PHYSICS 1B – Fall 2009

Electricity
&
Magnetism

Professor Brian Keating

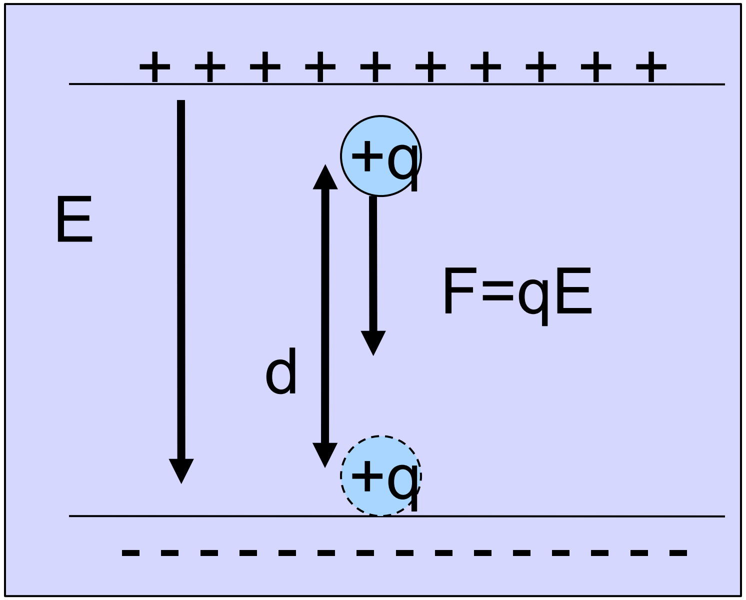
SERF Building. Room 333

Chapter 16 Electrical Potential

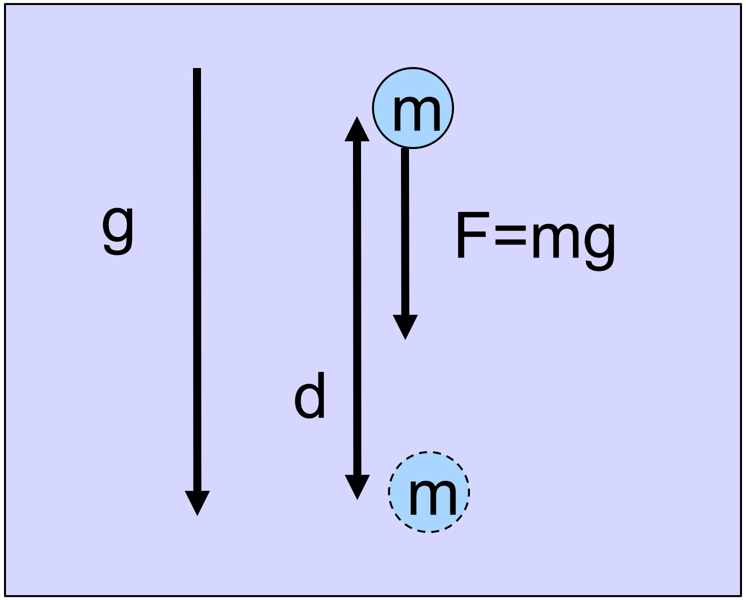
Electrical potential energy

Electrical potential

Potential Energy of a system of charges and masses (the field is uniform, constant)



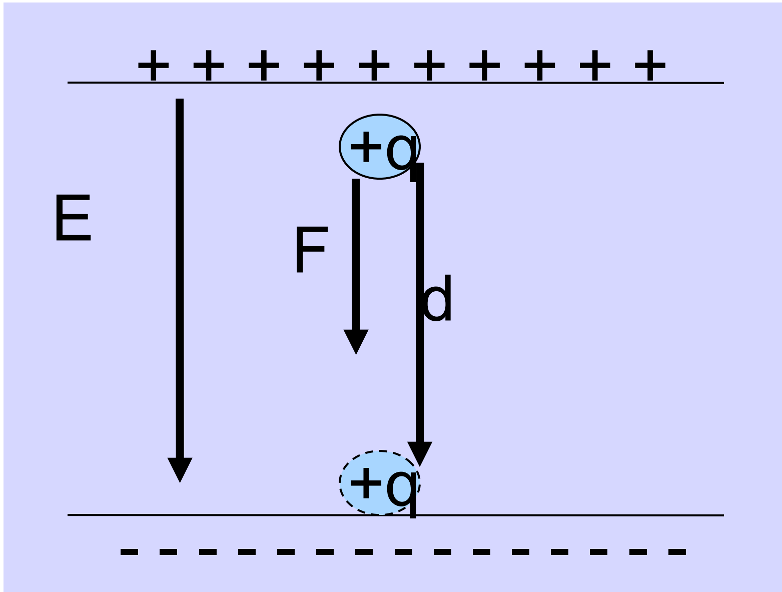
work done by Electric field



work done by Gravitational field

Change in PE =-work done by the field

Potential Energy of a system of charges



$\Delta PE = -qEd$

Work done by the Electric field decreases the PE of the system

$W = Fd$

$\Delta PE = -W = -Fd = -qEd$

Potential, V

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

Relation between E and V

$$V = Ed$$

$$E = \frac{V}{d}$$

E has units of V/m

Potential, V

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

Units $\frac{Joules}{Coulomb}$ =Volt (V)

Relation between E and V

$$\mathrm{V} = \mathrm{Ed}$$

$$\mathrm{E} = \frac{\mathrm{V}}{\mathrm{d}}$$

E has units of V/m

Difference between Potential Energy and Potential

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

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

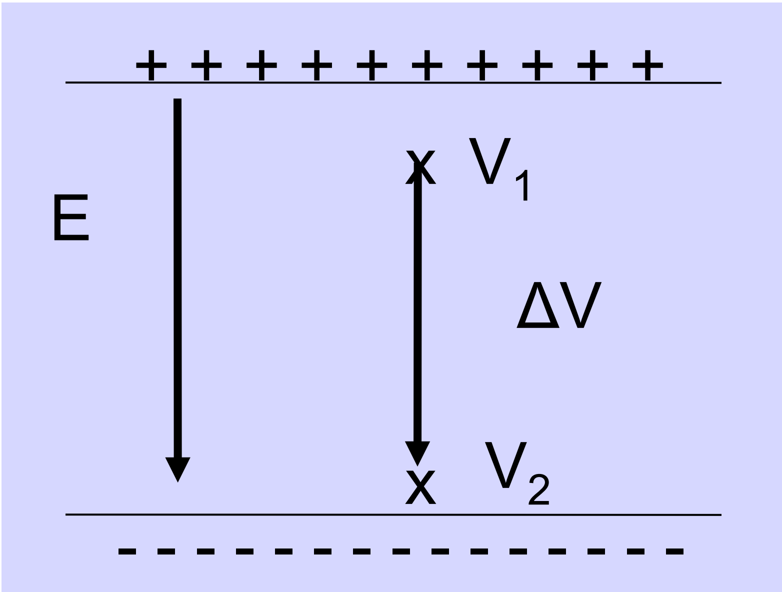
Related by

$$\Delta PE = q\Delta V$$

Both PE and V are relative.

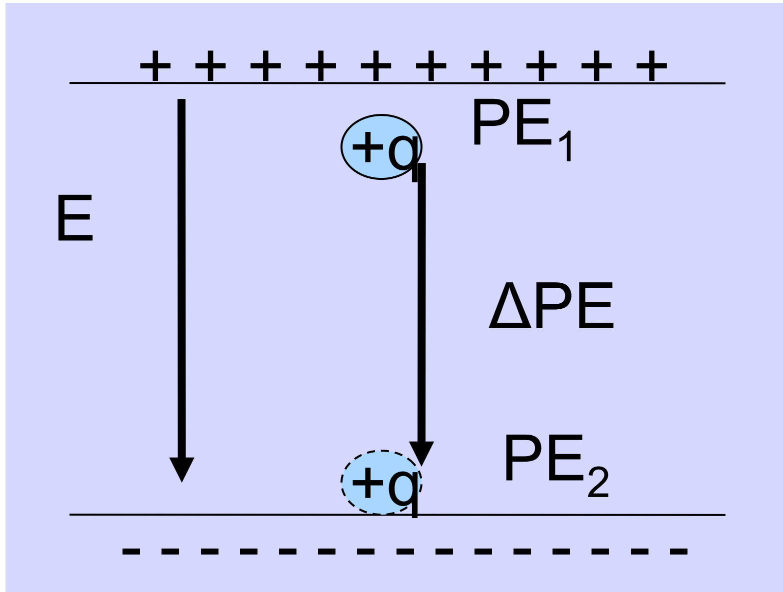
Only differences/changes in Potential Energy and Voltage (ΔPE and ΔV) are important.

Potential



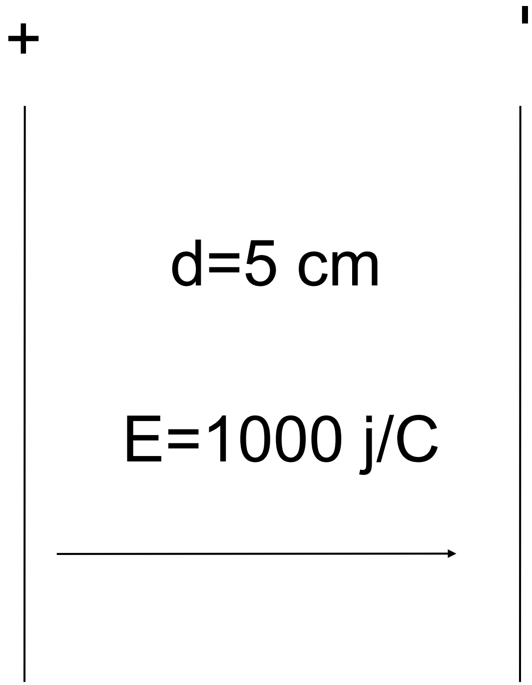
The potential field is a property of the space due to charges

Potential Energy



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

A parallel plate capacitor has a constant electric field of 1000V/m. The distance between the plates is 5 cm. Find the potential difference between the two plates.



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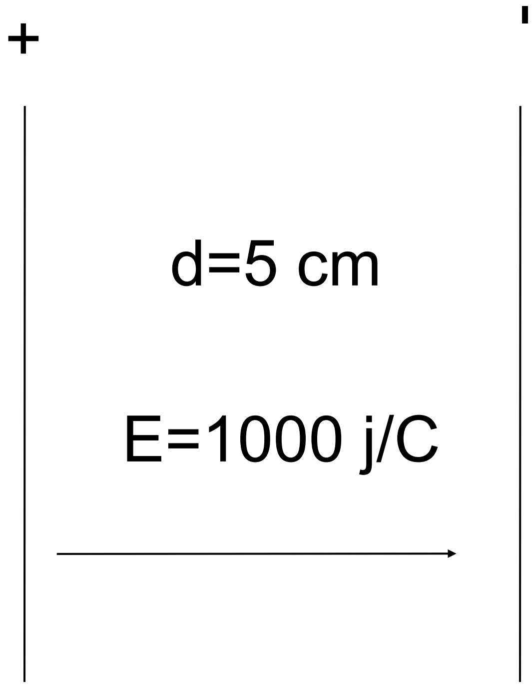


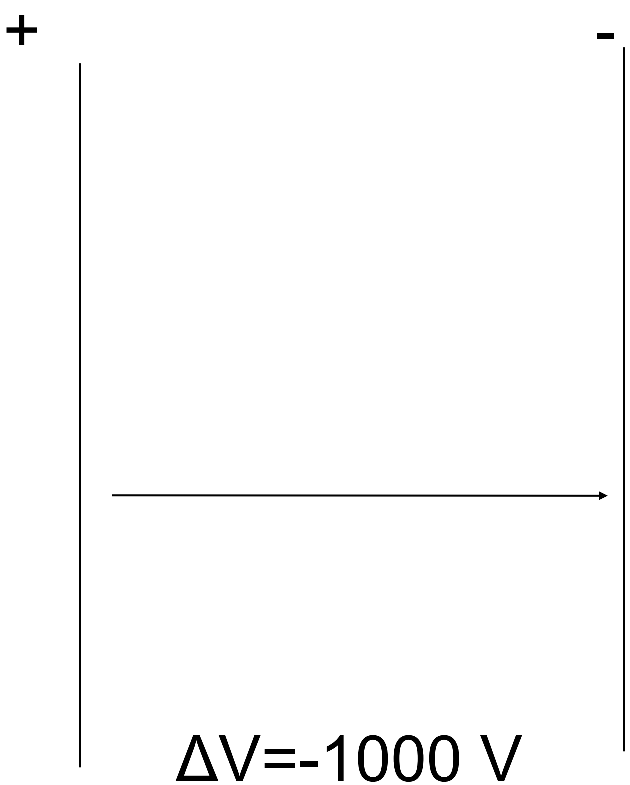
$$\Delta V = \frac{\Delta PE}{q} = \frac{qEd}{q} = Ed$$

$$\Delta V = 1000(0.05) = 50V$$

Potential Energy = Voltage?

- (T) True
- (F) False

An molecular ion CO^+ is accelerated from rest across a potential difference of 1000 V. Find the final velocity of the ion. Mass=4.7×10^{-26} kg



$\Delta PE = q\Delta V$

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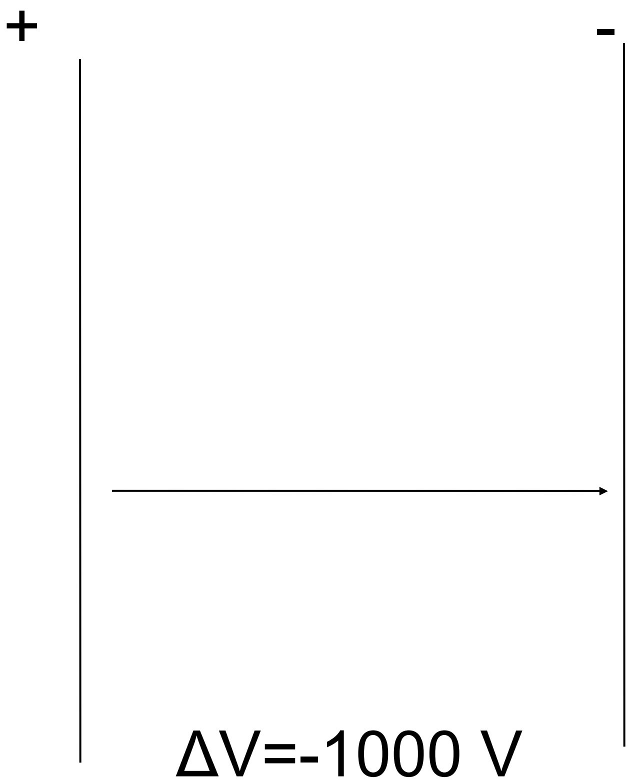

$\Delta PE = q\Delta V$

Conservation of Energy

$\Delta PE + \Delta KE = 0$

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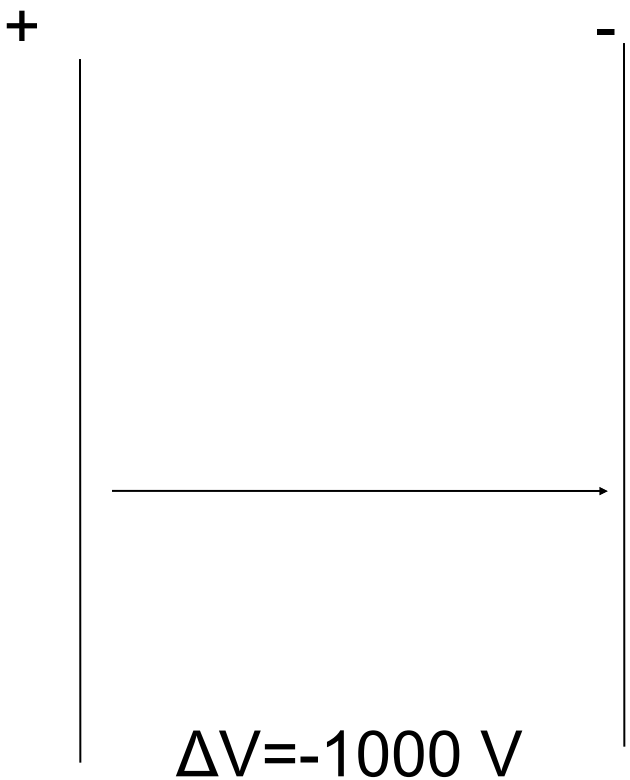

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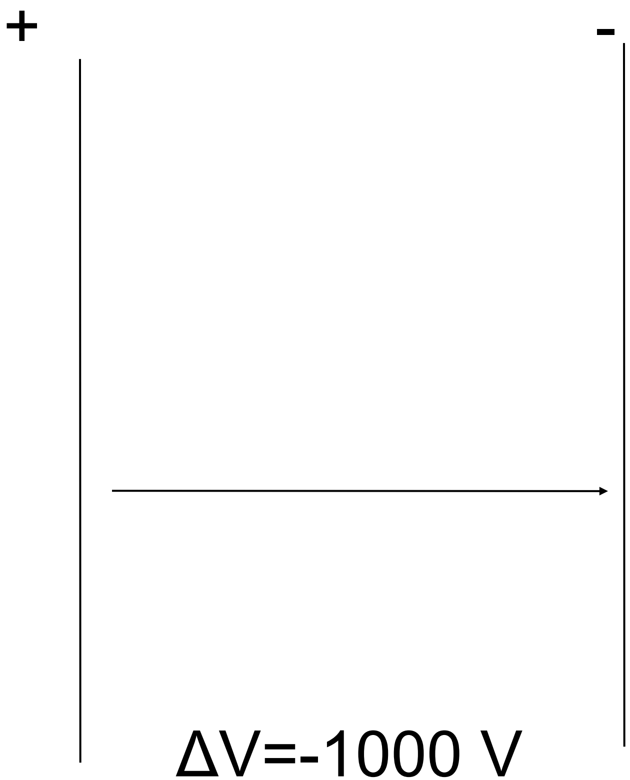


$$\Delta PE = q\Delta V$$

Conservation of Energy

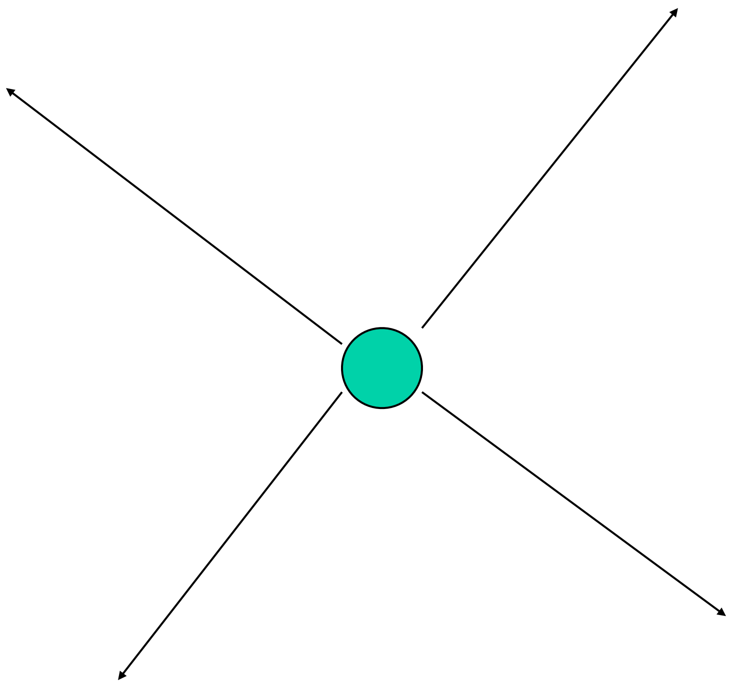
$$\Delta PE + \Delta KE = 0$$

$$\Delta KE = -\Delta PE = -q\Delta V = \frac{1}{2} m v^2$$

$$v = \sqrt{\frac{2q(-\Delta V)}{m}} = \sqrt{\frac{2(1.6x10^{-19})(1000)}{4.7x10^{-26}}}$$

$$v = 8.25x10^4 \, m/s$$

Potential due to a point charge



E field is not constant

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

E gets smaller with distance

The potential

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

V=0 at $r = \infty$

Dimensional arguments

V=Electric field x length e.g. for constant field

V=Ed

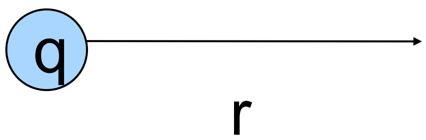
For point charge

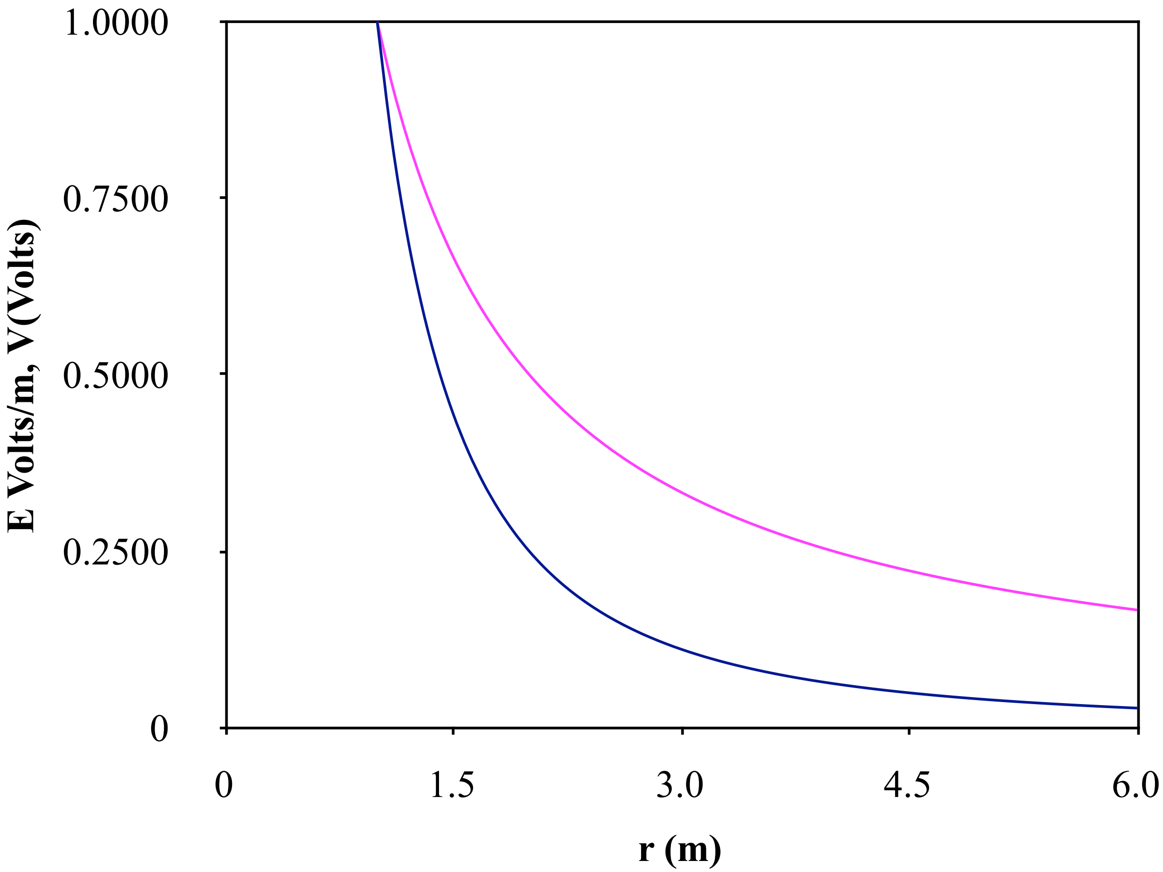
$$E = \frac{k_e q}{r^2}$$

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

V has the appropriate units of E times length

Potential and E field due to positive point charge





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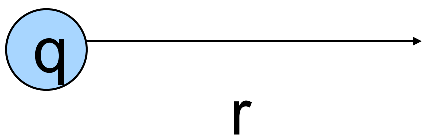

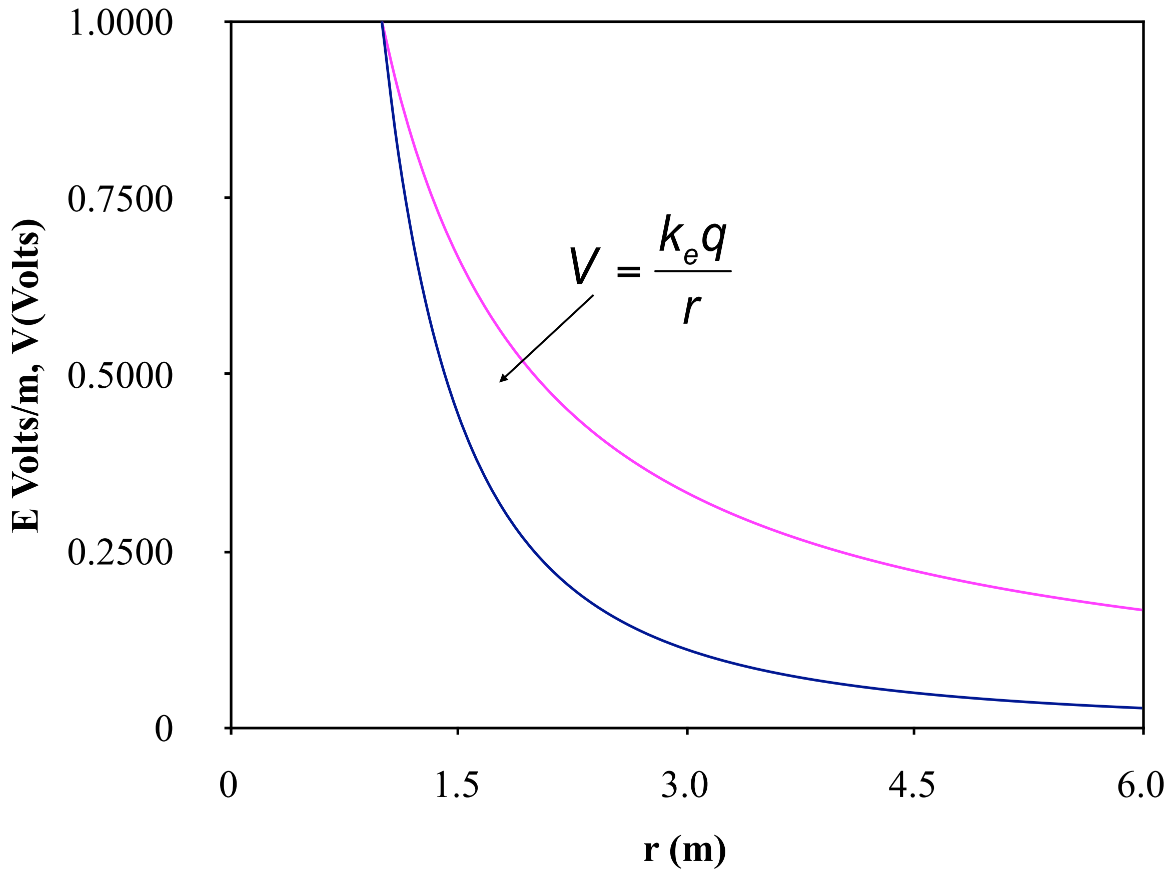

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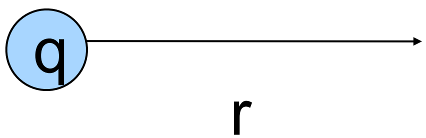
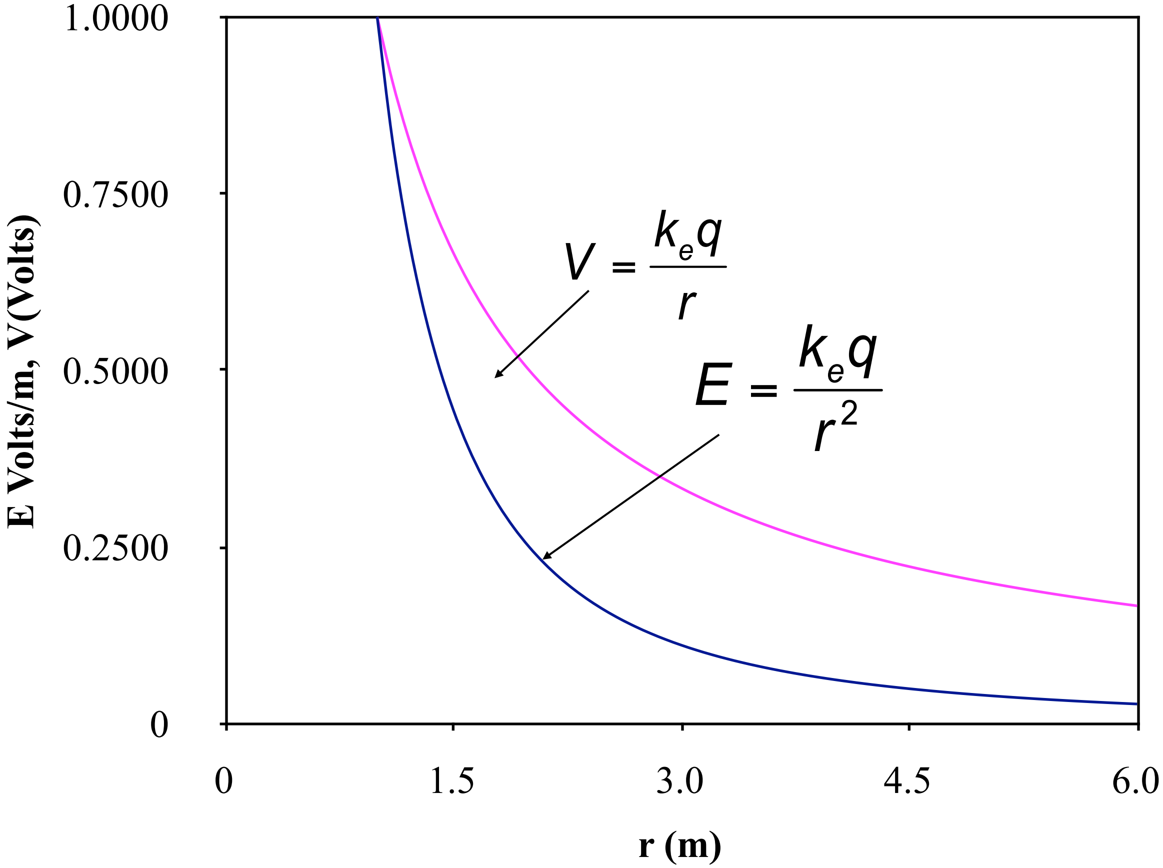
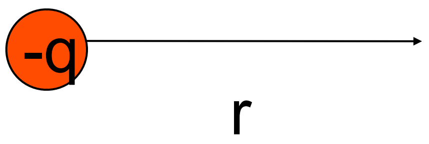
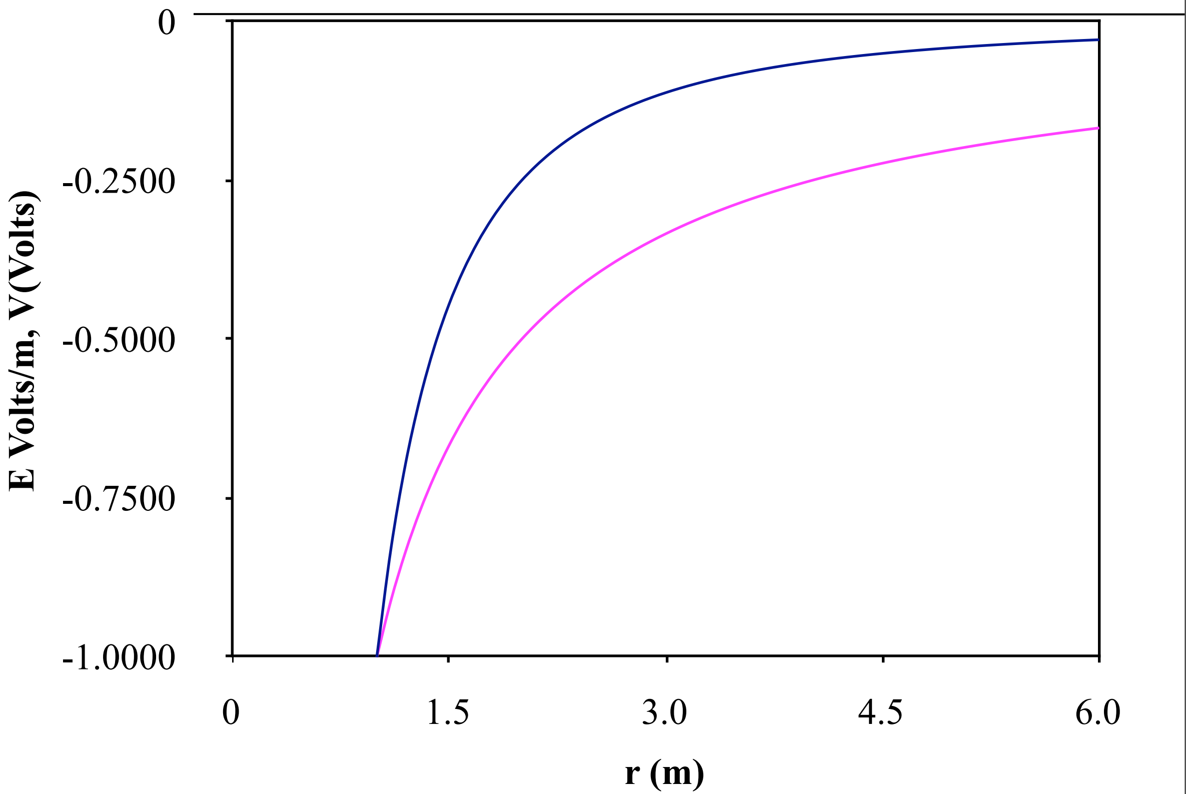




E and V due to a negative point charge





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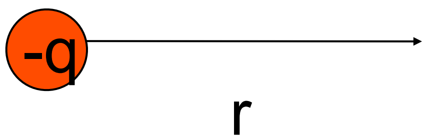

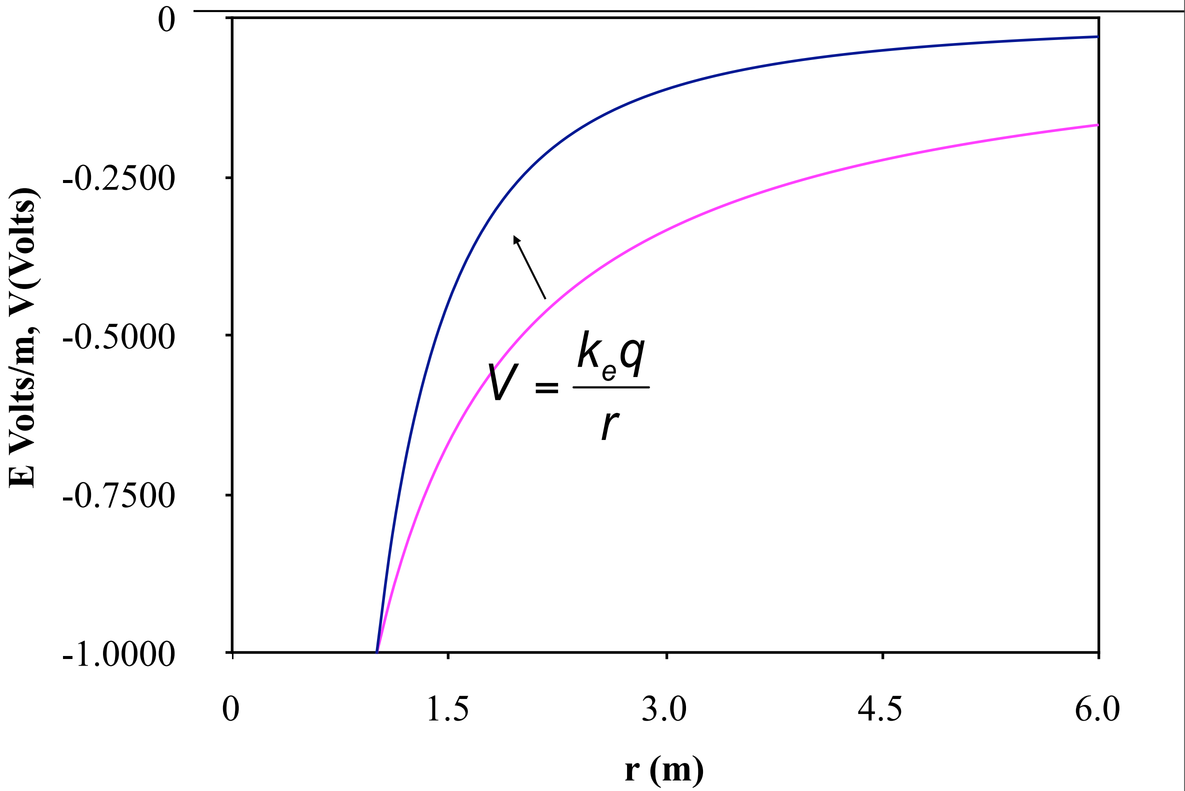

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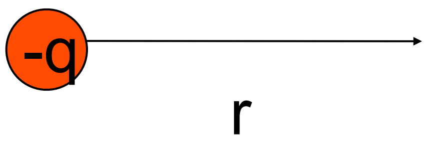
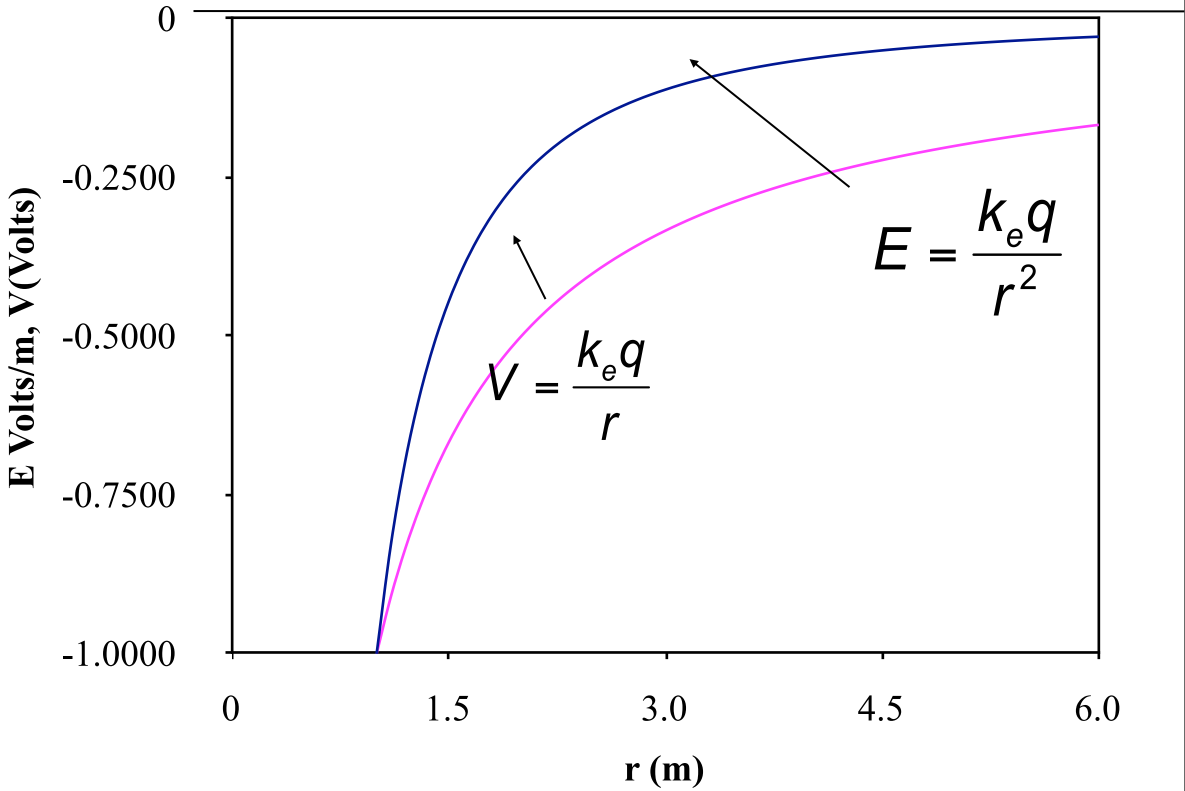




Potential energy of 2 point charges

$$PE = q_1 V_{21} = q_2 V_{12}$$

V_{21} is the potential due to charge2 at the position of charge1.

$$PE = \frac{k_e q_1 q_2}{r_{12}}$$

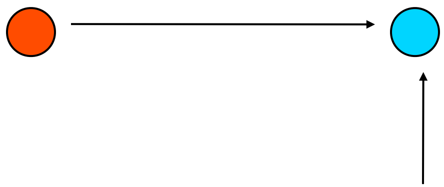
$PE = 0$ at r= ∞

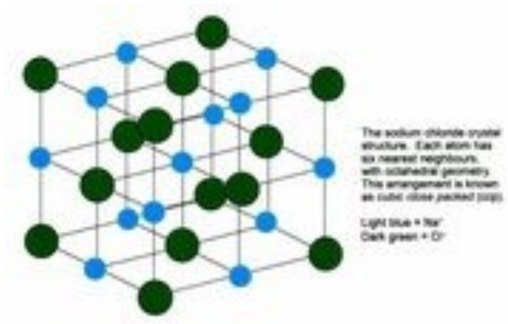
Potential energy and Potential are Scalar (not Vector) quantities

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^-.

r=0.24nm

Cl^- Na^+





at the position of Na+

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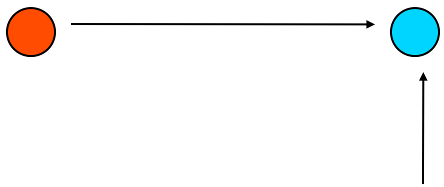
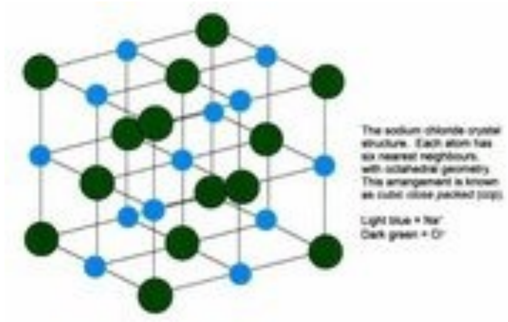
Cl^- Na^+





$$V = \frac{k_e q}{r} = \frac{9x10^9(-1.6x10^{-19})}{(0.24x10^{-9})} = -6.0V$$

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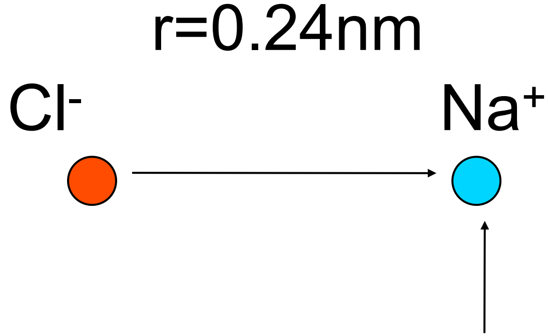

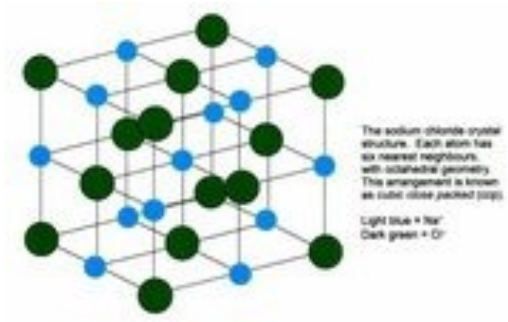

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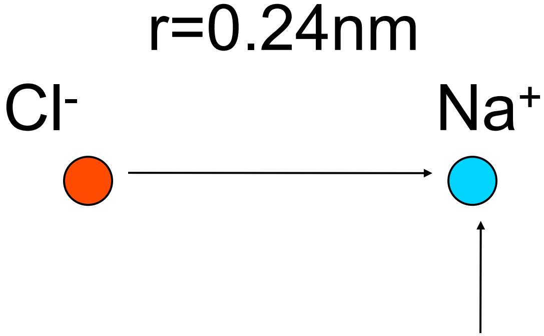

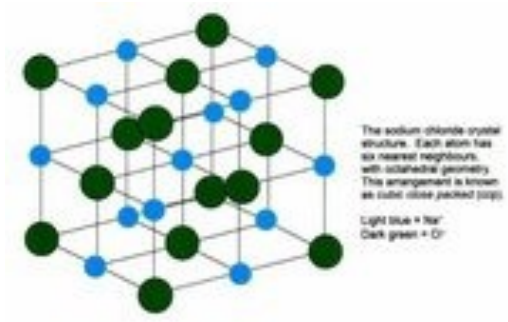

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at the position of Na+

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

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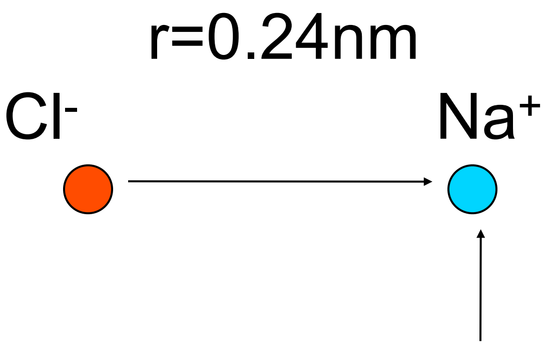

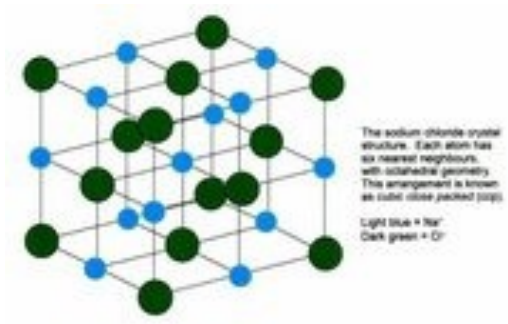

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at the position of Na+

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

ELECTRON VOLT (convenient unit for atomic physics)

1eV=$1.6x10^{-19}$ J

PE=-6.0 eV

(energy in eV is V times the charge in electron units)

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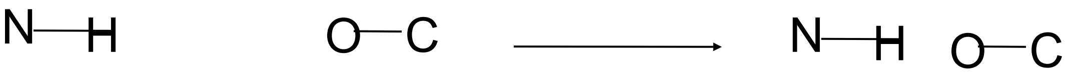
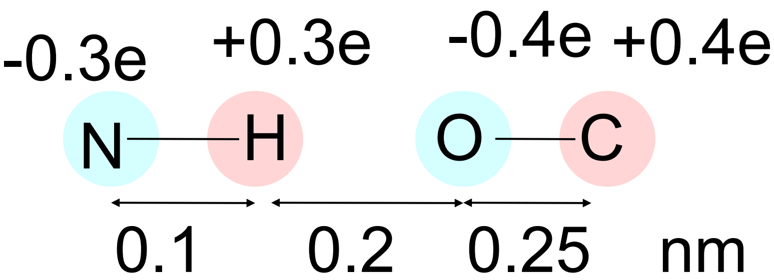
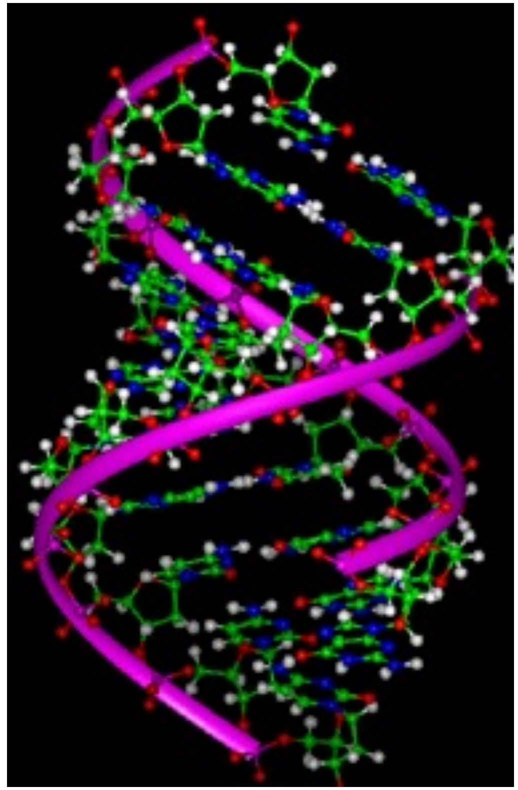
Hydrogen Bond



The hydrogen bond energy can be estimated by partial charges





DNA

Hydrogen Bond

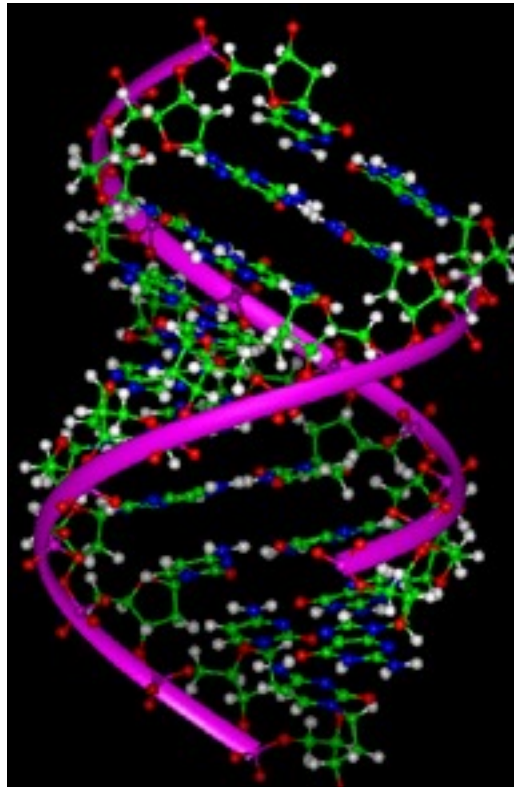
N—H O—C ⟶ N—H O—C

The hydrogen bond energy can be estimated by partial charges

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

N—H: 0.1, H···O: 0.2, O—C: 0.25 nm

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



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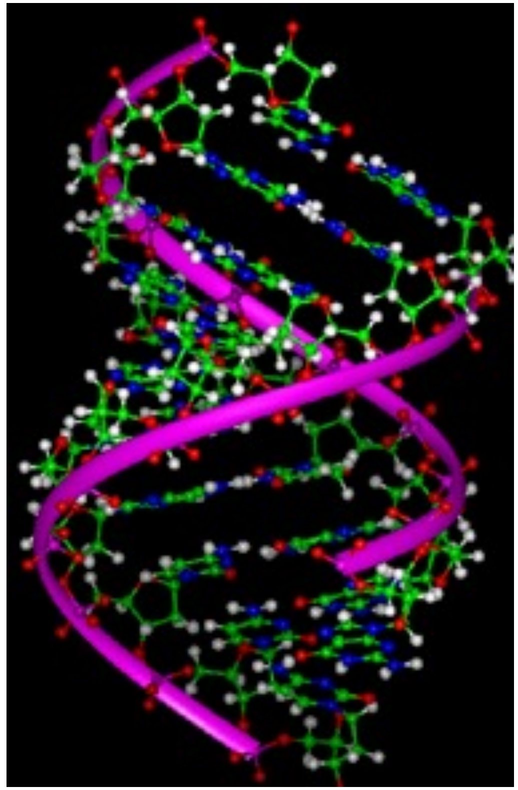

DNA

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

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

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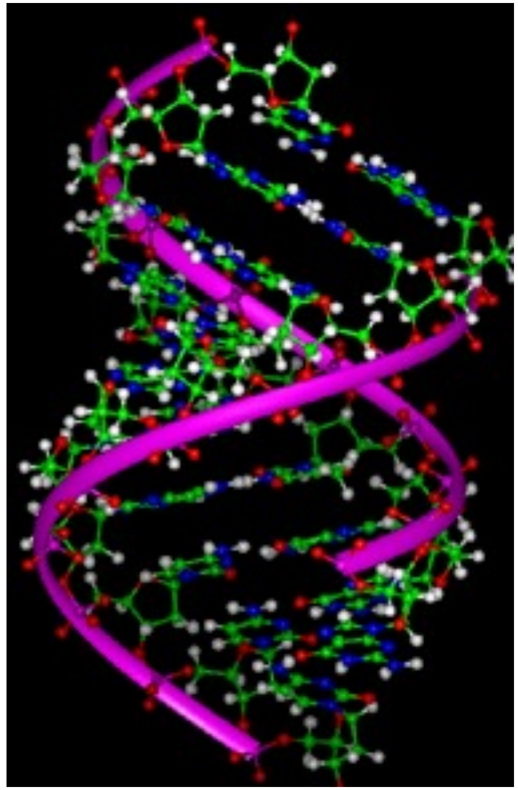

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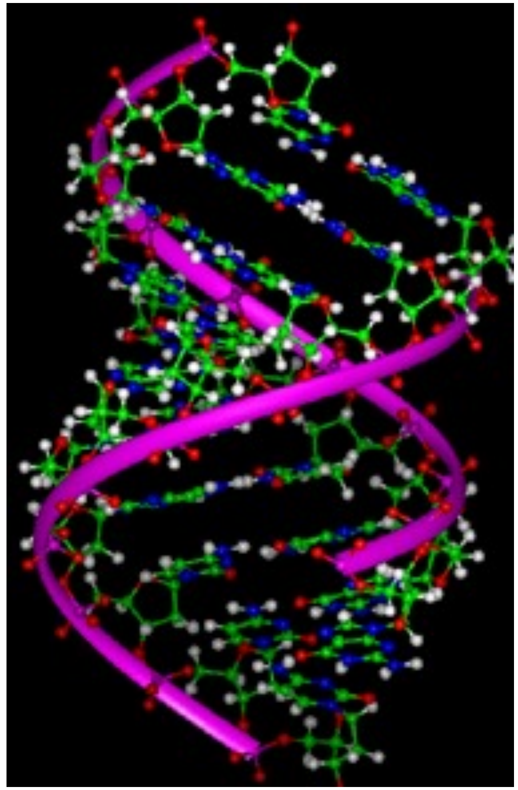

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ΔPE=-0.22 eV

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N—H   O—C ⟶ N—H O—C

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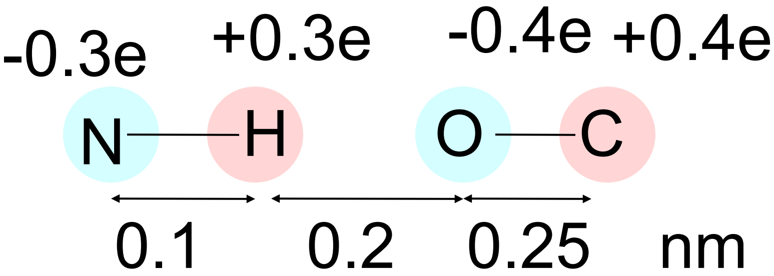

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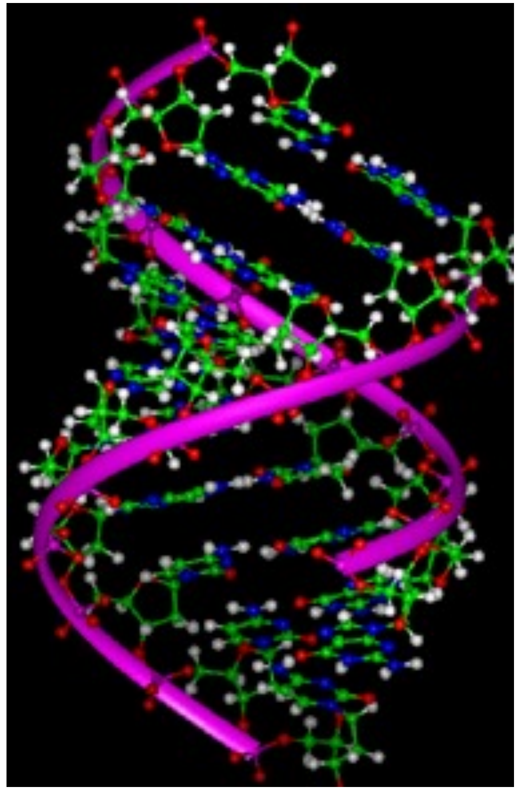

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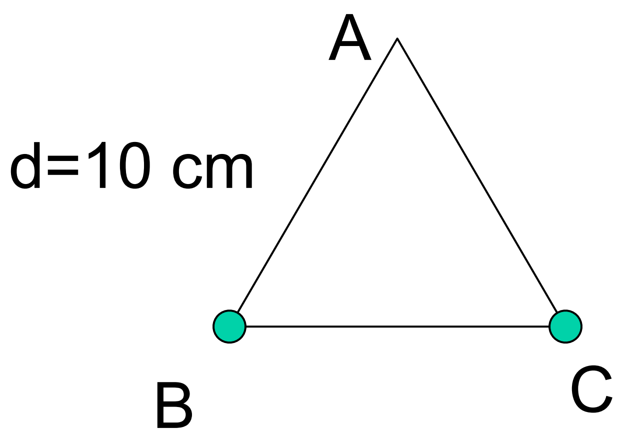
ΔPE=-0.22 eV

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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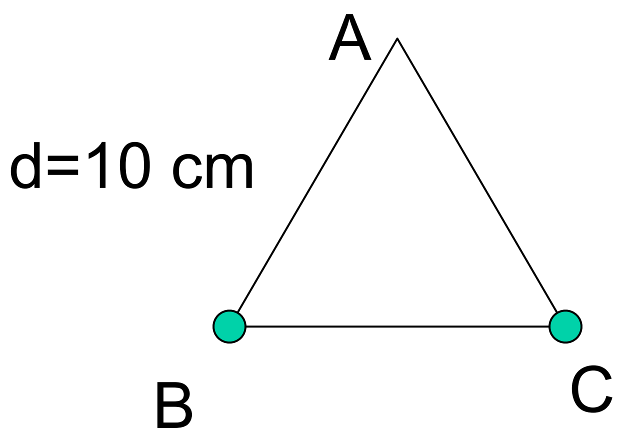
V at A due to each charge



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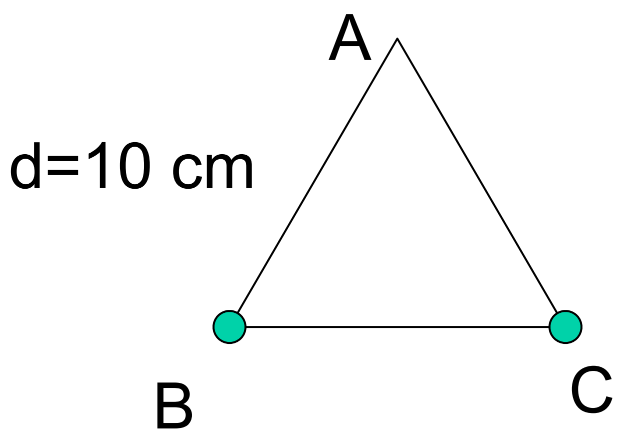

V at A due to each charge

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

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

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

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

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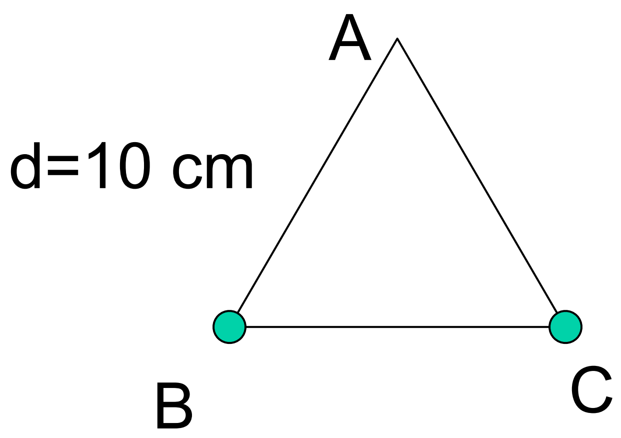

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$$\frac{E}{V} = \frac{1}{r}$$

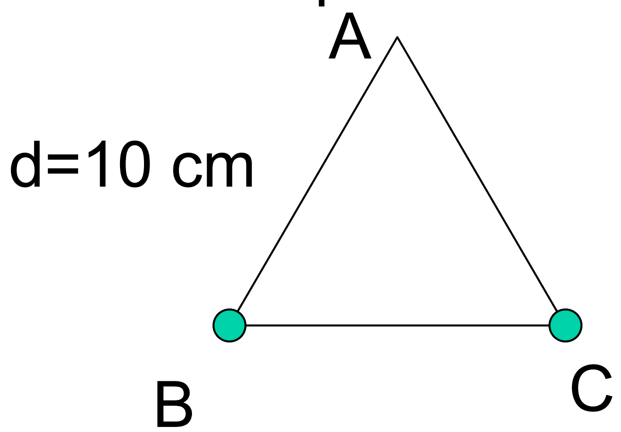
$$V = Er = 100(0.1) = 10V$$

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

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.

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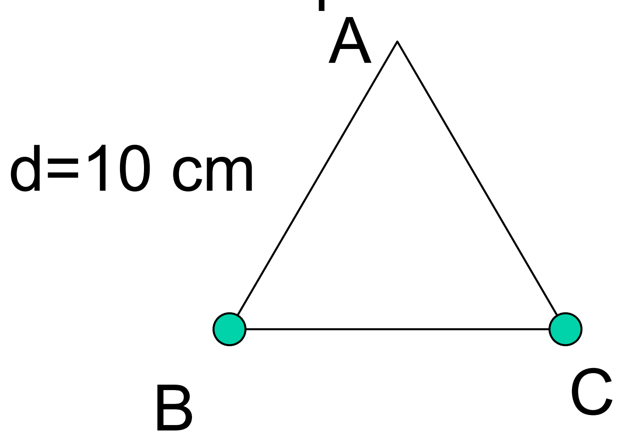

A. 10V
B. 100V
C. 1000V

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

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

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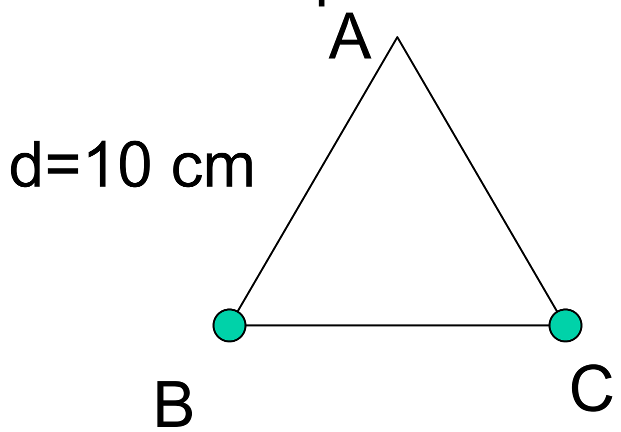

A. 10V

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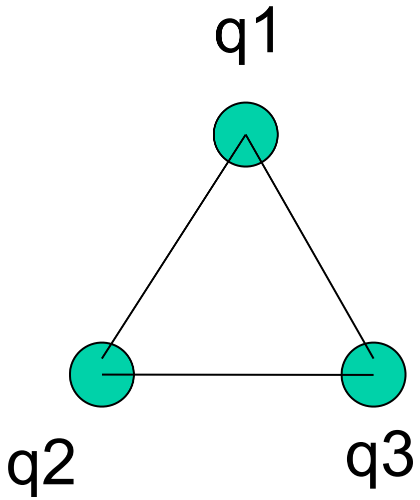
$$\frac{E}{V} = \frac{1}{r}$$

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

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

Potential is a scalar

3 charges of 1×10^{-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.

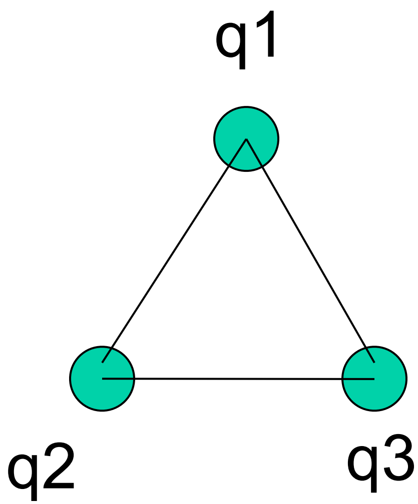


PE due to Coulomb interaction

How many interactions?

PE =

3 charges of 1×10^{-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.

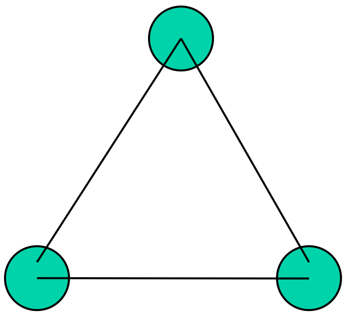


PE due to Coulomb interaction

How many interactions? 3

PE =

3 charges of 1×10^{-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.

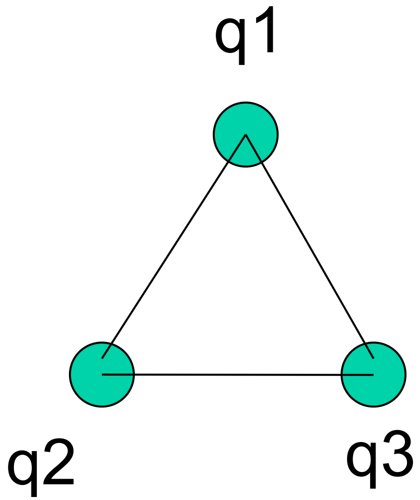


PE due to Coulomb interaction

How many interactions? 3

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

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? 3

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

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

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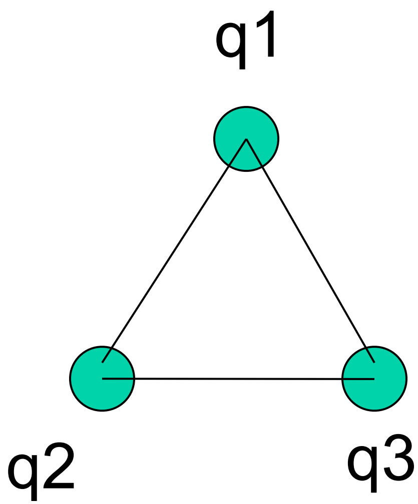


PE due to Coulomb interaction

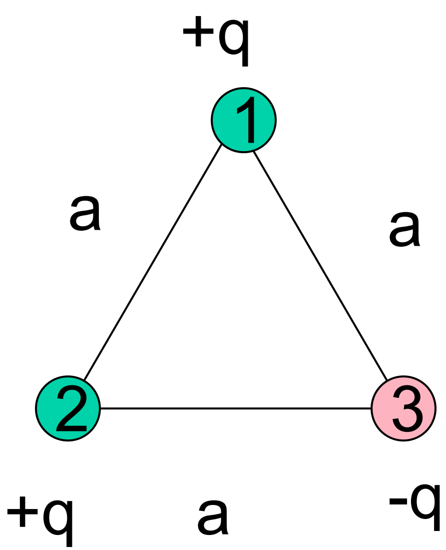
How many interactions? 3

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

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

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

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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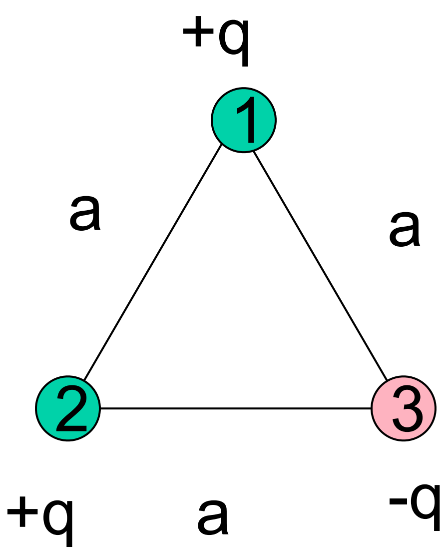


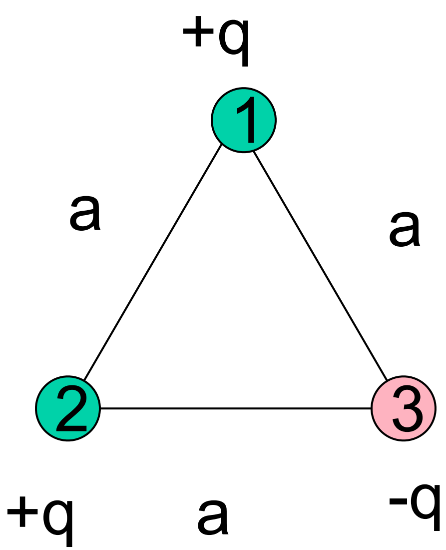
How many interactions?

How many positive?

How many negative?

What is the total change in PE?

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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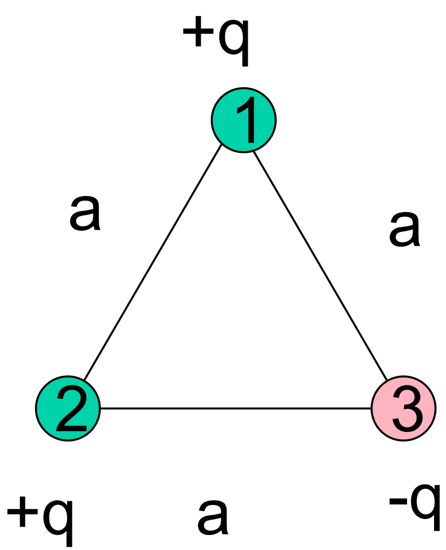


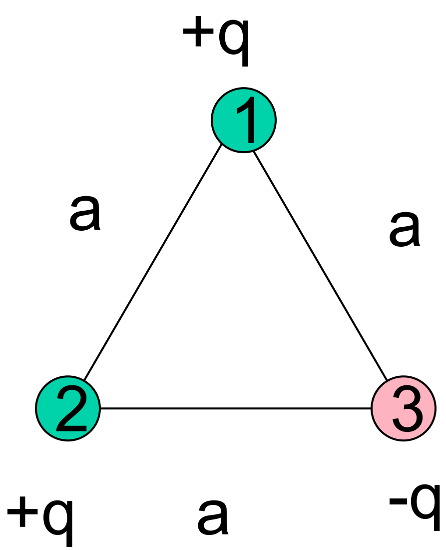
How many interactions? 3

How many positive? 1

How many negative?

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)



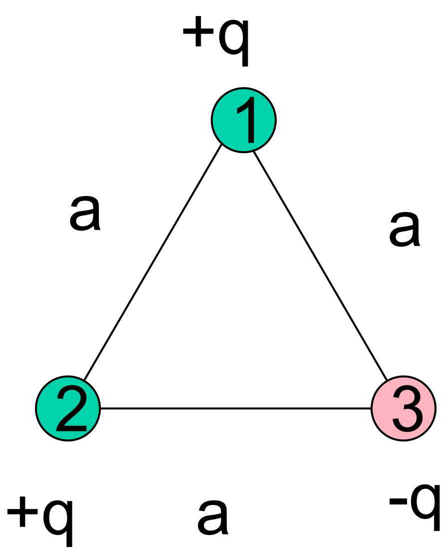
How many interactions? 3

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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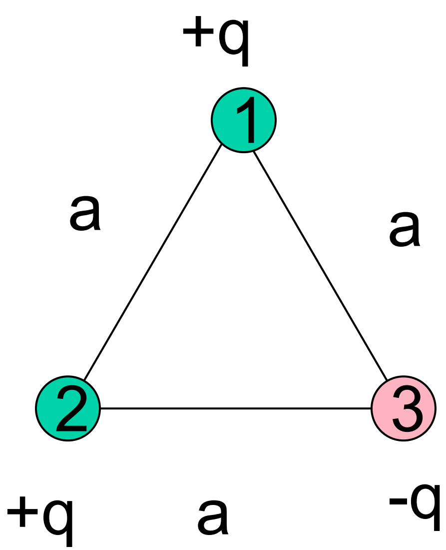

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What is the total change in PE?

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

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

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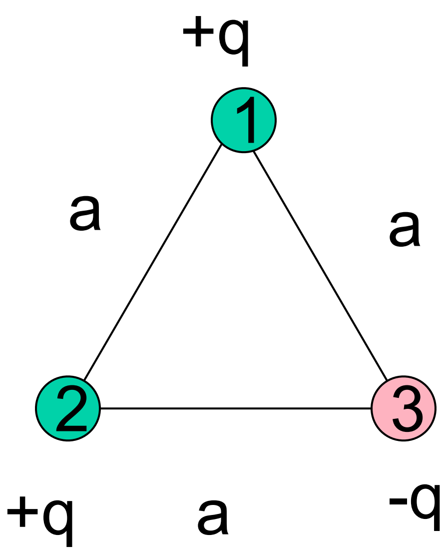

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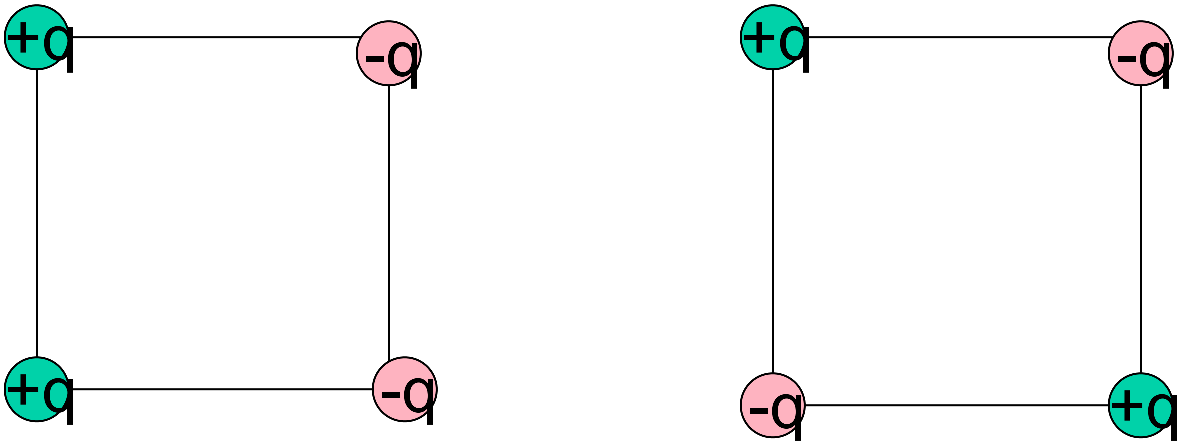
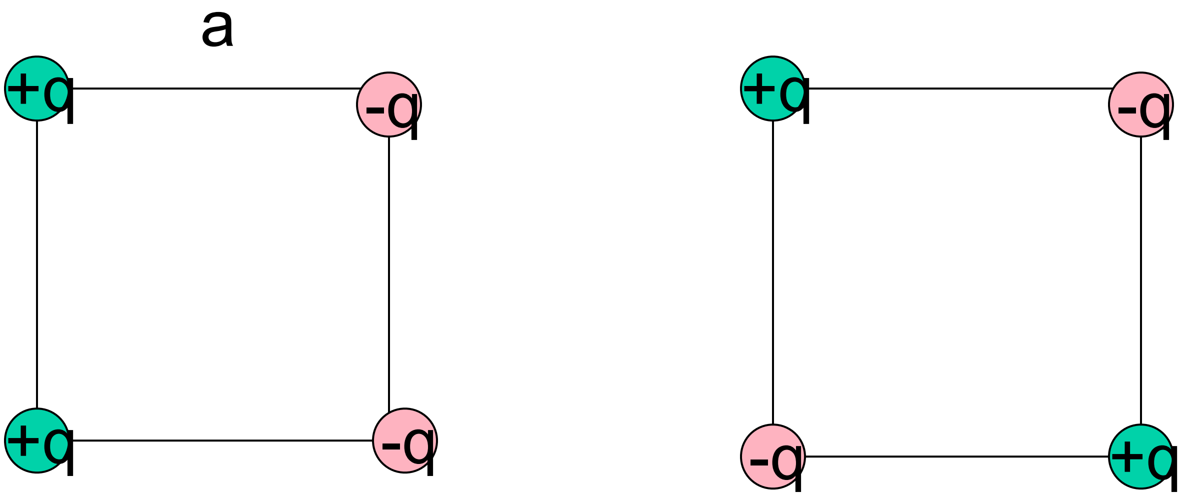
STABLE

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



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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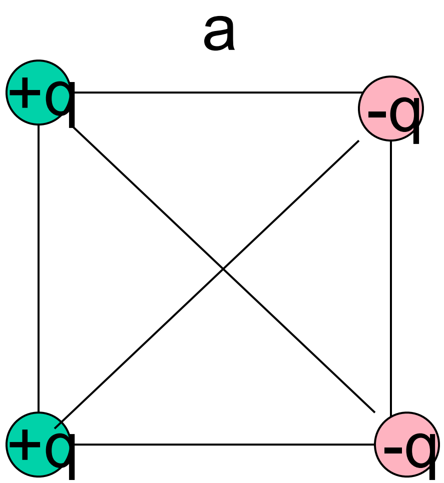
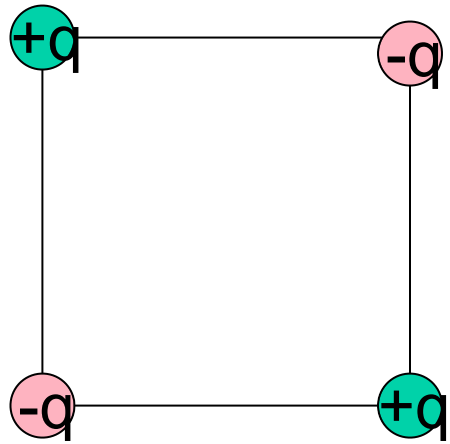




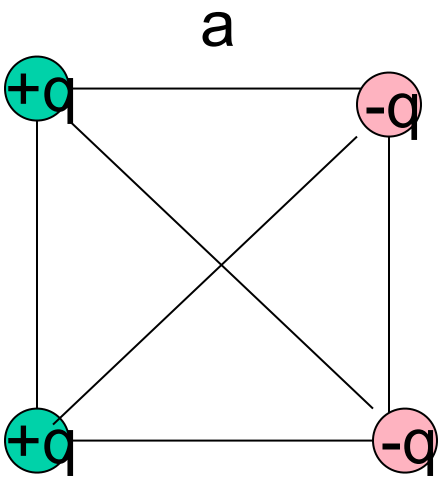
PE_0

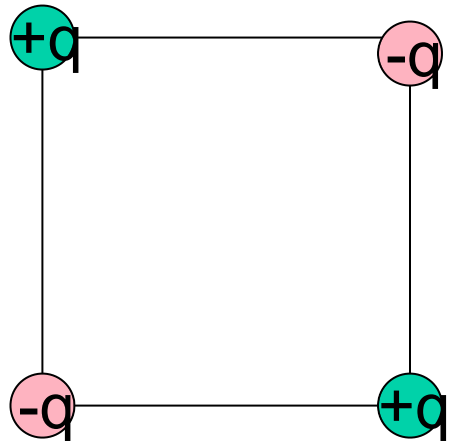
$PE_0/\sqrt{2}$

Total PE

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

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

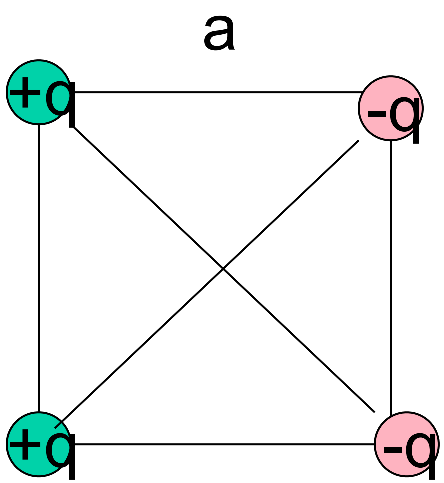


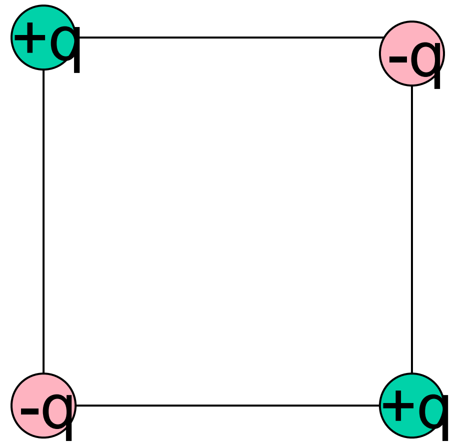


PE_0	+2	-2
$PE_0/\sqrt{2}$		
Total PE		

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

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





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

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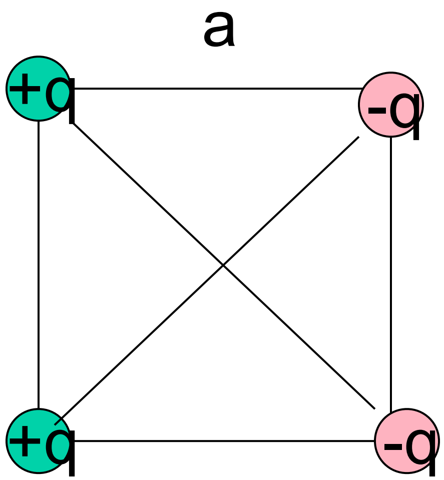
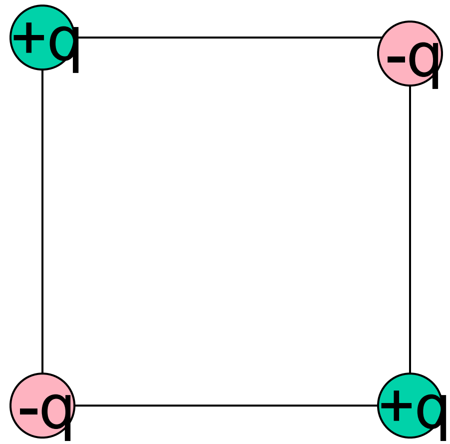
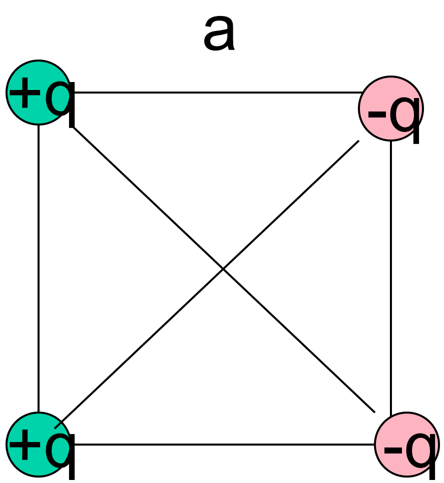


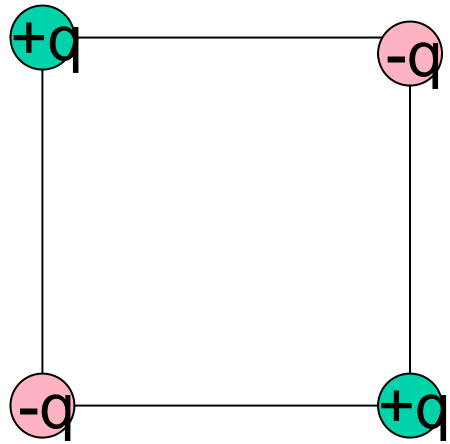


PE_0	+2	-2
$PE_0/\sqrt{2}$		-2
Total PE	$-\frac{2}{\sqrt{2}}PE_0 = -1.4PE_0$	

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

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

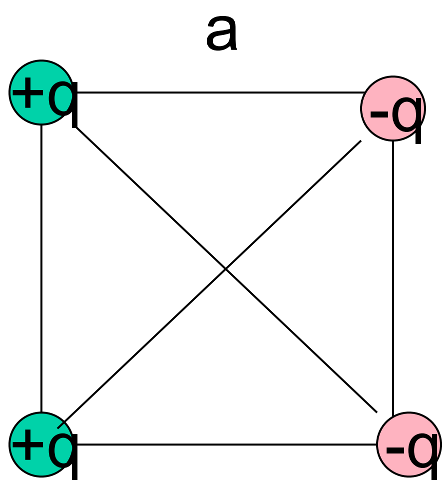


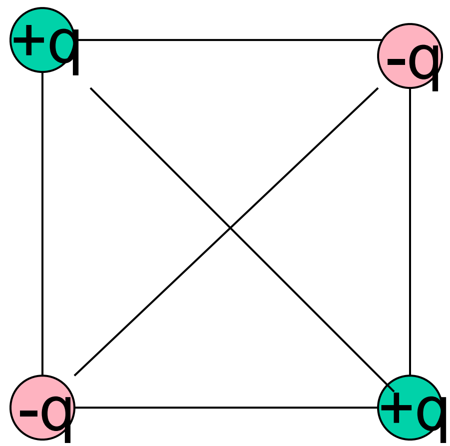


PE_0	+2	-2	-4
$PE_0/\sqrt{2}$		-2	
Total PE	$-\frac{2}{\sqrt{2}}PE_0 = -1.4PE_0$		

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

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





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

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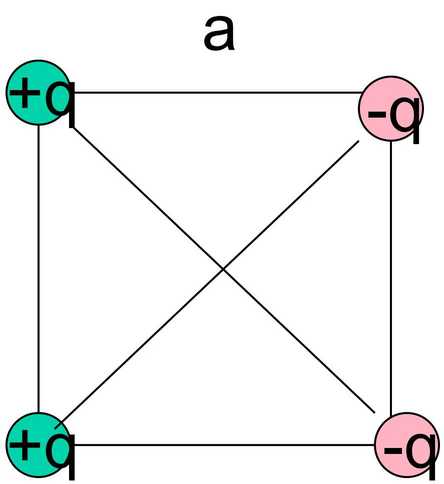
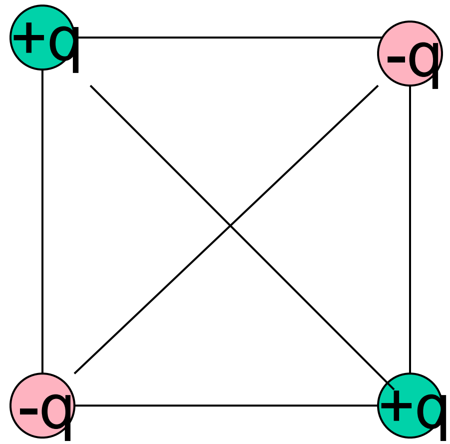
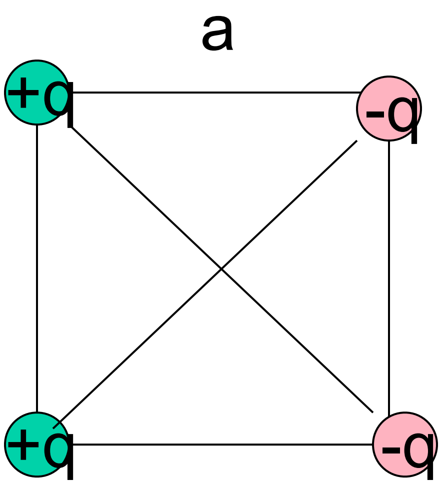


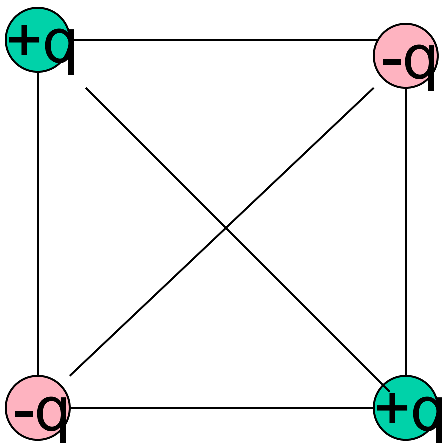


PE_0	+2 -2	-4
$PE_0/\sqrt{2}$	-2	+2
Total PE	$-\frac{2}{\sqrt{2}}PE_0 = -1.4PE_0$	$(-4+\frac{2}{\sqrt{2}})PE_o = -2.6PE_0$

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

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





STABLE

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