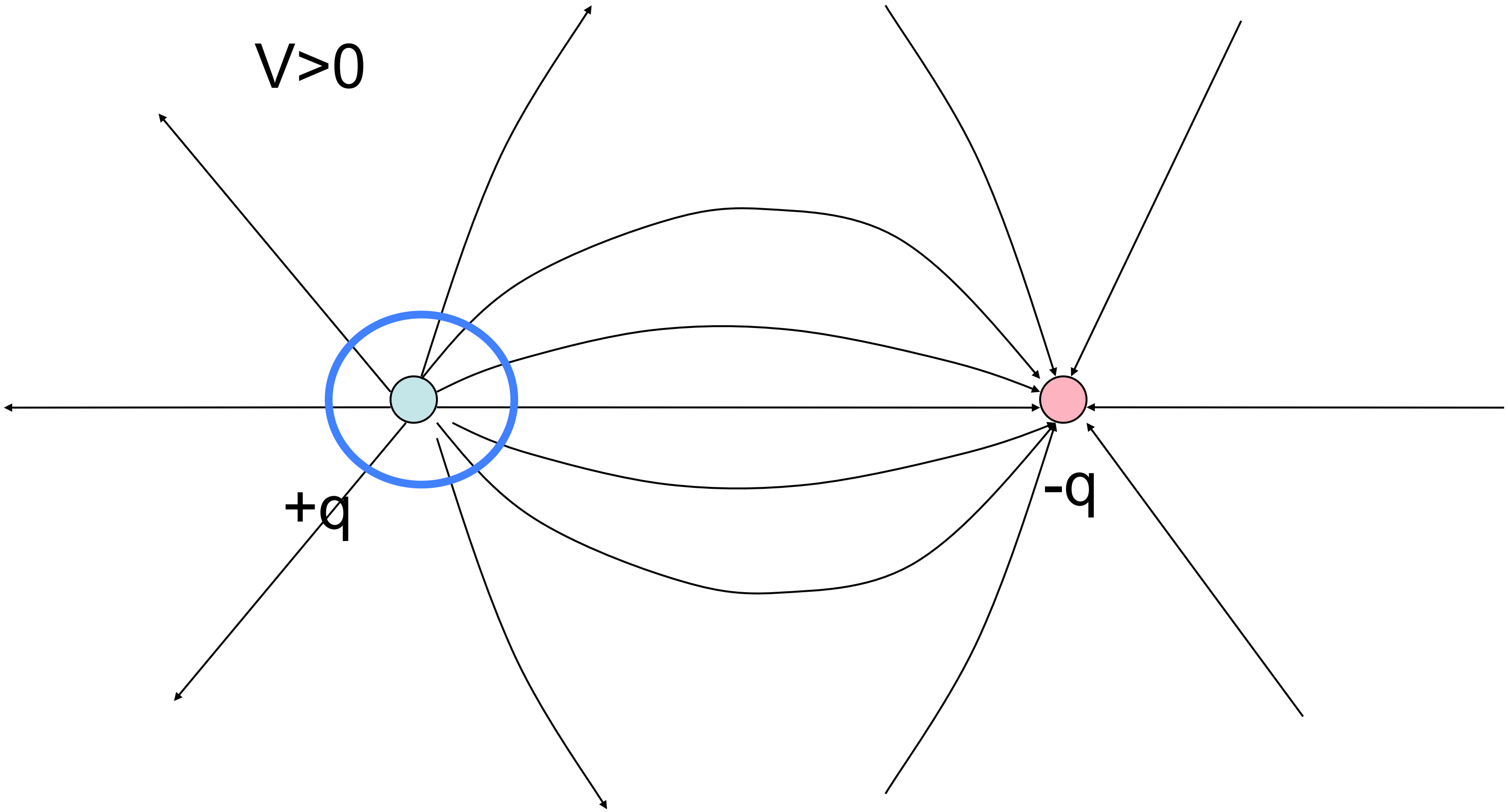

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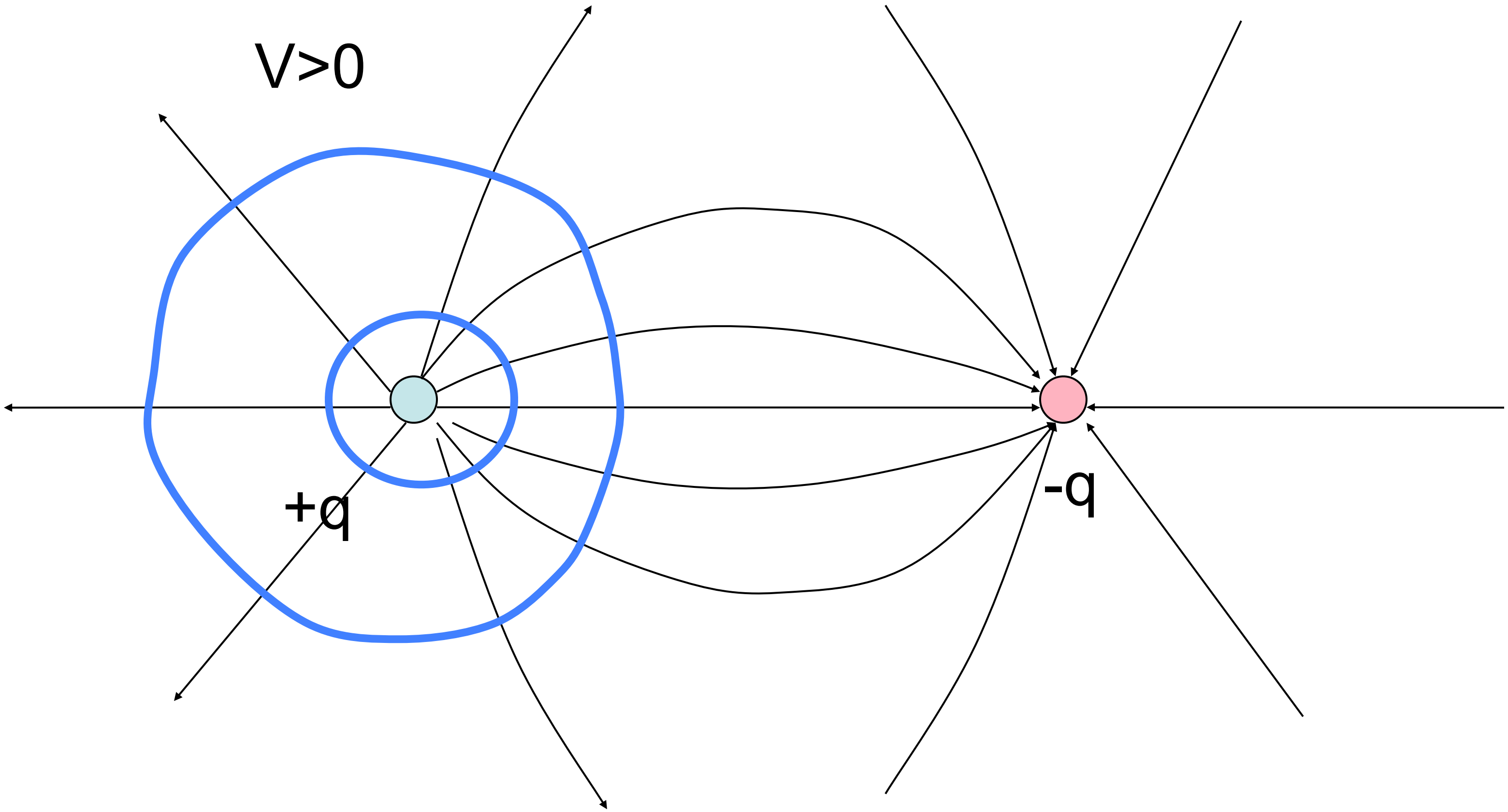

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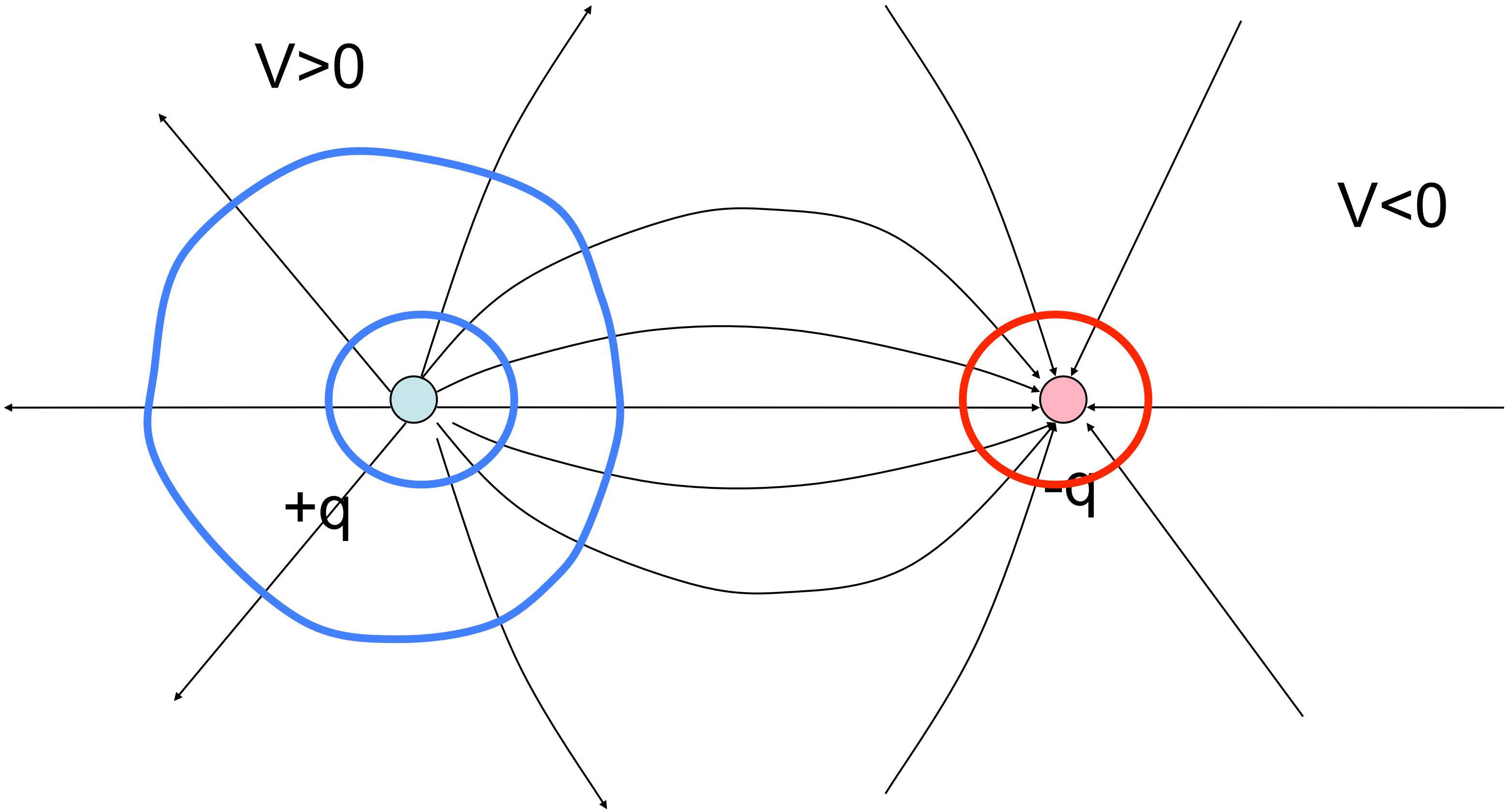

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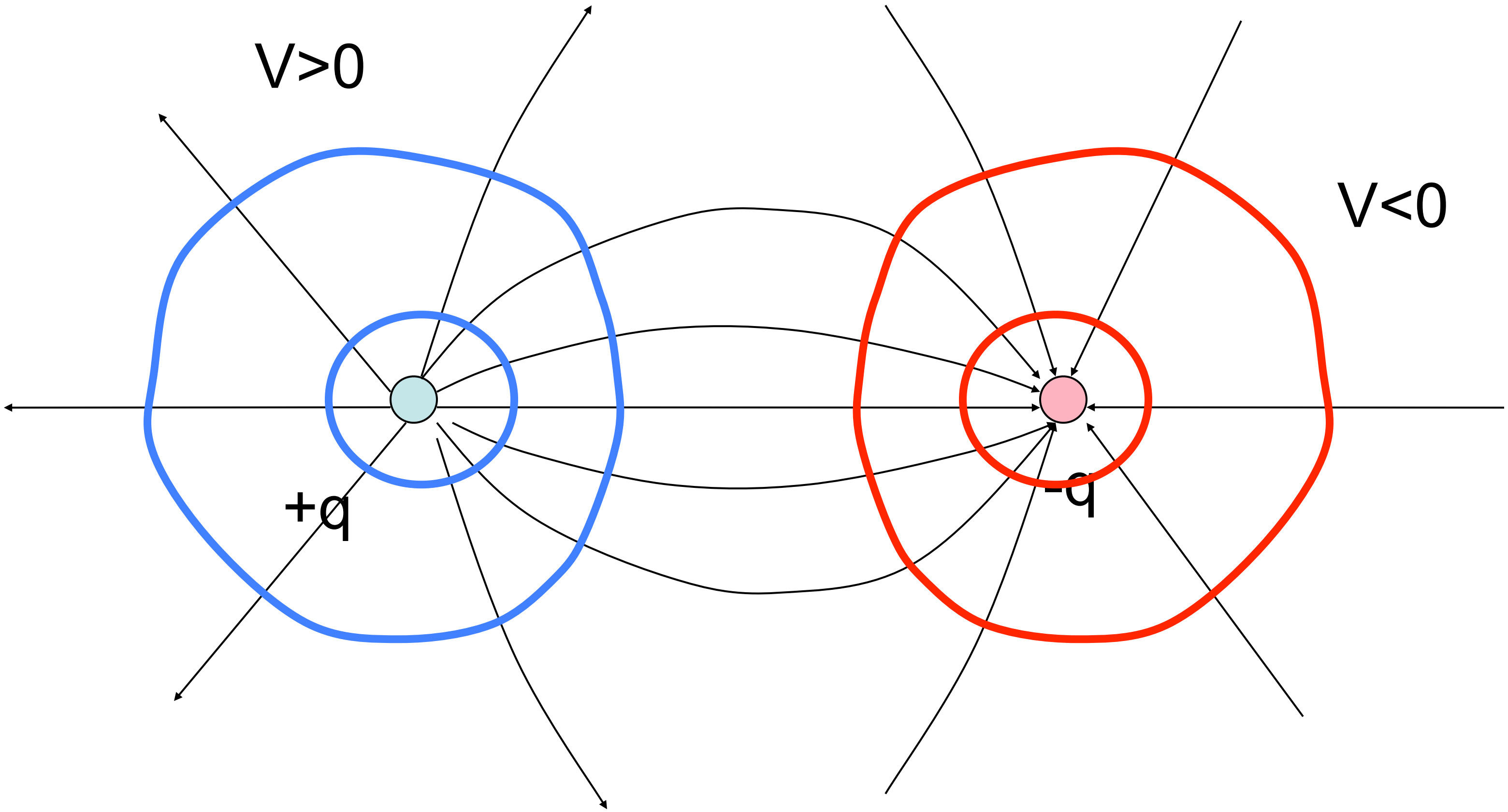

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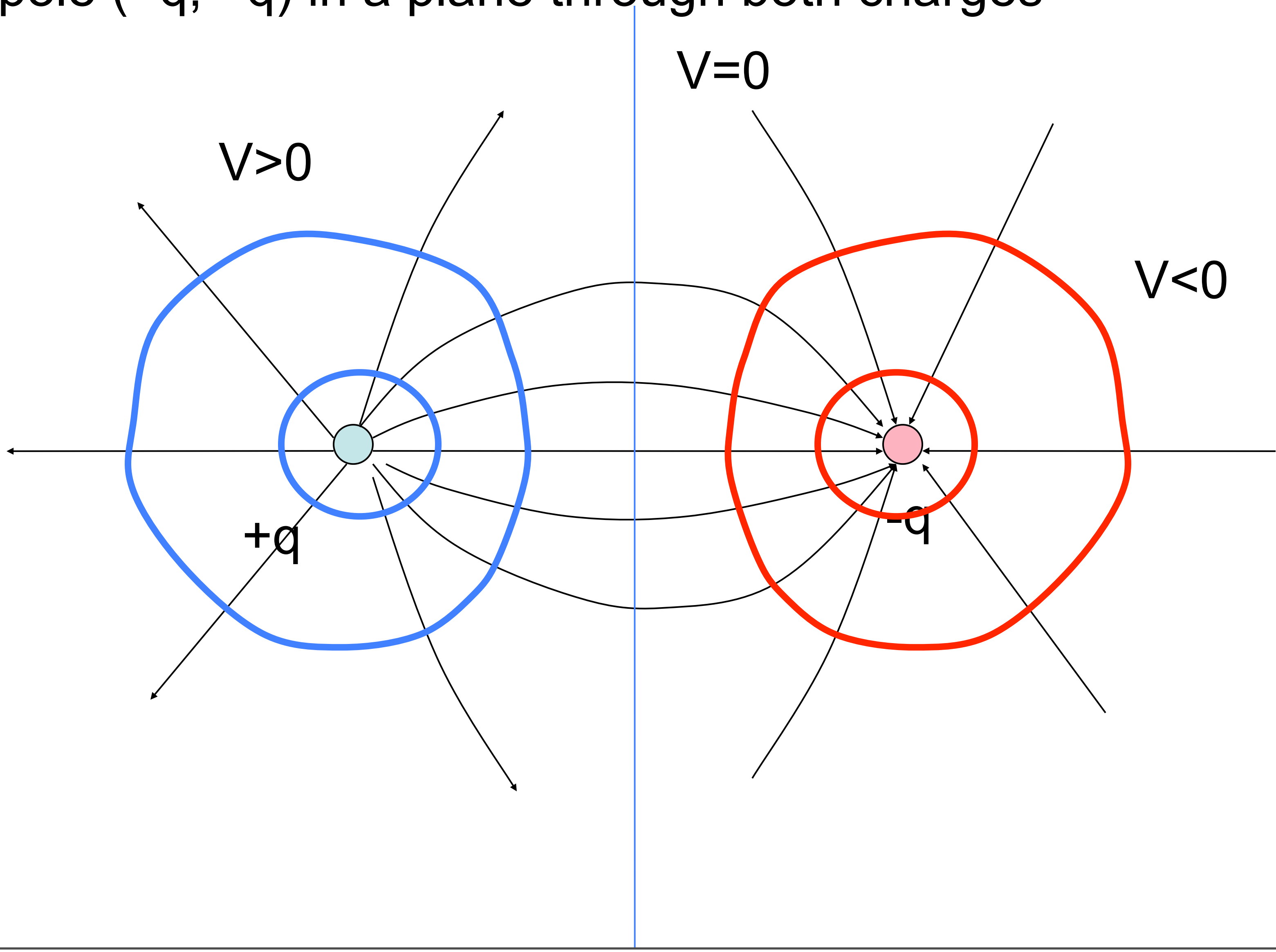
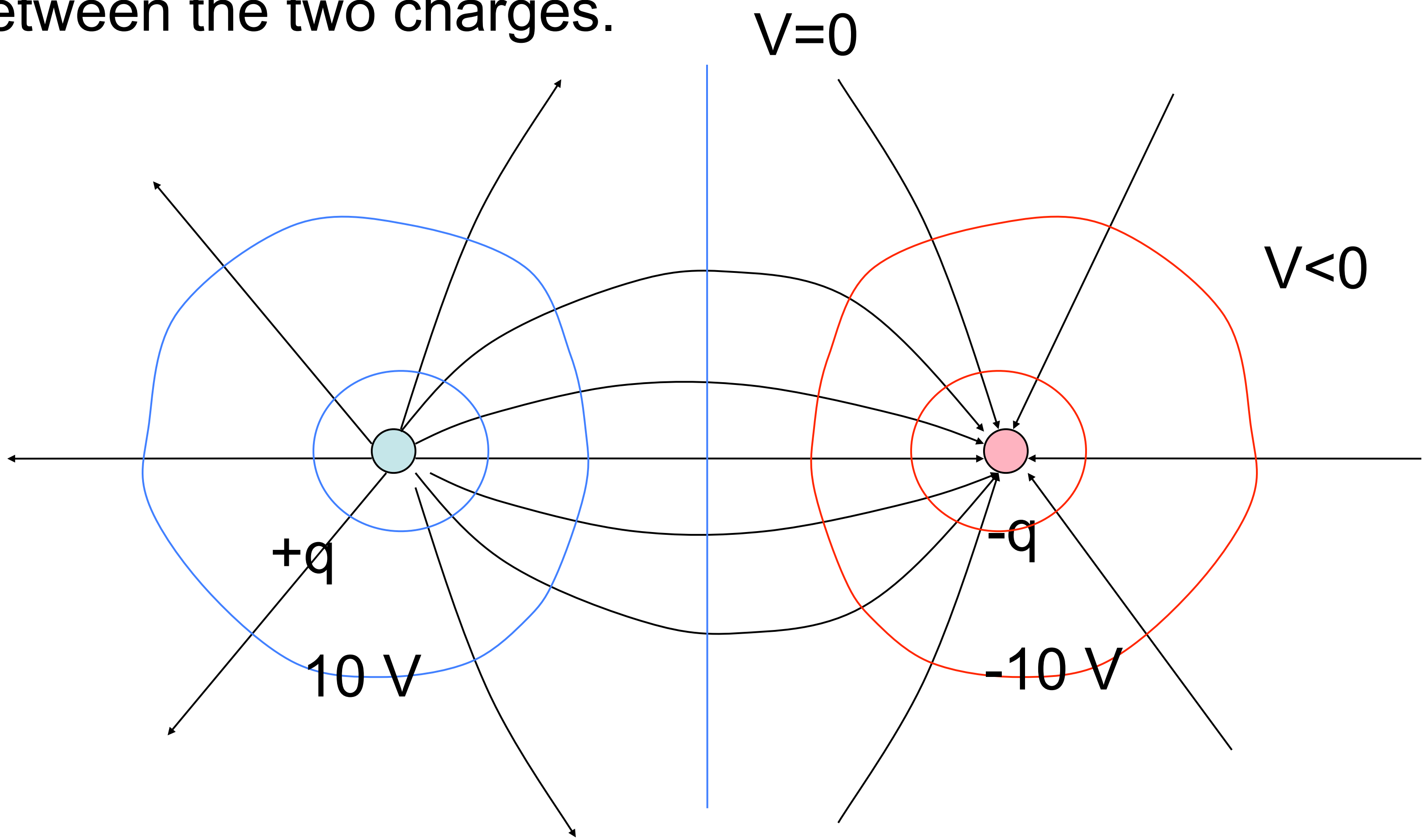


Suppose the two charges are 10 cm apart and the equipotential surfaces are as labeled estimate the E field between the two charges.



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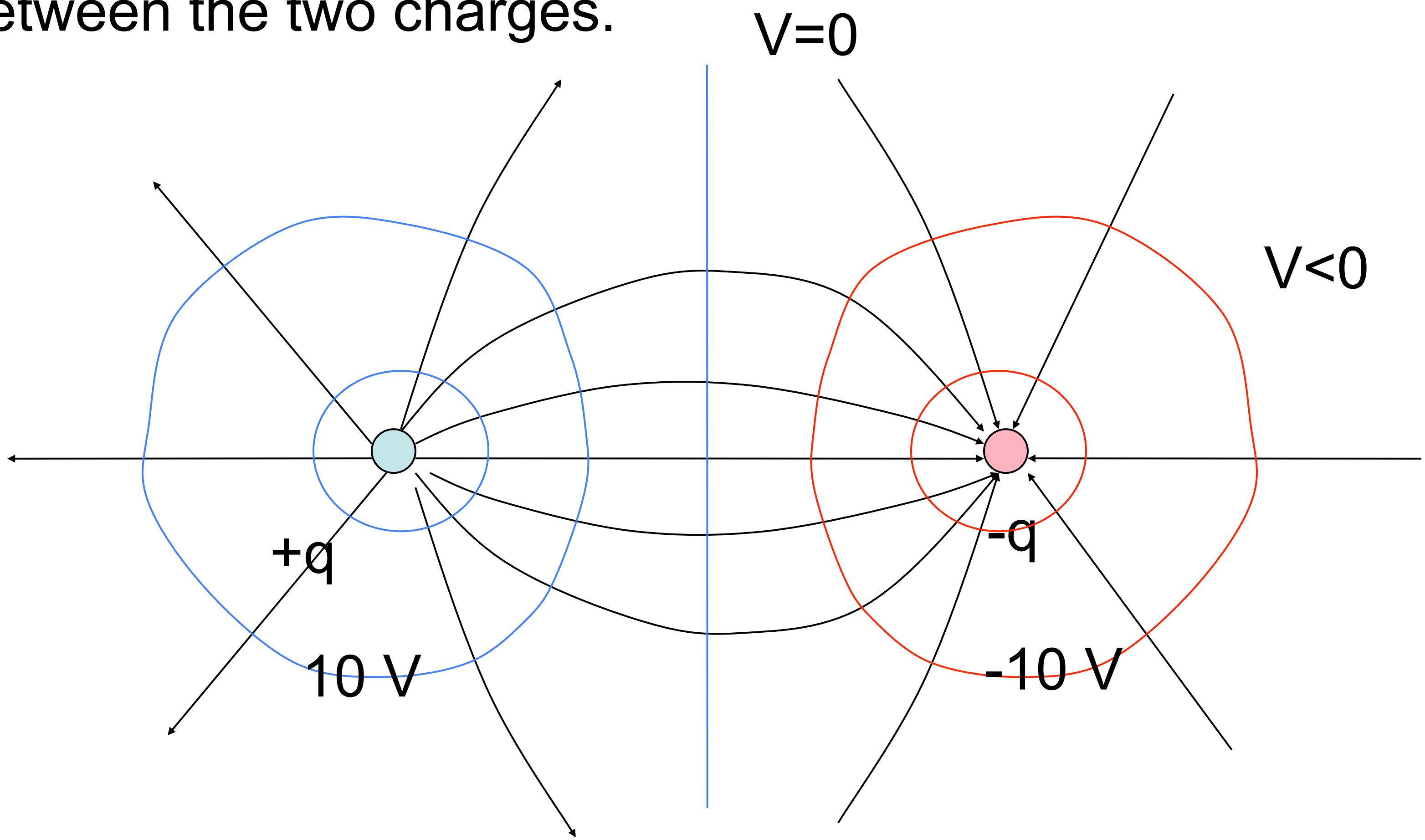


$$E = \frac{\Delta V}{d} \approx \frac{20}{0.05} \approx 400V/m$$

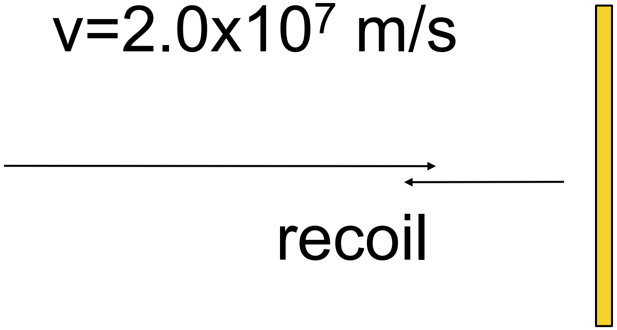
Rutherford Scattering experiment
Determination of the size of the nucleus

α particle He nucleus

$q=+2e$

$m = 6.64\times10^{-27}$ kg

$v=2.0\times10^{7}$ m/s



gold
foil

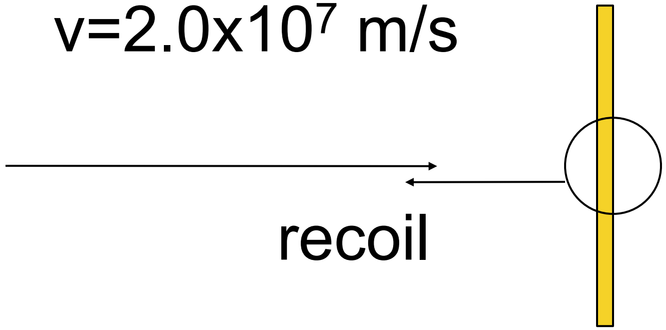
gold nuclei

$Q=+79e$

Rutherford Scattering experiment
Determination of the size of the nucleus

α particle He nucleus

$q=+2e$
$m = 6.64\times10^{-27}$ kg
$v=2.0\times10^{7}$ m/s



recoil

gold
foil

gold nuclei
$Q=+79e$

Rutherford Scattering experiment
Determination of the size of the nucleus

α particle He nucleus

$q=+2e$

$m = 6.64\times10^{-27}$ kg

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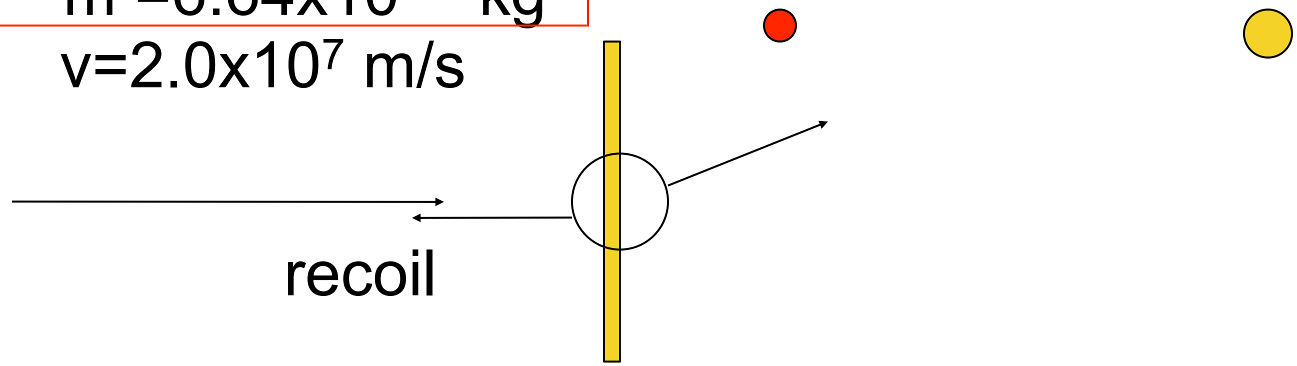

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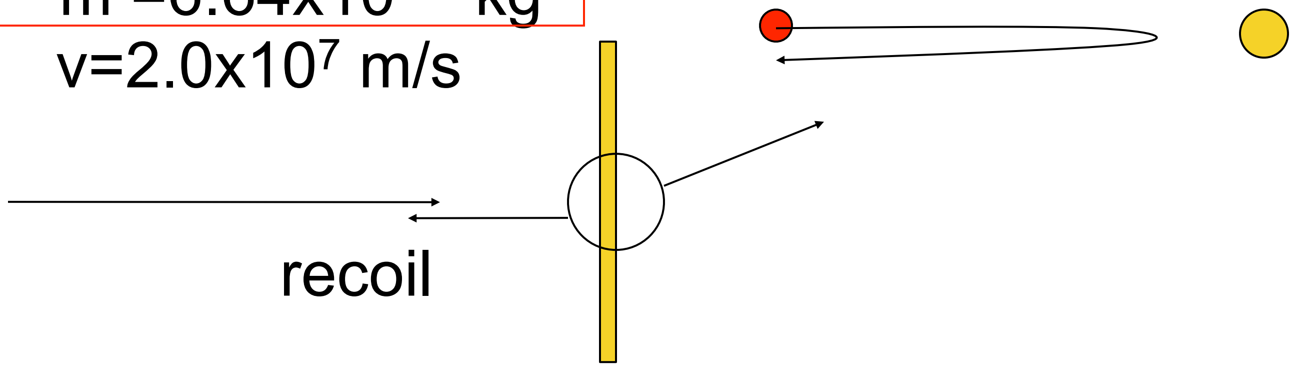

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foil

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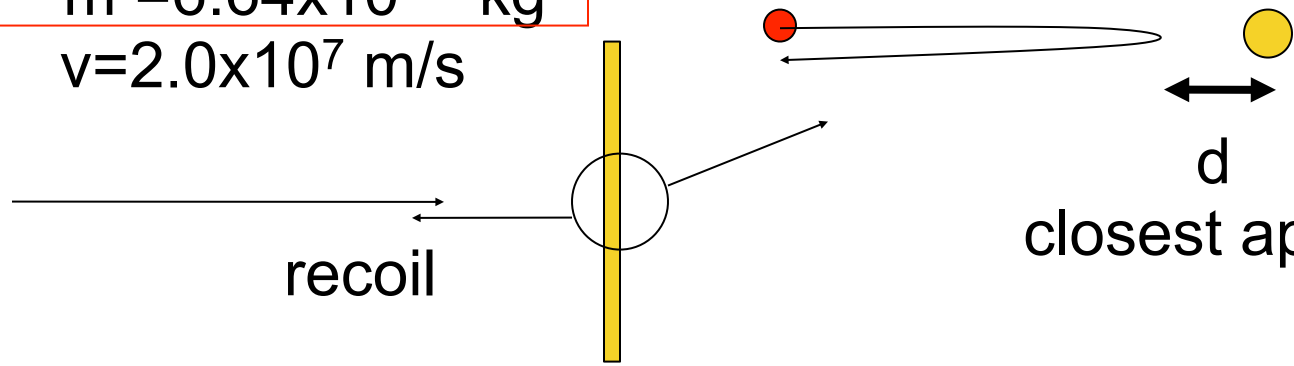

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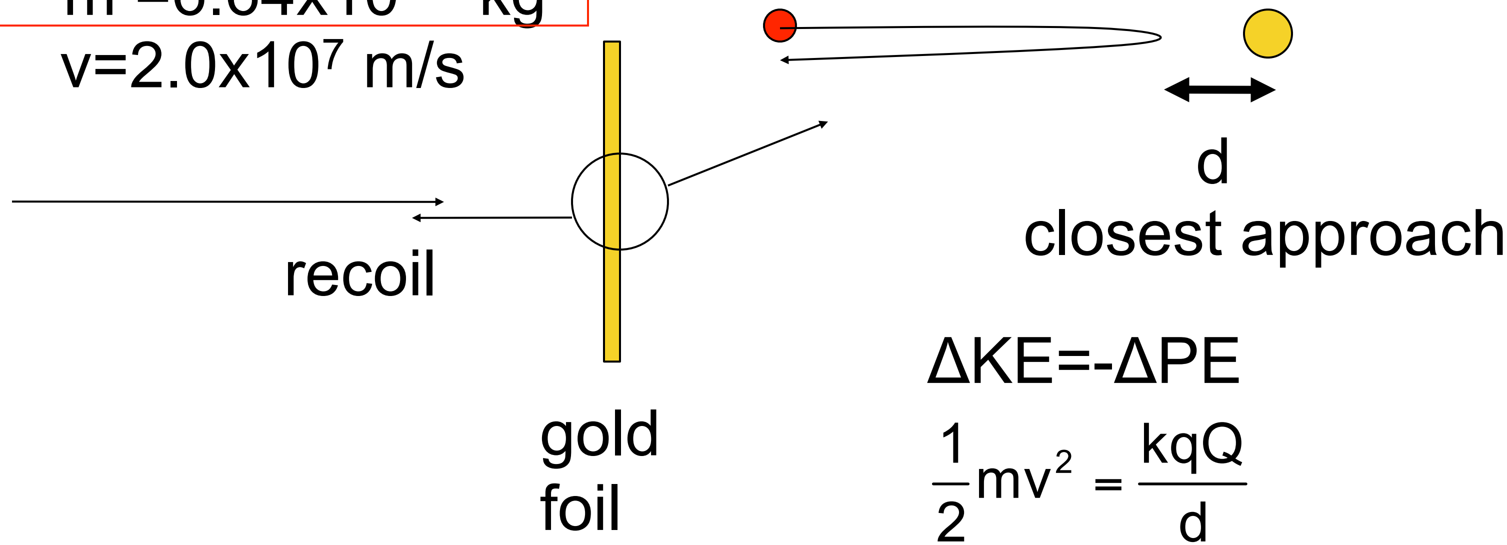

$\Delta KE = -\Delta PE$

$$\frac{1}{2}mv^2 = \frac{kqQ}{d}$$

gold nuclei

$Q=+79e$

Rutherford Scattering experiment
Determination of the size of the nucleus

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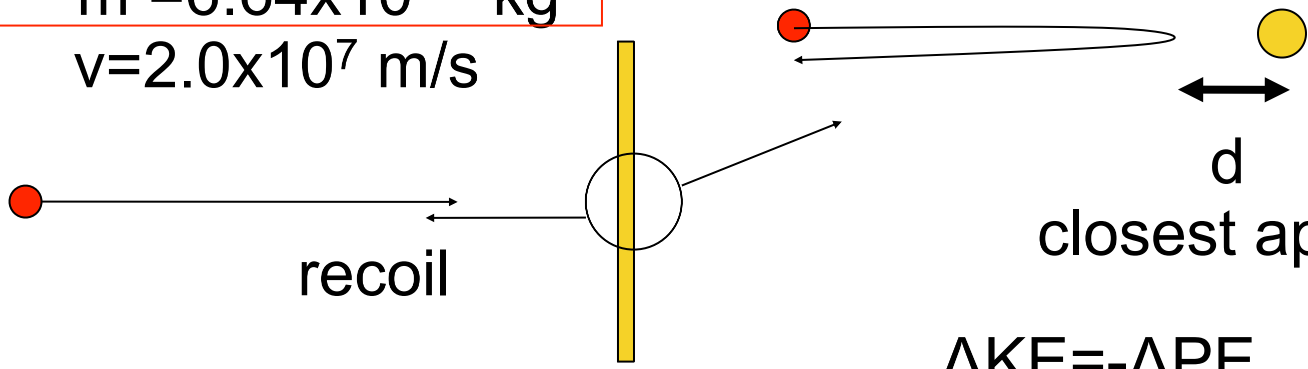


$\Delta KE = -\Delta PE$

$$\frac{1}{2}mv^2 = \frac{kqQ}{d}$$

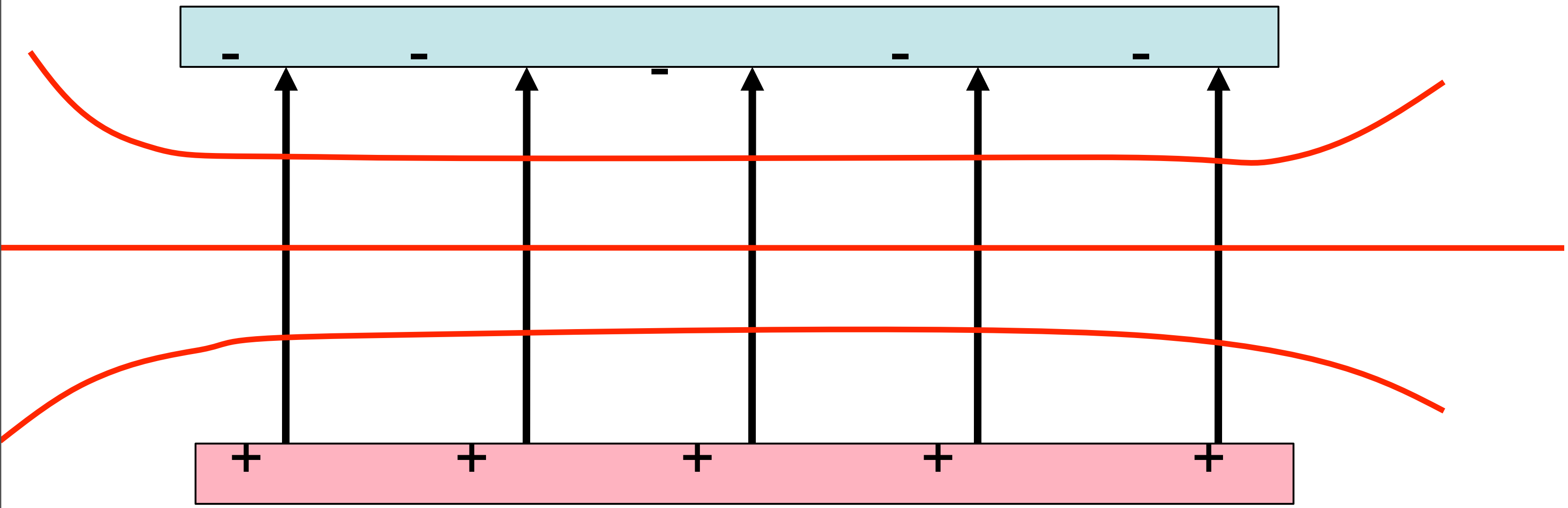
gold nuclei
$Q=+79e$

$$d = \frac{2k_e qQ}{mv^2} = \frac{2(9\times10^{9})(2)(79)(1.6\times10^{-19})^2}{6.64\times10^{-27}(2\times10^{7})^2}$$

$$d = 2.7\times10^{-14}\,\text{m}$$

nuclear size < d, much smaller than size of an atom~ 0.3×10^{-9} m

Parallel plate capacitor

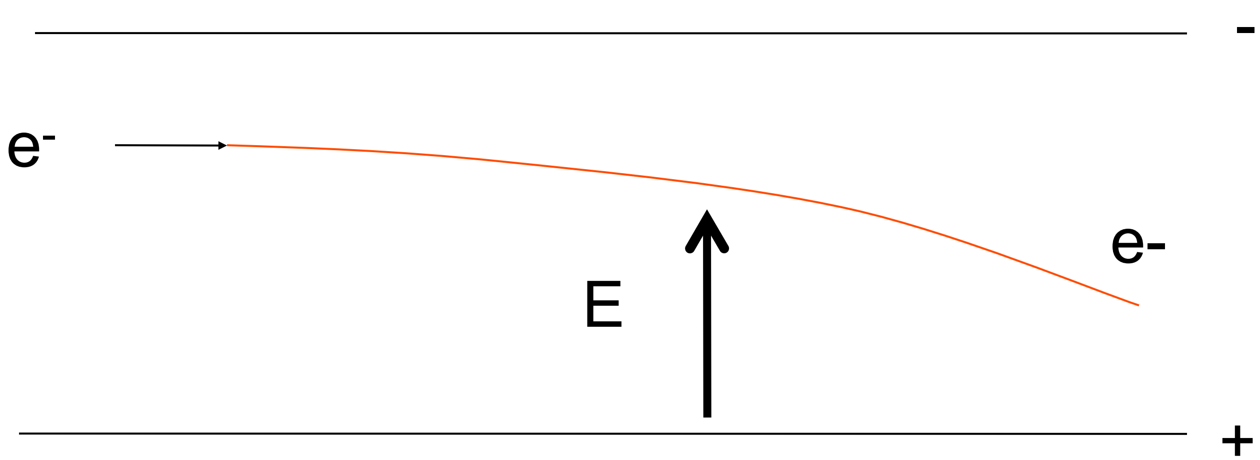


FIELD LINES IN BLACK (VECTORS)

POTENTIAL CONTOURS IN RED

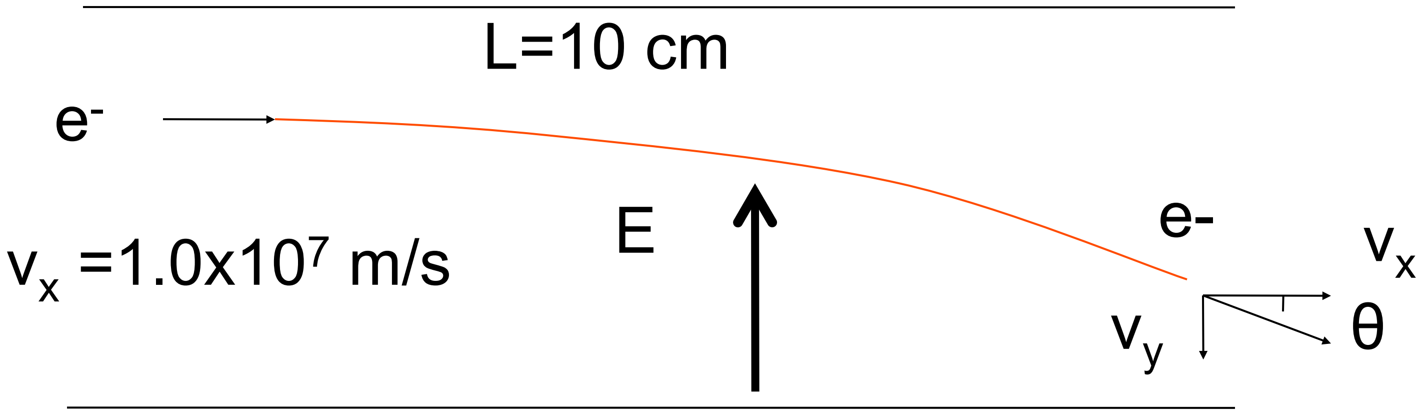
(NO ARROWS, BECAUSE NOT A VECTOR)

Deflection of an electron beam in an electric field



Calculation – velocity, acceleration – Next Slide: calculate the angle the electron exits at…

An electron beam passes through two parallel plates of a length 10 cm having an electric field of E. The initial velocity of the electron is 1.0×10^7 m/s. Find the angle through which the beam is deflected.



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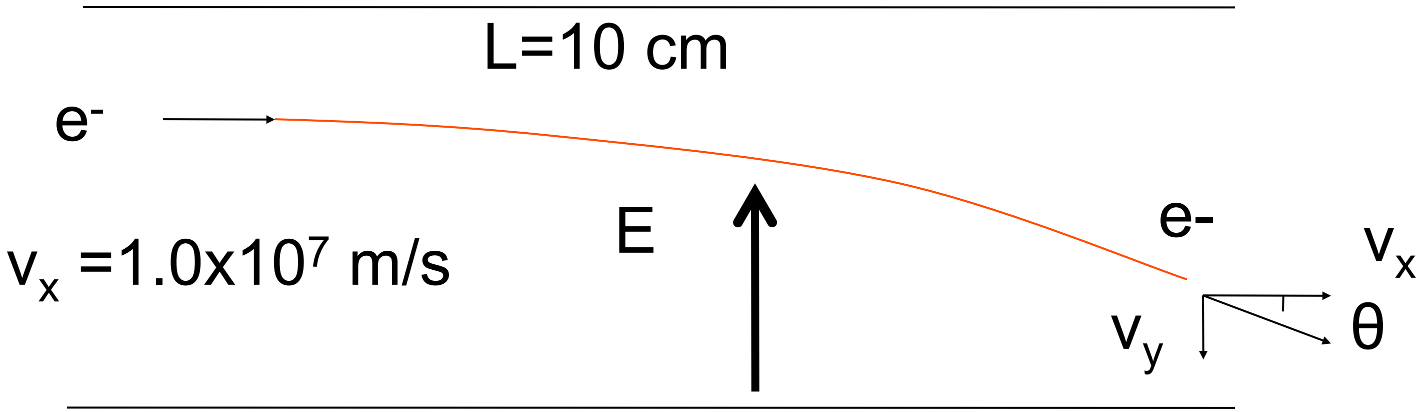

$F = qE = ma$

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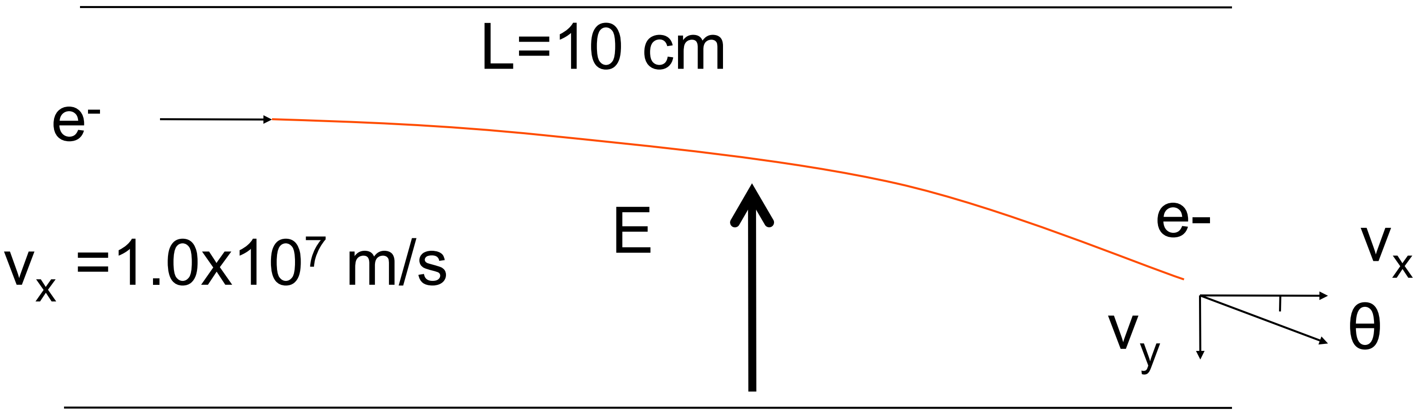

$$F = qE = ma$$

$$v_y = at = \frac{F}{m}t = \frac{qE}{m}t$$

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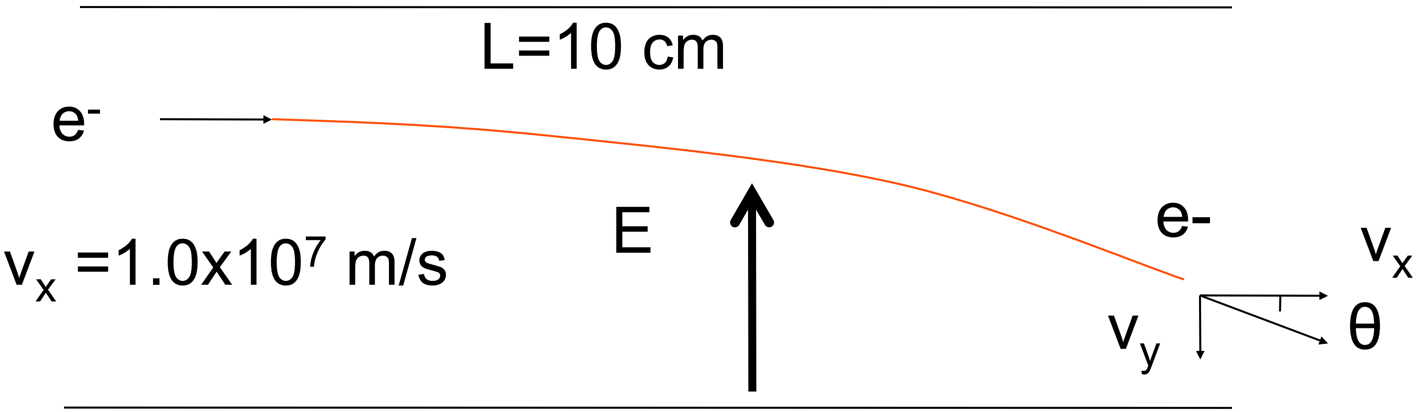

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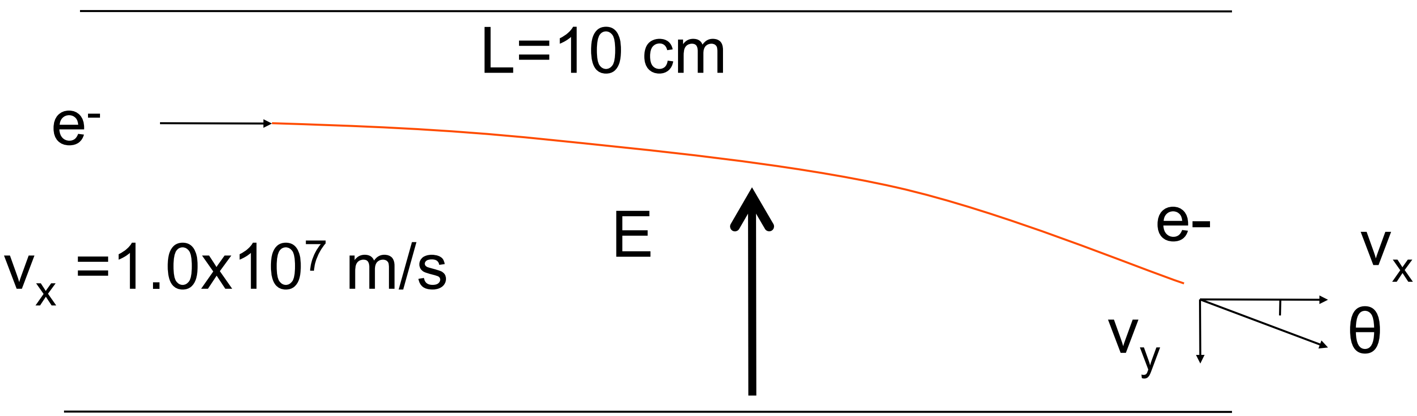

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$$\tan\theta = \frac{v_y}{v_x} = \frac{qEL}{v_x^2 m}$$

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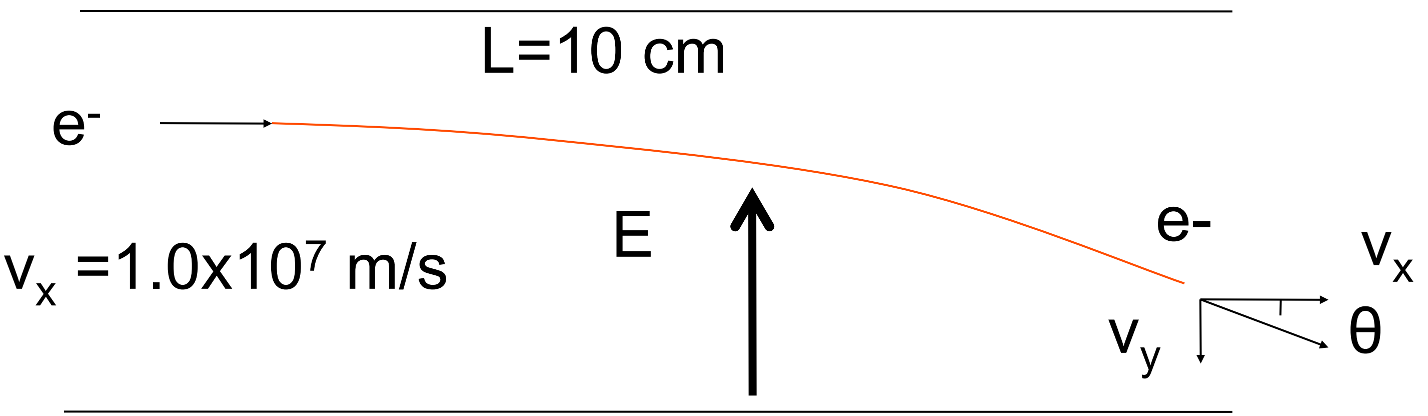

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$$\tan\theta = \frac{v_y}{v_x} = \frac{qEL}{v_x^2 m}$$

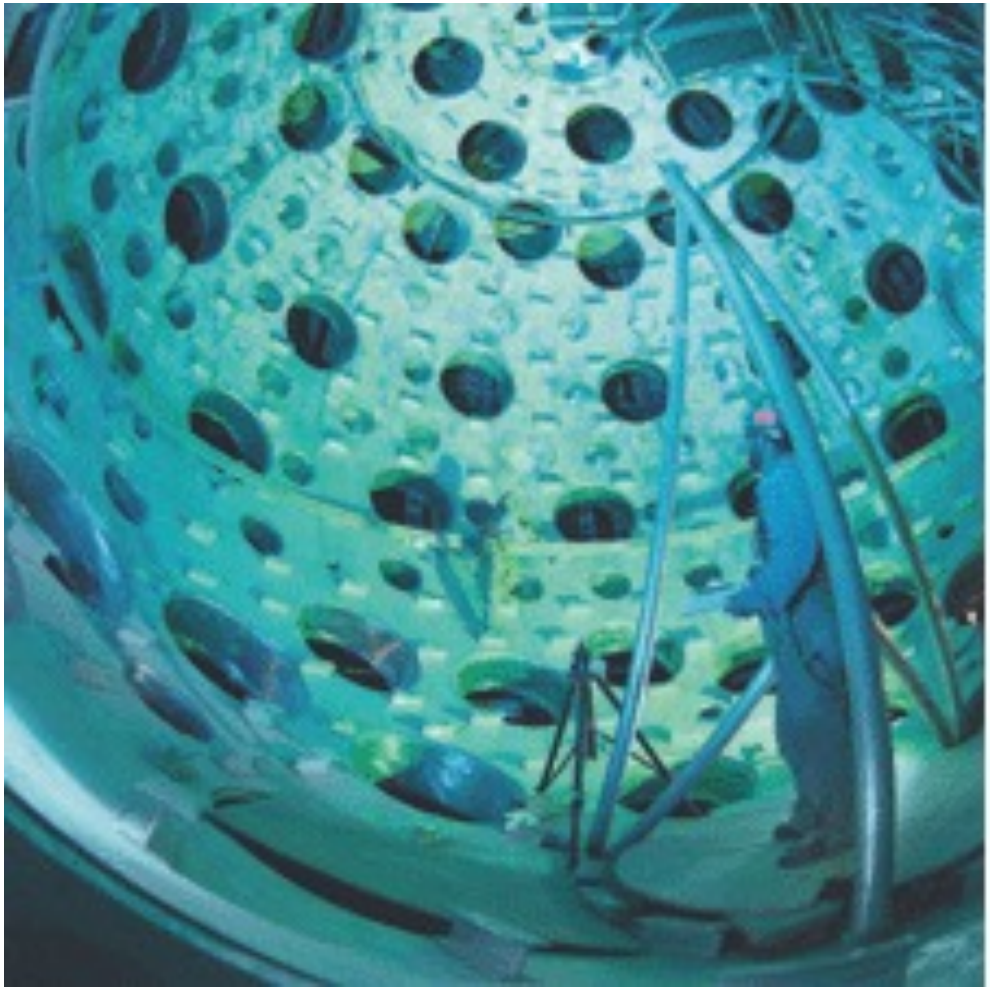
$$\theta = \tan^{-1}\left(\frac{qEL}{v_x^2 m}\right) = \tan^{-1}\left(\frac{1.6\text{x}10^{-19}(1000)(0.1)}{(10^7)^2(9\text{x}10^{-31})}\right) = 10^\circ$$

Capacitance

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

Applications

- Camera flash
- automobile starting system
- capacitors in electronic devices
- computer memories (store information)
- Laser flash lamp

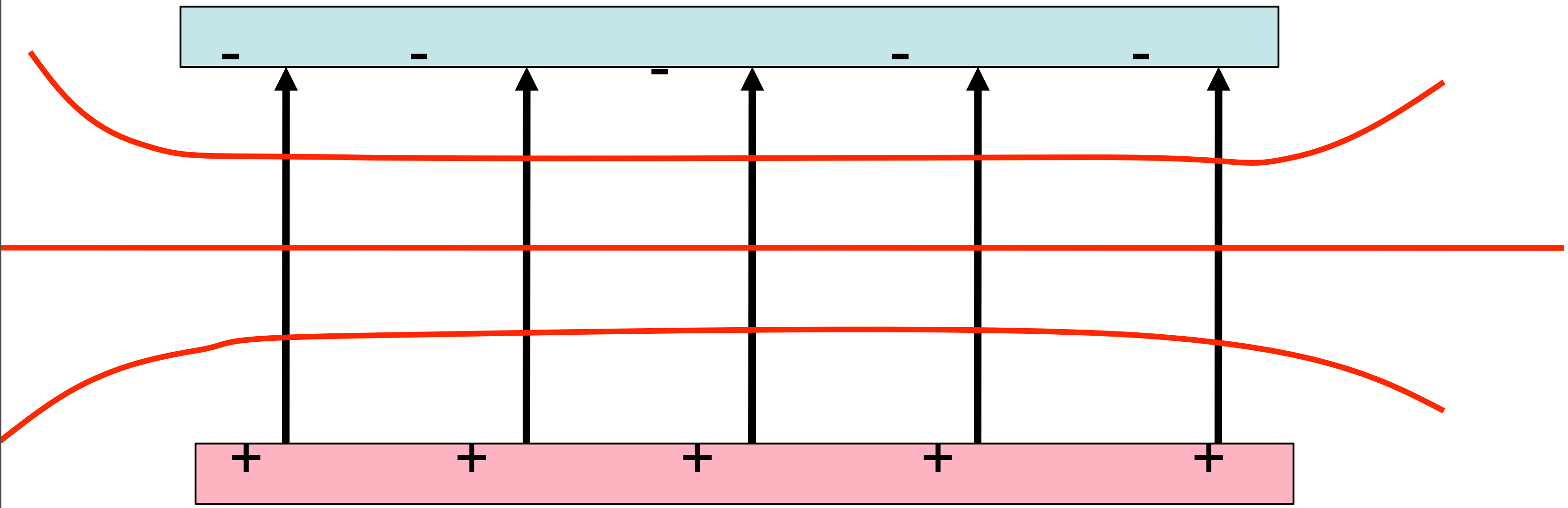


laser fusion

Energy stored in a capacitor 2 x10^6 J released in 1-2 x10^{-6} s.

High Power $\sim 10^{12}$ W

Parallel plate capacitor



FIELD LINES IN BLACK (VECTORS)

POTENTIAL CONTOURS IN RED

(NO ARROWS, BECAUSE NOT A VECTOR)

PHYSICS 1B – Fall 2009

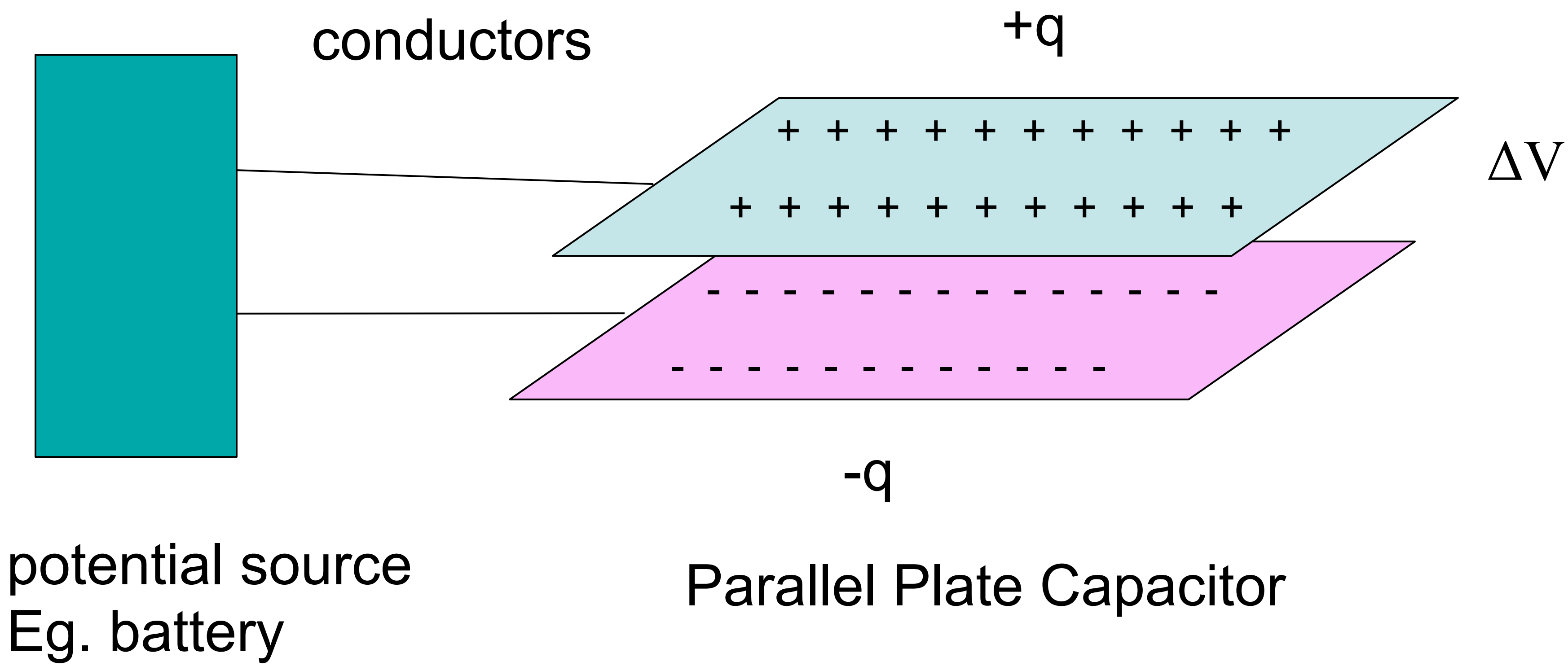
Electricity & Magnetism

Professor Brian Keating

SERF Building. Room 333

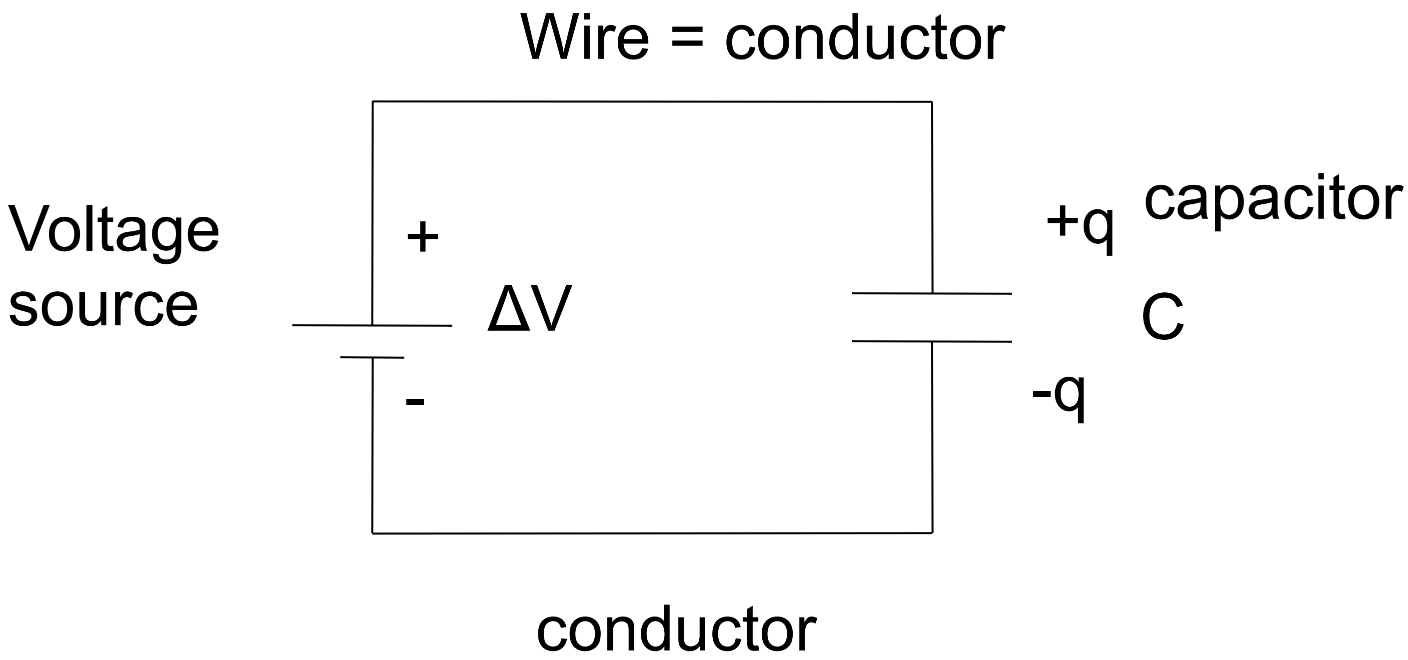
October 19, 2009

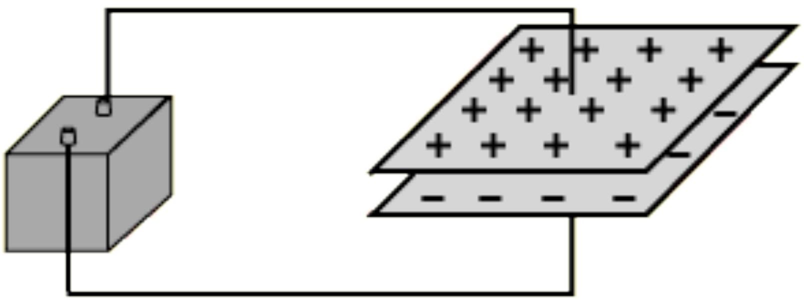
UCSD UCSD



Work is done to separate charges
Capacitor Stores Electrical Energy

Circuit Diagram





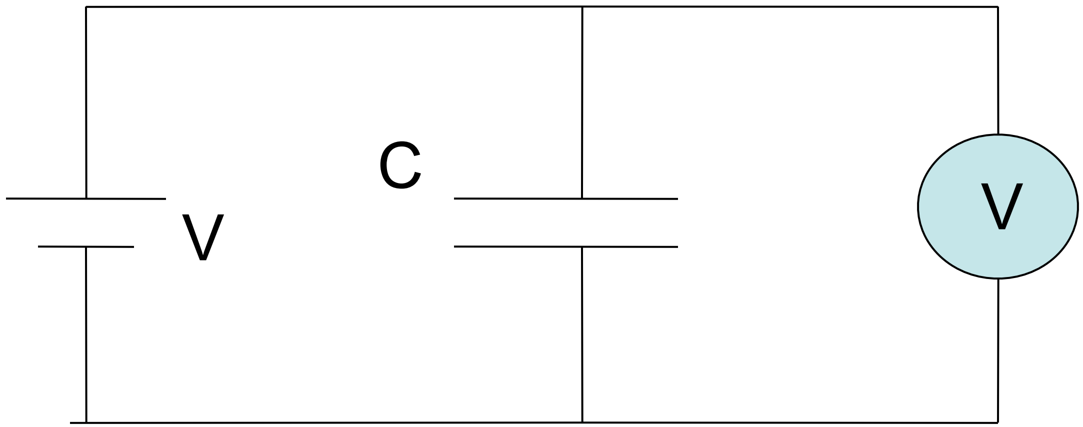
Capacitor

A battery will transport charge from one plate to the other until the voltage produced by the charge buildup is equal to the battery voltage.

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

$$\text{Unit} = \frac{\text{coulomb}}{\text{volt}} = \text{Farad}$$

Measuring voltage

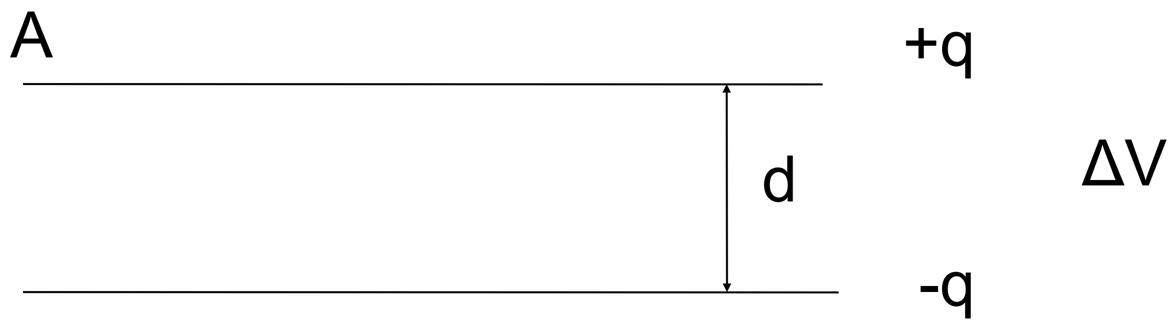


Voltmeter

Ideal voltmeter
Draws no charge
Perfect insulator

Parallel Plate Capacitor

Metal plates with area A, separated by a gap, d containing an insulating material. (eg. Air)



Capacitance – describes the ability to store separated charge

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

Units C/V, farad (F)

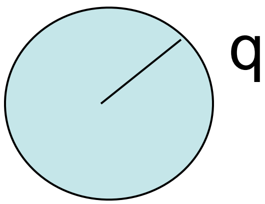
A 100 microfarad capacitor is charged to 100 V. How much charge does it store?

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

$$q = C(\Delta V) = 100x10^{-6}(100) = 10^{-2}C$$

This is a lot of charge. Recall that 10^{-2} C on a sphere of 1m radius generates a potential of

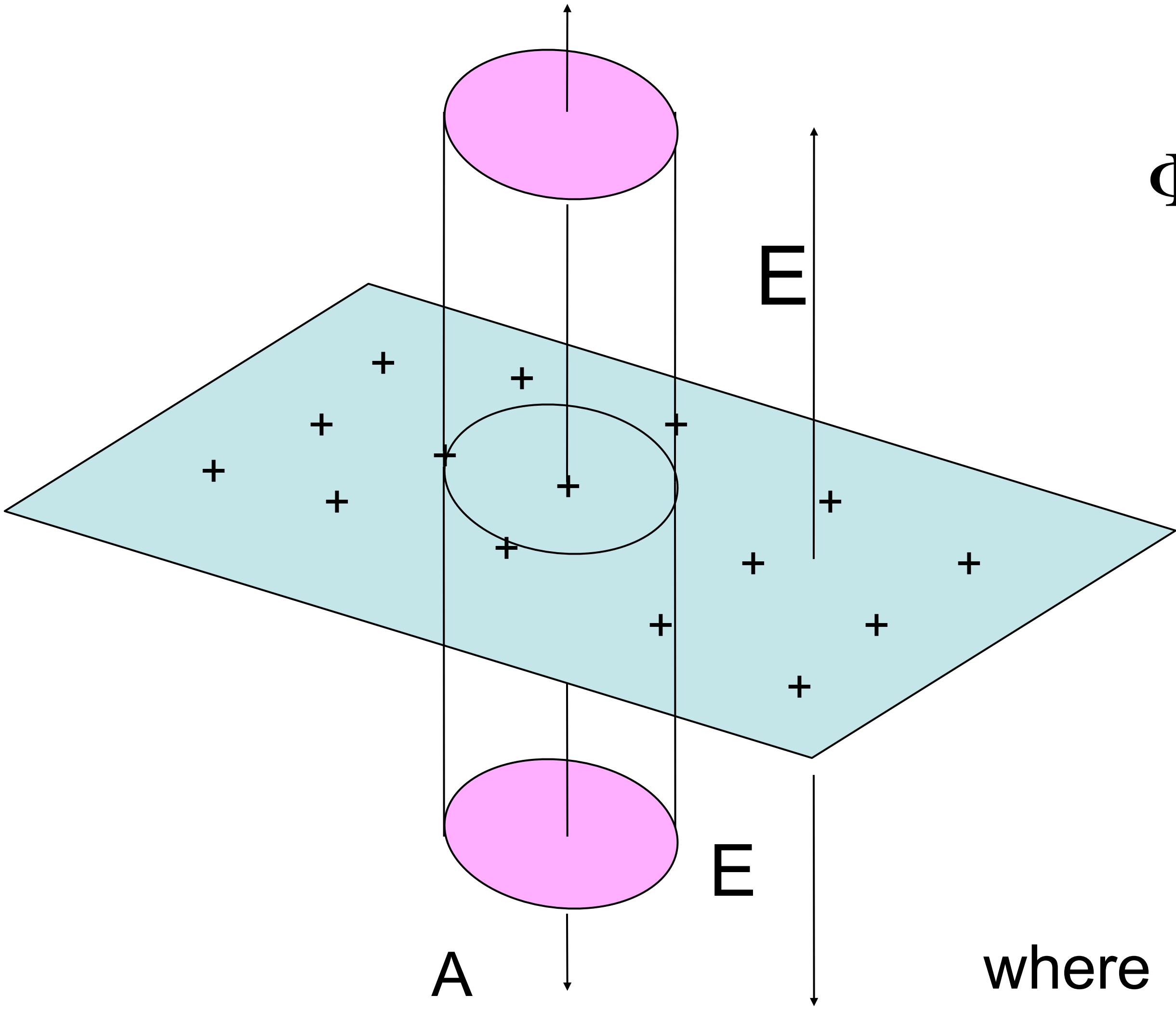
r=1m



$$V = \frac{k_e q}{r} = 9x10^7 V$$

How does the capacitor store this charge without high potentials? How do you get a large capacitance?

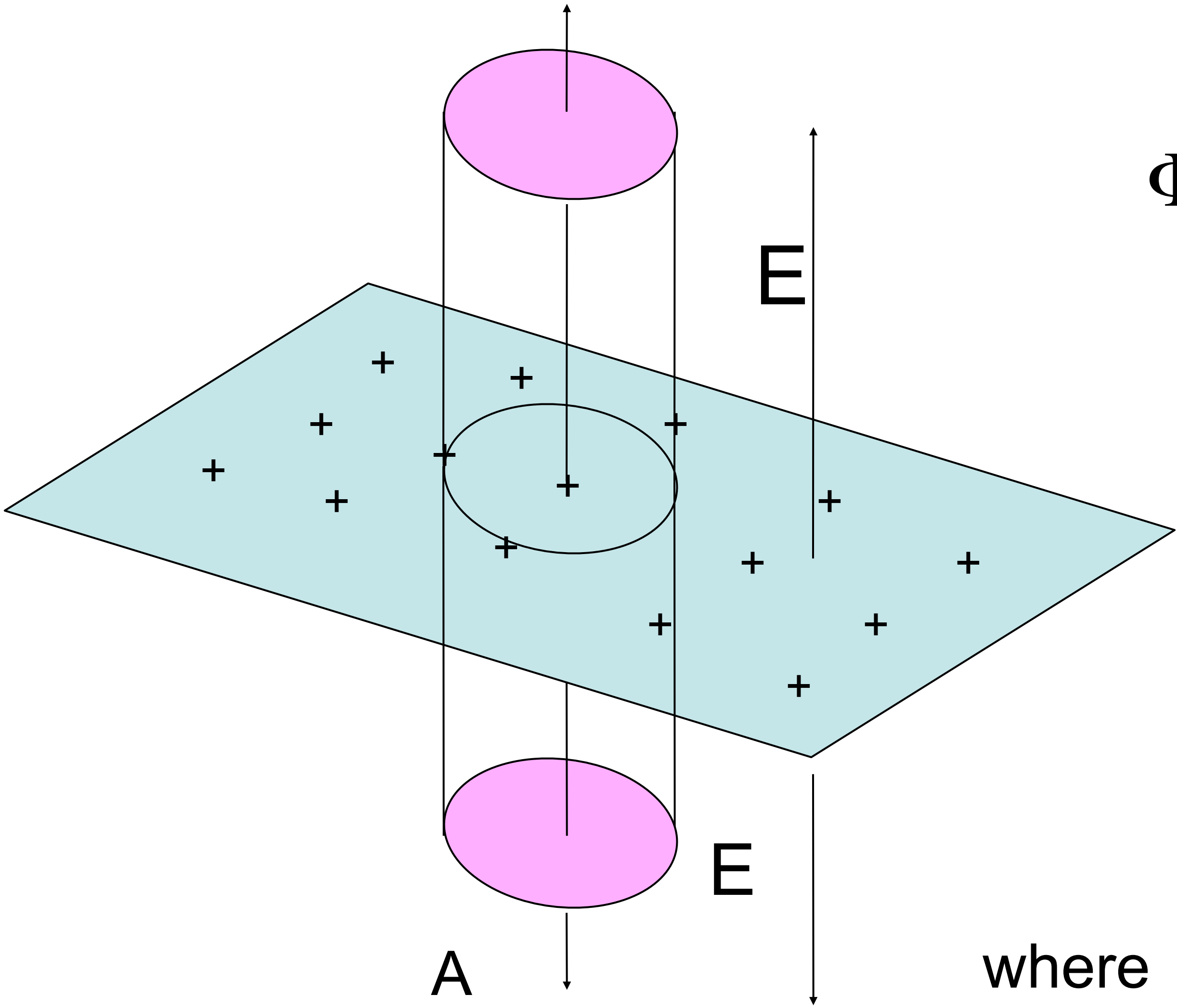
Gaussian surface- a cylinder with sides perpendicular to the plane. E is constant at ends. Flux through sides is zero.



$$\Phi_E = 2AE = \frac{q}{\varepsilon_o}$$

where

Gaussian surface- a cylinder with sides perpendicular to the plane. E is constant at ends. Flux through sides is zero.



$$\Phi_E = 2AE = \frac{q}{\varepsilon_o}$$

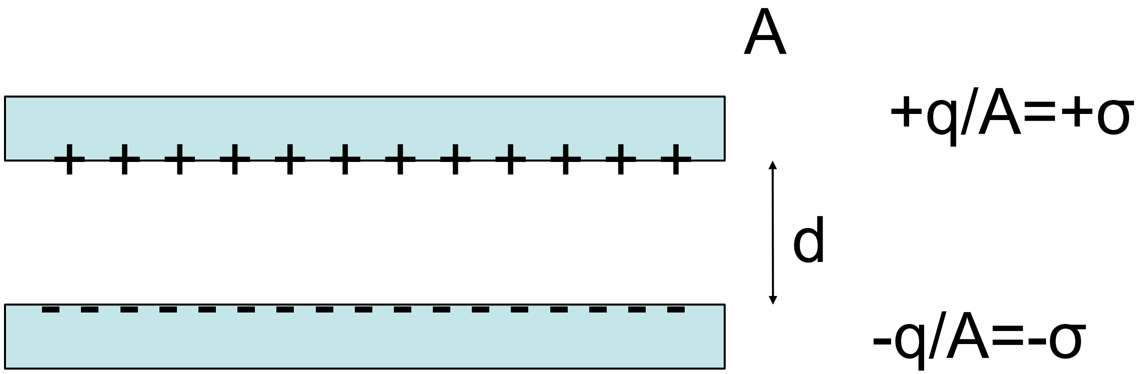
$$E = \frac{q}{2A\varepsilon_o}$$

$$E = \frac{\sigma}{2\varepsilon_o}$$

where $\sigma = \dfrac{q}{A}$

Parallel plate capacitor

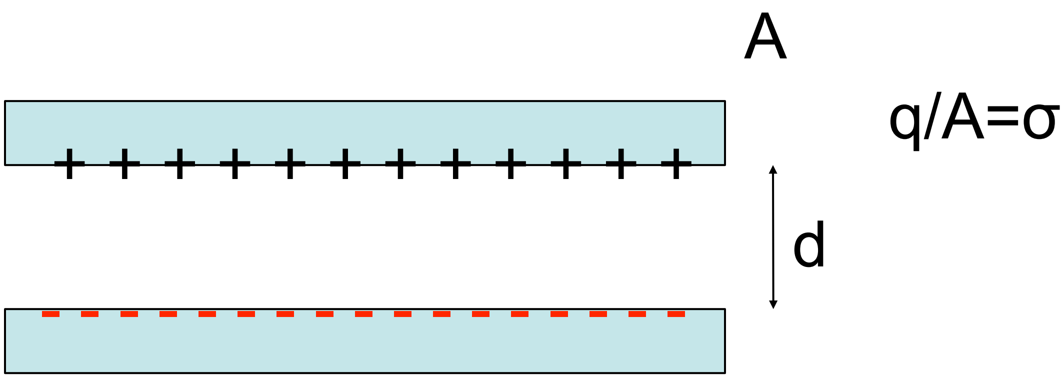
two “infinite” planes of charge area A separated by distance d where d<< A, carry charge +q, -q



The charges are at the inner surface of the capacitor

Field inside the capacitor plates

By superposition of charges due to sheet of charge



Field inside the capacitor plates

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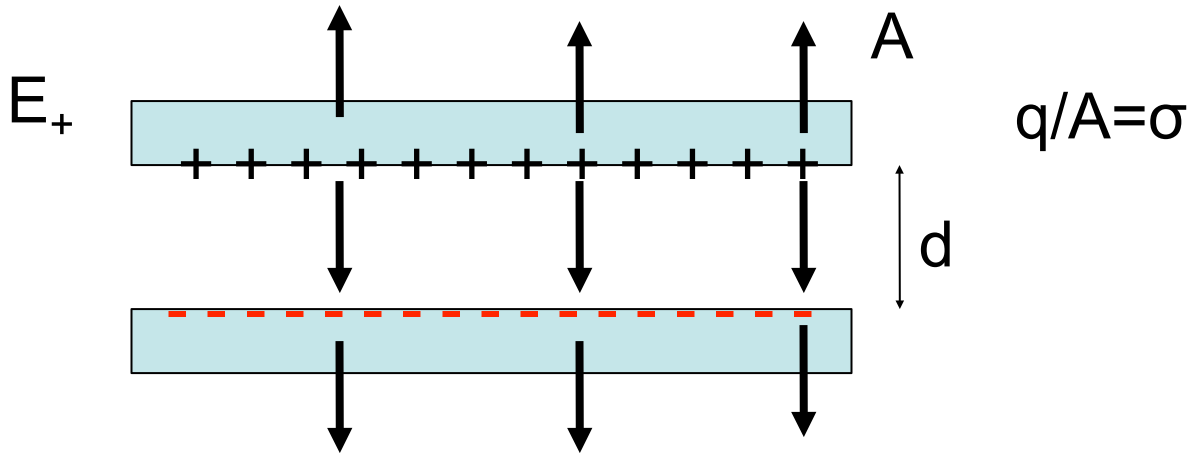

Field inside the capacitor plates

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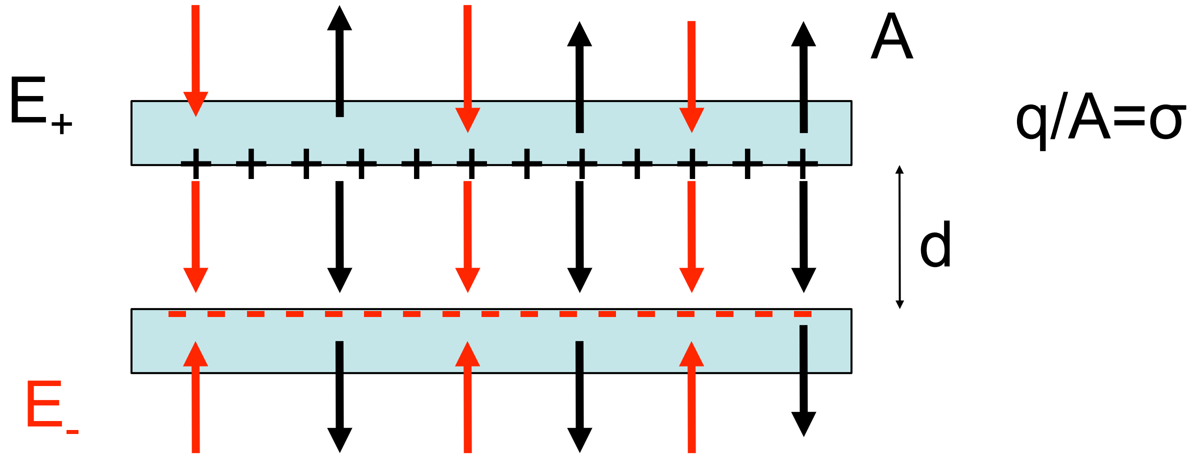

Field inside the capacitor plates

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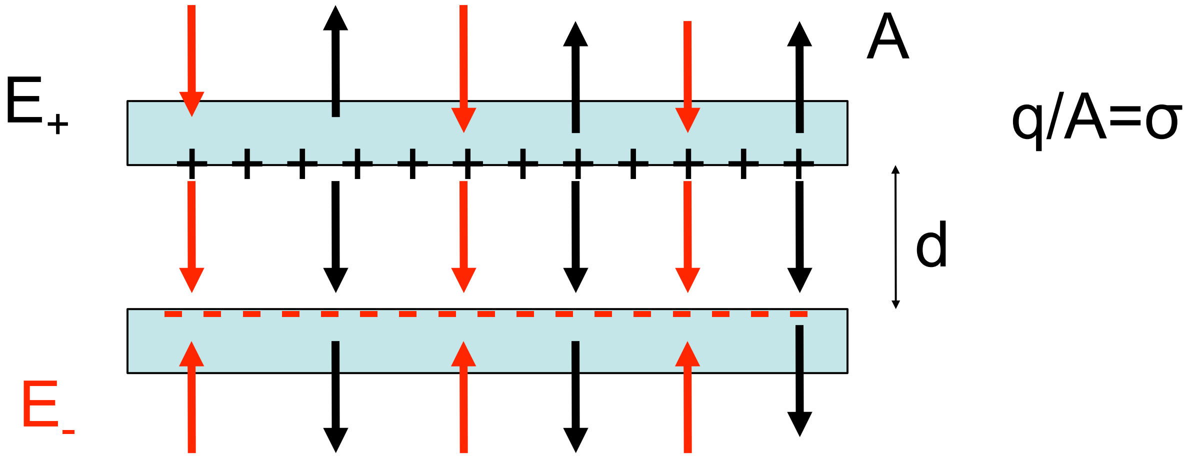
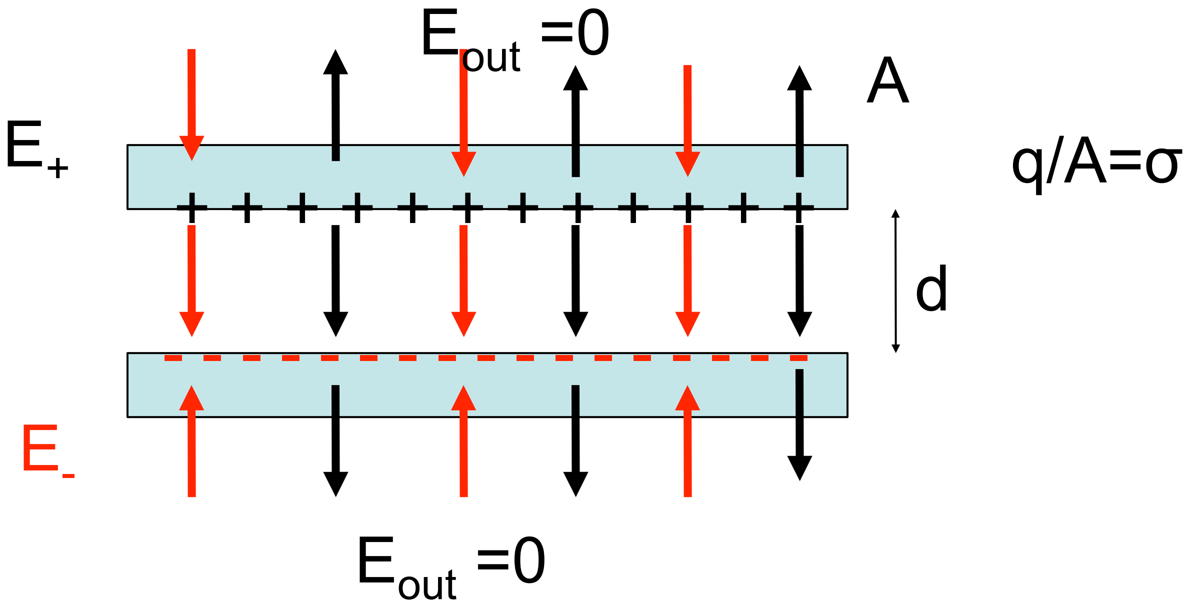


$$E_{in} = \frac{\sigma}{\varepsilon_o}$$

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

Field inside the capacitor plates

By superposition of charges due to sheet of charge



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

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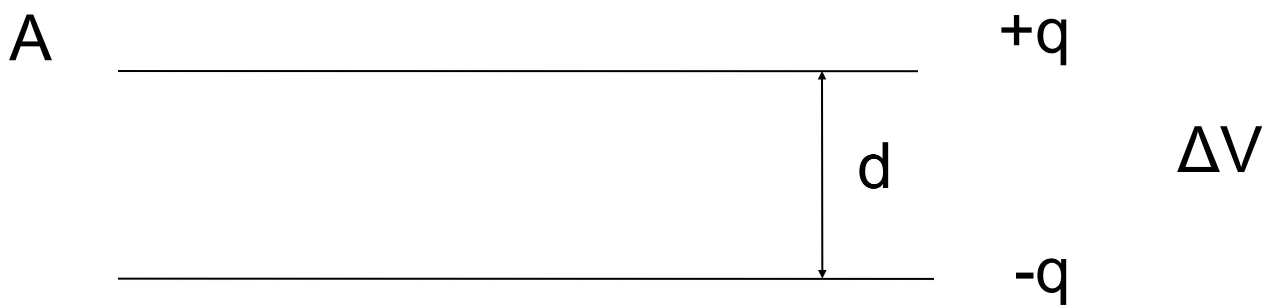
What is the capacitance of a parallel plate capacitor with plates of area A separated by distance d? (in air)



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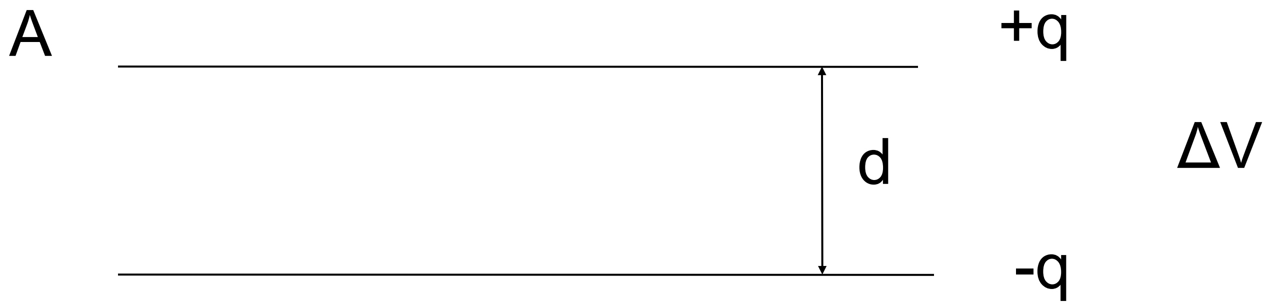

Recall from Gauss' law

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

E field increases with charge density

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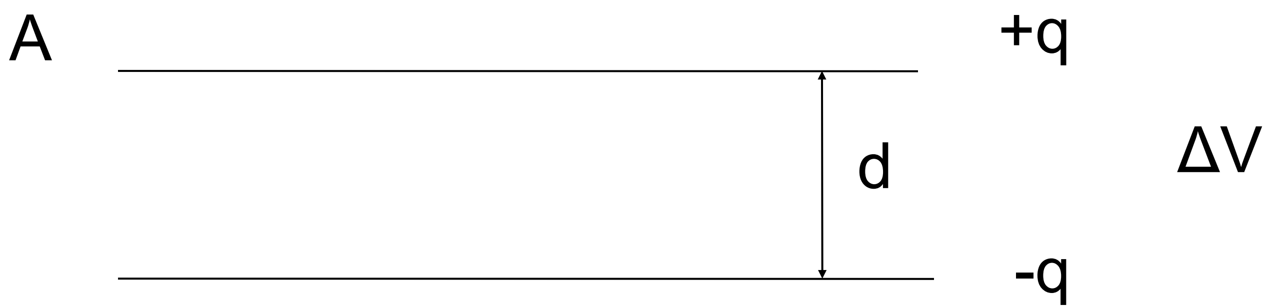

Recall from Gauss' law

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E field increases with charge density

rearrange

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

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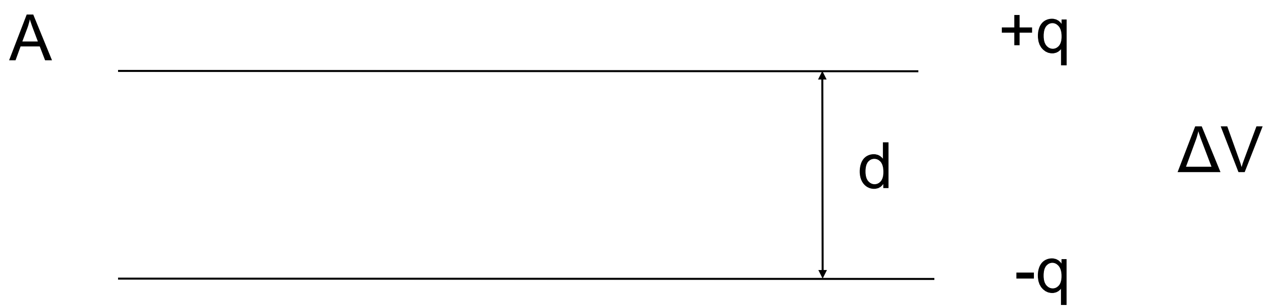

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E field increases with charge density

rearrange

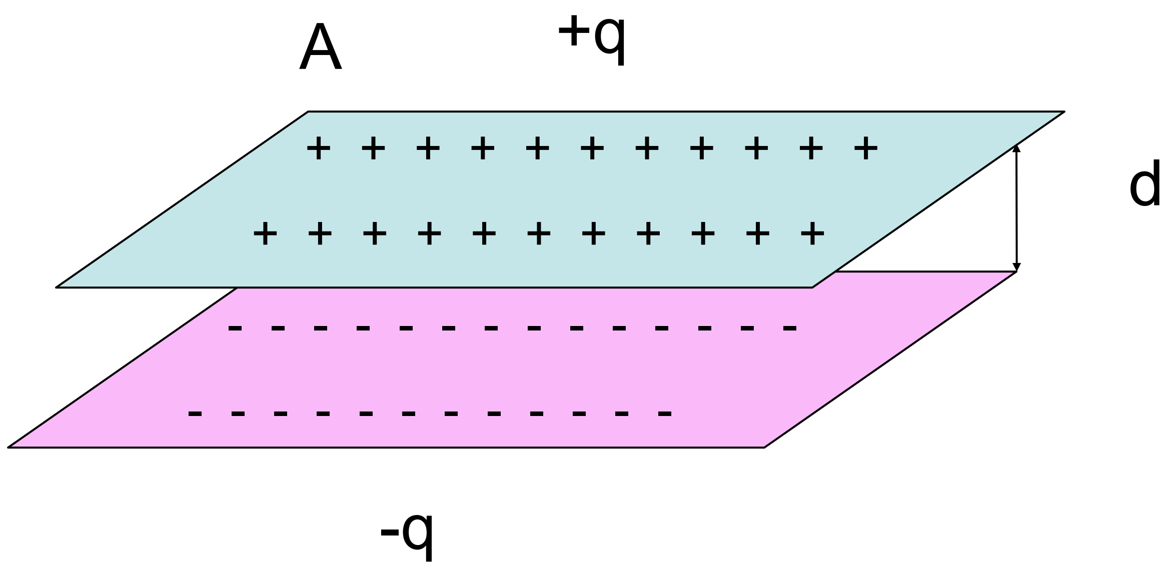
$$\frac{q}{\Delta V} = \frac{A\varepsilon_o}{d}$$

thus

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

to increase C
Increase A
Decrease d

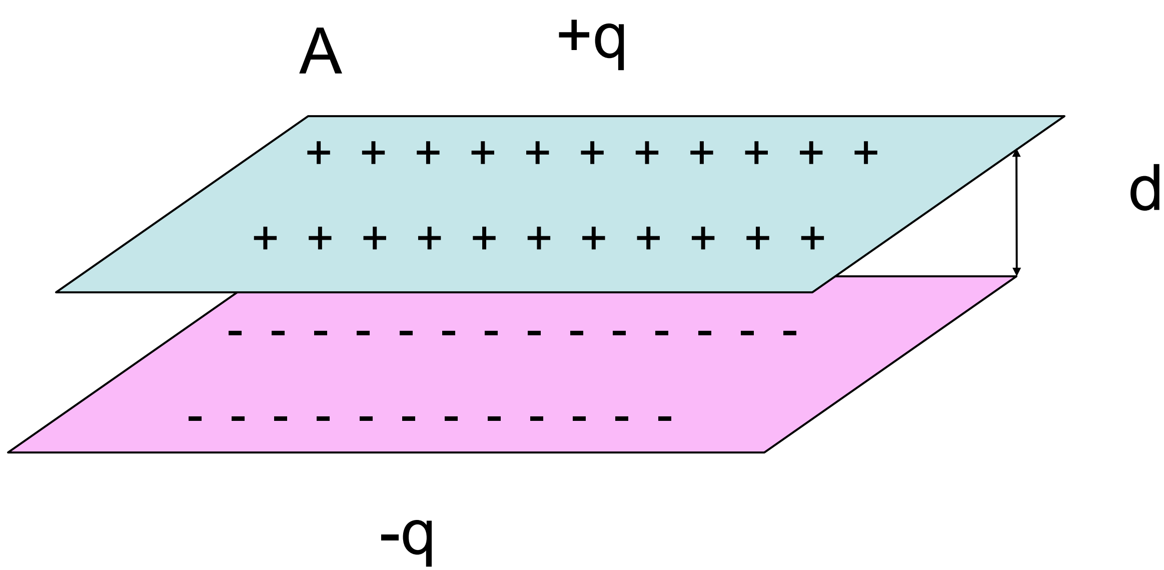
How do you stabilize the separated charge
i.e. make ΔV as small as possible for a given q
(high capacitance)



area A

distance d

How do you stabilize the separated charge
i.e. make ΔV as small as possible for a given q
(high capacitance)



area A as Large as possible

distance d

How do you stabilize the separated charge
i.e. make ΔV as small as possible for a given q
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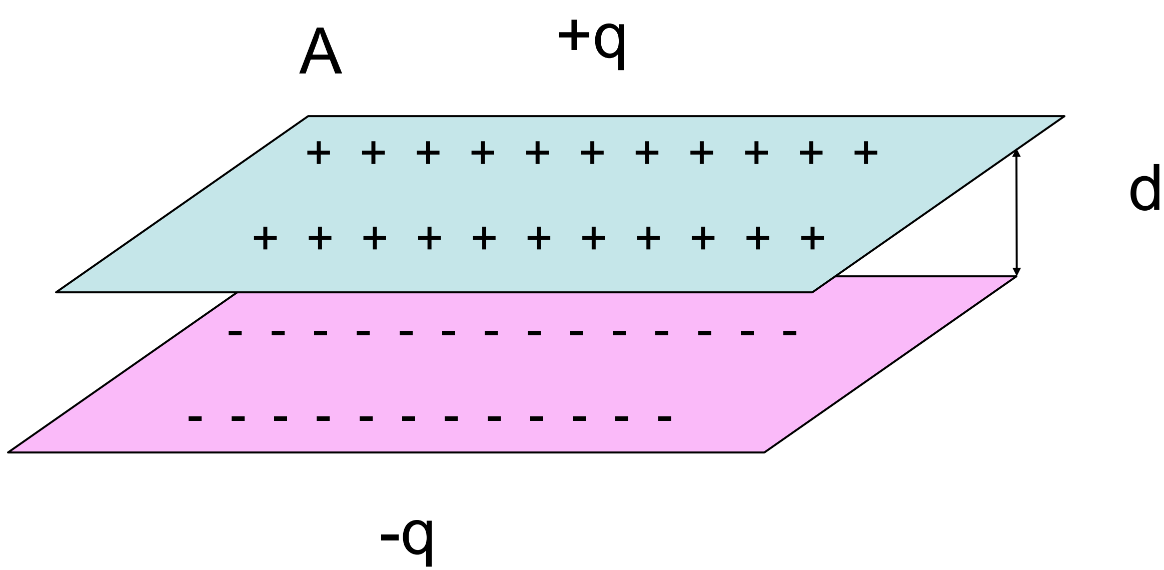


area A as Large as possible

distance d as SMALL as possible

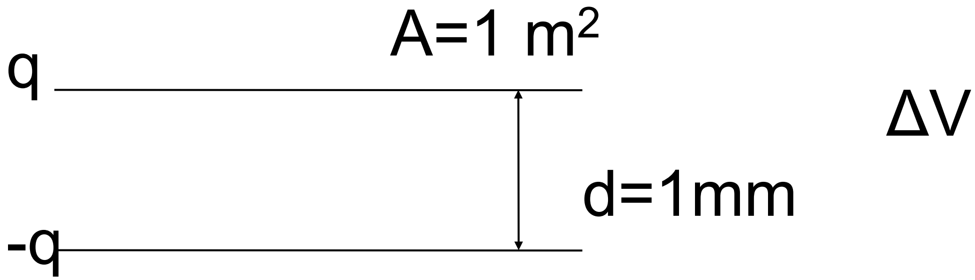
Thin film capacitors

Metal film separated by thin insulators

Making the area large and the insulating gap small increases C

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 in the capacitor (c) Find ΔV across the plates



C =

E=

ΔV=

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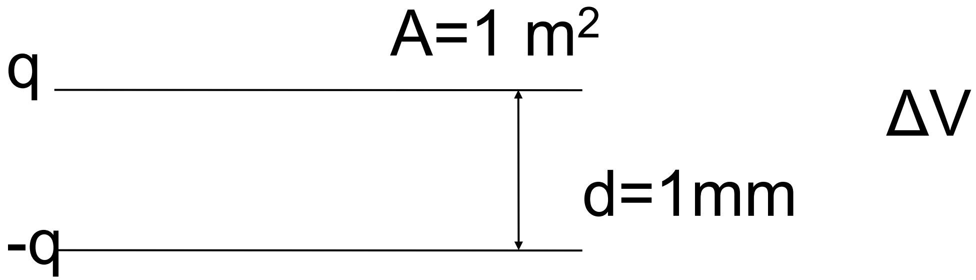

$$C = \frac{A\varepsilon_o}{d}$$

E=

ΔV=

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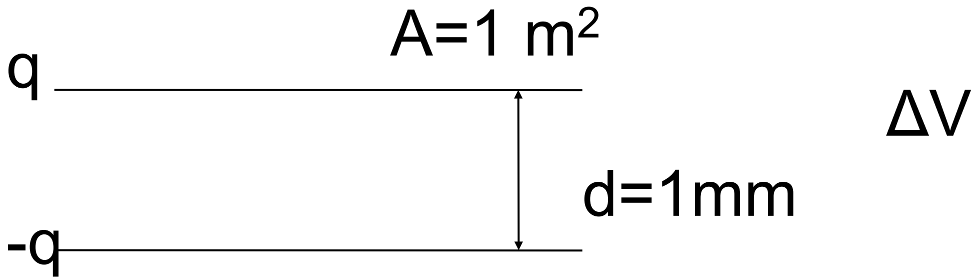

$$C = \frac{A\varepsilon_o}{d} = \frac{1(8.9x10^{-12})}{0.001} = 8.9x10^{-9}F = 8.9nF$$

E=

ΔV=

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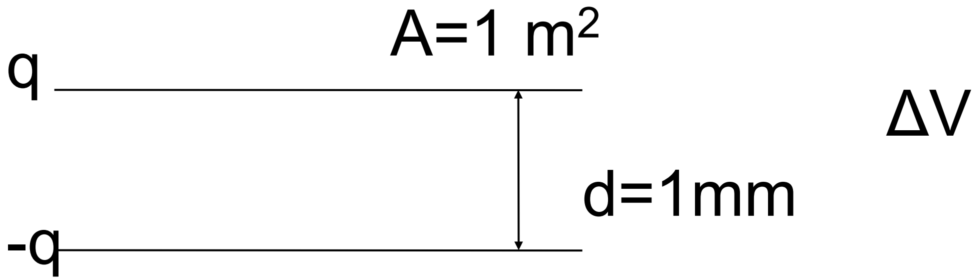

$$C = \frac{A\varepsilon_o}{d} = \frac{1(8.9x10^{-12})}{0.001} = 8.9x10^{-9}F = 8.9nF$$

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

ΔV=

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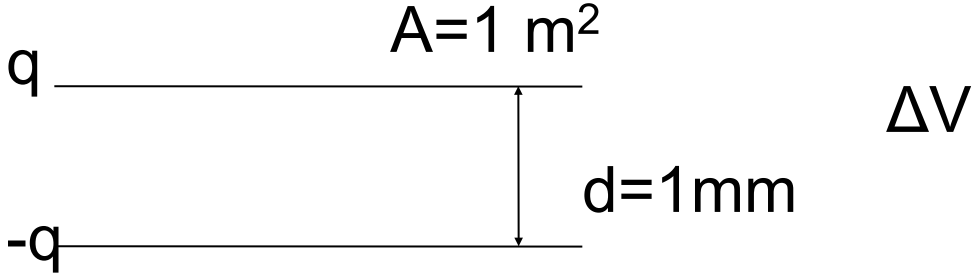

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$$E = \frac{q}{A\varepsilon_o} = \frac{1x10^{-6}}{(1)(8.9x10^{-12})} = 1.1x10^{5}V/m$$

ΔV=

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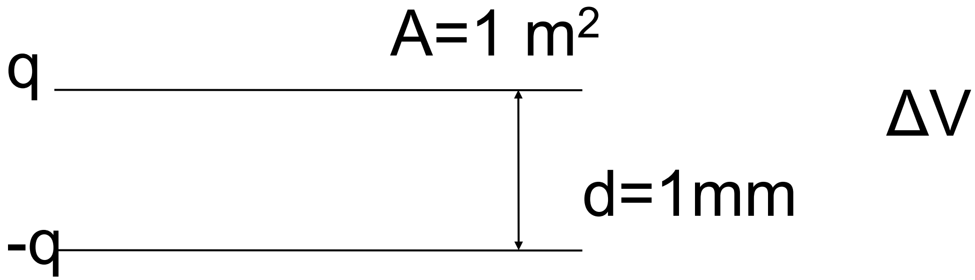
(a) Find the capacitance. (b) Find the E field in the capacitor (c) Find ΔV across the plates



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$$\Delta V = Ed$$

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, $q=10^{-6}C$

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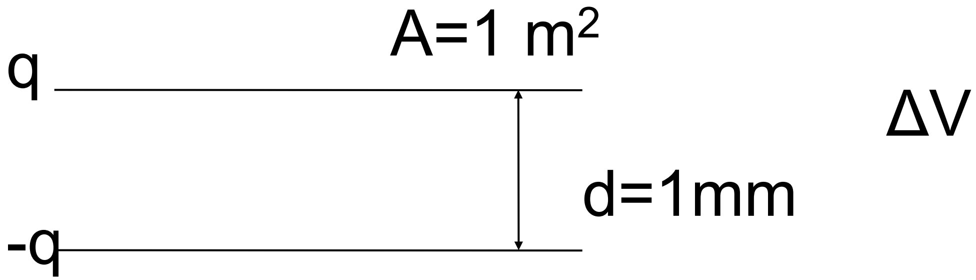

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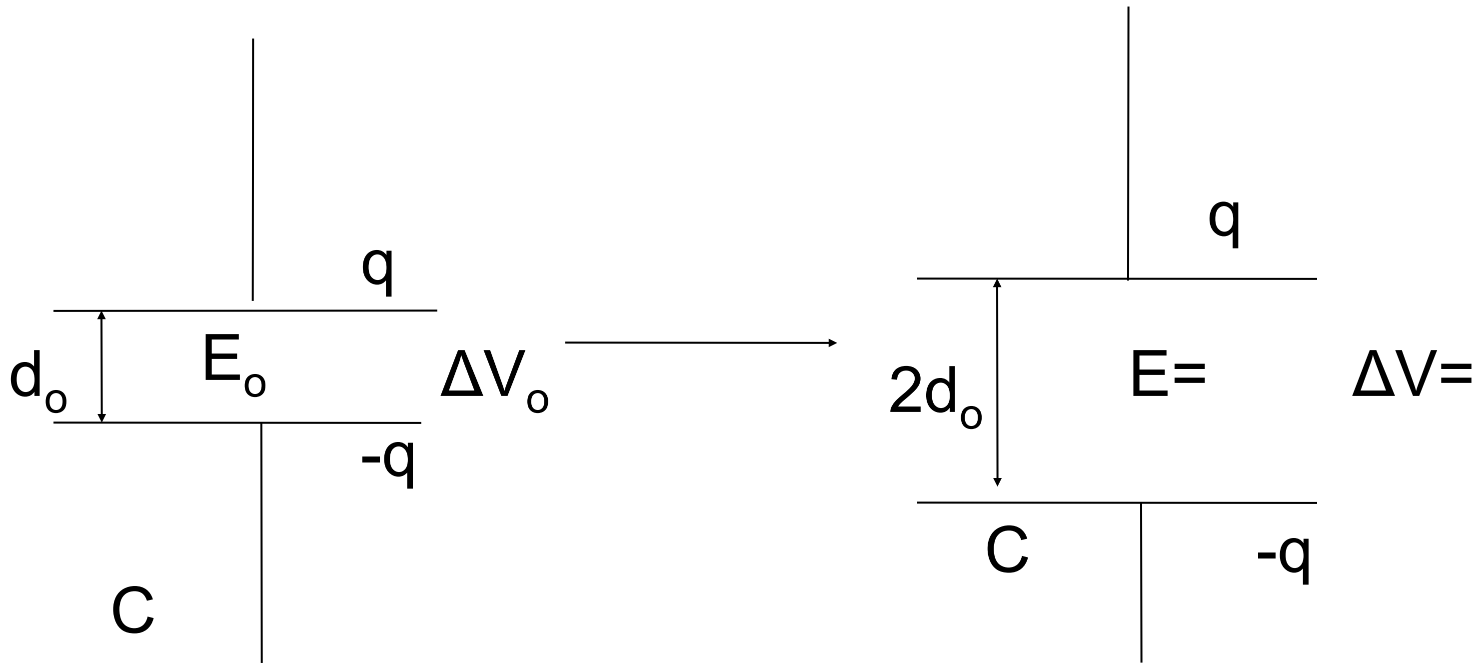
$$\Delta V = Ed = 1.1x10^{5}(1x10^{-3}) = 1.1x10^{2}V$$

A parallel plate capacitor (infinite) with a constant charge q has its separation increased by a factor of 2.
How does this change E and ΔV?



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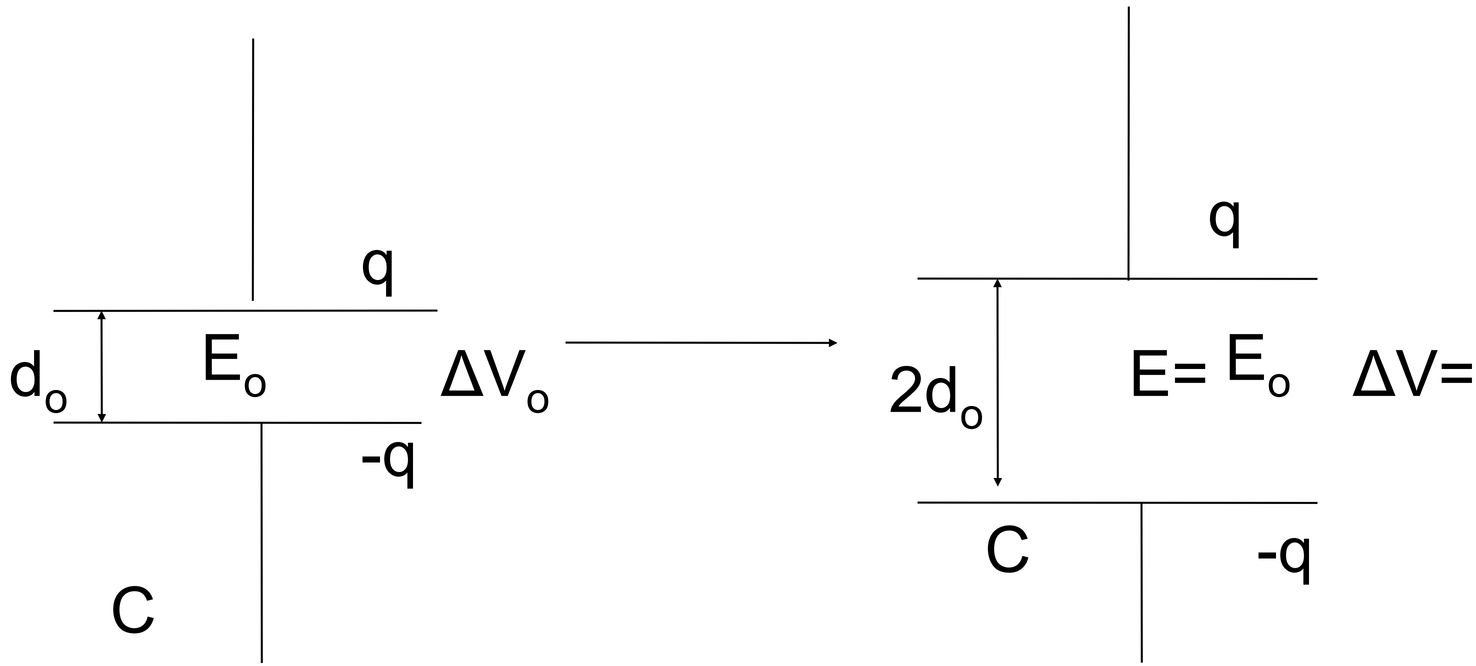

$$E = \frac{q}{A\varepsilon_o}$$ is constant

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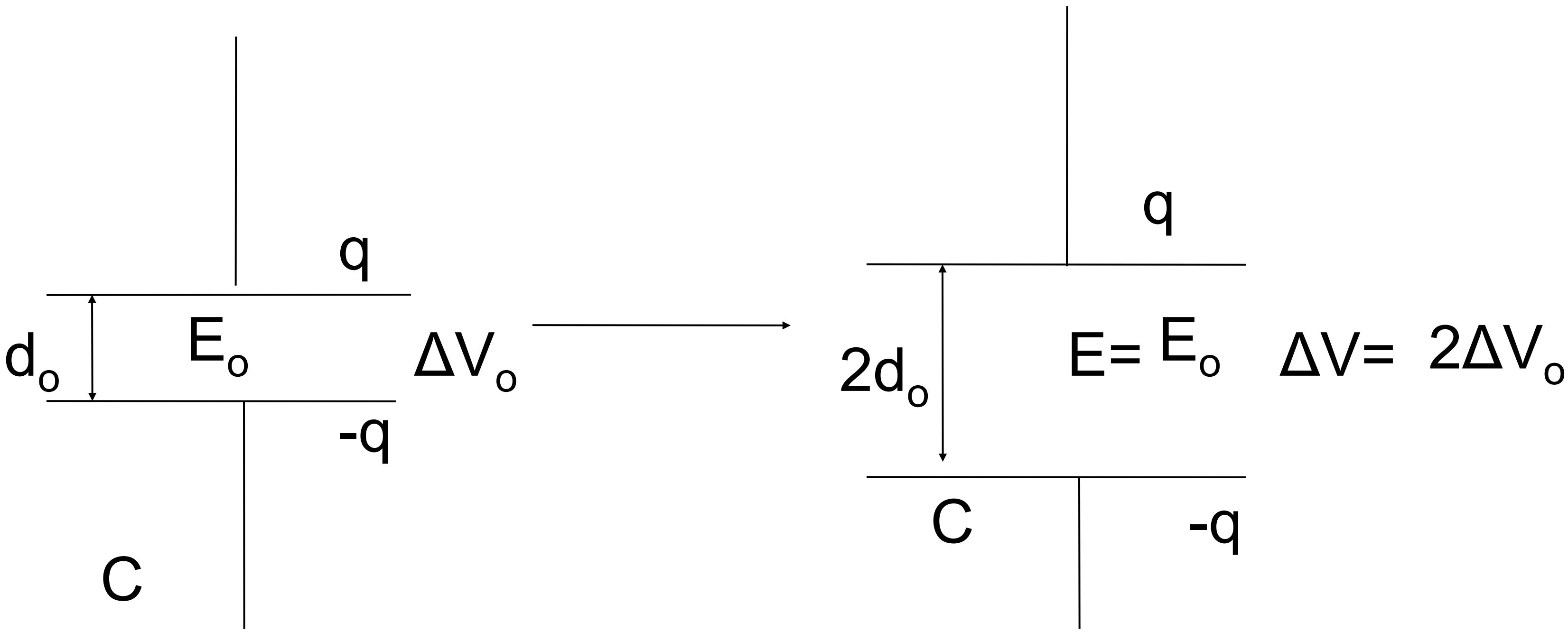
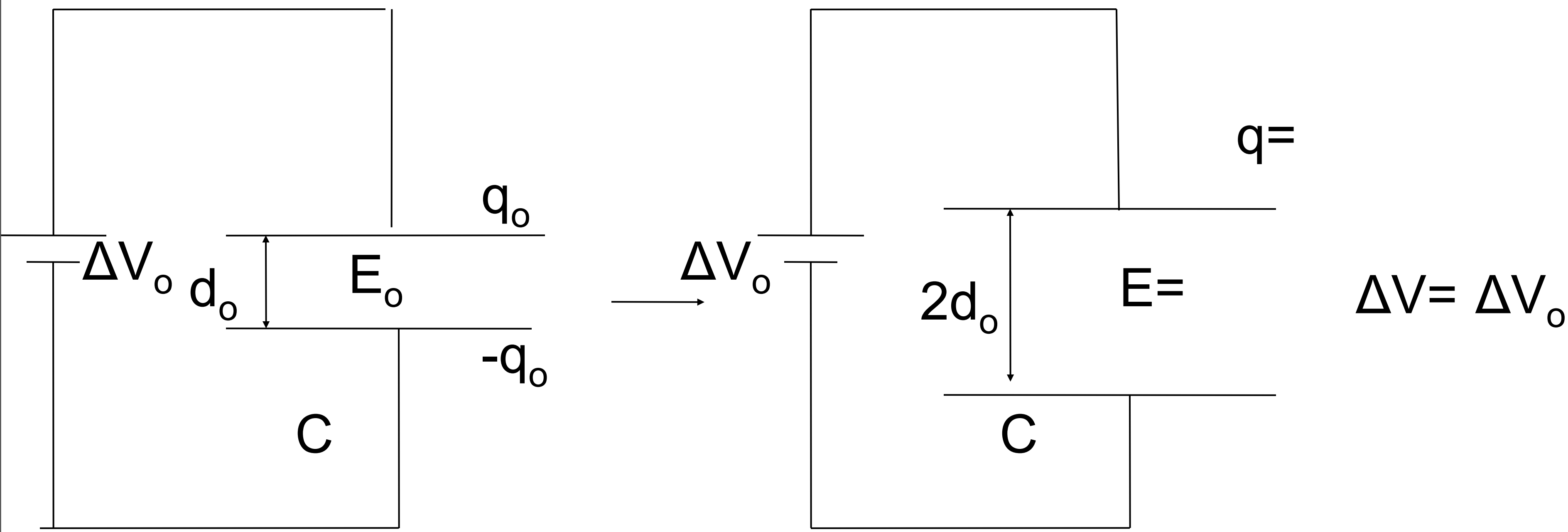


$$E = \frac{q}{A\varepsilon_o} \text{ is constant}$$

$$\Delta V = dE = 2\Delta V_o$$

A parallel plate capacitor (infinite) with a constant voltage difference ΔV has its separation increased by a factor of 2. How does this change E and q?



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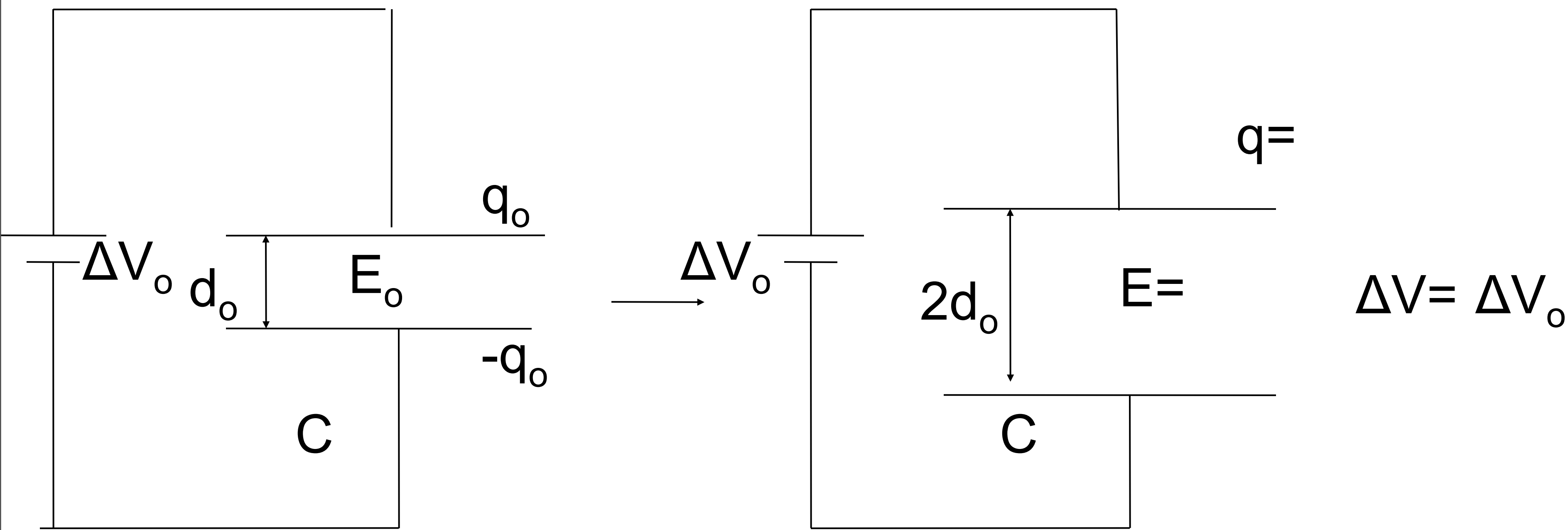

$\Delta V=dE$

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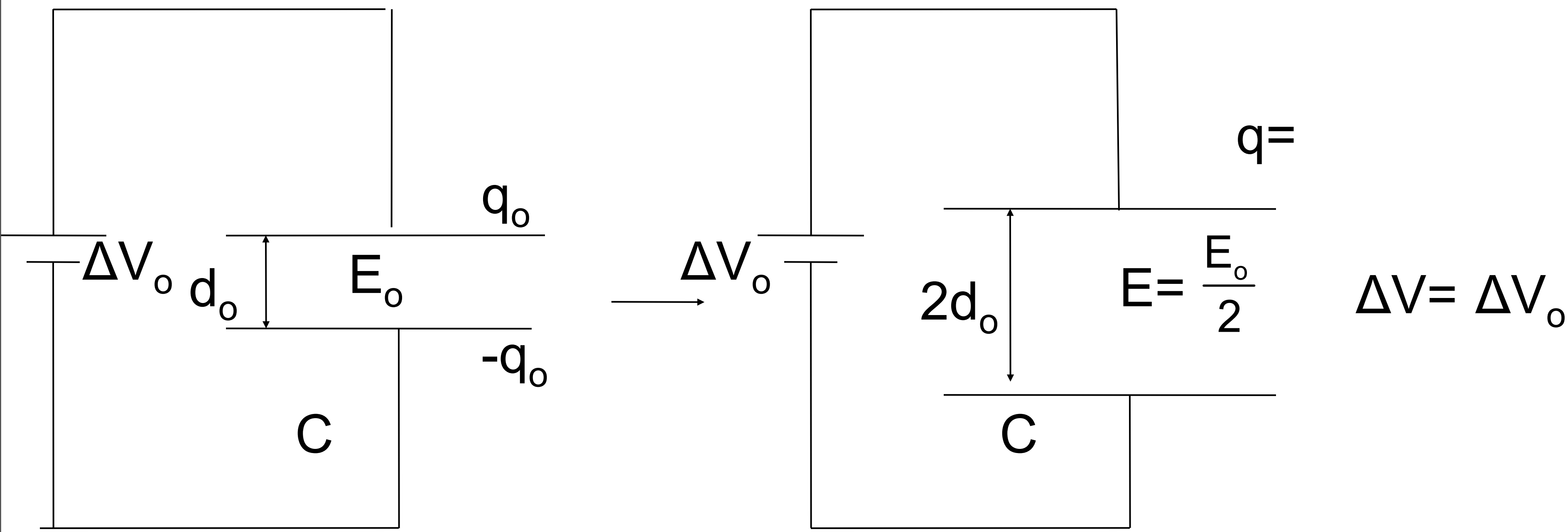

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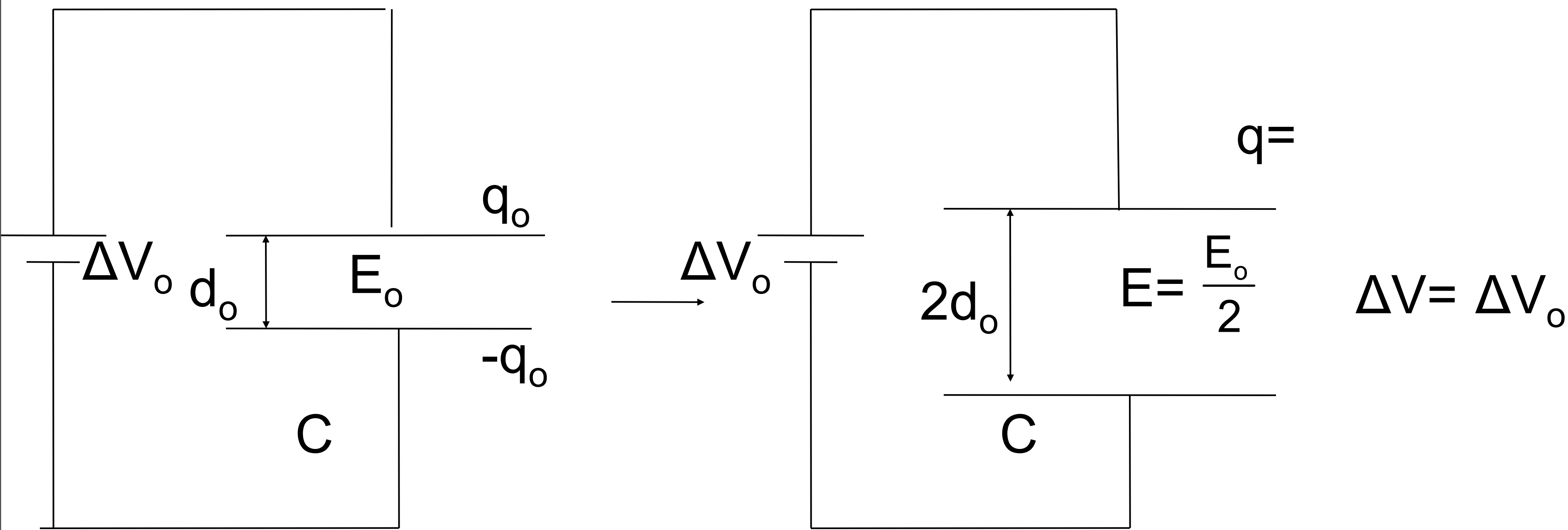

$$\Delta V = dE$$

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

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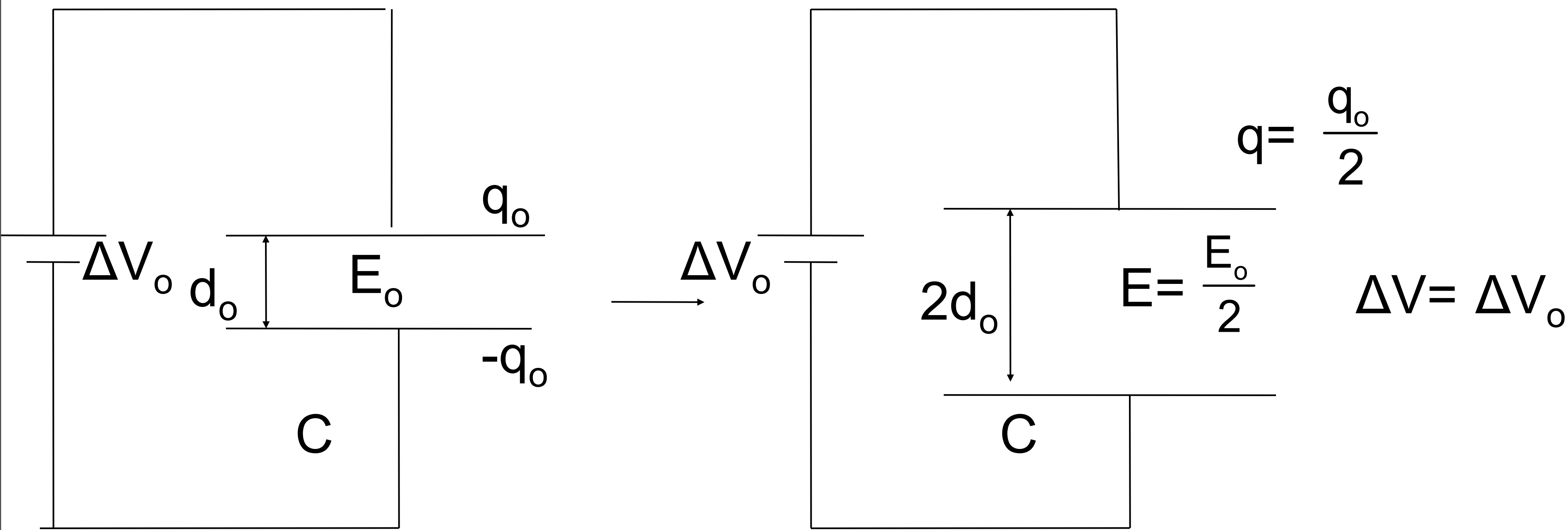

$$\Delta V = dE$$

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

Capacitor combinations

Capacitors connected in series and parallel