# Phys 102 – Lecture 4

**Electric potential energy & work**

# ***Today we will...***

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

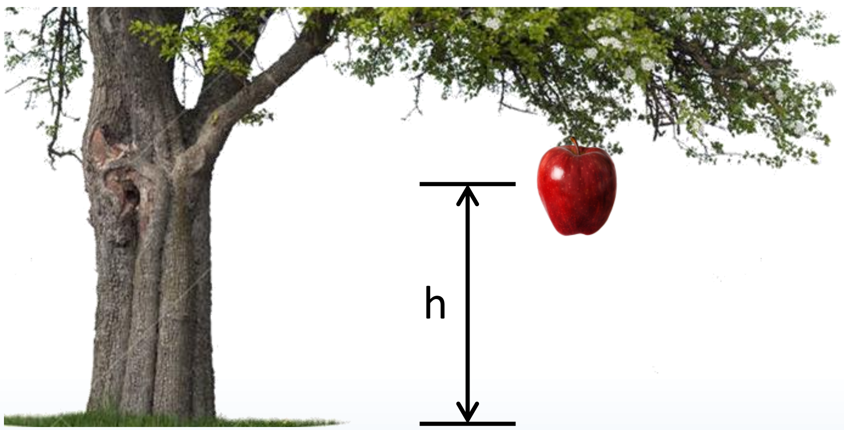
  Ex: charge in uniform electric field, point charges
- Apply these concepts

  Ex: electron microscope, assembly of point charges, dipole energy

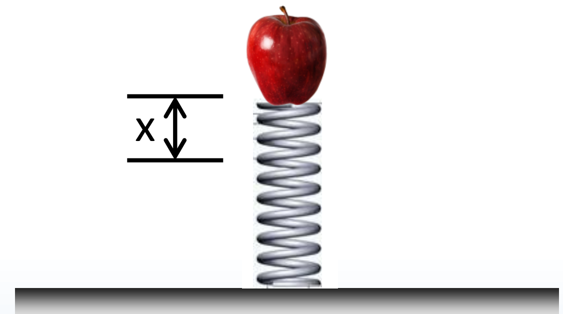
# *Potential energy*

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

Review Phys. 101



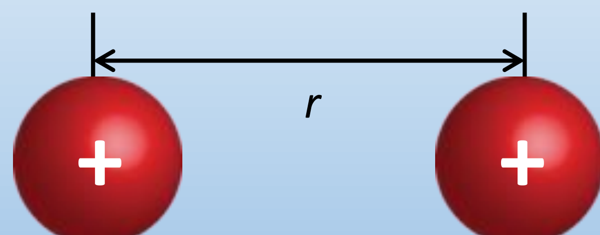

Gravitational potential energy (ex: falling object)




Elastic potential energy (ex: spring)

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

Same ideas apply to electricity




Electric potential energy (ex: repelling charges)

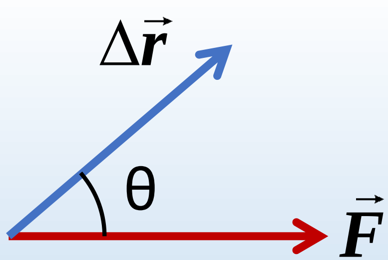
# ***Work***

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 ($\Delta r$)
- Angle between force and displacement ($\theta$)
- Change in potential energy ($\Delta U$)




Units: J ("Joules")

It matters who does the work

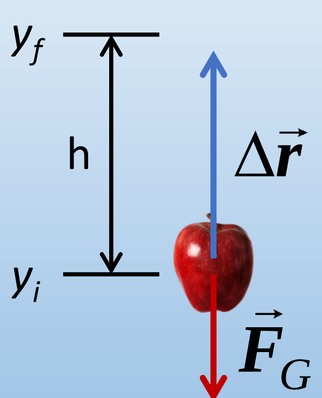
For *conservative* forces, work is related to potential energy

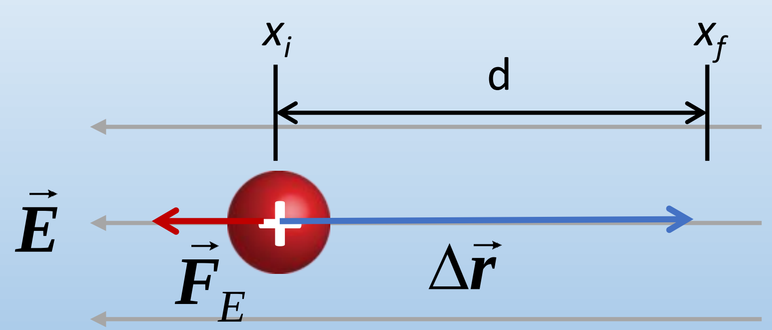
# Electric potential energy & work

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

Gravity ⟷ Electricity

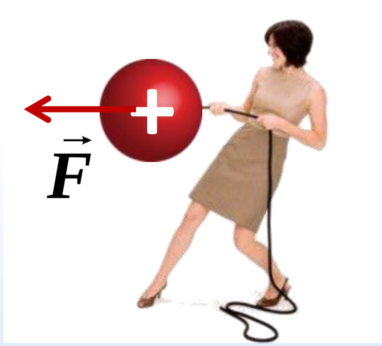
| Mass raised $y_i \rightarrow y_f$ | Charge moved $x_i \rightarrow x_f$ (in uniform E field to left) |
|---|---|
| $F_G = mg$ down | $F_E = qE$ left |
| $W_G = -mgh$ | $W_E = -qEd$ |
| $W_{you} = +mgh$ | $W_{you} = +qEd$ |
| $\Delta U_G = +mgh$ | $\Delta U_E = +qEd$ |



# *Positive and negative work*

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

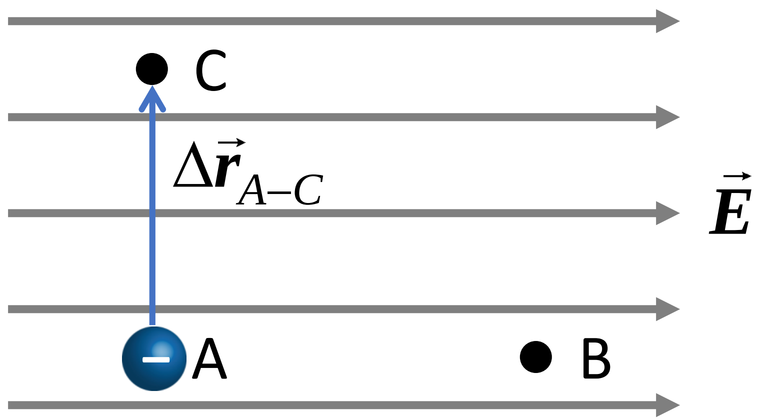




$W_{you} > 0 \quad W_F < 0$ $\qquad$ $W_{you} < 0 \quad W_F > 0$

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

# Checkpoint 1.2



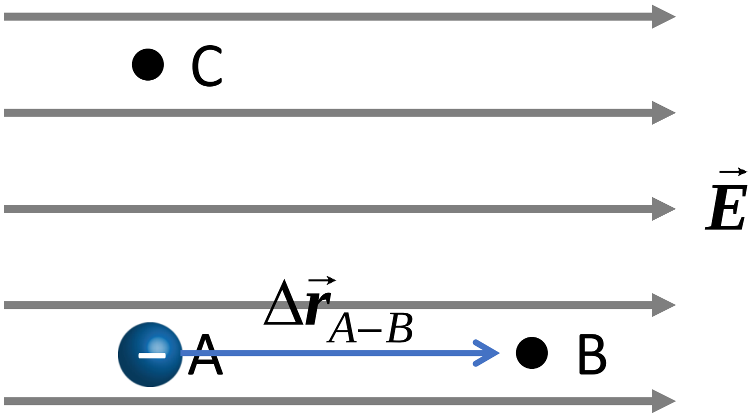

When a negative charge is moved from A to C the ELECTRIC force does

A. positive work

B. zero work

C. negative work

# ACT: Checkpoint 1.3



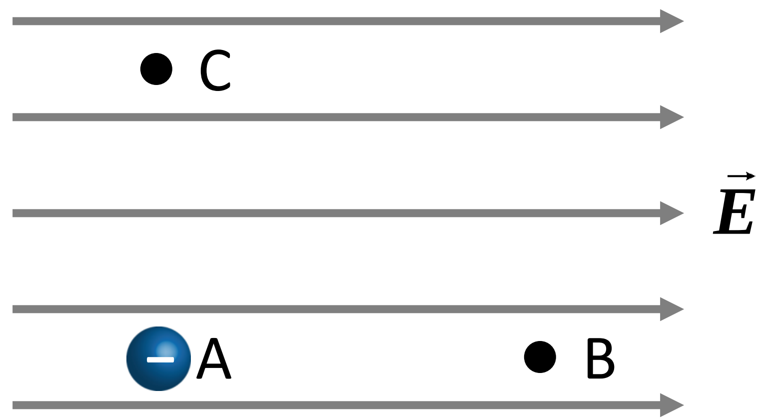

When a negative charge is moved from A to B the ELECTRIC force does

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

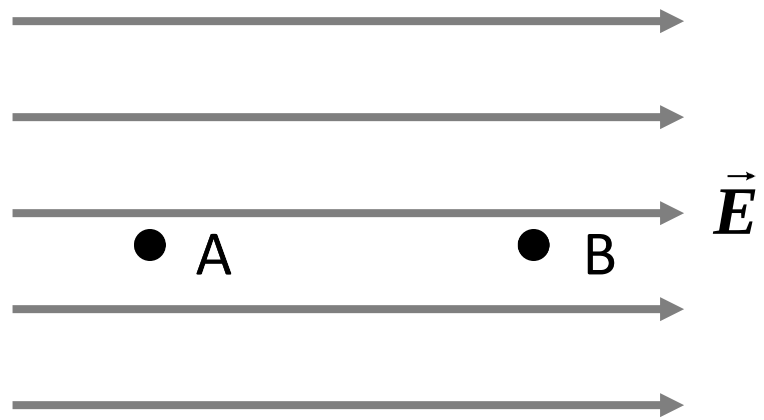
The negative charge is now moved from A to C to B. The work done by the electric force is

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.

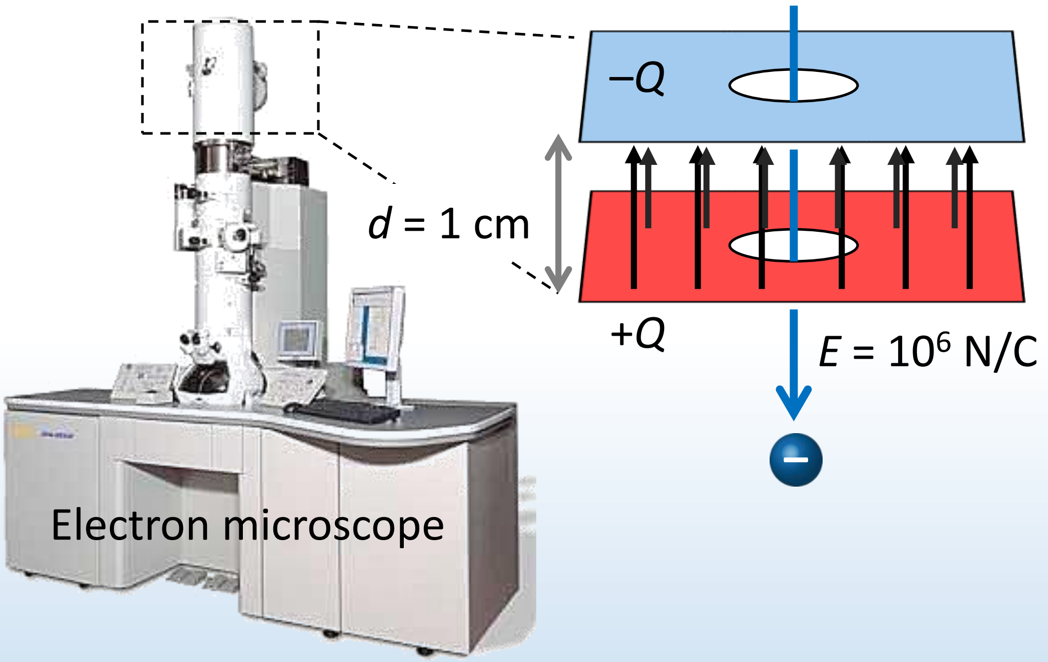
$$W_{A-B} = -\Delta U = -(U_B - U_A)$$

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 $r$

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

Note: NOT $r^2$

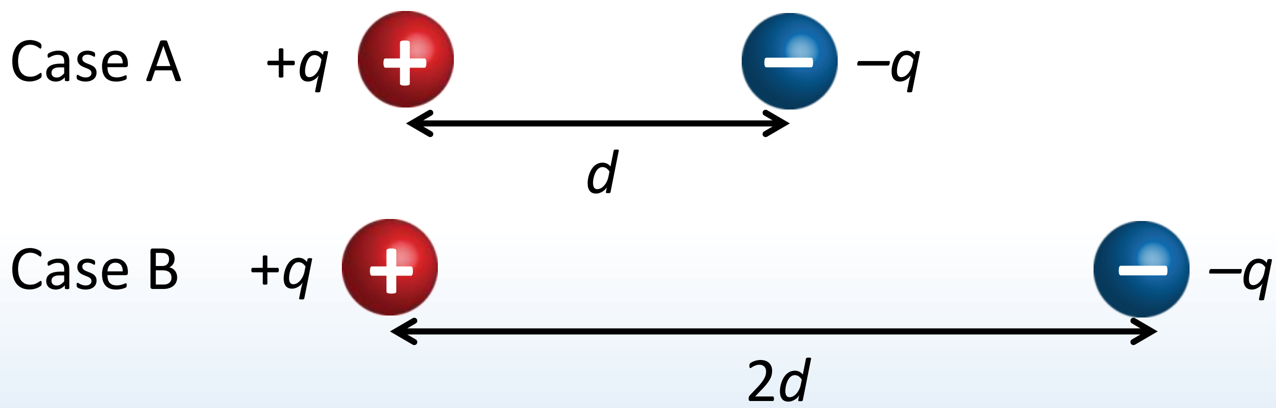
$+1.6 \times 10^{-19}$ C = $q_1$ $\quad$ $q_2$ = $-1.6 \times 10^{-19}$ C

$r$ = $0.53 \times 10^{-10}$ 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 2*d*.




Which configuration has a higher electric potential energy?

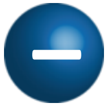
A. Case A has a higher E.P.E.
B. Case B has a higher E.P.E.
C. Both have the same E.P.E.

# *Sign of potential energy*

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

Ex: H atom

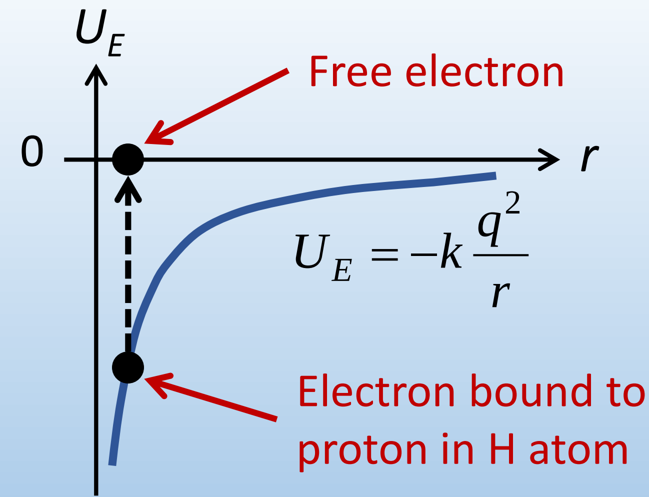
Proton



Electron

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

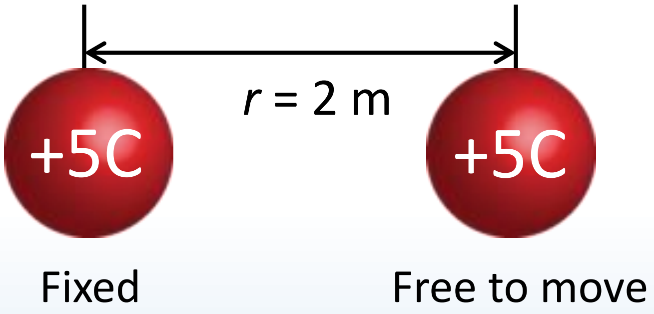
Energy must be added in order to free electron bound to proton



# Calculation: two charges

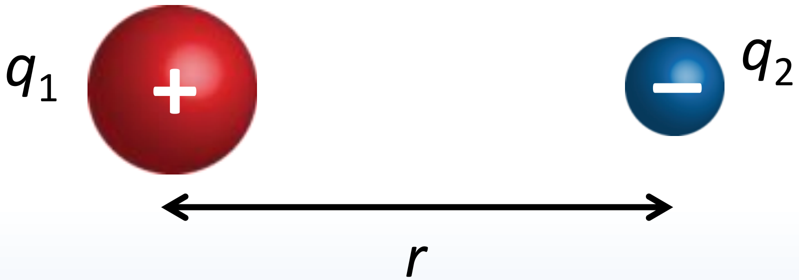
Two +5 C, 1 kg charges are separated by a distance of 2 m. At $t = 0$ the charge on the right is released from rest (the left charge is fixed). What is the speed of the right charge after a long time ($t \to \infty$)?

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*

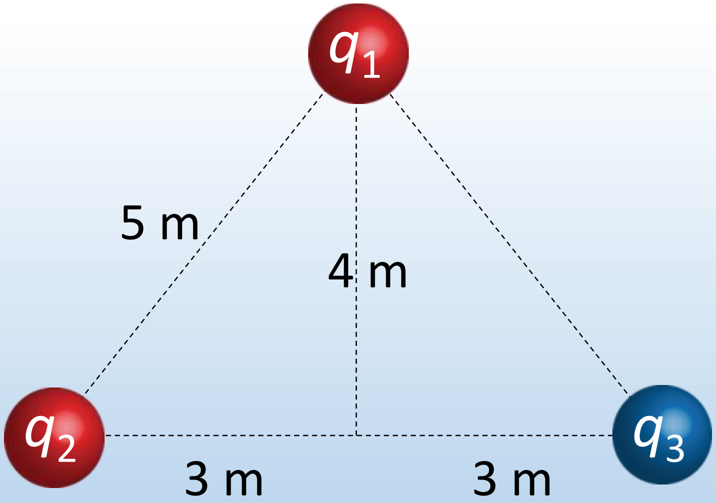
$$W_{you} = +\Delta U_E = k\frac{q_1 q_2}{r} - 0$$

Potential energy of charges infinitely far

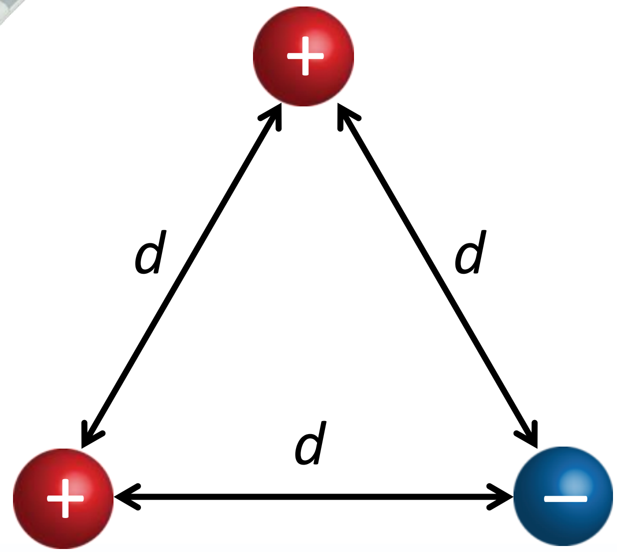
Potential energy of charges in final configuration

# Calculation: assembling charges

How much work do you do 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:

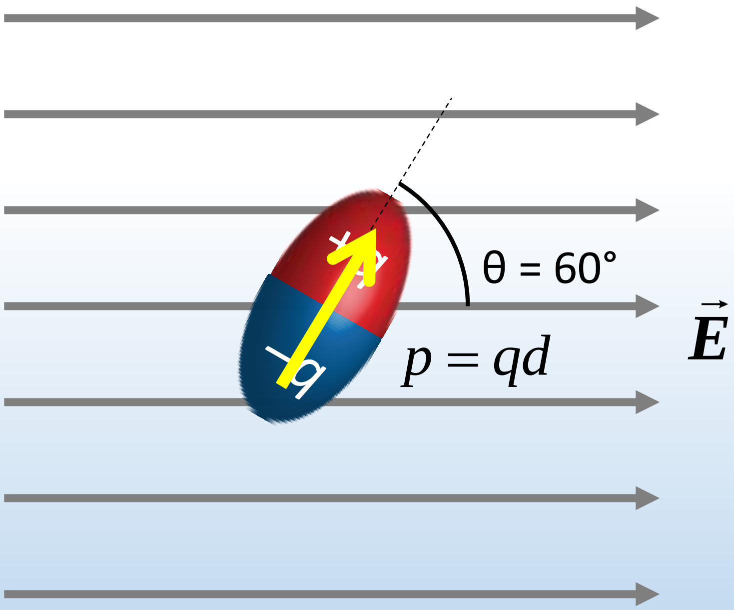
A. positive

B. zero

C. negative

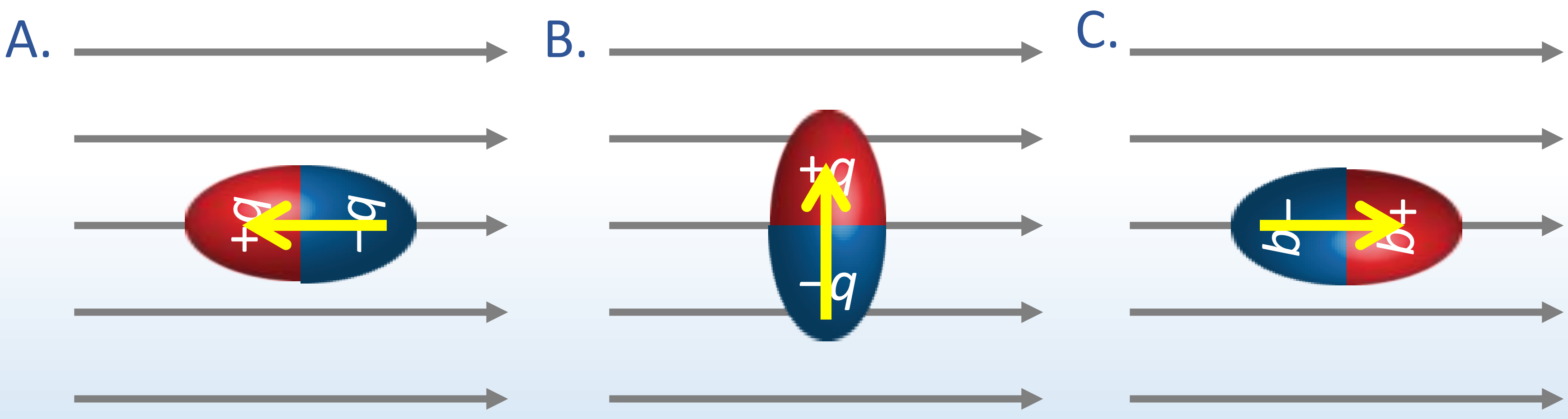
# *Calculation: dipole in E-field*

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?



# *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 $U_E = k\dfrac{q_1 q_2}{r}$