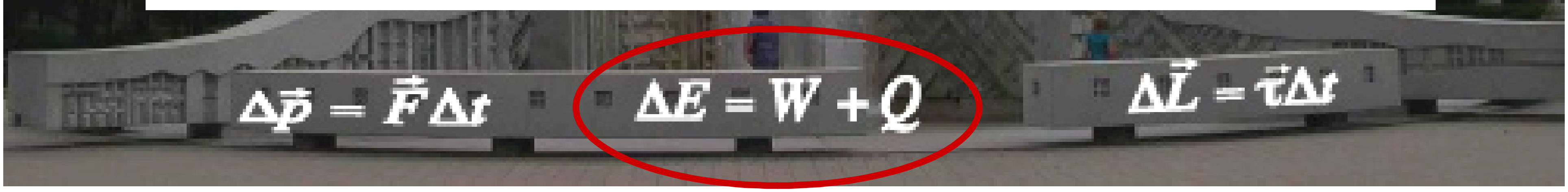
EXAM 1 results

Multiple choice: AVERAGE is 60%
Handgraded part: being graded (at least 1 more week)

Misregistered iClickers

If you see no scores at all on CHIP, take your iClicker to **Prof. Saxena (Rm 176)** ASAP. You must have correct iClicker registered **by Friday afternoon (hard deadline).**

Scores for Lectures 1-9 will be finalized by Tuesday next week.



Lecture 10: **The Energy Principle**

Read 6.1 – 6.7

TODAY

- The Energy Principle
- Energy is Conserved
- Rest Energy and Kinetic Energy
- Work = $\vec{F} \cdot \Delta\vec{r}$

The Energy Principle

$$\boxed{\Delta E_{system} = \underbrace{W_{surr} + Q}_{\text{“cause” (due to interactions)}}}$$

“effect”

* We mean the Work done ON a System by a Force in the Surroundings*

Energy is A Conserved Quantity

Energy is a useful thing to consider because energy can’t be destroyed: it can only change forms.

$$\boxed{\Delta E_{system} + \Delta E_{surroundings} = 0}$$

Energy of a Single Particle System

$$E_{\text{single particle system}} = \gamma mc^2 = \frac{mc^2}{\sqrt{1 - v^2/c^2}}$$

Experimentally, this is the expression that works in a conservation law

Rest energy = mc² $\quad (\mathrm{v} = 0 \;\rightarrow\; \gamma = 1)$

Kinetic energy $\mathrm{K} \equiv \gamma mc^2 - mc^2$

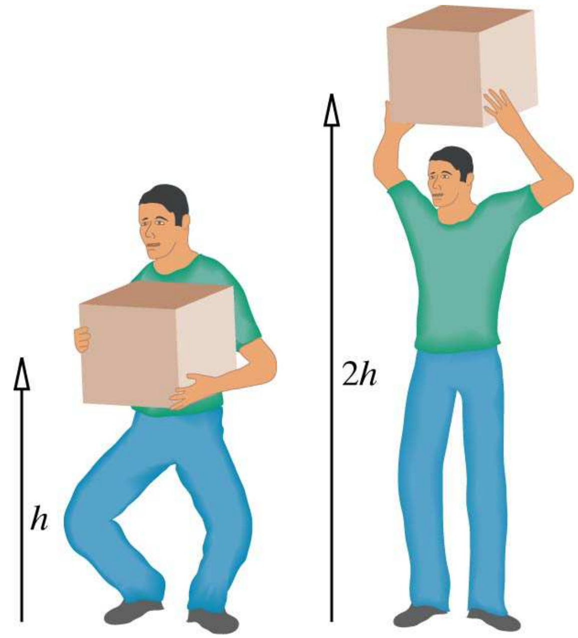
$$K \approx \frac{1}{2}mv^2 \quad \text{for} \quad v/c \ll 1$$

$$E^2 - (pc)^2 = m^2c^4$$

ALWAYS TRUE.
EVERY REFERENCE FRAME.

Energy and Force

It takes twice as much energy to raise a heavy box a distance *2h*, compared to lifting it only *h*. Thus, it is distance that seems to matter, not time.



Does this match your real-world experience?

Energy and Force

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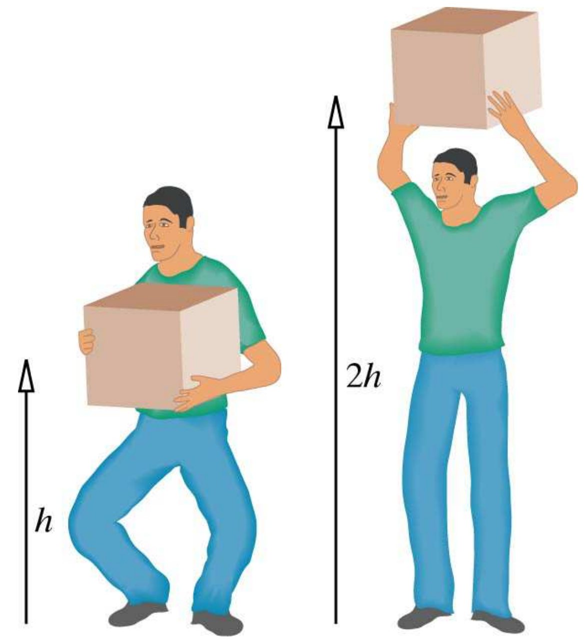


WORK due to mechanical energy transfer:

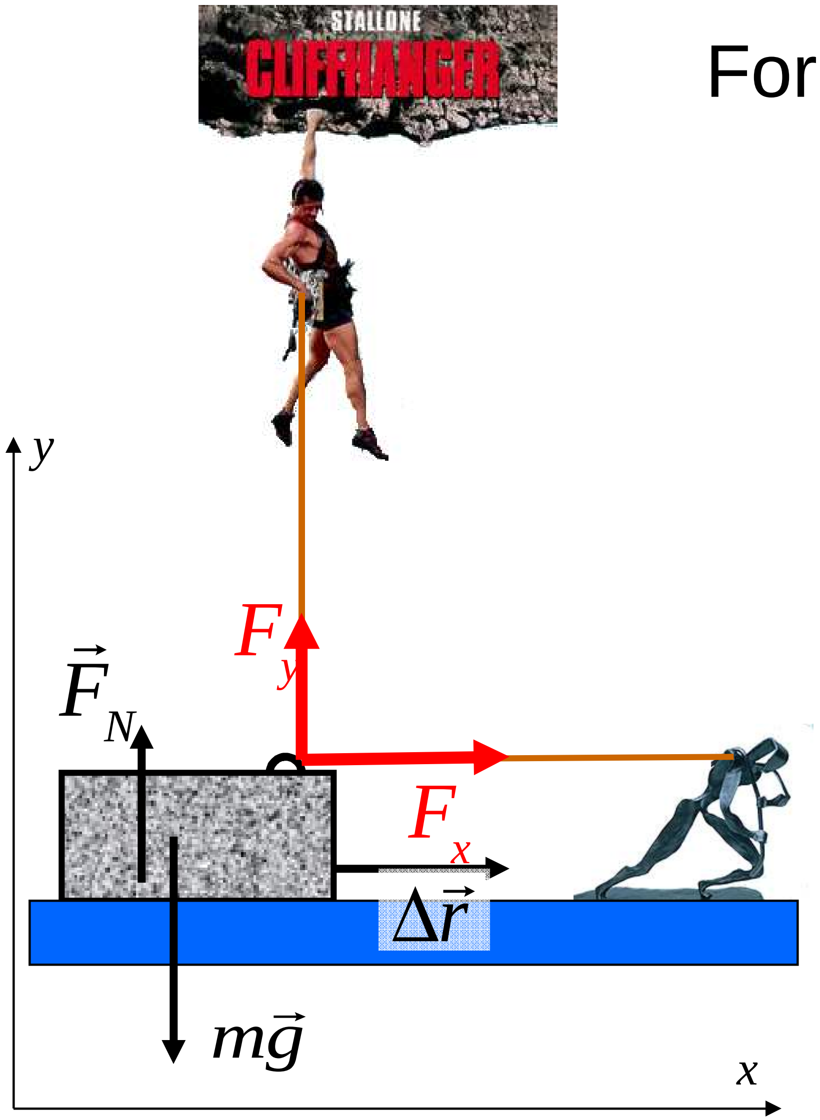
$$W = F_x \Delta x + F_y \Delta y + F_z \Delta z$$

In more general vector notation, this is:

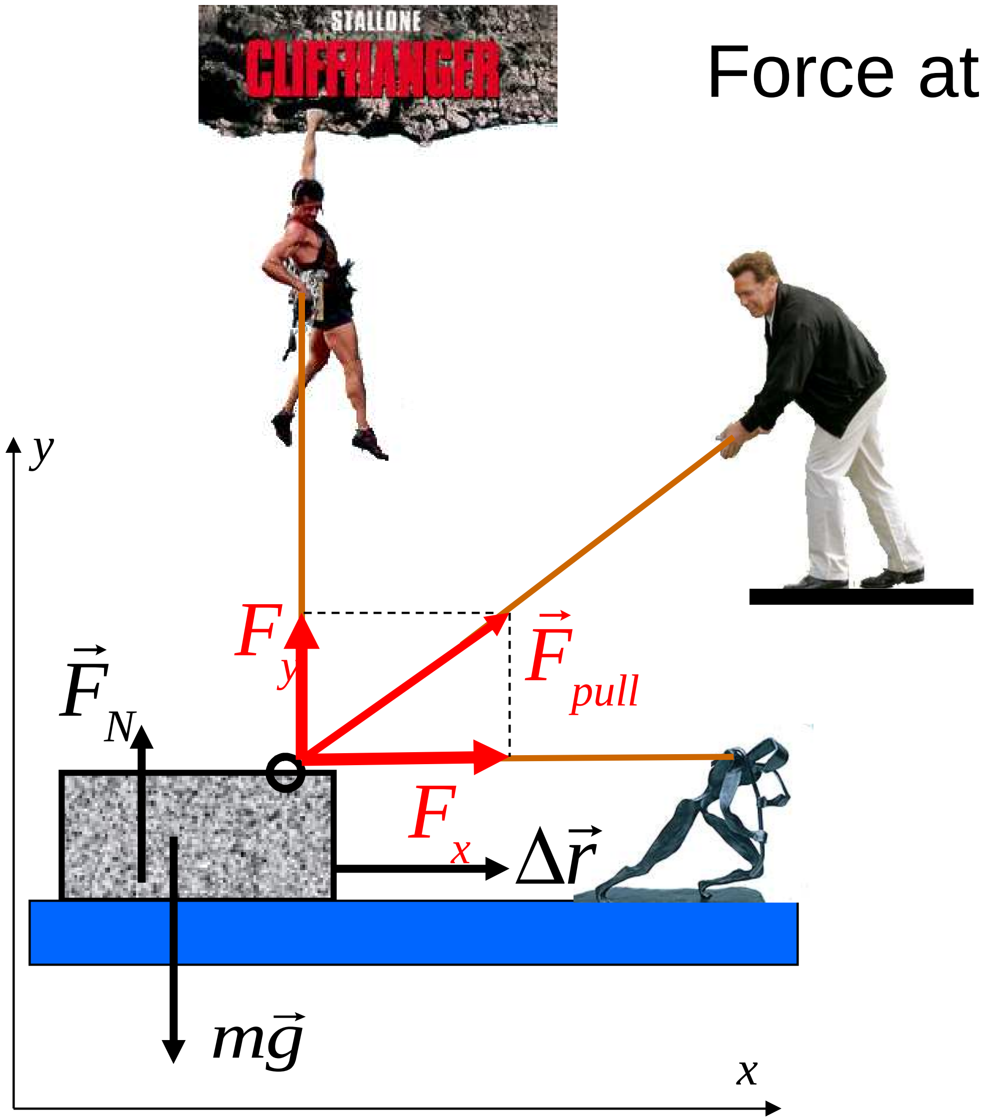
$$W_F = \vec{F} \bullet \Delta \vec{r} = F \Delta r \cos\theta = F_x \Delta r_x + F_y \Delta r_y + F_z \Delta r_z$$

* We mean the Work done ON a System by a Force in the Surroundings*

Force at an angle



Force at an angle



$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

$$\Delta p_y = F_{net,y}\Delta t = 0$$

Only x-component of force "works"!

$$work \sim F_x \Delta r_x$$

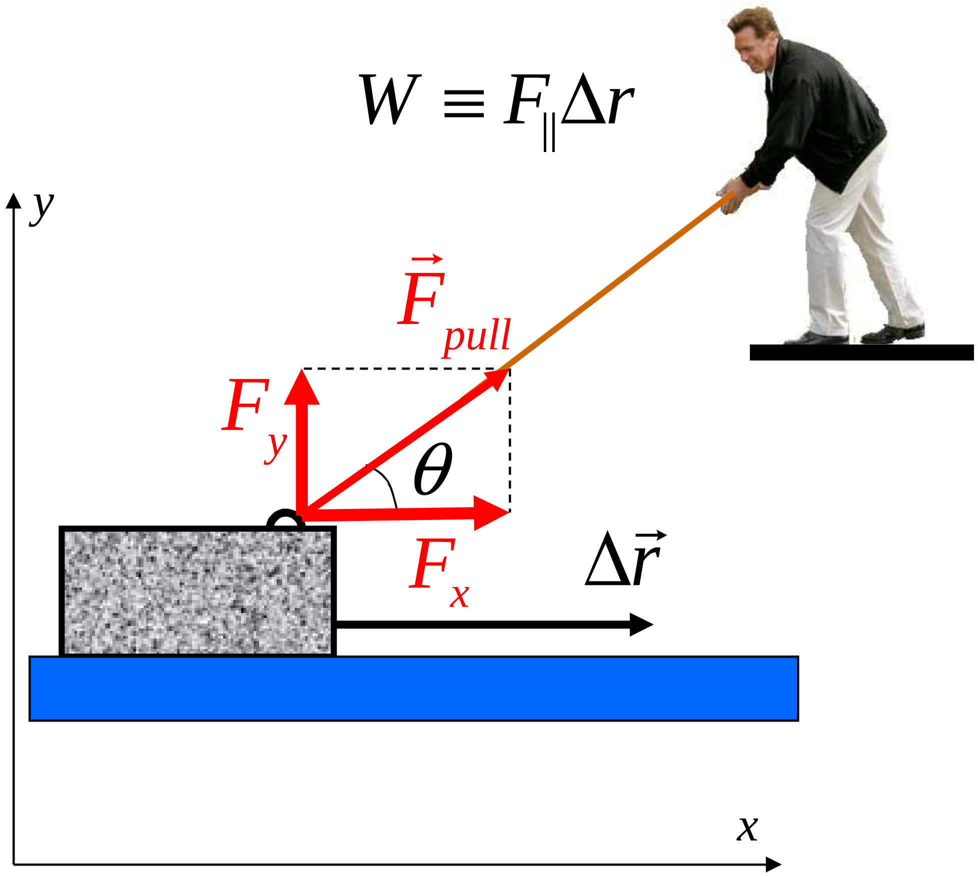
Definition of work

$$W \equiv F_{\|}\Delta r$$

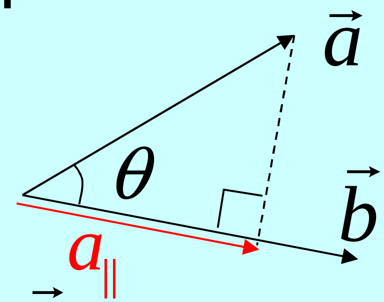
Force component along the path of motion

Work as a dot product

$$W \equiv F_{\parallel} \Delta r$$



Dot product:



$$\vec{a} \cdot \vec{b} \equiv ab\cos\theta = a_{\parallel} b$$

$$\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z$$

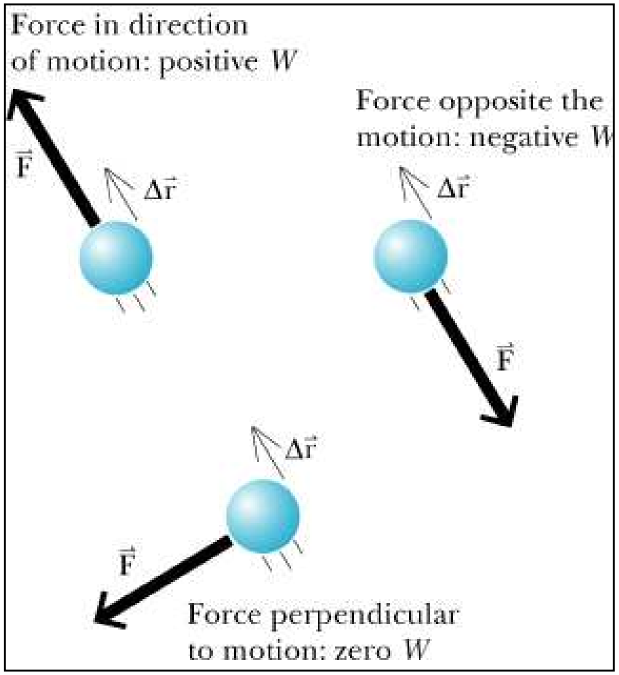
$$W = \vec{F} \cdot \Delta\vec{r}$$

$$W = F \Delta r \cos\theta$$

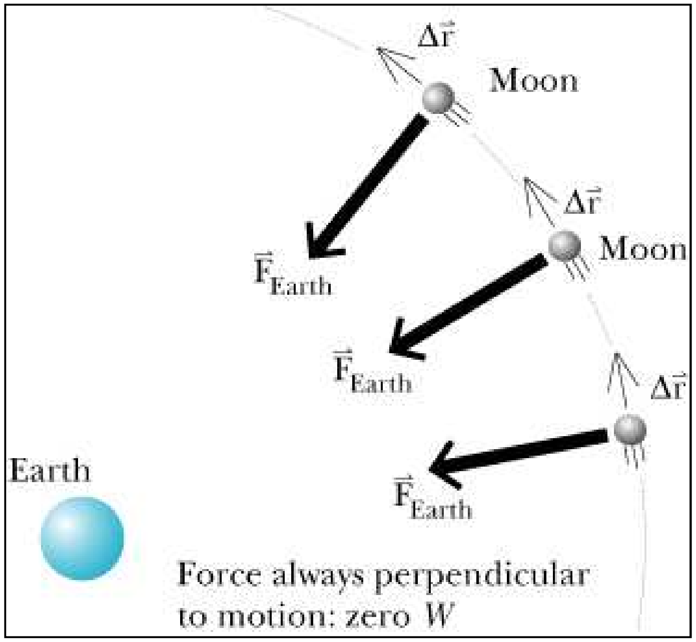
$$W = F_x \Delta r_x + F_y \Delta r_y + F_z \Delta r_z$$

Sign of Work

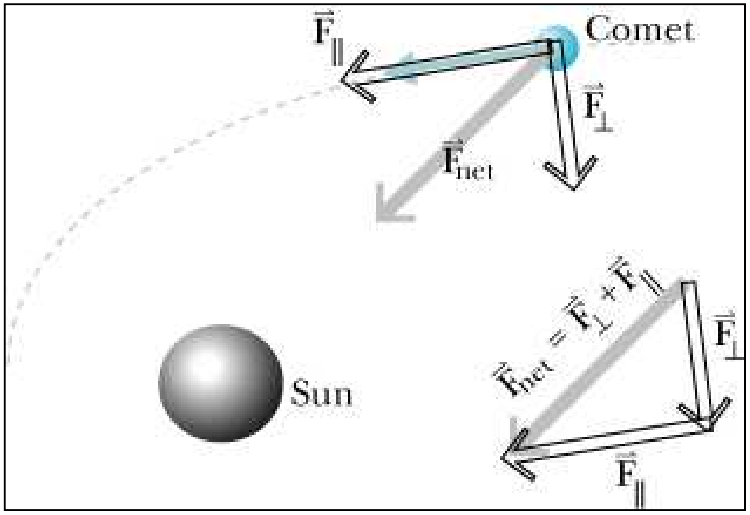
$$W_F = \vec{F} \bullet \Delta\vec{r} = F\Delta r\cos\theta$$
$$= F_x\Delta r_x + F_y\Delta r_y + F_z\Delta r_z$$



Circular orbit

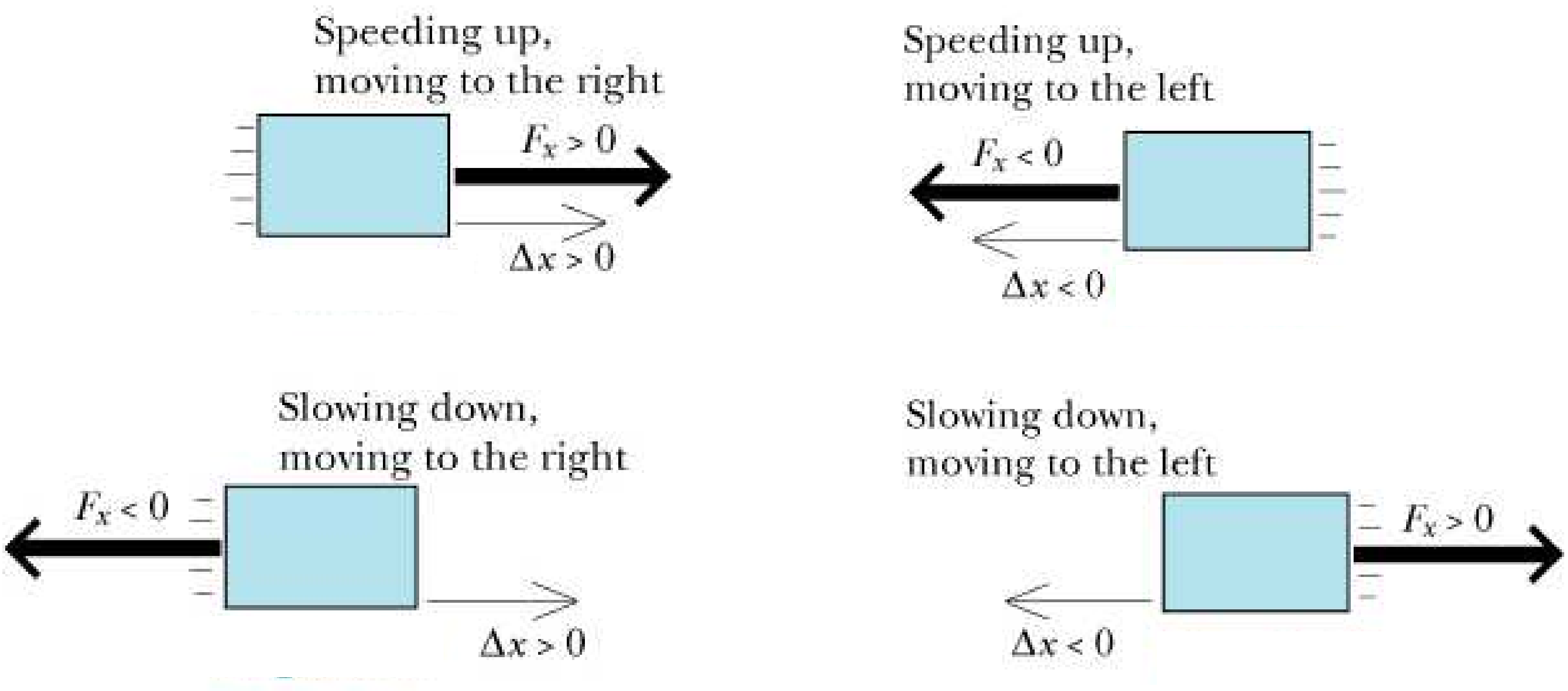


Earth does no work
on the Moon.



Sun does work on comet,
speeding it up.

Game: What's the Sign of the Work?



* We mean the Work done ON a System by a Force in the Surroundings*

What Causes The Energy of A System to Change?

Reminder: Momentum Principle

Interactions: some $P_{surroundings}$ transforms into P_{system}.

Forces transfer momentum from one object to another.

Energy can be transferred from the surroundings to a system in two ways:

- Energy transfer by **<u>heat</u>** (next chapter)
- Energy transfer by **<u>work</u>**

set = 0 for now

$$\Delta E_{system} = W_{surr} + \cancel{Q}$$

Example

You hold a ball of mass 0.5 kg at rest in your hand and throw it forward so that it leaves your hand at speed 20 m/s. How much work did you do on the ball?

$$E_{sys,f} = E_{sys,i} + W_{surr}$$

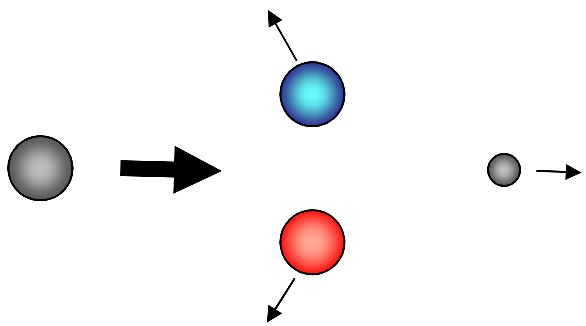
$$\left(\cancel{mc^2} + K_f\right) = \left(\cancel{mc^2} + K_i\right) + W_{surr}$$

Rest energy did not change

$$W_{surr} = K_f - K_i = \Delta K = \frac{mv_f^2}{2} - \frac{mv_i^2}{2}$$

$$W_{surr} = 100J$$

Change of identity – change of rest energy



$$n \to p^+ + e^- + \bar{\nu}$$

Neutron decay

How much kinetic energy do the products have?

$$E_f = E_i + \underset{\uparrow =0}{W}$$

$$\left(m_p c^2 + K_p\right) + \left(m_e c^2 + K_e\right) + \left(K_{\bar{\nu}}\right) = m_n c^2$$

$$K_p + K_e + K_{\bar{\nu}} = \underbrace{\left(m_n - m_p - m_e\right)}_{>0} c^2$$

Mass of products is smaller than mass of reactant!

Mass is converted into kinetic energy

$$K_p + K_e + K_{\bar{\nu}} = m_n c^2 - m_p c^2 - m_e c^2$$

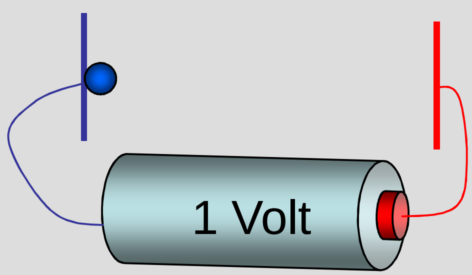
$$= 939.6MeV - 938.3MeV - 0.511MeV$$

$$\boxed{K_p + K_p + K_{\bar{\nu}} = 0.8MeV}$$

An electron-volt (eV) unit:

1 eV = 1.6×10^{-19} J

1 MeV = 10^6 eV



WHAT WE DID TODAY

- The Energy Principle
- Energy is Conserved
- Rest Energy and Kinetic Energy
- Work = $\vec{F} \cdot \Delta\vec{r}$