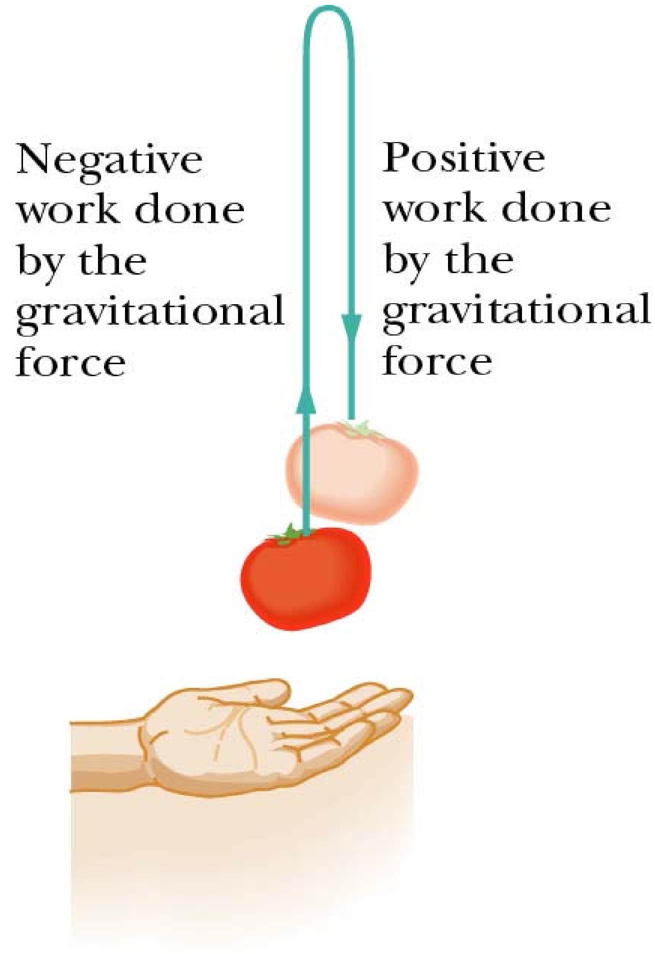
Work done by Gravity

- Gravitational force near the surface of the earth points down.
- Apple thrown up loses kinetic energy – we say that the work done by the gravitational force on the apple is negative.
- The work transforms the kinetic energy into a positive change of the potential energy of the field-apple system

$$\Delta U = U_f - U_i = -W$$



Work done by Gravity

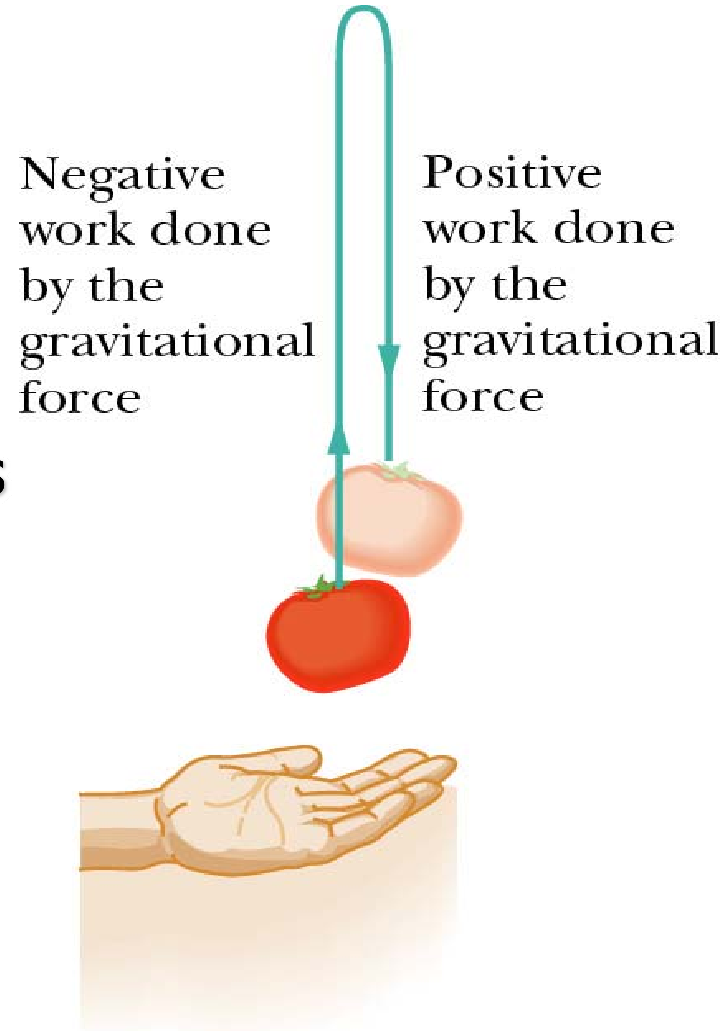
- General equation for work is

$$W = \vec{F} \bullet \vec{d}$$

- *F* points down.
- When the apple goes up *d* points up and

$$W = -Fd$$

- In this case there is a positive change in the potential energy.

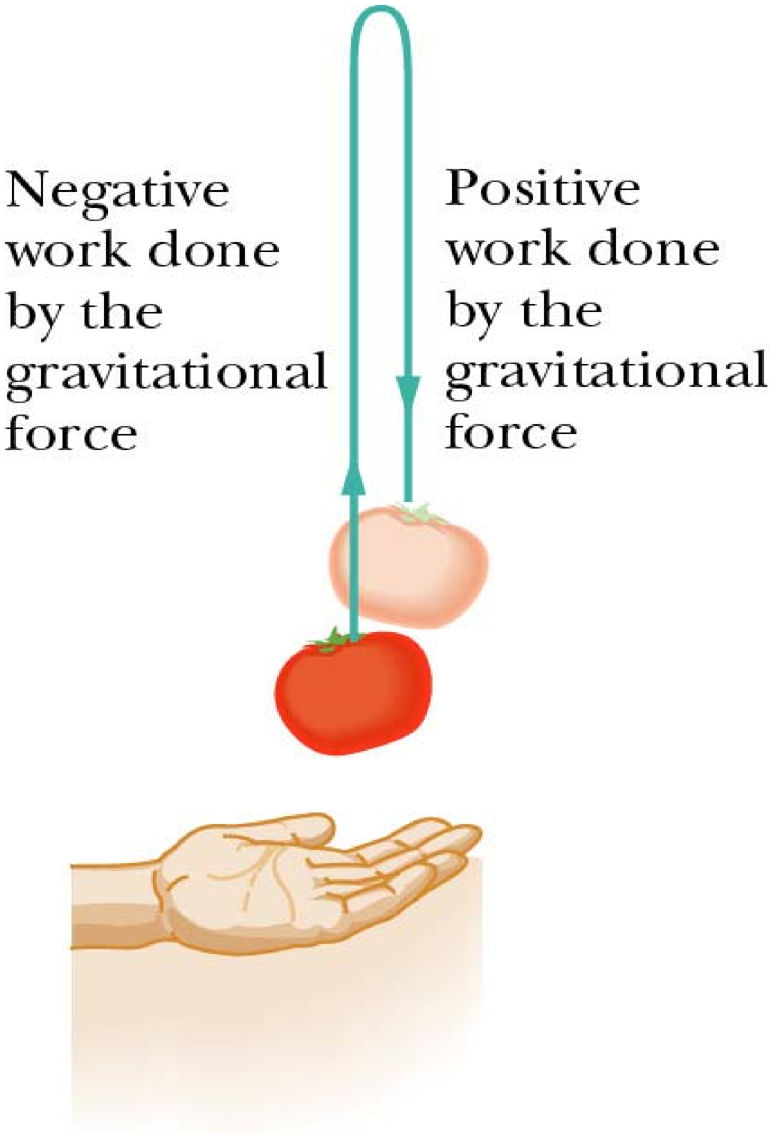


Work done by Gravity

- When the apple goes down *d* points down

$$W = Fd$$

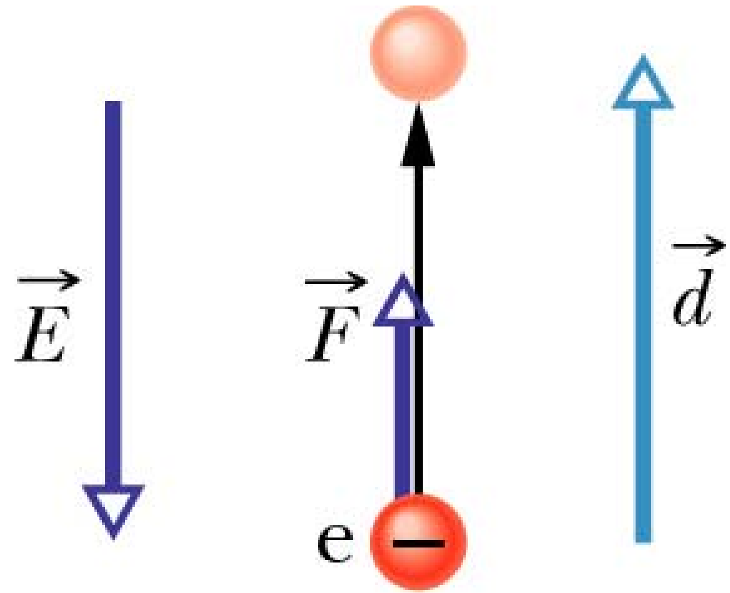
- In this case there is a negative change in the potential energy.



Work done by Electric Field

- Electric field near the surface of the earth points down (ignore gravity).
- When the electron moves up the work done on an electron by the electric field is:

$$W = Fd$$



- This results in a decrease in the potential energy of the field-electron system.

$$\Delta U = U_f - U_i = -W$$

Electric Potential Energy

- When electrostatic force acts between charged particles assign an electric potential energy, *U*
- Difference in *U* of a charge at two different points, initial *i* and final *f* is

$$\Delta U = U_f - U_i$$

Electric Potential Energy

- When the system changes from initial state *i* to final state *f* electrostatic force does work

$$\Delta U = U_f - U_i = -W$$

- Electrostatic force is conservative
- Work done by force is path independent
  - Work is same for all paths between points *i* and *f*

Electric Potential Energy & Reference Point

- Potential energy, U, is a scalar
- Need to choose a reference point where $U=0$
  - Choose sea level to be zero altitude
  - What if we define Denver to be zero altitude?
  - Does the difference in altitude change?
- Choose $U=0$ at $i=\infty$ for electric potential

Electric Potential Energy & Reference Point

- Have several charges initially at infinity so $U_i = 0$

$$\Delta U = U_f - U_i = U_f$$

- Move charges close together to state f

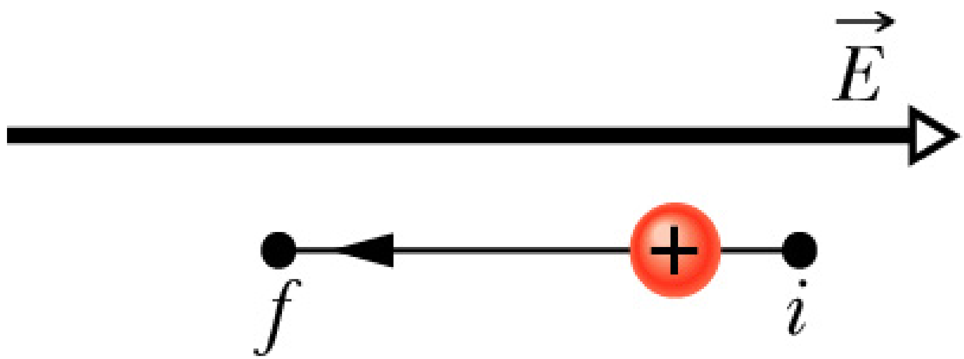
$$\Delta U = -W$$

- W_∞ is work done by force to move particles together from infinity

$$U_f = -W_\infty$$

Electric Potential Energy (Exercise)

- A proton moves from point *i* to point *f* in a uniform electric field.



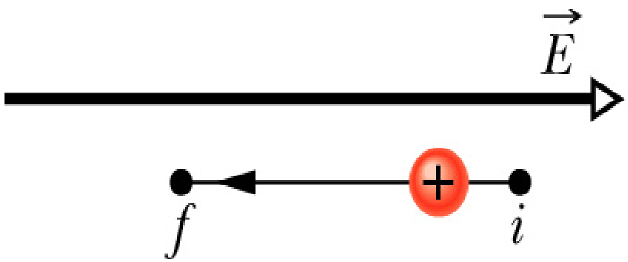
- Does the electric field do positive or negative work on the proton?

Electric Potential Energy (Exercise)

- What is the work done by an electric field?

$$W = \vec{F} \bullet \vec{d}$$

$$\vec{F} = q\vec{E}$$



$$W = q\vec{E} \bullet \vec{d} = qEd\cos\theta$$

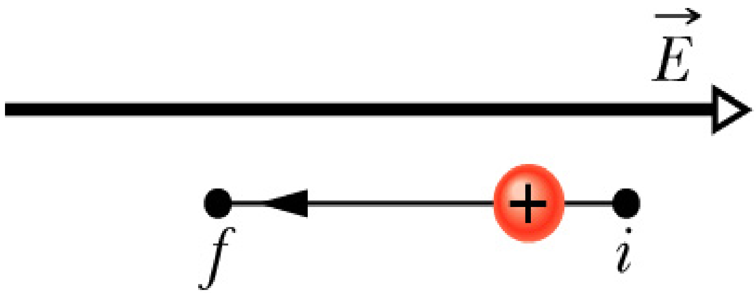
$$W = qEd\cos(180) = -qEd$$

Negative work

Electric Potential Energy (Exercise)

- Does the electric potential energy of the proton increase or decrease?

$$\Delta U = U_f - U_i = -W$$



$$\Delta U = -(-qEd) = qEd$$

Increases

Electric Potential

- Electric potential, *V*, is defined as the electric potential energy, *U*, per unit charge

$$V = \frac{U}{q}$$

- Potential, *V*, is characteristic of the electric field only
  - Unique value at any point in an electric field

Electric Potential

- Electrostatic potential difference, ΔV, between points i and f

$$\Delta V = V_f - V_i = \frac{U_f}{q} - \frac{U_i}{q} = \frac{\Delta U}{q} = -\frac{W}{q}$$

- V is a scalar and can be +, -, or 0
- Using reference point of $U_i=0$ at infinity

$$V = -\frac{W_\infty}{q}$$

Electric Potential

- Important difference between U and V
- Electric Potential Energy, U, is energy of a charged object in an external E field
  - Measured in Joules (J)
- Electric Potential, V, is property of E field
  - Doesn't care if charged object is placed in E field or not
  - Measured in Joules per Coulomb (J/C)

Electric Potential Units

- Define new SI unit for *V* (volt)
- 1 volt = 1 joule per coulomb, V=J/C
- Define *E* field in volts per meter (V/m)

$$E = \frac{F}{q}$$

$$\frac{N}{C} = \left(\frac{N}{C}\right)\left(\frac{V \cdot C}{J}\right)\left(\frac{J}{N \cdot m}\right) = \frac{V}{m}$$

Equipotential Surface

- Equipotential surface - all points are at same electric potential, *V*

$$\Delta V = V_f - V_i = -\frac{W}{q}$$

- $W = 0$ if move between points *i* and *f* which lie on same potential surface
  - True regardless of path taken between points

Equipotential Surfaces

- For paths I and II

$$W = -q\,\Delta V = -q\,(V_1 - V_1) = 0$$

$$W = -q\,\Delta V = -q\,(V_3 - V_3) = 0$$

- For paths III and IV

$$W = -q\Delta V = -q(V_2 - V_1)$$