

# Work and Energy

Ch. 6

- **Work** is defined (in physics) as **force × distance** .
- Work increases the **energy** of an object.
- **Energy** can be converted back to work.
- Therefore, energy and work have the **same unit**:

$$\text{Newton} \times \text{meter} = \text{N m}$$

# Energy

Energy comes in many forms 

Kinetic  
Gravitational  
Electrical  
Thermal  
Solar  
Chemical  
Nuclear ...

That leads to many other energy units:

$\text{N m} = \text{kg m}^2/\text{s}^2$ , from  $F = ma$  and from  
the definition of the force unit Newton:

$\text{N} = \text{kg m}/\text{s}^2$  (the force that accelerates 1 kg by  $1 \text{ m}/\text{s}^2$ ).

Also: Joule (J), Watt-second (Ws):  $\text{N m} = \text{kg m}^2/\text{s}^2 = \text{J} = \text{W s}$

Furthermore: kiloWatt-hours (kWh), electron-Volt (eV), ...

Convert units at: <http://physics.nist.gov/cuu/Constants/energy.html>

# Kinetic Energy (Energy of Motion)

- Work = Force  $\times$  Distance
- An applied force leads to an acceleration ( $F = ma$ ).
- After a certain time, a body is traveling at some velocity  $v$ .
- So the result of the work is a change in the body's velocity from zero to  $v$ .
- Therefore, the kinetic energy depends on the velocity  $v$ .

# Kinetic Energy Formula

The kinetic energy of an object with mass  $m$  is:

$$E_{\text{kin}} = \frac{1}{2} m v^2 \quad v = \text{velocity}$$

# Gravitational energy

- An object in a gravitational field can do work when it falls.
- We might say that there is gravitational energy stored in the object.
- The gravitational energy  $E$  is :

Gravitational force  $F$  x Height difference  $d$

$$F = G \cdot \frac{m_1 \cdot m_2}{d^2}$$

$$E = -G \cdot \frac{m_1 \cdot m_2}{d}$$

# Electric Energy

- Charged particles interact by an electric force that is analogous to the gravitational force.
- The electric force is proportional to the product of two charges  $q_1 \cdot q_2$  (instead of two masses).
- The sign is opposite to gravity: Equal charges repel each other, while equal masses attract.

$$F = -G_e \cdot \frac{q_1 \cdot q_2}{d^2}$$

$$E = G_e \cdot \frac{q_1 \cdot q_2}{d}$$

# Thermal Energy

- Also known as heat.
- The amount of thermal energy stored in an object is proportional to the (absolute) temperature (in degrees Kelvin = K).
- The energy is stored as kinetic energy of the atoms (due to their thermal motion).

# Storing energy

- Energy is neither created nor destroyed, but is just moved around (**energy conservation** law).
- Or more accurately, it changes form.
- Sometimes we say that energy is lost, for example when driving a gas-guzzler. Looking at the energy balance, one finds that in this case chemical energy from the fuel is converted into unwanted thermal energy, not into kinetic energy for moving the car.

# Energy conversion, Efficiency

- In general, one can say that **thermal energy** has **lower quality** than other types of energy, because it cannot be fully converted into other energies.
- Kinetic, gravitational, electrical energy are fully convertible.
- The **energy efficiency** is the **ratio** of fully convertible, **high-quality output energy** over **input energy**.
- There is a **maximum efficiency** for converting thermal energy to high quality energies (mechanical, electrical, ...).

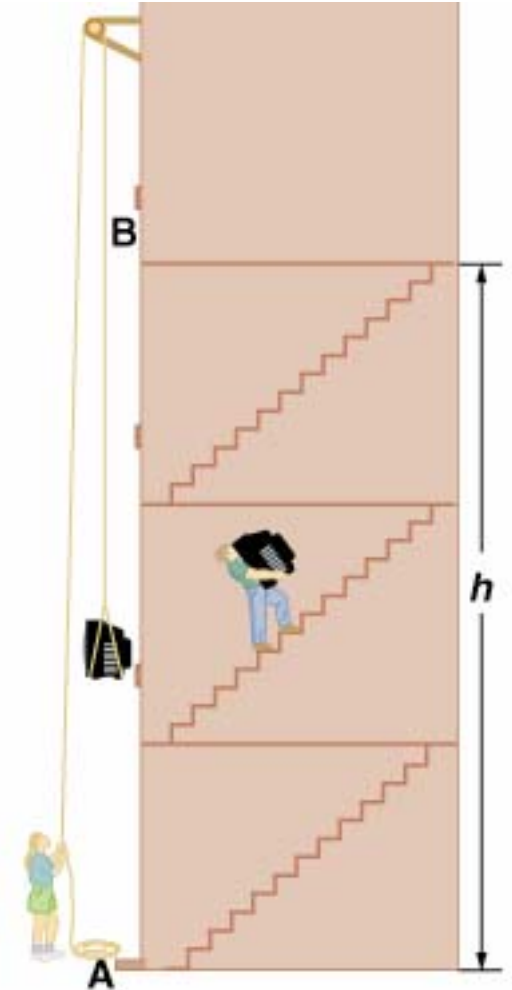
# Work is independent of the path

- Change in gravitational energy:

$$E = F h = m g h$$

$m$  = mass,  $g \cong 10 \text{ m/s}^2$ ,  $h$  = height

- A falling object converts gravitational energy to kinetic energy.
- Work needs to be done on an object to move it up vertically. The work is the same no matter what path is taken.
- If that is not true, the concept of energy gets trickier (in chemistry).



# Power

$$P = \frac{\textit{Work}}{\textit{time}}, \frac{\text{Joules(J)}}{\text{second(s)}} \equiv \text{Watts (W)}$$

Power is the work output (**energy** output) **per second**.

It is measured in Watts.

(1 Horsepower = 750 Watts)

# Power

- Distinguish power from energy:
- A power plant produces power (GigaWatts).
- A light bulb uses power (100 Watt).
- The power company charges us for energy (kWh).
- It does not matter how fast we consume that energy.

# Energy conservation law

- The sum of all types of energy remains constant (is conserved) in a closed system.
- This is also the **first law of thermodynamics**.

# Conservation laws

- Apart from energy conservation, there are other conservation laws, for example for momentum and angular momentum.

$$\text{Momentum} = \text{Velocity} \times \text{Mass}$$

$$\text{Angular Momentum} = \text{Tangential Momentum} \times \text{Radius}$$

# Conservation laws from symmetry

- **Energy conservation** follows from the **invariance** of the laws of physics under **translation in time**.  
(Experiments done yesterday and today give the same result.)
- Likewise, **momentum conservation** is tied to **translation in space**
- ... and **angular momentum conservation** to **rotation in space**.
- Emmy Noether proved a general theorem that ties invariance (symmetry) properties to conservation laws.