Phys 102 – Lecture 4

Electric potential energy & work

Today we will...

- Learn about the *electric potential energy*
- Relate it to *work*

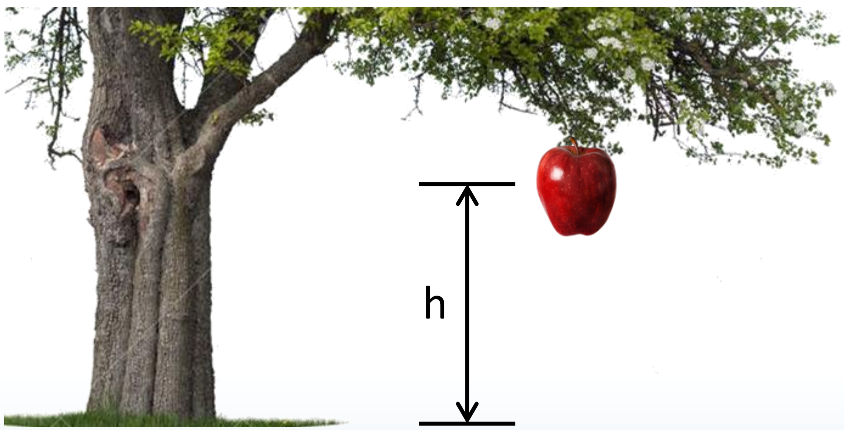
  Ex: charge in uniform electric field, point charges
- Apply these concepts

  Ex: electron microscope, assembly of point charges, dipole energy & hydration shells

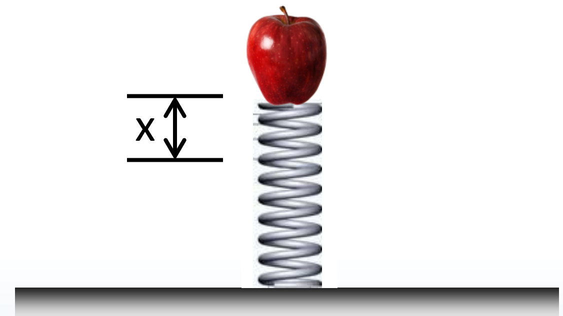
Potential energy

Potential energy U – stored energy, can convert to kinetic energy *K*

Review Phys. 101



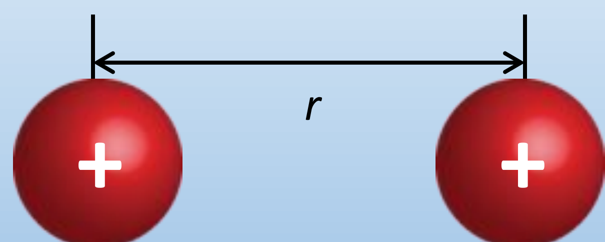
Gravitational potential energy (ex: falling object)



Elastic potential energy (ex: spring)

Total energy *K* + *U* is *conserved*

Same ideas apply to electricity



Electric potential energy (ex: repelling charges)

Work

Review Phys. 101

Work – transfer of energy when a force acts on a moving object

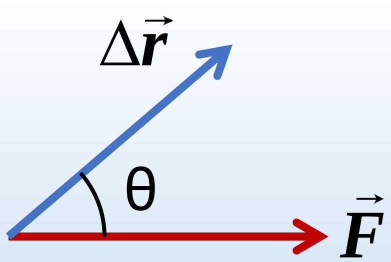
Work done by force *F*

$$\boxed{W_F = F\Delta r\cos\theta} = -W_{you} = -\Delta U$$

Displacement

Angle between force and displacement

Change in potential energy



Units: J ("Joules")

It matters who does the work

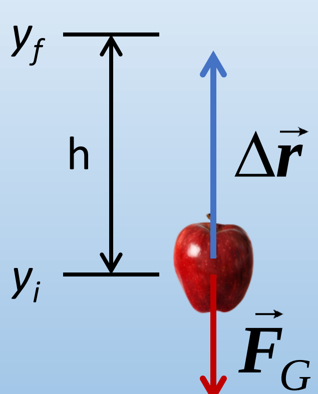
For *conservative* forces, work is related to potential energy

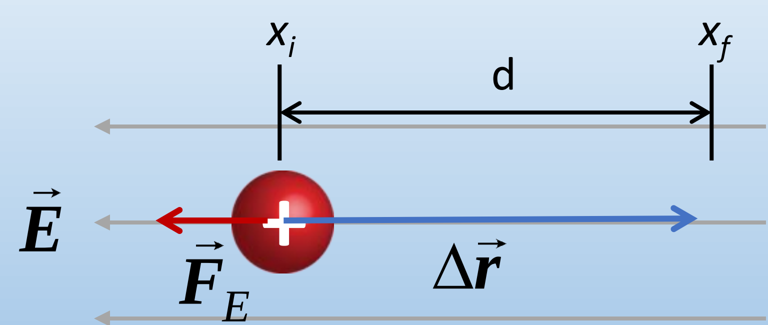
Electric potential energy & work

$$W_F = -W_{you} = -\Delta U = F\Delta r\cos\theta$$

Gravity ⟷ Electricity

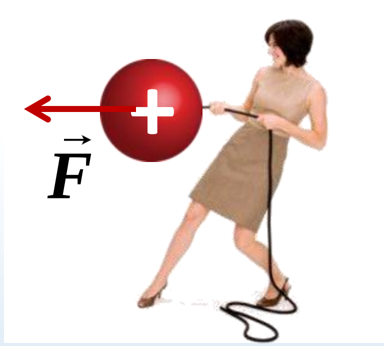
Mass raised $y_i \rightarrow y_f$	Charge moved $x_i \rightarrow x_f$ (in uniform E field to left)
$F_G = mg$ down	$F_E = qE$ left
$W_G = -mgh$	$W_E = -qEd$
$W_{you} = +mgh$	$W_{you} = +qEd$
$\Delta U_G = +mgh$	$\Delta U_E = +qEd$





Positive and negative work

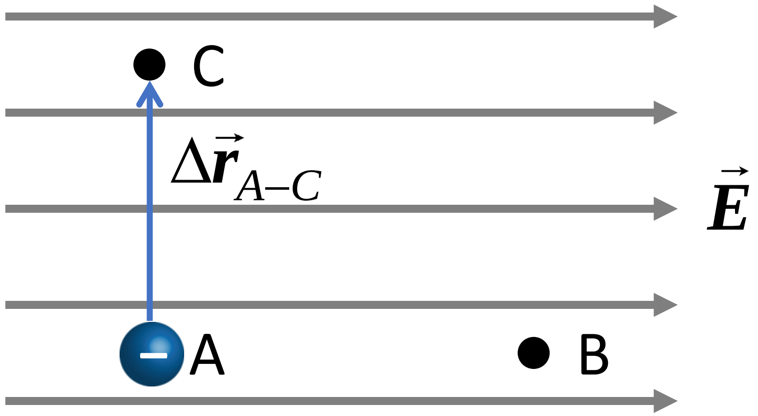
If you moved object against external force (gravitational, electric, etc.), you did *positive* work, force did *negative* work



$W_{you} > 0 \quad W_F < 0$ $\qquad$ $W_{you} < 0 \quad W_F > 0$

If you moved object along external force (gravitational, electric, etc.), you did *negative* work, force did *positive* work

Checkpoint 1.2



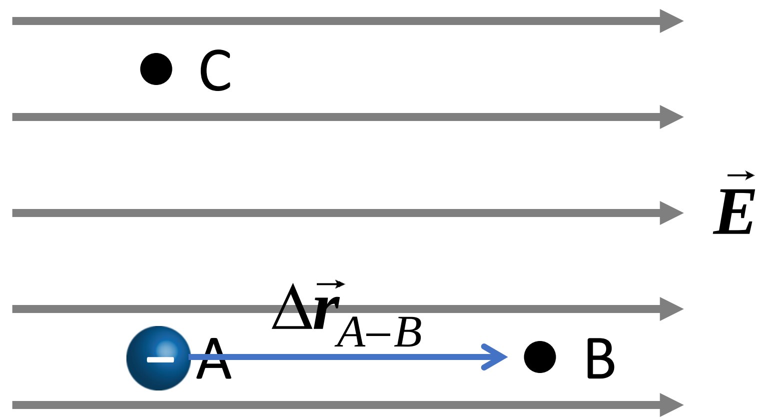
When a negative charge is moved from A to C the ELECTRIC force does

A. positive work

B. zero work

C. negative work

ACT: Checkpoint 1.3



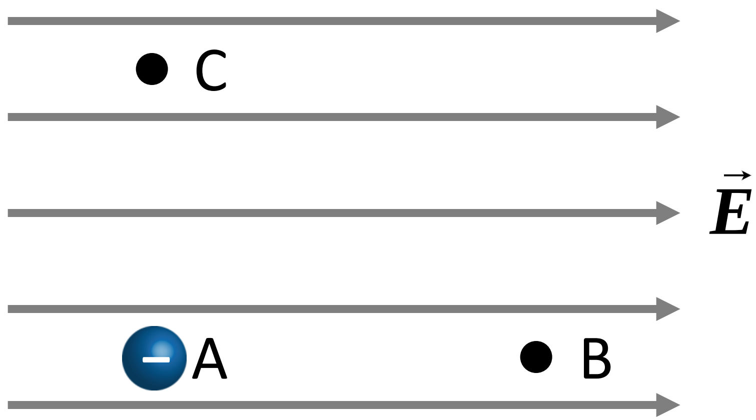
When a negative charge is moved from A to B the ELECTRIC force does

A. positive work

B. zero work

C. negative work

ACT: Work in a uniform E field



Let $W_{A\text{-}B}$ be the answer to the previous problem

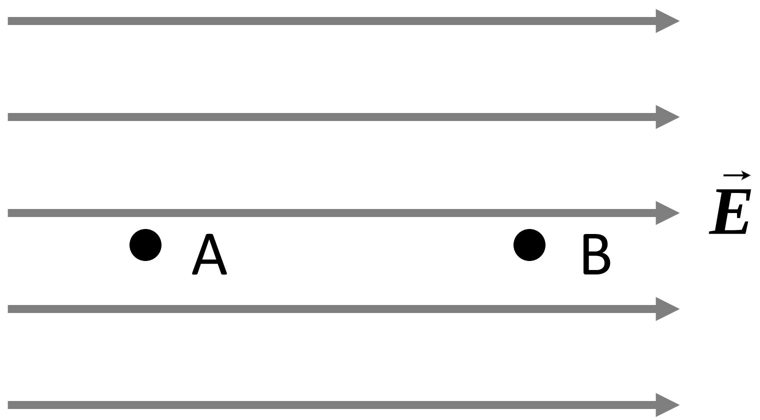
The negative charge is now moved from A to C to B. The work done by the electric force is

A. Greater than $W_{A\text{-}B}$

B. Same as $W_{A\text{-}B}$

C. Less than $W_{A\text{-}B}$

Path independence of work



For conservative forces (ex: gravitational, electric), work is *independent* of path. Work depends *only* on end points.

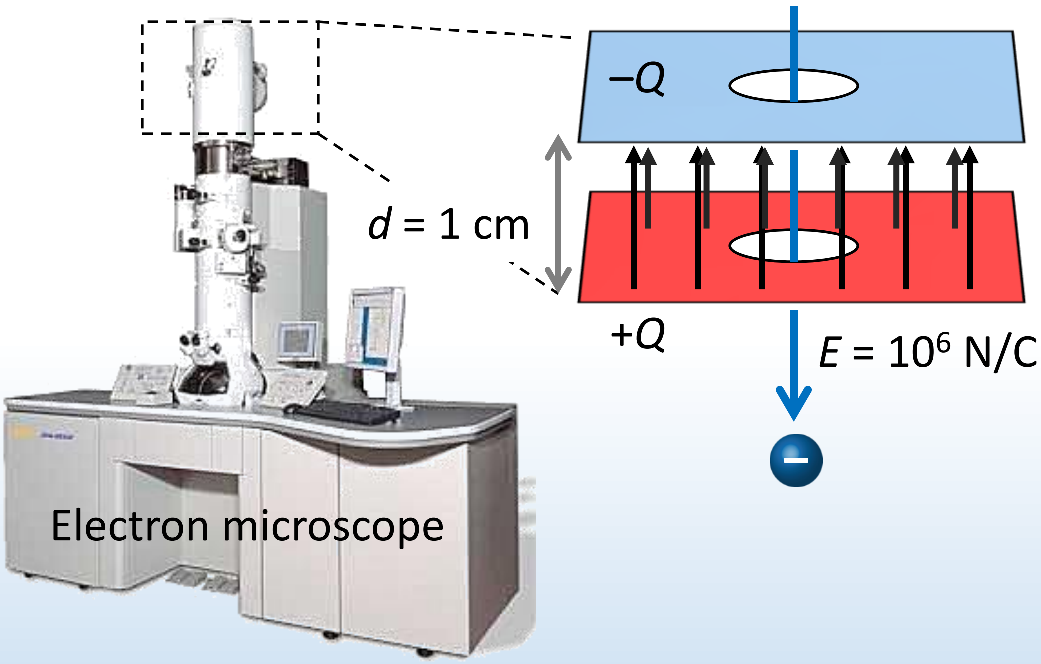
$$W_{A-B} = -\Delta U = -(U_B - U_A)$$

Potential energy of charge at position A

Potential energy of charge at position B

Calculation: Electron microscope (*revisited*)

A uniform E field generated by parallel plates accelerates electrons in an electron microscope. If an electron starts from rest at the top plate what is its final velocity?



E.P.E of two point charges

Electric potential energy of two charges q_1 and q_2 separated by a distance r

$$\boxed{U_E = k\frac{q_1 q_2}{r}}$$

Note: NOT r^2

$+1.6 \times 10^{-19}$ C = q_1

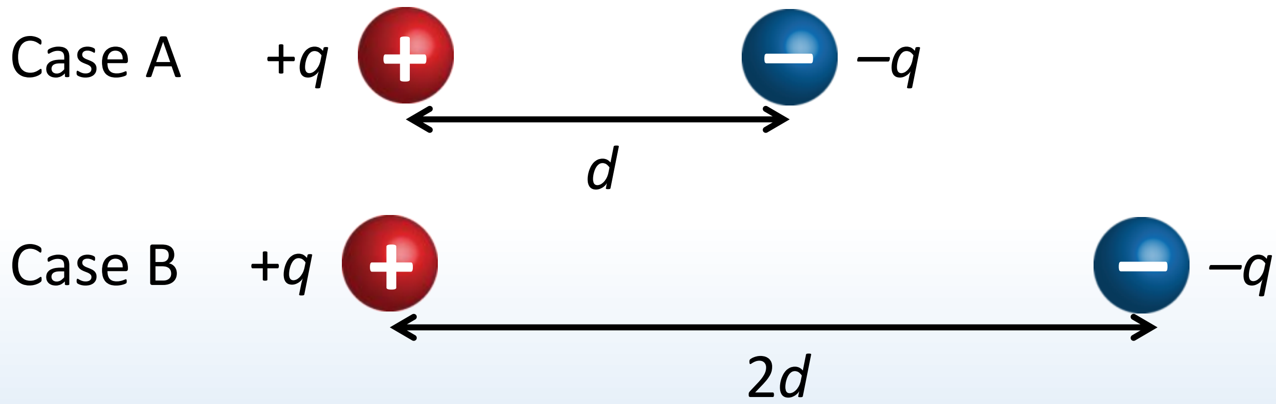
q_2 = -1.6×10^{-19} C

r = 0.53×10^{-10} m

Ex: What is the electric potential energy of the proton and the electron in H?

ACT: E.P.E. of 2 charges

In case A, two charges of equal magnitude but opposite sign are separated by a distance d. In case B, they are separated by $2d$.



Which configuration has a higher electric potential energy?

A. Case A has a higher E.P.E.
B. Case B has a higher E.P.E.
C. Both have the same E.P.E.

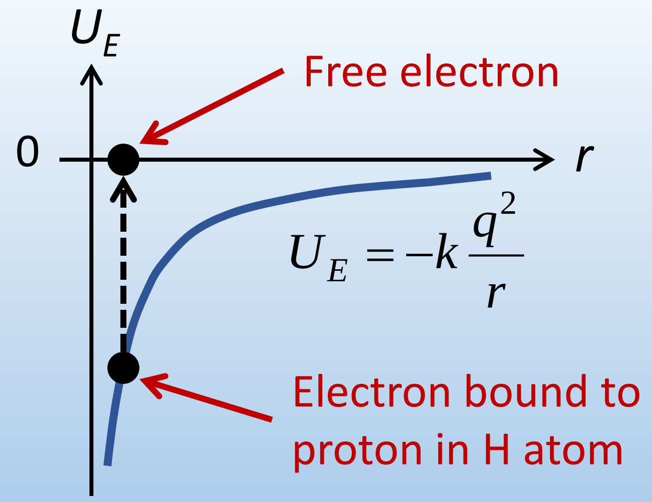
Sign of potential energy

What does it mean to have a ***negative*** electric potential energy?

Ex: H atom

$U_E < 0$ relative to energy of an electron very far away ($r \to \infty$), away from E field of proton, i.e. a "free" electron

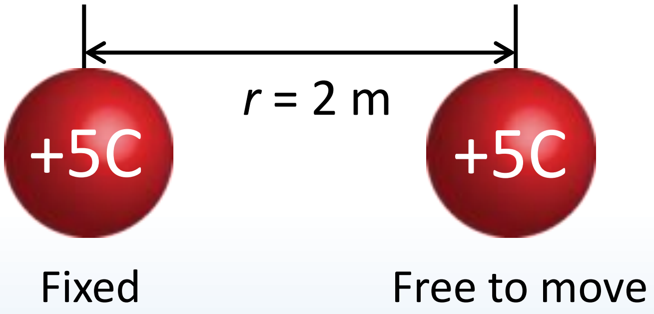
Energy must be added in order to free electron bound to proton



Calculation: two charges

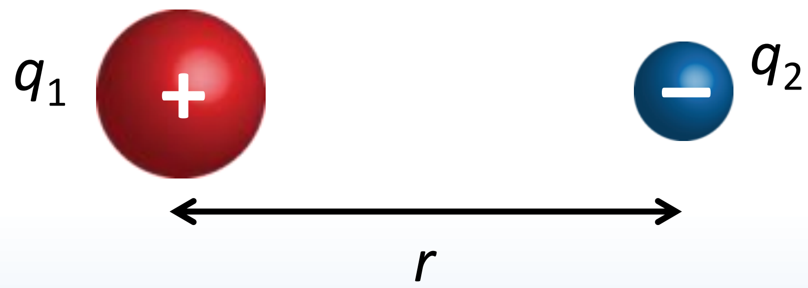
Two +5 C, 1 kg charges are separated by a distance of 2 m. At $t = 0$ the charge on the right is released from rest (the left charge is fixed). What is the speed of the right charge after a long time ($t \to \infty$)?

From EX 1, SPRING '10



Work done to assemble charges

How much work do *you* do assembling configuration of charges?



Imagine bringing charges from infinitely far away to a separation *r*

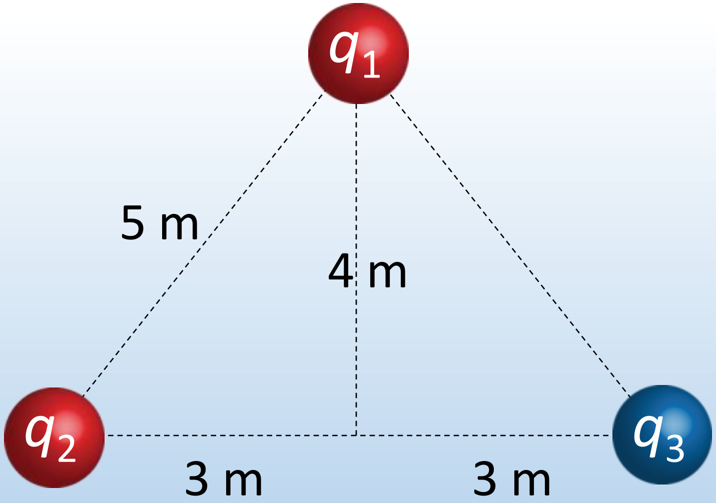
$$W_{you} = +\Delta U_E = k\frac{q_1 q_2}{r} - 0$$

Potential energy of charges infinitely far

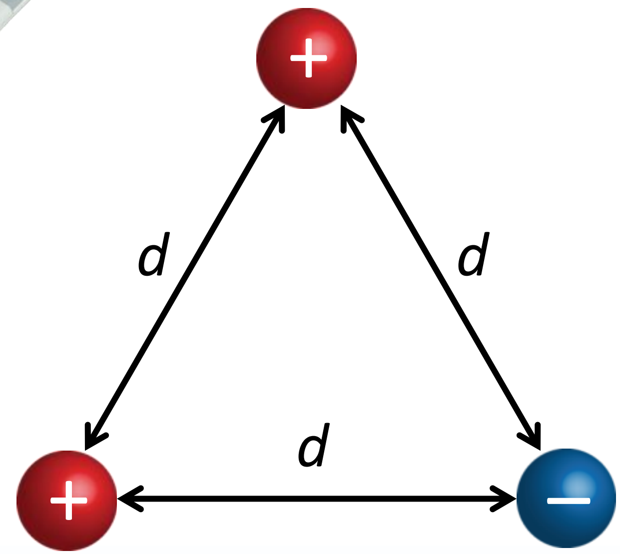
Potential energy of charges in final configuration

Calculation: assembling charges

How much work <u>do you do</u> to assemble the charges $q_1 = +2\ \mu C$, $q_2 = +7\ \mu C$, and $q_3 = -3.5\ \mu C$ into a triangle?



ACT: Checkpoint 2.1



Charges of equal magnitude are assembled into an equilateral triangle

The total work required *by you* to assemble this set of charges is:

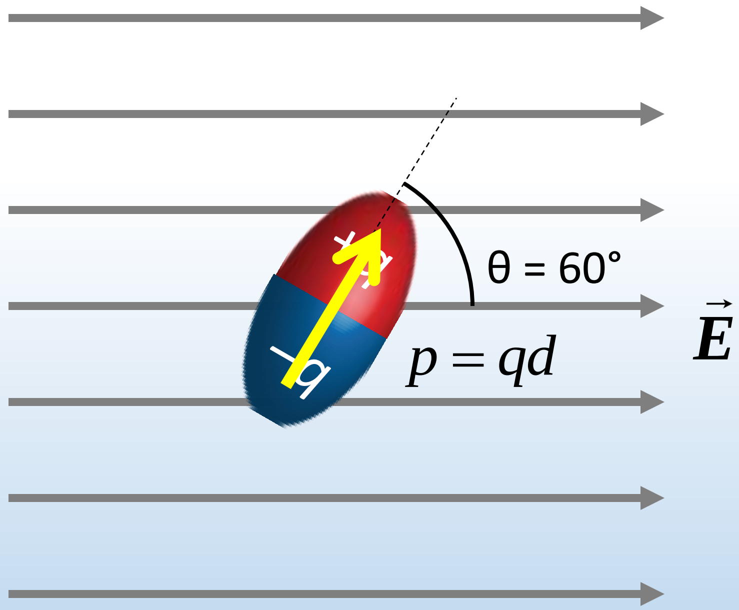
A. positive

B. zero

C. negative

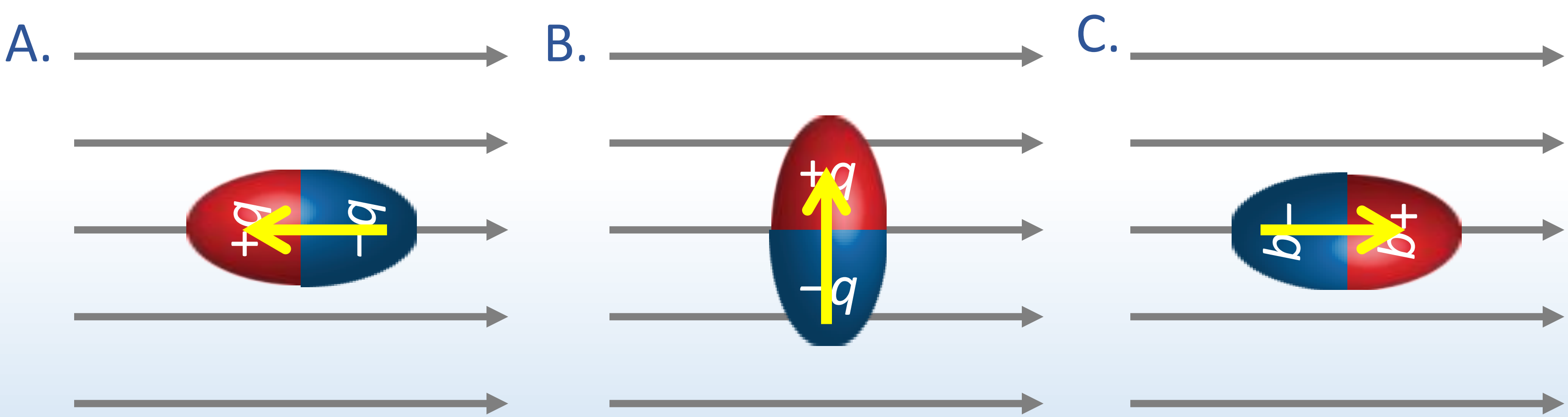
Calculation: dipole in E-field

An electric dipole with moment p = 6.2 x 10^{-30} C·m is placed in a uniform external electric field E = 10^6 N/C at an angle θ = 60°. Calculate the total *electric potential energy* of the dipole.



ACT: dipole energy

Which configuration of dipole in a uniform electric field has the lowest electric potential energy?



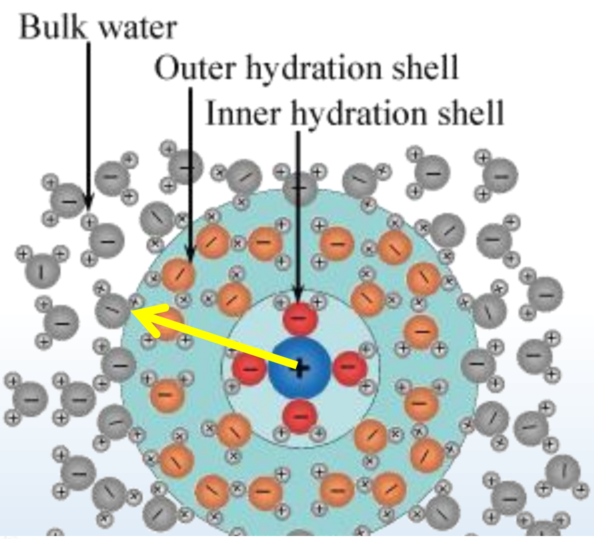
Hydration shell radius

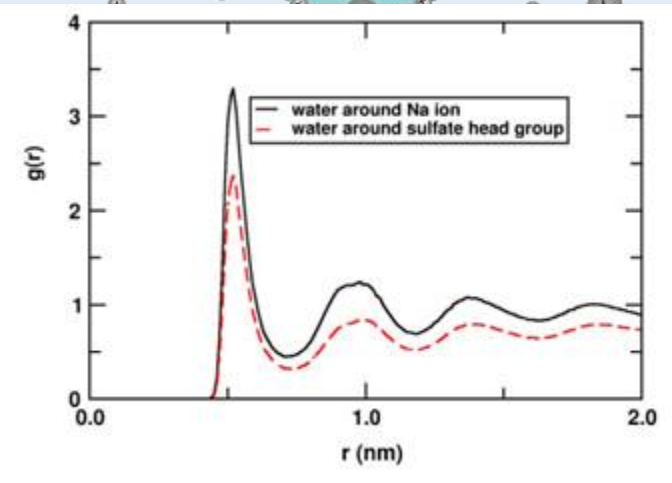
Recall that H_2O dipole aligns to electric field of ions. However, at room temperature, H_2O also has rotational kinetic energy that tends to randomize dipole orientation

$K_{dip.} + U_{dip.} \geq 0$ Dipoles are randomized (bulk water)

$K_{dip.} + U_{dip.} < 0$ Dipoles tend to be aligned (hydration shell)

We can estimate distance to interface between bulk and ordered water for a monovalent ion (Ex: Na^+)





Summary of today's lecture

- Electric potential energy & work

  $$W_F = -W_{you} = -\Delta U = F\Delta r\cos\theta$$

  Path independence

  Conservation of energy

- Electric potential energy for point charges $U_E = k\dfrac{q_1 q_2}{r}$