Today

- Force & Acceleration
- Work and Energy
- Forms of Energy
- Power

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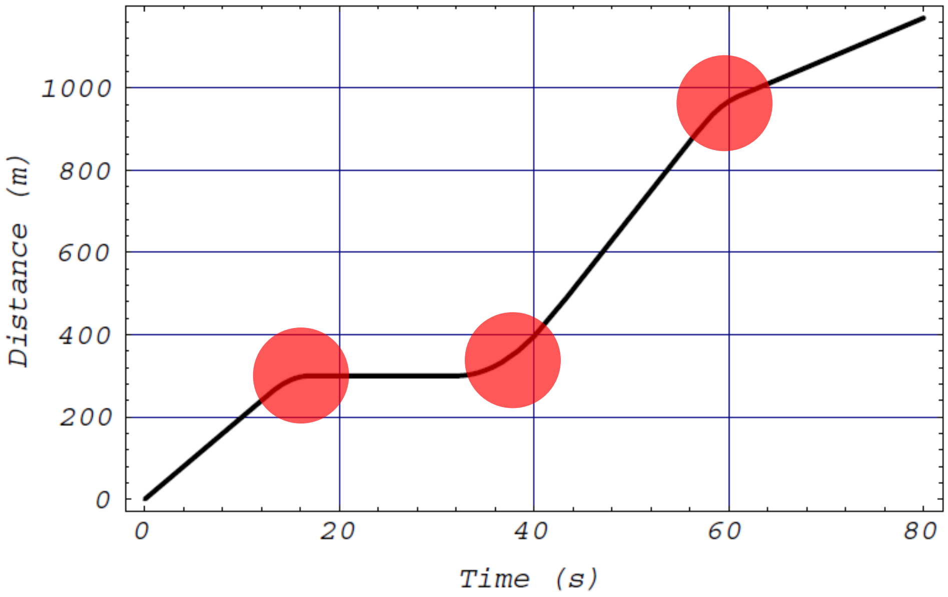
Force & Acceleration

Review: Acceleration



- Where does the car accelerate?

→ Look for kinks in the slopes

Review: Acceleration

- *Acceleration:* is the rate of change of velocity.

$$\vec{a} = \text{acceleration} = \frac{\text{change in velocity}}{\text{time to make the change}}$$

$$\text{change in velocity} = \vec{v}_2 - \vec{v}_1 \equiv \Delta\vec{v}$$

$$\text{time to make change} = t_2 - t_1 \equiv \Delta t$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

- For the same time interval, Δt, the larger the change in velocity, the larger the acceleration.
- For the same change in velocity, the smaller the time interval the larger the acceleration.
  (ex. Sudden break at stop light.)

Review: Force

- Force designates an "external influence" (i.e. an *action*) on an object.
- Force is a vector, having a magnitude and a direction.
- Newton's Second Law:

$$\vec{F}_{net} = \text{net force} = m\vec{a}$$

- An acceleration changes the motion (i.e. velocity)

Work and Energy

Work: Moving an object by applying a Force

- Work has a strict definition involving the force along the direction of displacement and the displacement.

- No motion…

… no work

- No force…

(along direction of displacement)

… no work

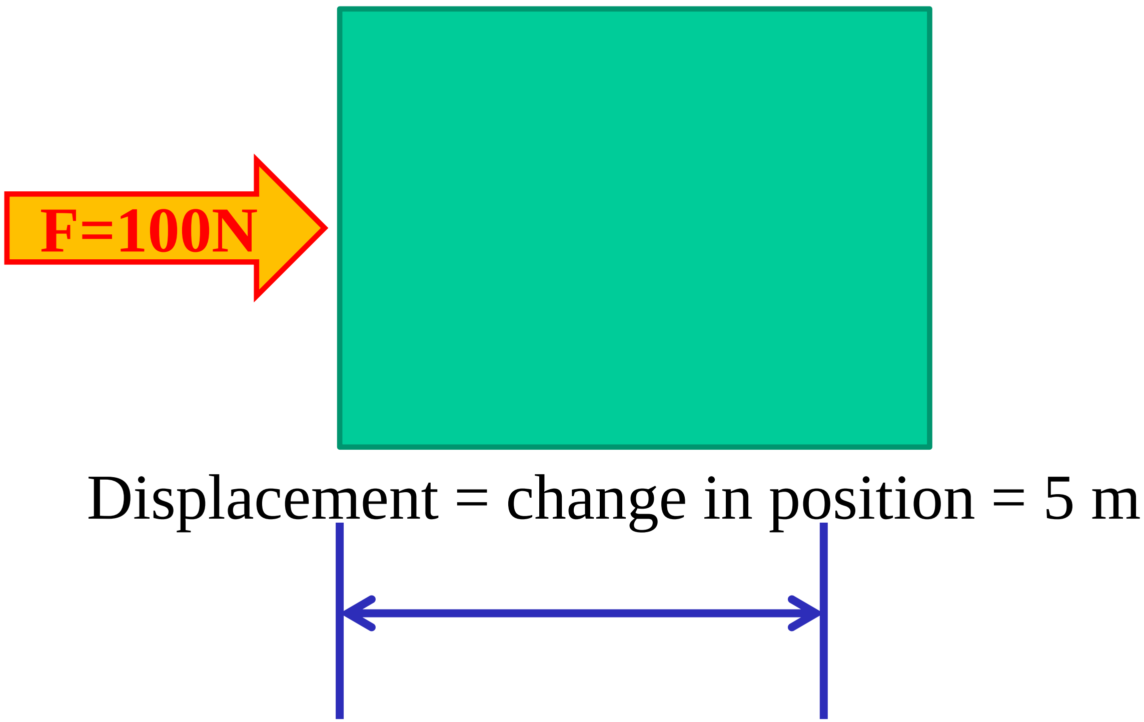
Work: definition

- Work = Force × Displacement
- Force and Displacement are vectors and Work is a scalar. We call such a product a “scalar product between two vectors”.
- The SI unit of Work is the Joule (J).

  1 Joule = (1 Newton)×(1 meter)

Work: example

- Work = Force × Displacement



$F = 100\ N$

$d = 5\ m$

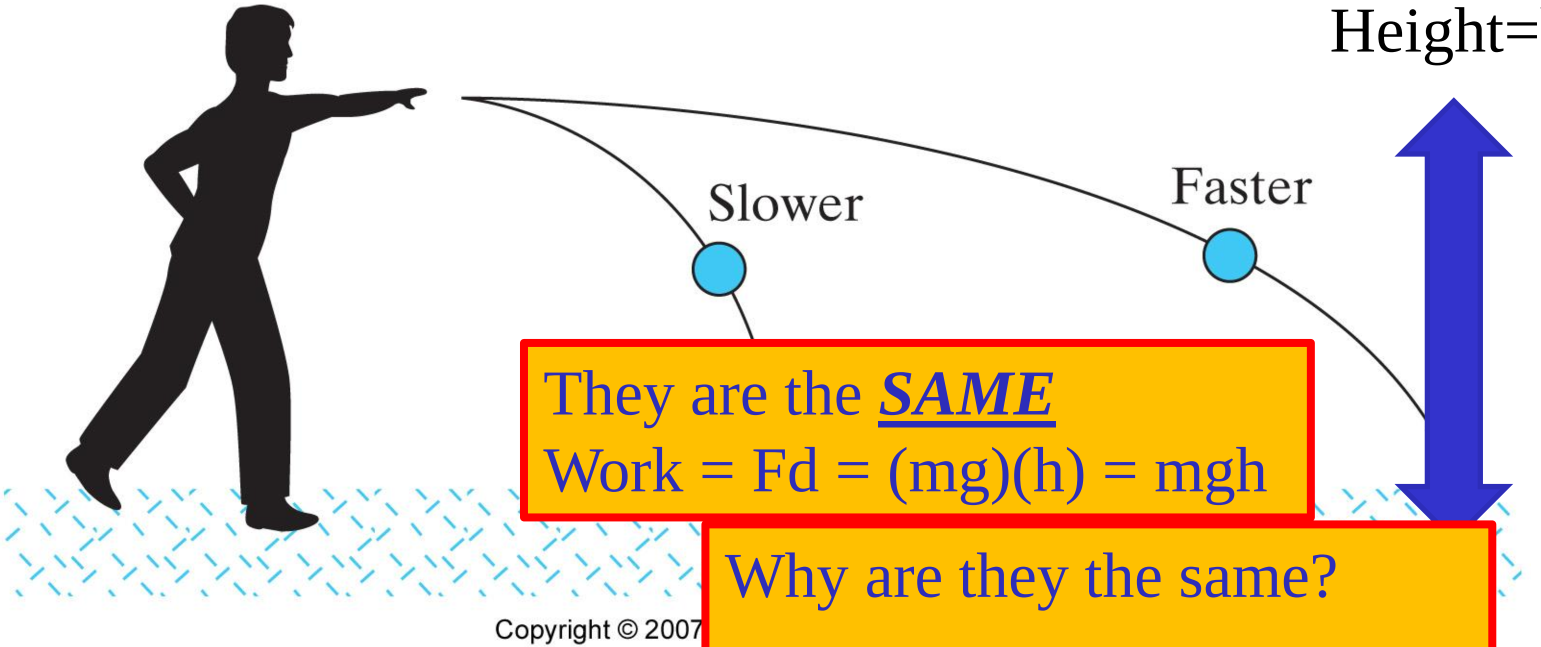
$W = Fd$

$W = (100\ N)(5\ m)$

$W = 500$ Joules (J)

Work: example

- Is the Work done by gravity the same or different between these two examples?



They are the ***SAME***
Work = Fd = (mg)(h) = mgh

Why are they the same?

Only Displacement along the direction of the Force counts!

- Force = Gravity = mg

Work and Energy

- The work exerted on a system enables to accumulate energy or to change energy from one form to another.

The work against the tension force of the bow and string resulted in the accumulation of “potential” energy. This potential energy is ready to be converted into “kinetic” energy.

Forms of Energy

Energy

- Energy is the ability to do work.
- You must have energy to accomplish work.

- Unit of energy is the Joule (J) (same as work).
- In terms of the basic SI units we have:

$$1\text{ J} = (1\text{ N})\times(1\text{ m}) = (1\text{ kg m/s}^2)\times(1\text{ m})$$

$$= 1\text{ kg m}^2/\text{s}^2$$

Other units

- 1 Calorie = 1 kcal = 4184 J

- A Snickers bar contains 280 Calorie. How many Joules is this?

A) 280 J

B) 4184 J = 4.184 kJ

C) 1.172×10^6 J = 1.172 MJ

D) 1.172 J

Fundamental forms of energy

- Energy comes in two main forms
  - Kinetic (KE) – energy of motion
  - Potential (PE) – energy of position

- There are many variants of these two main types (e.g. thermal, chemical, nuclear,…) which, at the fundamental (elementary) level, reduce to these two types.

Examples

- ***Potential energy***: energy of an object due to its position relative to some "source"

    - ***Gravitational energy***: energy associated with an object raised at some distance from the Earth (or other mass)

    - ***Elastic energy***: energy of a stretched or deformed object

    - ***Electromagnetic energy:*** energy associated with electric and magnetic fields

More examples

- ***Kinetic energy***: energy of motion
- ***Thermal energy***: energy in the form of heat due to the Random microscopic motion of atoms and molecules
- ***Radiant energy:*** energy of electromagnetic waves such as light, infrared, and X-rays
- ***Chemical energy:*** energy involved in chemical reactions
- ***Nuclear energy:*** energy involved in nuclear reactions

Kinetic energy

- Any mass in motion (i.e. with some velocity) has “kinetic energy”

$$KE = \frac{1}{2}mv^2$$

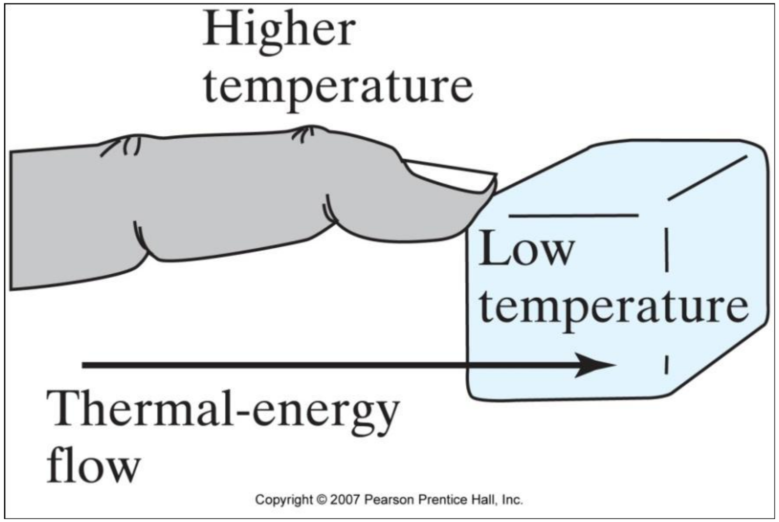
m – mass; v – velocity

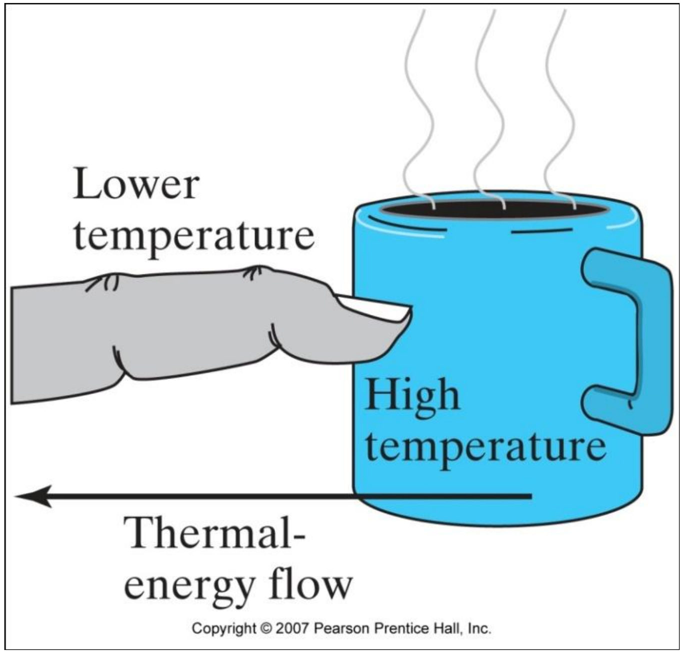
- Example: a car with twice the velocity of a truck but 4 times smaller mass has the same KE as the truck.

Thermal energy

What happens if you put a cold object in contact with a warm object?

The cold object warms up while the warm object cools down.





Potential energy

- Energy of an object due to its position relative to some source or due to deformation.

- Potential gravitational energy near the Earth surface:

$$PE = mgh$$

m – mass (kg)
g – gravitational acceleration (m/s^2)
h – height relative to a reference level (m)

Examples

- A mass of 1.0 kg is raised 1.0 m. How much work was done?

$W = \Delta PE = mgh$ = 1.0 kg x 9.81 m/s^2 x 1.0 m = 9.81 J

- A 90.0 kg person walks up 6 m vertically. How much did his/her potential energy increase?

ΔPE = 90.0 kg x 9.81 m/s^2 x 6 m = 5.29 kJ

Mass energy

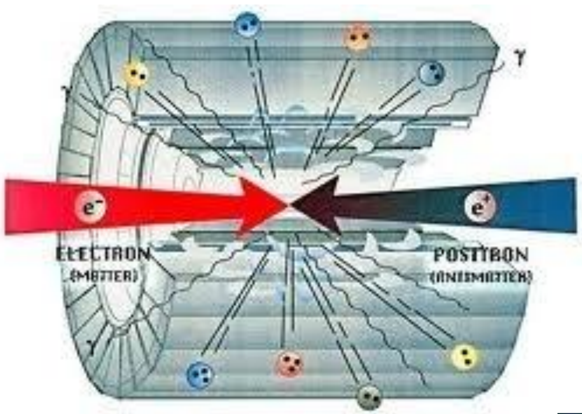
- Einstein's Energy-mass relation:

$$E = mc^2$$

$$c - \text{speed of light}$$

- The effect of the mass energy is easier evidenced in processes where the kinetic energies are comparable to the mass energies (ex. particles at high velocities).

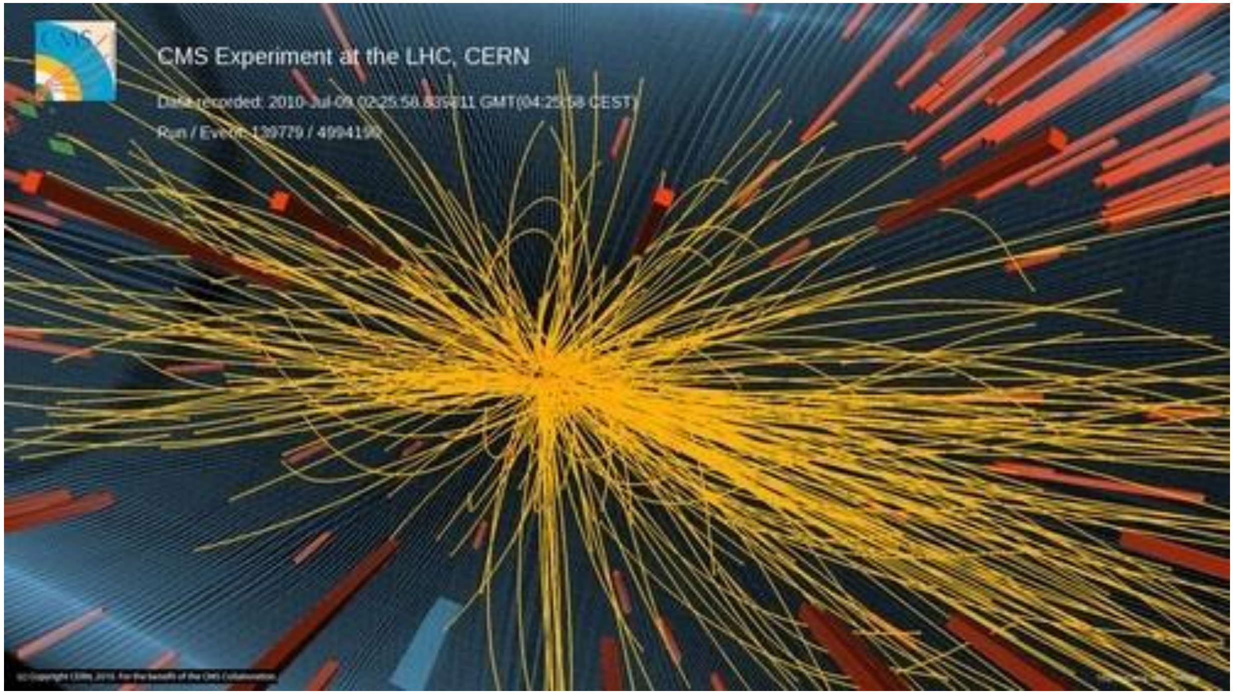
Converting kinetic into mass energy



electron-positron collision

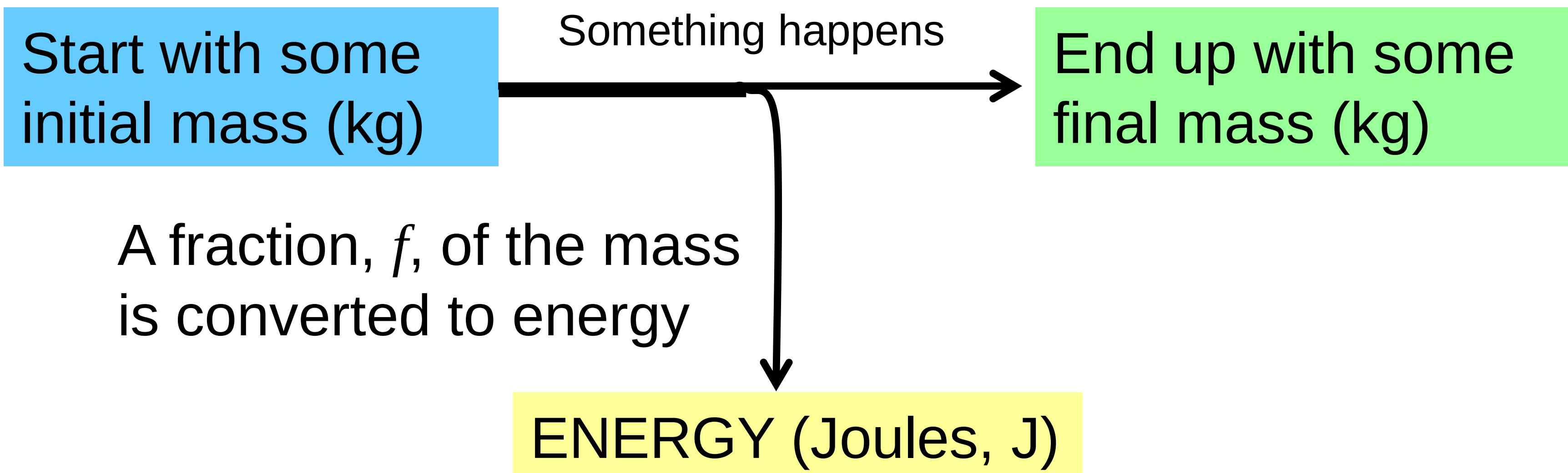
(colliding beams have kinetic energy)

proton-proton collision



Mass energy conversion

A scheme of a chemical reaction:



The amount of energy is $E = m_{converted}\, c^2$

$m_{converted}$ = (Initial mass) x fraction

Fractions of converted energy

- The fraction of mass converted to energy depends on the kind of reaction. In a chemical reaction, only a small fraction of mass is actually converted.

Reaction	Fraction	Example
Matter-Antimatter Annihilation	1	In astrophysical explosive environments and at particle accelerators
Fusion	0.007	Power source of the Sun
Fission	0.001	Nuclear power plant
Chemical	$1x10^{-10}$	Burning coal
Mechanical	$1x10^{-15}$	Compressing a spring

Power

Power

- Power is the rate at which work is being done.

$$\text{Power} = \frac{\text{work done}}{\text{time to do it}}$$

- Unit of power is the joule per second (J/s)
  - This is also called the watt (W)

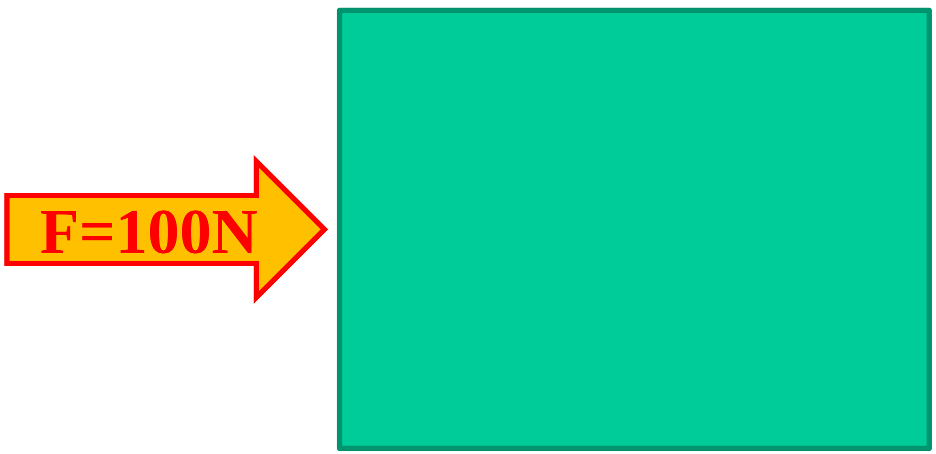
Appliance	Power (W)
Cooking range	12,000
Clothes dryer	5,000
Water heater	4,500
Microwave oven	1,400
Toaster	1,200
Color TV	350
Incandescent Light bulb	60

Power: example

$$\text{Power} = \frac{\text{work done}}{\text{time to do it}} = \frac{(500\text{ J})}{(50\text{ s})} = 10\text{ W}$$

F=100 N
d = 5 m

W=Fd



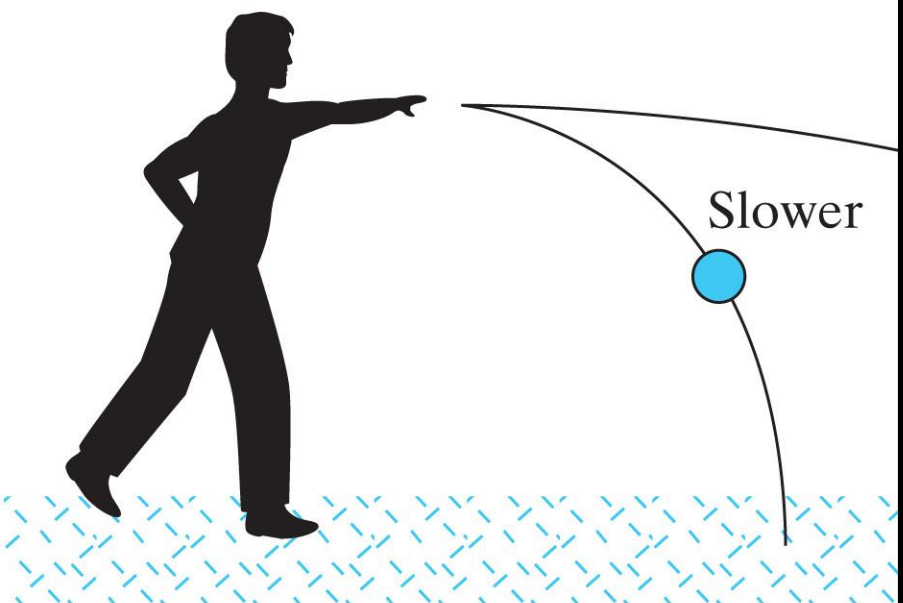
Displacement = change in position = 5 m

time = 50 seconds

W=(100 N)(5 m)
W=500 Joules (J)

Power: example

$$\text{Power} = \frac{\text{work done}}{\text{time to do it}}$$



Thrown baseball

mass=0.150 kg g=9.8 m/s^2

height=2.0 m

time = 0.65 s

W=mgh

W=(0.150 kg)(9.8 m/s^2)(2 m)

W=2.94 J

Power = (2.94 J)/(0.65 s)

Power = 4.5 W

- Force = Gravity = mg

Work = Fd = (mg)(h) = mgh

Energy

- Energy exists in many forms with the potential to do work.
- Energy is converted from one form to another
- The total Energy is conserved!!