NEWTON'S LAWS OF MOTION

Fundamentals of Physics

NEWTON'S FIRST LAW

Law of Inertia:

An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

REAL WORLD EXAMPLES

- Blood rushes from your head to your feet when quickly stopping on a descending elevator.
- A brick is broken painlessly over a person’s hand with a hammer.
- Headrests are installed in cars to prevent whiplash injuries during rear-end collisions.
- While riding a bicycle, you fly forward off the bike when hitting an object that stops the motion of the bicycle.
- Coffee spills in a car when accelerating or decelerating quickly.

NEWTON'S SECOND LAW

Law of Acceleration:

The acceleration produced by a net force on an object is directly proportional to the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

$$a = \frac{F}{m}$$

As **force** increases, **acceleration**

As **mass** increases, **acceleration**

$$a = \frac{F}{m}$$

As **force** increases, **acceleration** increases

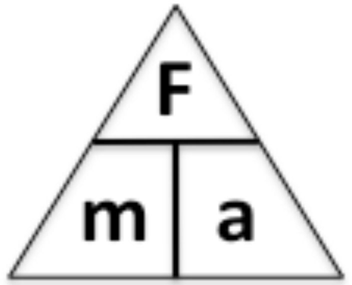
As **mass** increases, **acceleration**

$$a = \frac{F}{m}$$

As **force** increases, **acceleration** increases

As **mass** increases, **acceleration** decreases

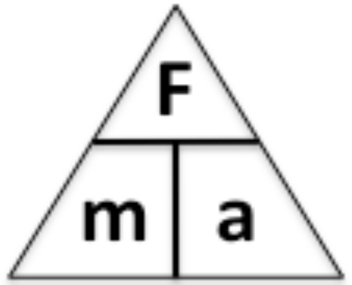
How much force is required to accelerate a 50 kg object 5 m/s^2?



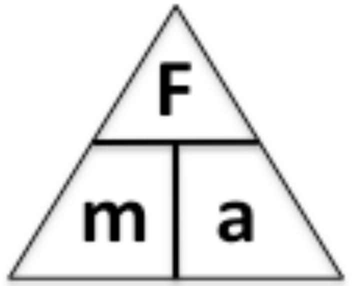
$$\boxed{F = ma = (50\ kg)(5\ m/s^2) = 250\ N}$$

What is the acceleration of a 25 kg object if pushed with a force of 100 N?

$$\boxed{a = F\ /\ m = (100\ N)\ /\ (25\ kg) = 4\ m/s^2}$$



What is the mass of an object that is accelerating at 3 m/s^2 with a force of 60 N applied?



$$\boxed{m = F\ /\ a = (60\ N)\ /\ (3\ m/s^2) = 20\ kg}$$

How much force is required to accelerate a 50 kg object 5 m/s²?

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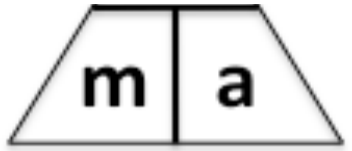

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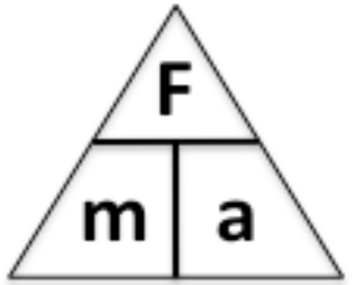

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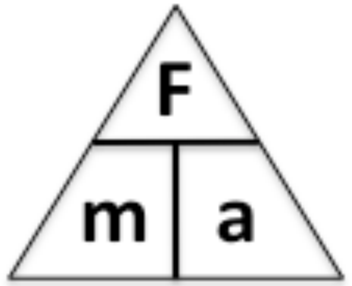

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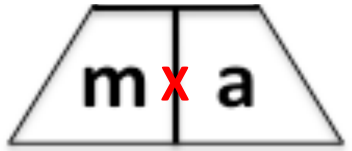

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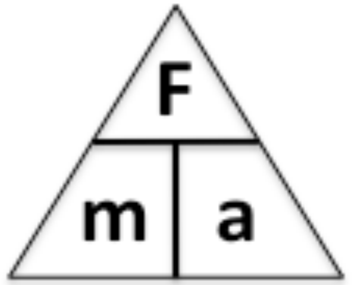

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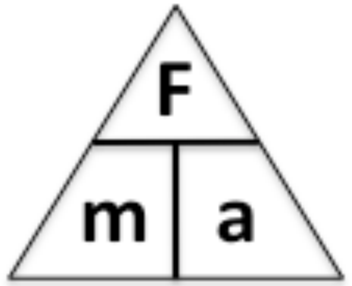

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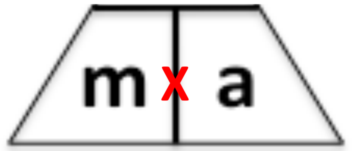

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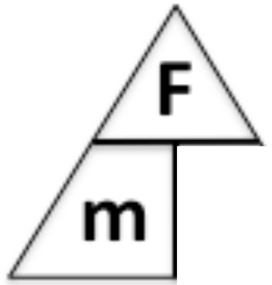

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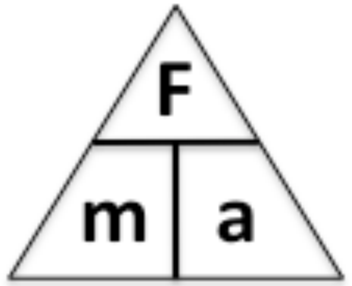

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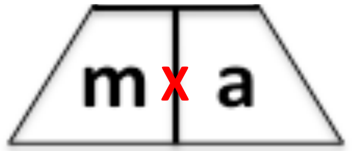

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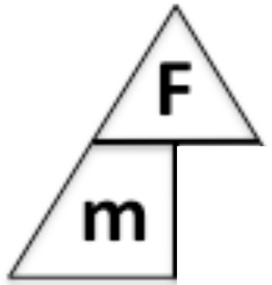

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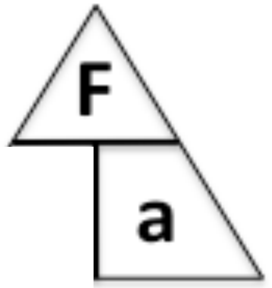

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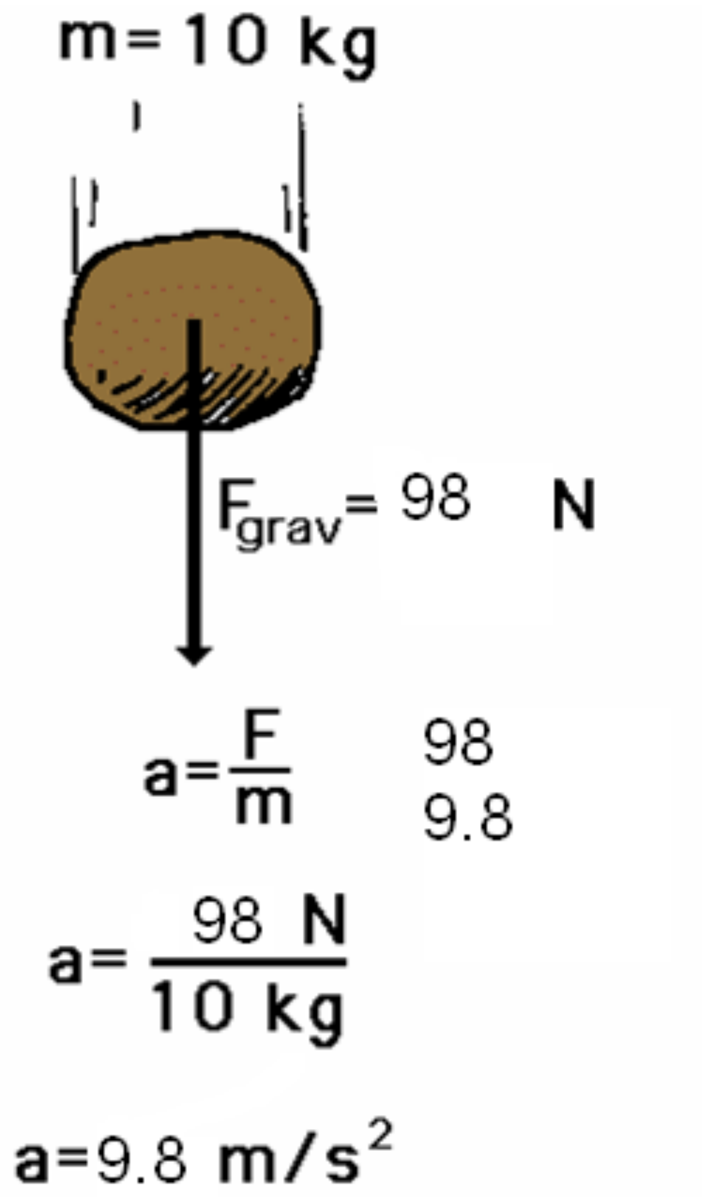
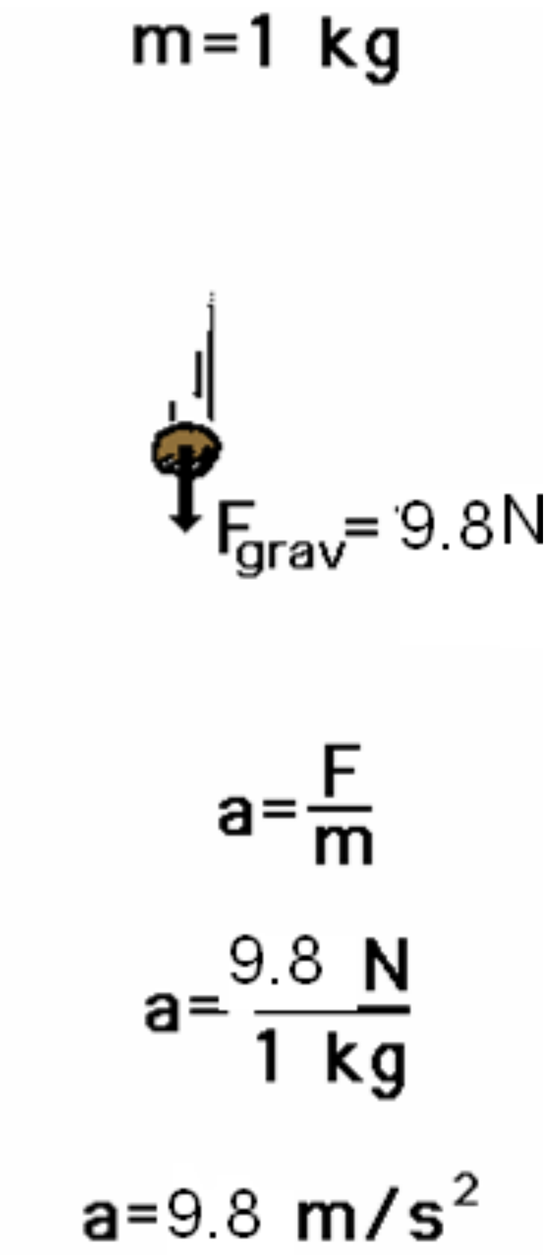


The ratio of force to mass (**F/m**) always equals g in free fall!

(This is why all objects, regardless of mass, hit the ground at the same time when air resistance is negligible.)



In a **vacuum**, a feather and a hammer will hit the ground at the same time when dropped from the same height!

g

g

https://www.youtube.com/watch?v=5C5_dOEyAfk

FORCES

Force is a push or pull on an object.

Contact forces

Action-at-a-distance forces

Forces always come in pairs!

NEWTON'S THIRD LAW

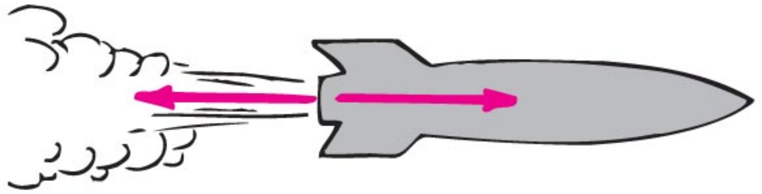
Law of Action-Reaction:

Whenever one object exerts a force on a second object, the second object exerts an **equal and opposite** force on the first.

REAL WORLD EXAMPLES

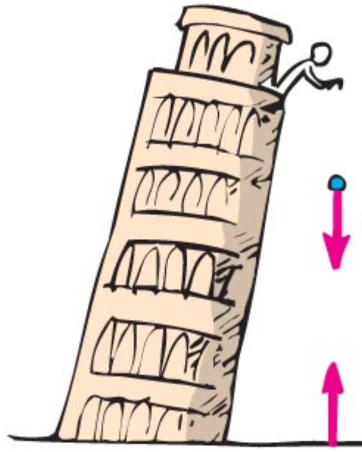
Action: tire pushes on road Reaction: road pushes on tire

$$F_{\text{on road}} = F_{\text{on tire}}$$



Action: rocket pushes on gas Reaction: gas pushes on rocket

$$F_{\text{on gas}} = F_{\text{on rocket}}$$



Action: Earth pulls on ball

Reaction: ball pulls on Earth

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$m_{\text{ball}} a_{\text{ball}} = m_{\text{Earth}} a_{\text{Earth}}$$

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$\underbrace{m_{\text{ball}}}_{\text{very small}} a_{\text{ball}} = m_{\text{Earth}} \underbrace{a_{\text{Earth}}}_{\text{very small}}$$

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$m_{\text{ball}} a_{\text{ball}} = m_{\text{Earth}} a_{\text{Earth}}$$

very small

very large

very small

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$m_{\text{ball}}a_{\text{ball}} = m_{\text{Earth}}a_{\text{Earth}}$$

very small | very large | very large | very small

$$F_{\text{on Earth}} = F_{\text{on ball}}$$

$$m_{\text{ball}}a_{\text{ball}} = m_{\text{Earth}}a_{\text{Earth}}$$

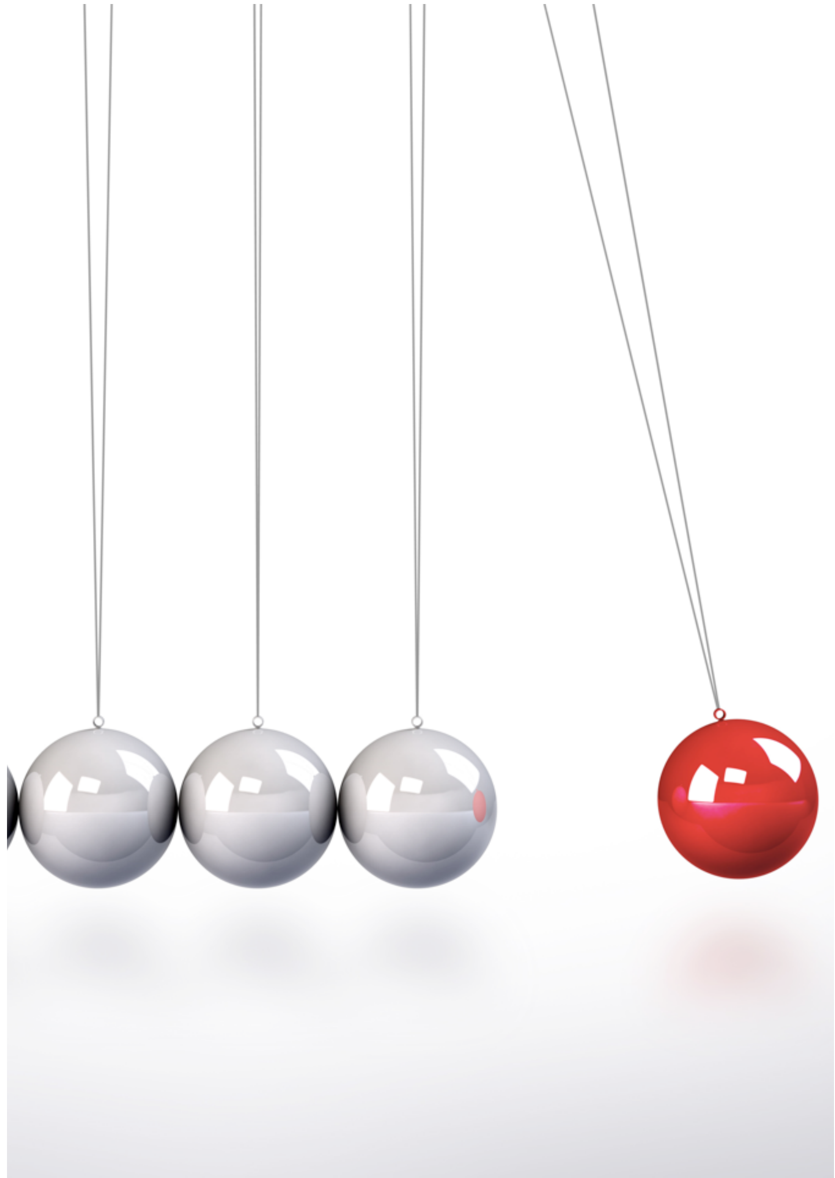
very small | very large | very large | very small

Acceleration balances the equation!

MOMENTUM AND ENERGY

Fundamentals of Physics

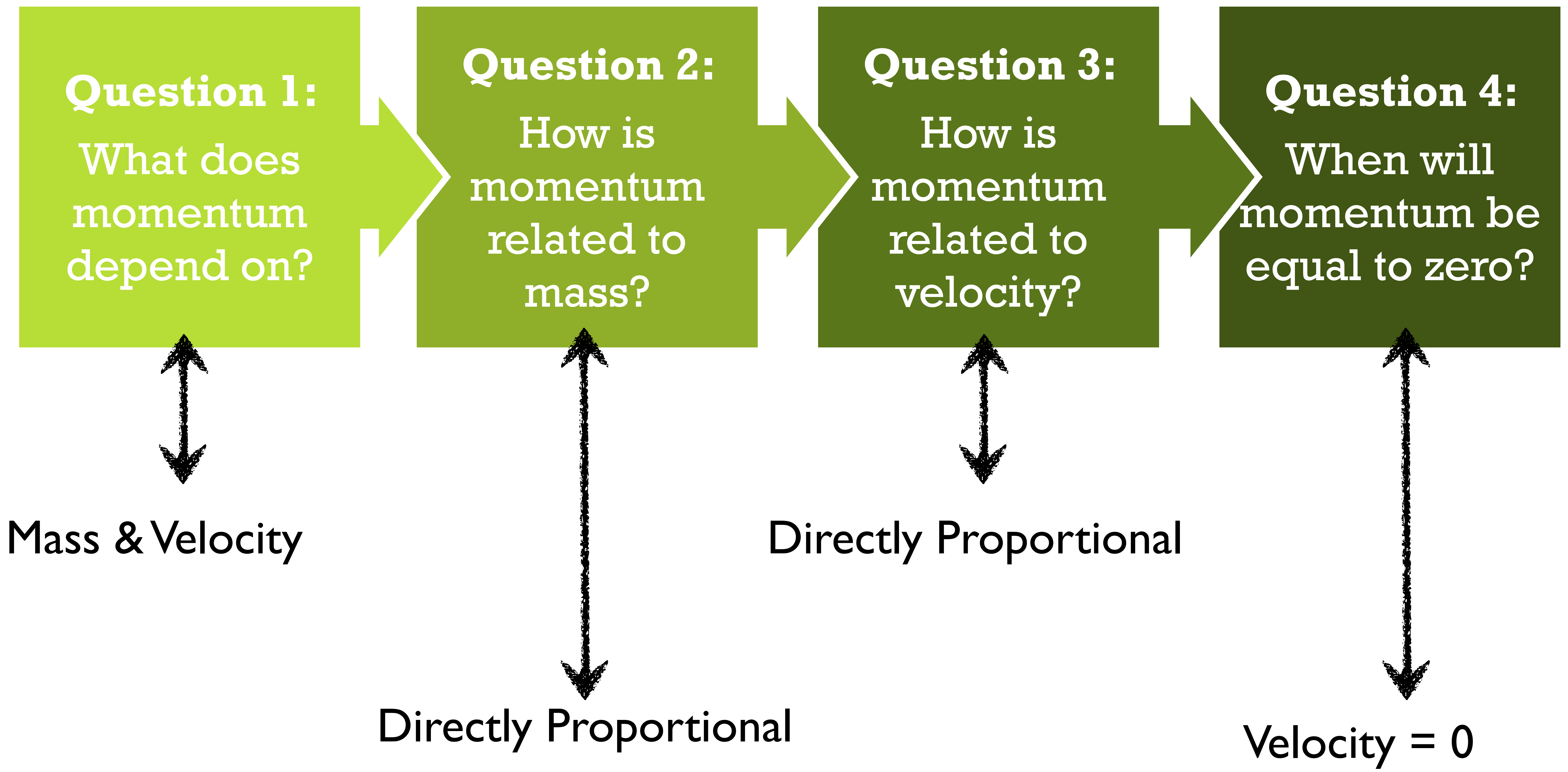
MOMENTUM



The quantity of motion of a moving body.

$$p = mv$$

p = momentum (kgm/s) **m** = mass (kg) **v** = velocity (m/s)



Question 1:
What does momentum depend on?
Question 2:
How is momentum related to mass?
Question 3:
How is momentum related to velocity?
Question 4:
When will momentum be equal to zero?
Mass & Velocity
Directly Proportional
Directly Proportional
Velocity = 0

How much momentum does a truck with a mass of 10,000 kg have if it is moving at 10 m/s?

$$p = mv$$

$$p = (10{,}000\ \text{kg})(10\ \text{m/s})$$

$$p = 100{,}000\ \text{kgm/s}$$

Momentum is **directly proportional** to mass

p increases as **m** increases

and **directly proportional** to velocity

p increases as **v** increases

Physically, a more massive object is harder to stop. An object moving faster is harder to stop. A massive object moving quickly is REALLY hard to stop!

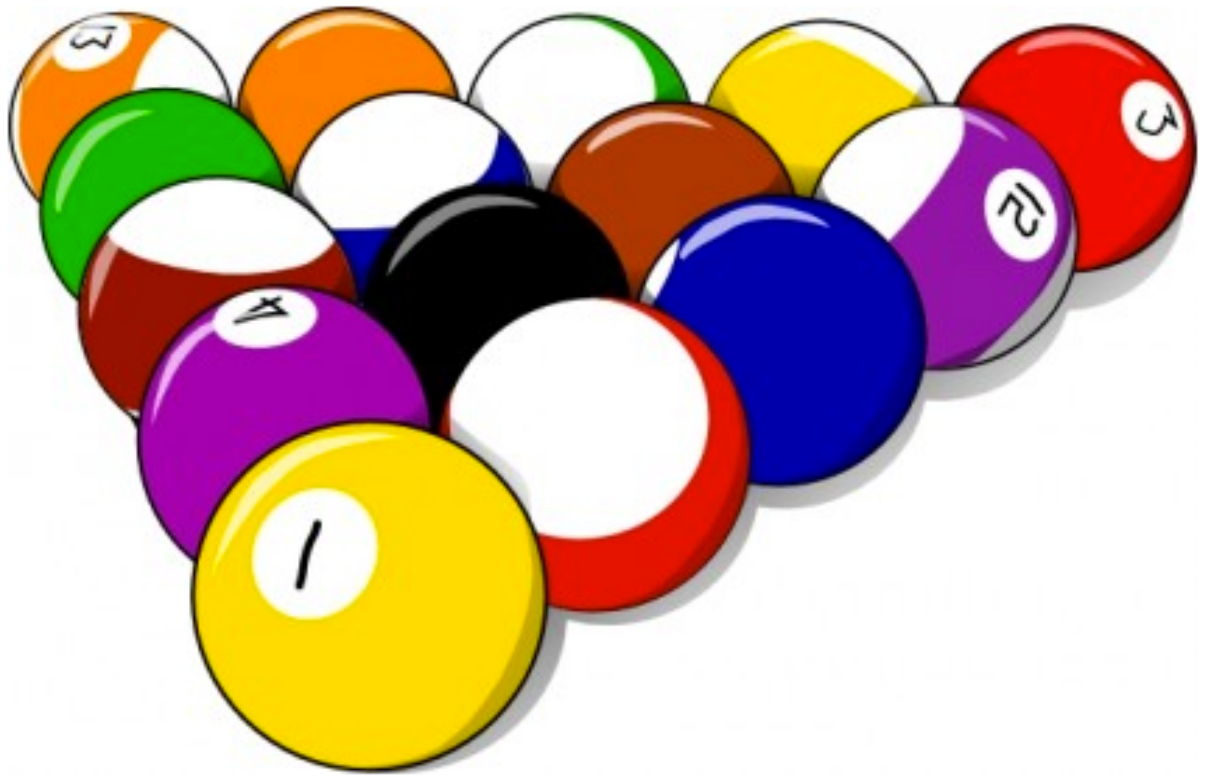
The **Conservation of Momentum** states that in the absence of an external force, the momentum of a system during a collision remains unchanged.

$$\boxed{p_{before} = p_{after}}$$

Two types of collisions:

1. Elastic collisions
2. Inelastic collisions

An **elastic collision** occurs when objects collide, and then bounce off one another.



$$\boxed{p_{before} = p_{after}}$$

An **elastic collision** occurs when objects collide, and then bounce off one another.

$$\boxed{p_{before} = p_{after}}$$

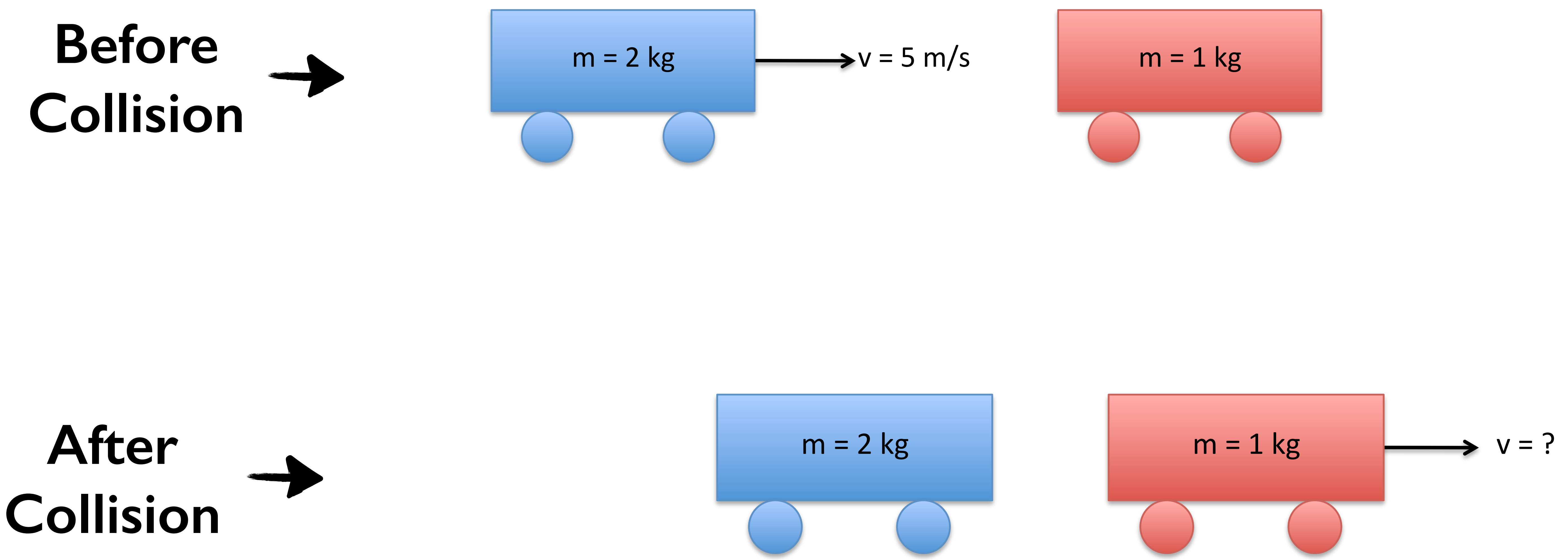
$$\boxed{(m_1v_1+m_2v_2)_{before} = (m_1v_1+m_2v_2)_{after}}$$

An **elastic collision** occurs when objects collide, and then bounce off one another.

$$p_{before} = p_{after}$$

$$(m_1 v_1 + m_2 v_2)_{before} = (m_1 v_1 + m_2 v_2)_{after}$$

A cart of 2-kg moving at 5 m/s runs into another 1-kg cart sitting still. If the blue cart comes to a stop after the collision, what is the velocity of the red cart after the collision?



A cart of 2-kg moving at 5 m/s runs into another 1-kg cart sitting still. If the blue cart comes to a stop after the collision, what is the velocity of the red cart after the collision?

$$\boxed{(m_1v_1+m_2v_2)_{before} = (m_1v_1+m_2v_2)_{after}}$$

$(2\text{ kg})(5\text{ m/s}) + (1\text{ kg})(0\text{ m/s}) = (2\text{ kg})(0\text{ m/s}) + (1\text{ kg})(v_2)$

$10\text{ kgm/s} + 0\text{ kgm/s} = 0\text{ kgm/s} + (1\text{ kg})(v_2)$

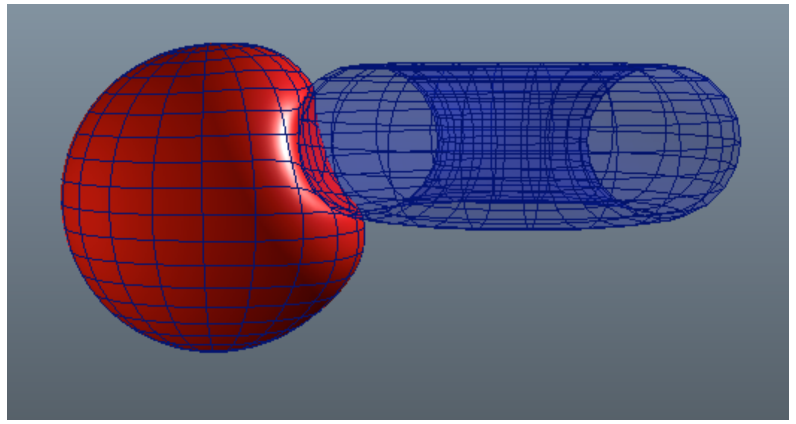
$10\text{ kgm/s} = (1\text{ kg})(v_2)$

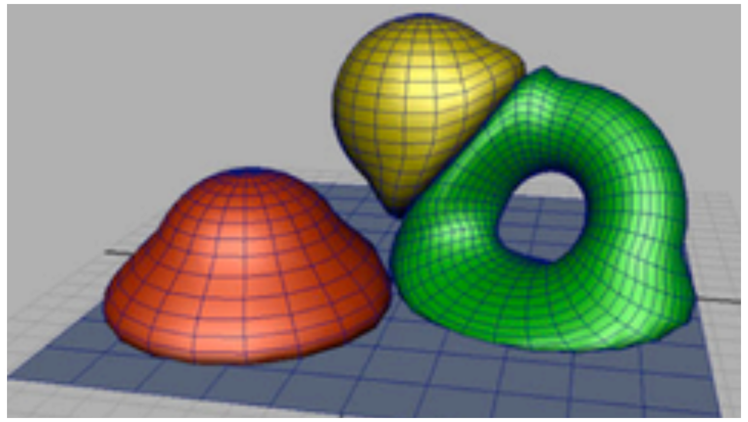
$v_2 = 10$ m/s

An **inelastic collision** occurs when objects collide, stick together, then continue moving attached to one another.

$$\boxed{p_{before} = p_{after}}$$

Whenever an object is **deformed** in a collision, it is considered an **inelastic collision** as well.





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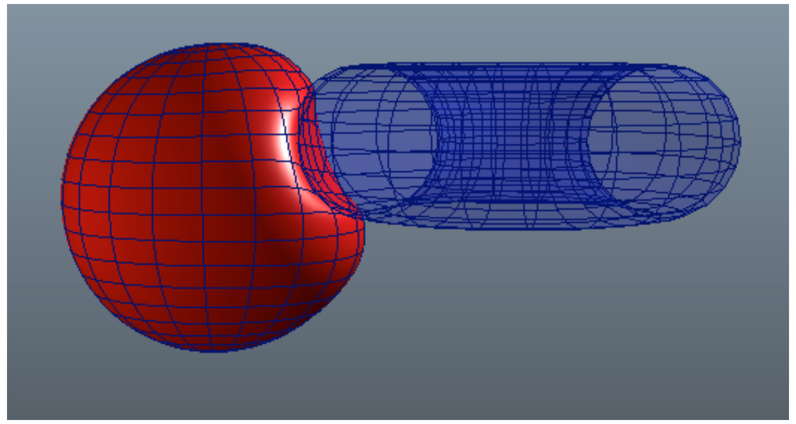
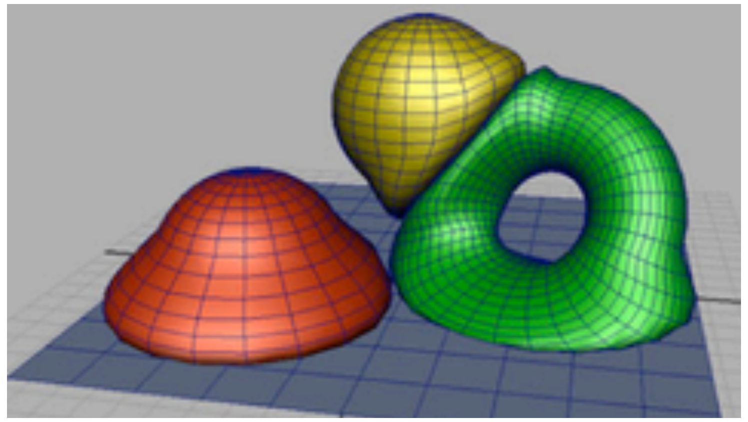
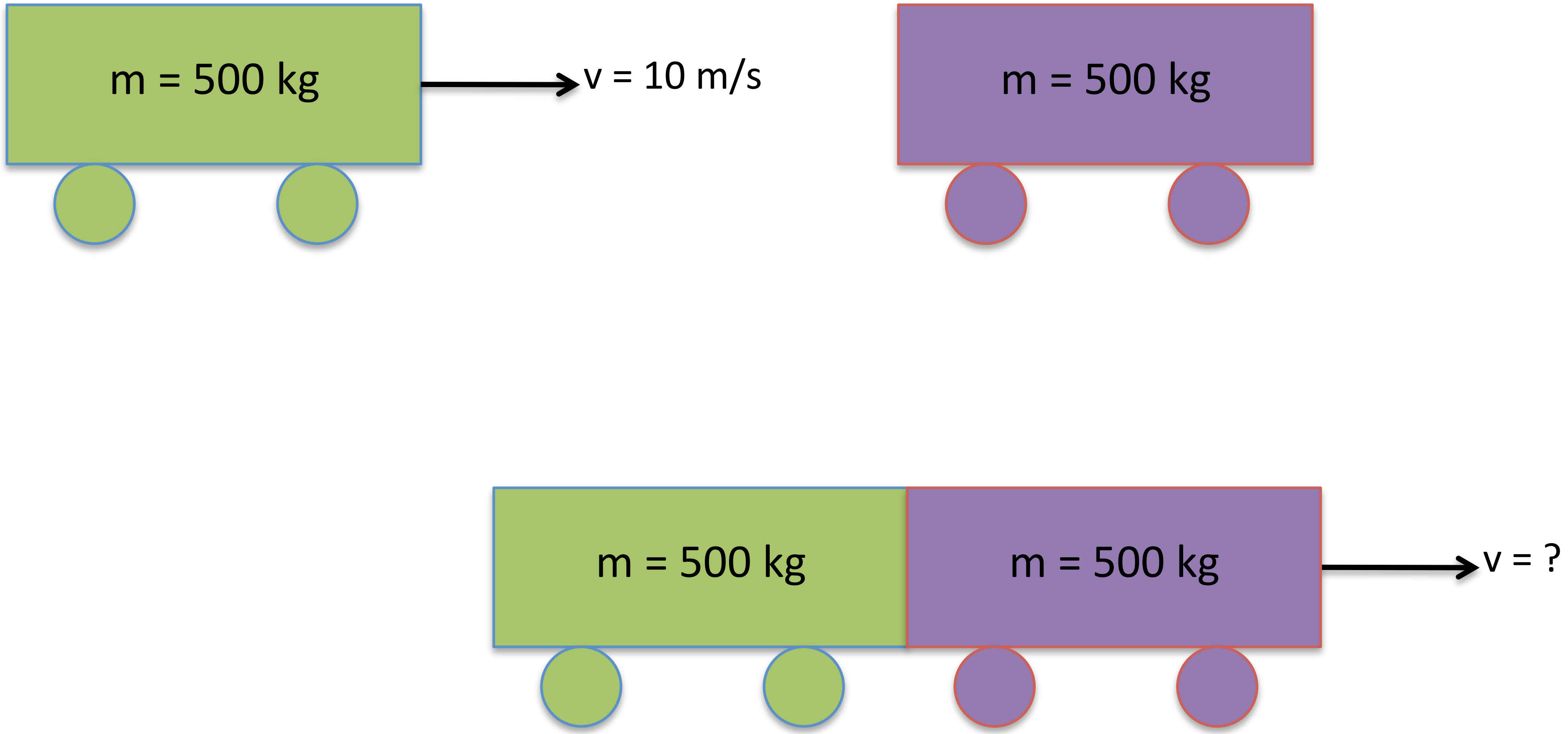




A cart of 500 kg moving at 10 m/s runs into another 500 kg cart sitting still. If they lock together, what is their velocity after the collision?

Before Collision →

After Collision →



CONSERVATION OF MOMENTUM EXAMPLE

A cart of 500 kg moving at 10 m/s runs into another 500 kg cart sitting still. If they lock together, what is their velocity after the collision?

$$\boxed{(m_1v_1+m_2v_2)_{before} = (m_1+m_2)v_{after}}$$

$$(500\ kg)(10\ m/s) + (500\ kg)(0\ m/s) = (500\ kg + 500\ kg)(v_{after})$$

$$5000\ kgm/s + 0\ kgm/s = (1000\ kg)(v_{after})$$

$$5000\ kgm/s = (1000\ kg)(v_{after})$$

$$\mathbf{v_{after} = 5\ m/s}$$

WORK

When applied force displaces an object.

$$W = Fd$$

W = Work (J) **F** = Force (N) **d** = distance (m)

Is this Work?

Definition:

Work is done on an object when an applied force succeeds in moving the object a distance.

A student applies a force to a wall and becomes exhausted.

No. **The force did not succeed in moving the wall.**

A man lifts bricks into the back of a pickup truck.

Yes. **The force succeeded in moving the bricks.**

A book falls off of a table and free falls to the ground.

Yes. **The force (gravity) displaced the book.**

A waiter carries a tray full of meals above his head by one arm straight across the room at constant speed.

No. **The upward force of the arm did not cause the plate to move horizontally across the room.**

How much work needs to be done to accelerate a 500 kg object 3 m/s^2 to 2 meters?

STEP 1:

Define what you know.

$m = 500$ kg
$a = 3\ m/s^2$
$d = 2$ m

What is the velocity of a car that travels 150 meters East in 2 seconds?

STEP 1:

Define what you know.

STEP 2:

Figure out what are solving for.

$m = 500$ kg
$a = 3$ m/s^2
$d = 2$ m

$W = ?$

What is the velocity of a car that travels 150 meters East in 2 seconds?

STEP 1: Define what you know.

STEP 2: Figure out what are solving for.

STEP 3: Decide which equation to use.

Distance fallen in free fall			
distance	d	m (meters)	$d = \frac{1}{2}gt^2$ $\left(g = 9.8\frac{m}{s^2}\right)$
gravity	g	m/s^2 (meters per seconds squared)	
time	t	s (seconds)	
Weight			
weight	w	N (Newtons)	$w = mg$ $\left(g = 9.8\frac{m}{s^2}\right)$
mass	m	kg (kilograms)	
gravity	g	m/s^2 (meters per seconds squared)	
Force (Newton's 2nd Law)			
force	F	N (Newtons)	$F = ma$
mass	m	kg (kilograms)	
acceleration	a	m/s^2 (meters per seconds squared)	
Momentum			
momentum	p	kgm/s (kilograms meters per second)	$p = mv$
mass	m	kg (kilograms)	
velocity	v	m/s (meters per second)	
Work			
work	W	J (Joules)	$W = Fd$
force	F	N (Newtons)	
distance	d	m (meters)	
Power			
power	P	W (Watts)	$P = \frac{W}{t}$
work	W	J (Joules)	
time	t	s (seconds)	

m = 500 kg

$a = 3\ m/s^2$

d = 2 m

W = ?

W = Fd

What is the velocity of a car that travels 150 meters East in 2 seconds?

STEP 1: Define what you know.

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mass	m	kg (kilograms)	
velocity	v	m/s (meters per second)	
Work			
work	W	J (Joules)	$W = Fd$
force	F	N (Newtons)	
distance	d	m (meters)	
Power			
power	P	W (Watts)	$P = \frac{W}{t}$
work	W	J (Joules)	
time	t	s (seconds)	

m = 500 kg

a = 3 m/s^2

d = 2 m

W = ?

W = Fd

Since the problem does not state force directly, we will need to use the equation for Force (F=ma) to ultimately solve for work.

W = Fd = (ma)d

What is the velocity of a car that travels 150 meters East in 2 seconds?

STEP 1: Define what you know.

STEP 2: Figure out what are solving for.

STEP 3: Decide which equation to use.

STEP 4: Place values from Step 1 into equation.

$m = 800\ kg$
$a = 3\ m/s^2$
$d = 2\ m$

$W = ?$

$W = Fd$

Since the problem does not state force directly, we will need to use the equation for Force (F=ma) to ultimately solve for work.

$$W = Fd = (ma)d$$
$$W = (500\ kg)(3\ m/s^2)(2\ m)$$

What is the velocity of a car that travels 150 meters East in 2 seconds?

STEP 1: Define what you know.

STEP 2: Figure out what are solving for.

STEP 3: Decide which equation to use.

STEP 4: Place values from Step 1 into equation.

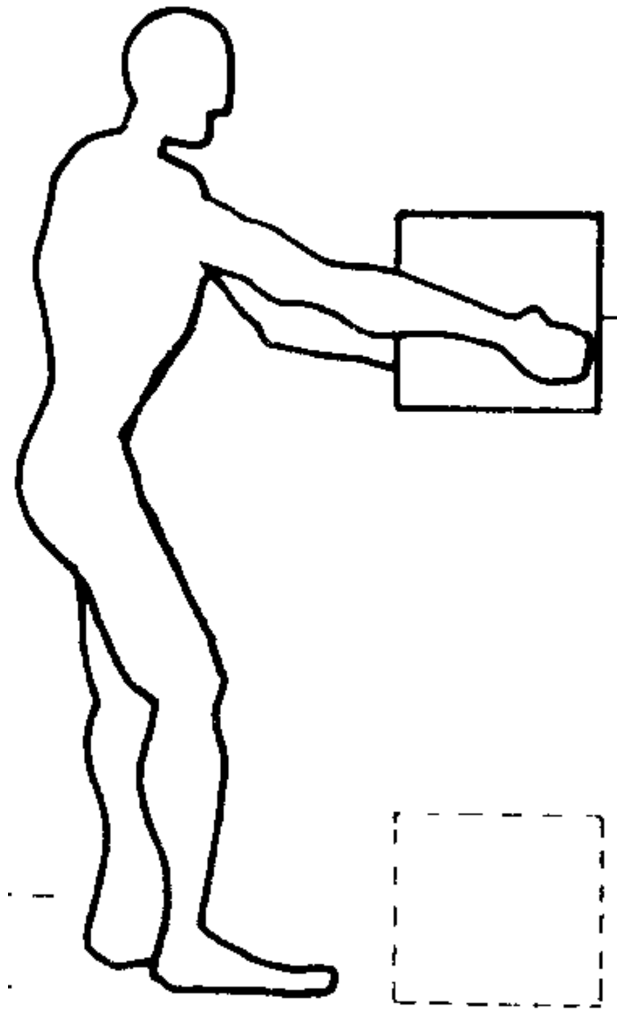
STEP 5: Solve.

$$W = Fd = (ma)d$$

$$W = (500\ \text{kg})(3\ \text{m/s}^2)(2\ \text{m})$$

$$\mathbf{W = 3000\ J}$$

VERTICAL WORK



Work being done to LIFT an object.

$$W = wh$$

W = Work (J) **w** = weight (N) **h** = height (m)

How much work needs to be done to lift a 500-kg object to 2 meters height?

$$W = wh$$

$$W = (mg)h$$

$$W = (500\ \text{kg})(9.8\ \text{m/s}^2)(2\ \text{m})$$

$$W = 9{,}800\ \text{J}$$

POWER

Amount of work done per unit time.

$$P = \frac{W}{t}$$

P = Power (W) **W** = Work (J) **t** = time (s)

How much power is needed to accelerate a 2000 kg car 5 m/s^2 a distance of 200 meters in 10 seconds?

$$P = W / t$$

$$P = (Fd) / t$$

$$P = (mad) / t$$

$$P = ((2000\ kg)(5\ m/s^2)(200\ m)) / (10\ s)$$

$$P = 2{,}000{,}000 / 10\ s$$

$$P = 200{,}000\ W$$




Energy

- Energy produces changes in matter.
- Energy cannot be created or destroyed, only changed in form.
- Effects of energy are only observed when it is being transferred from one place to another **or** when it is transformed from one form to another.
- Energy is measured in **Joules**.

Thermal energy: Heat

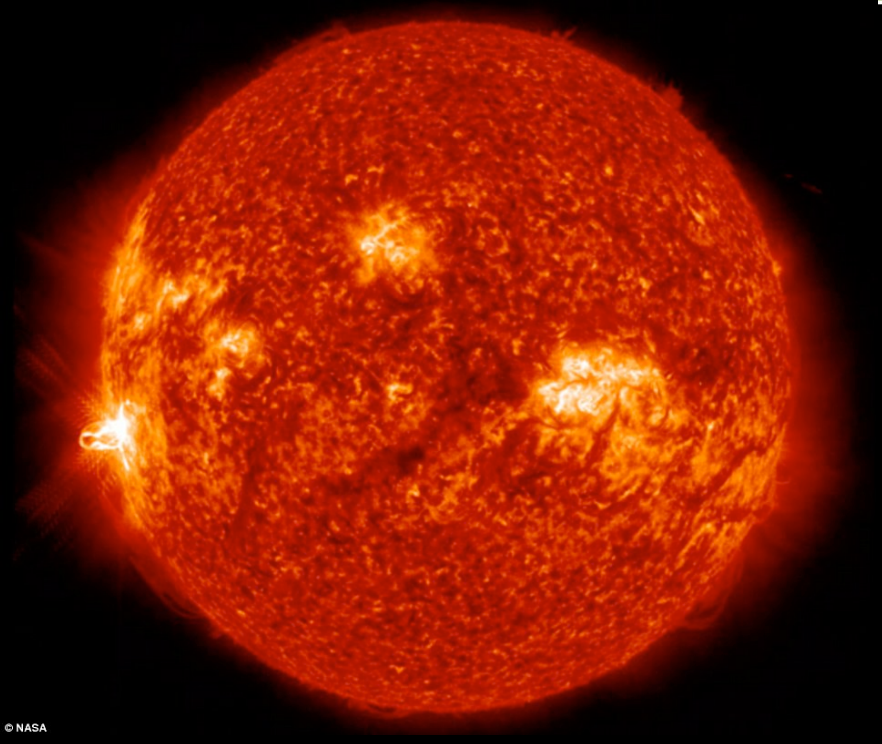
Acoustic Energy: Sound

Magnetic Energy: Magnetic Fields

Electrical Energy: Electricity

Mechanical Energy: Movement

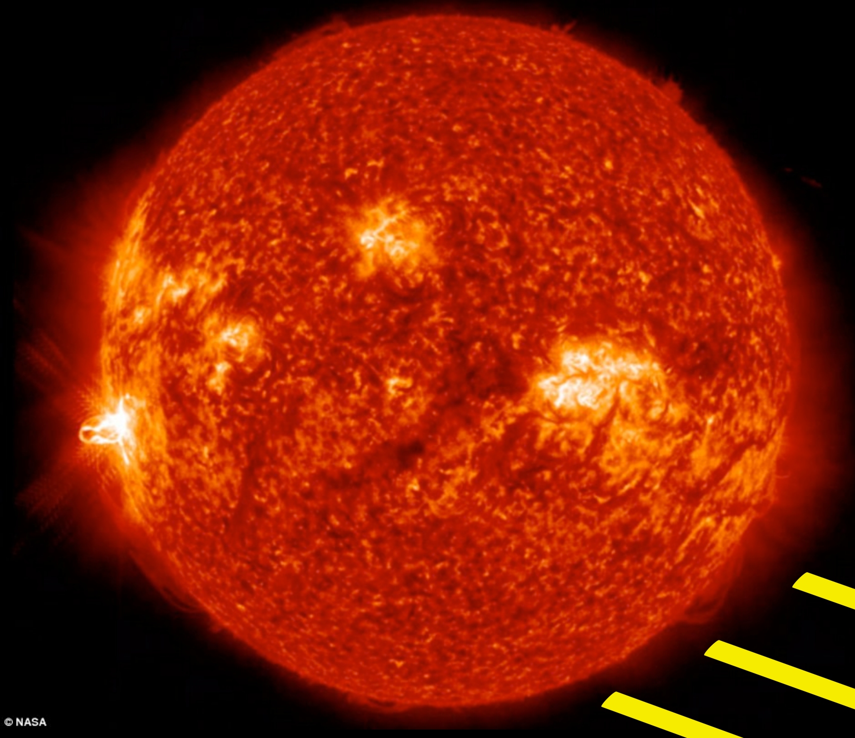
Chemical Energy: Chemical Bonds



Fusion is the fuel of stars.

Two atoms are forced together at high speeds to make a new element. The new atom has less mass than the original two atoms, so that mass is converted into energy by:

$$E = mc^2$$



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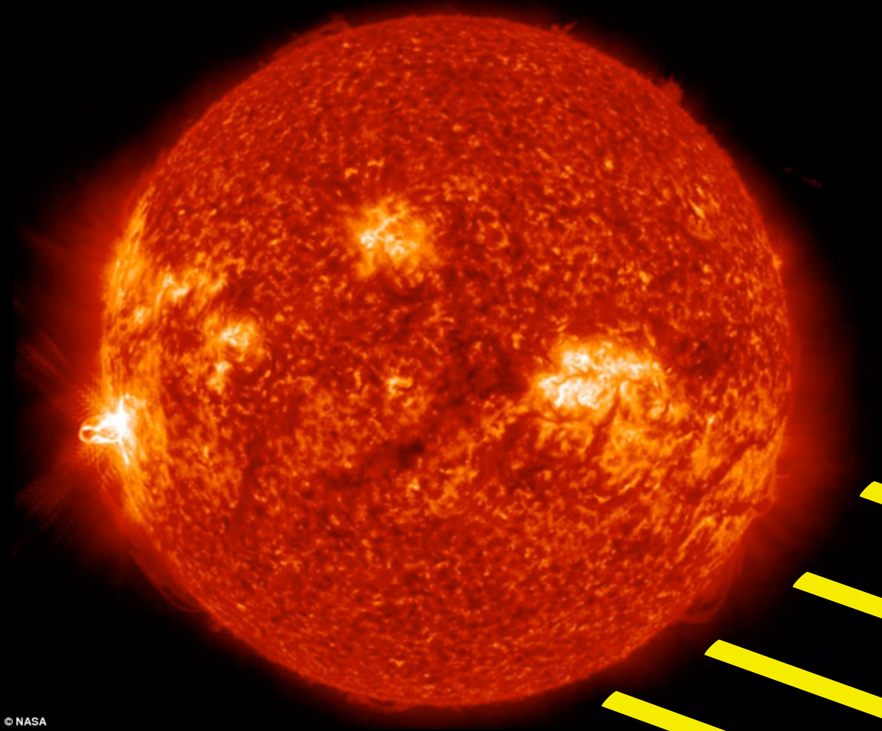

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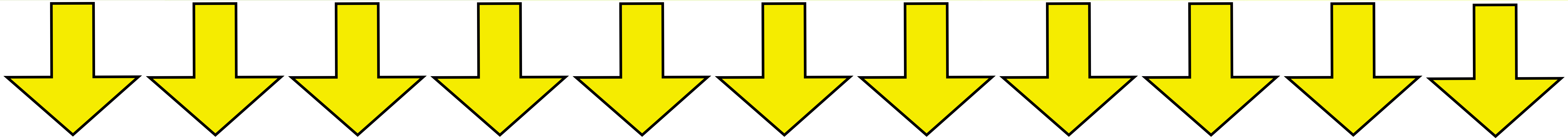
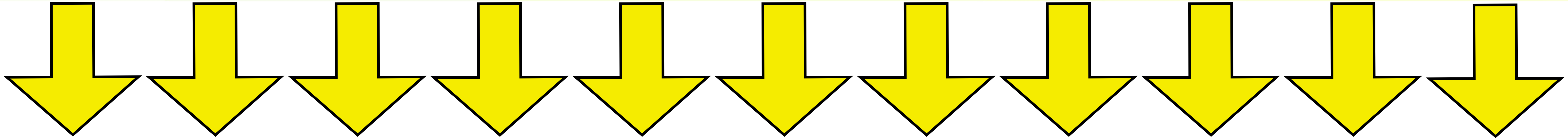
Mass → Photonic (Light) Energy



Plants convert the energy in the light to chemical energy through **photosynthesis**.



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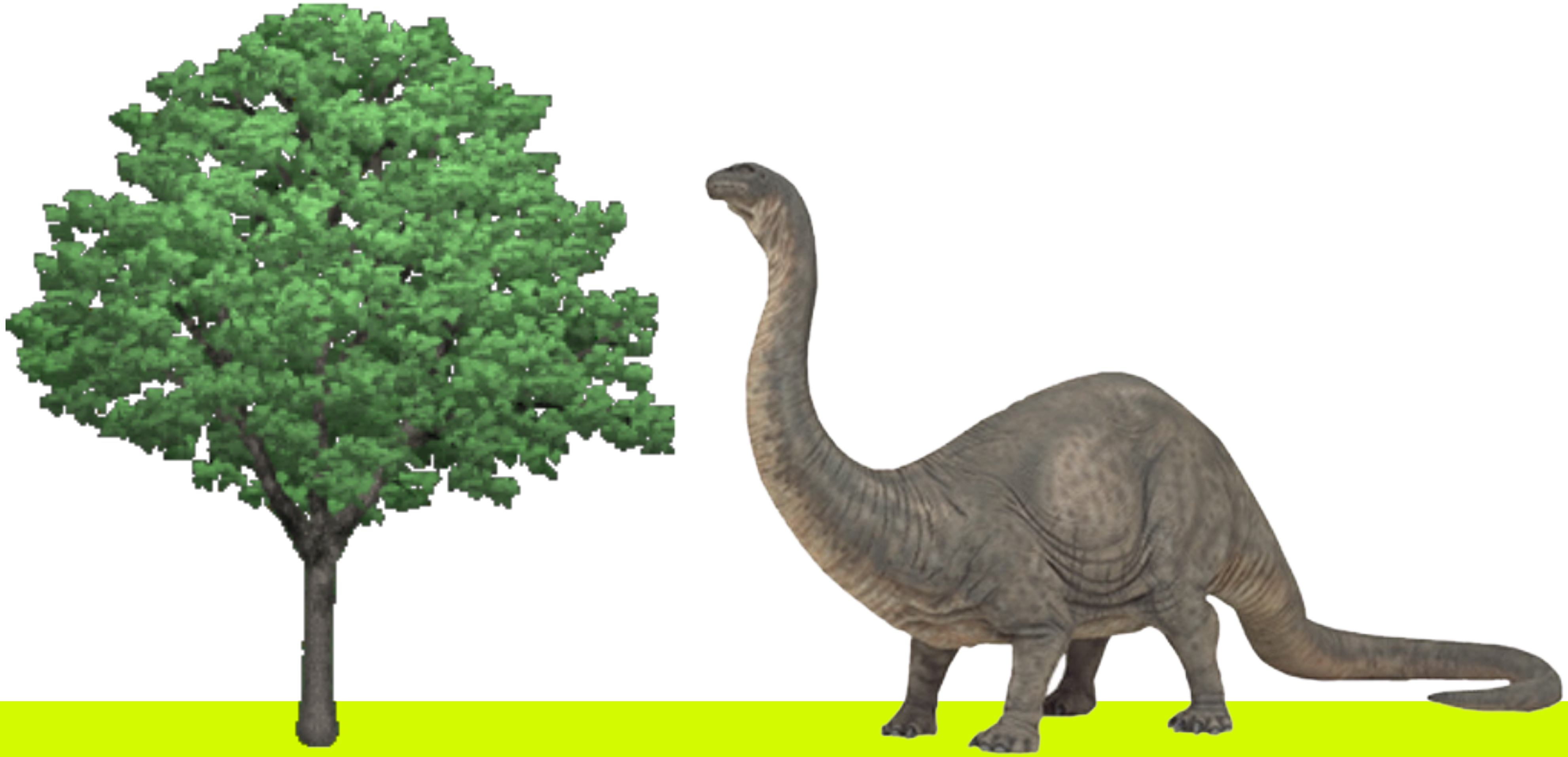
Light Energy → Chemical Energy



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Light Energy → **Chemical Energy**

Animals eat the plants and convert the chemical energy into the energy of movement.

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Chemical Energy

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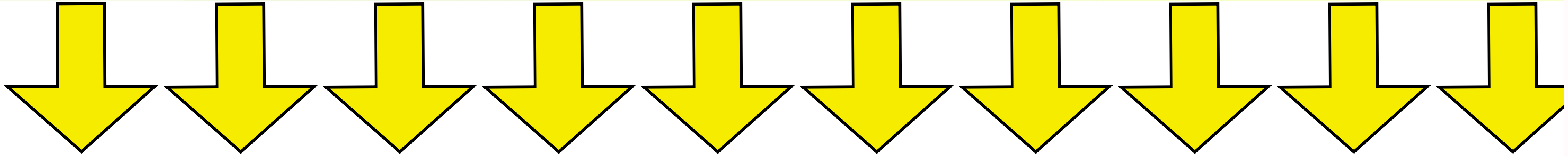
Mechanical Energy



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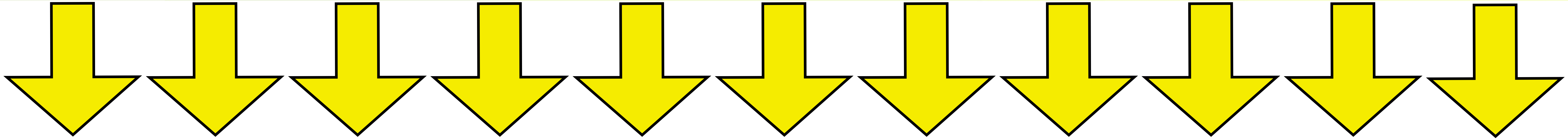

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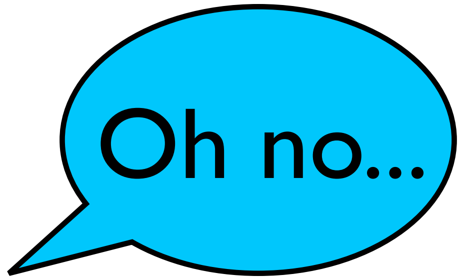

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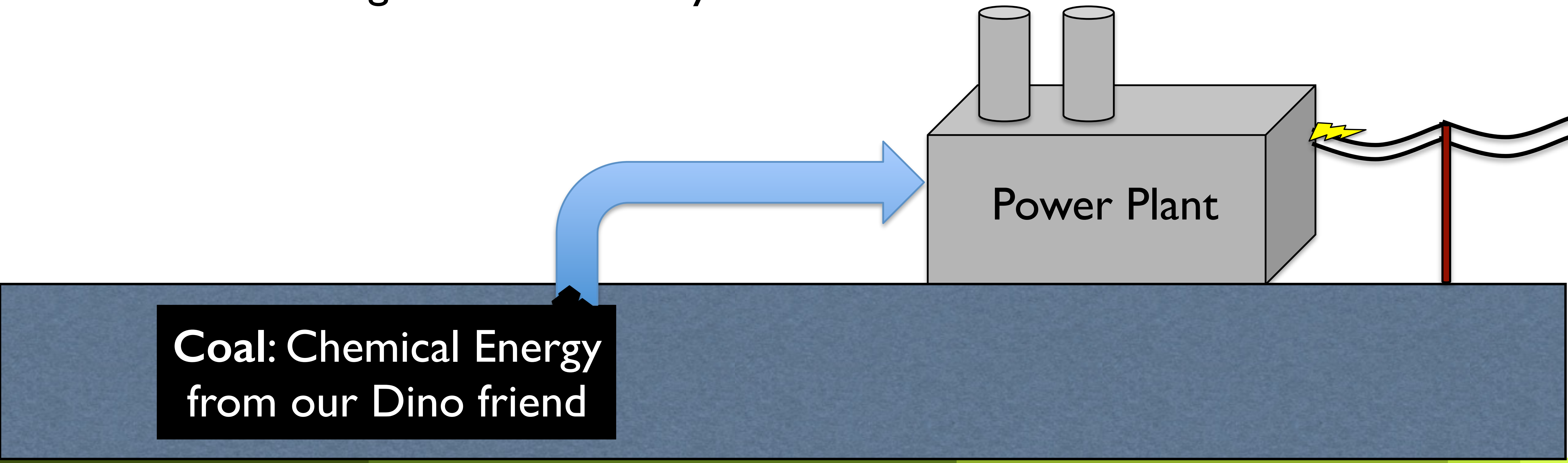
Chemical Energy
↓
Mechanical Energy

Power plants convert coal and natural gas into electricity.



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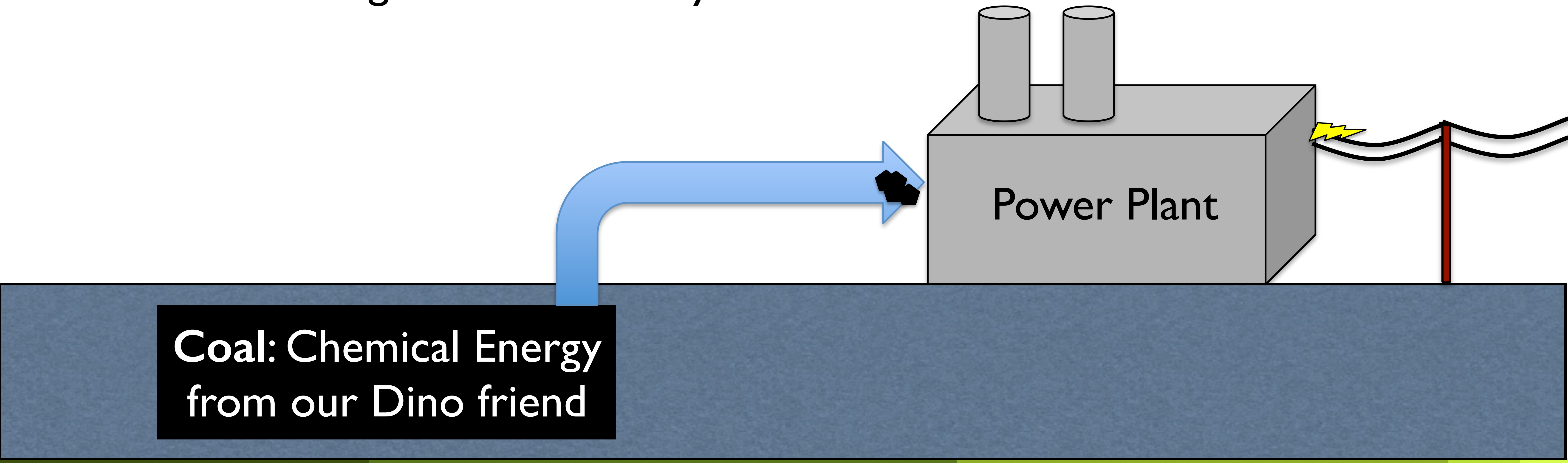

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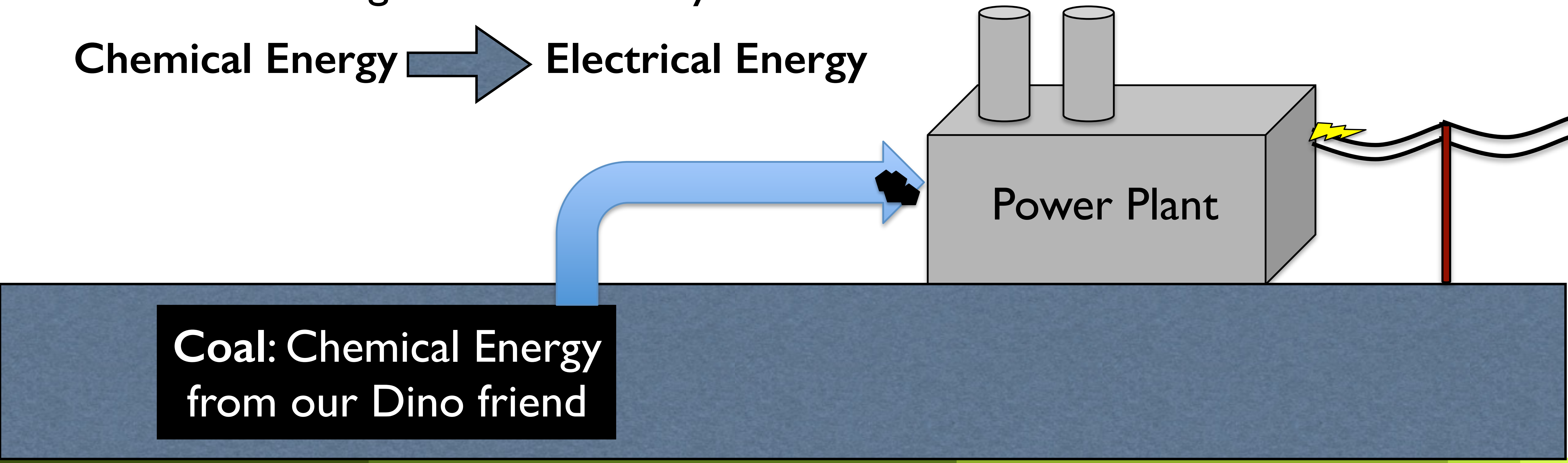
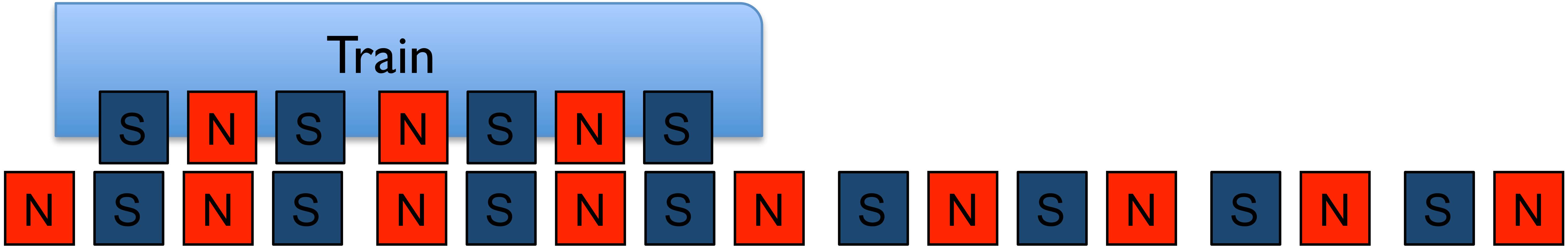
Chemical Energy ⇨ Electrical Energy



A Maglev train uses the electricity to create powerful magnetic fields to float and move.



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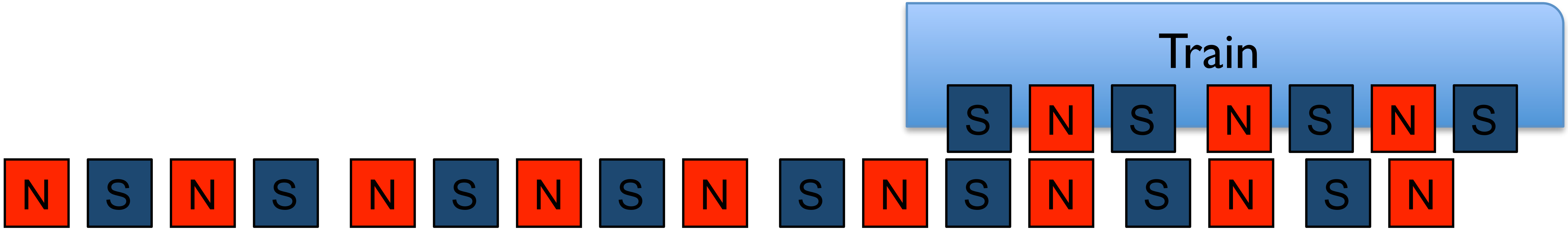
Electrical Energy → Magnetic Energy



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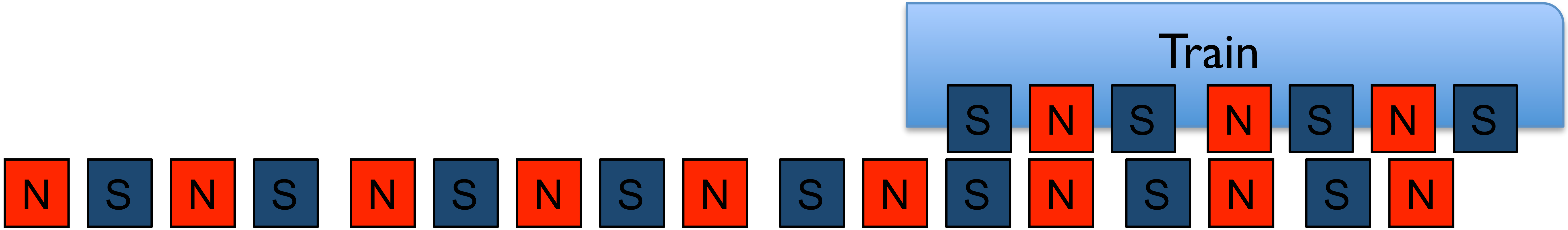
Electrical Energy → **Magnetic Energy**



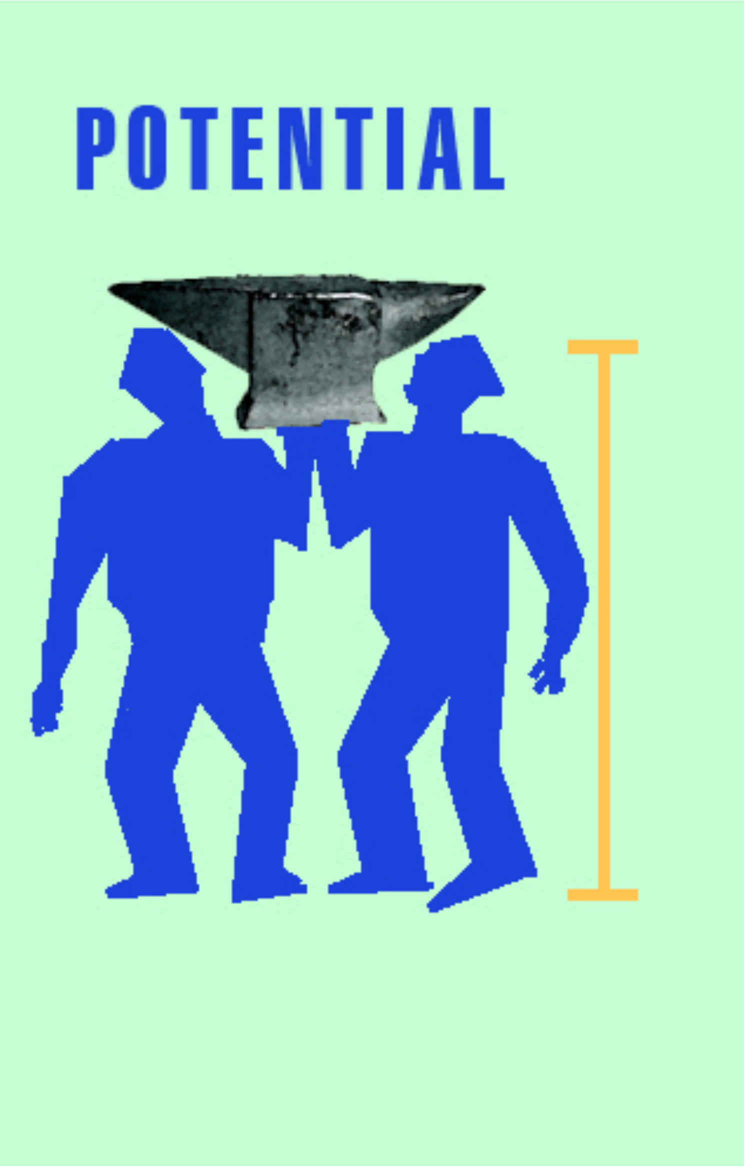
Moving at high speeds creates a lot of friction with the air producing noise (**Acoustic Energy**) and heat **(Thermal Energy)**.

GRAVITATIONAL POTENTIAL ENERGY

Energy of an object due to height.

$$PE = mgh$$

PE = Potential Energy (J) **m** = mass (kg)
g = acceleration of gravity (m/s^2) **h** = height (m)



How much potential energy does a 25 kg mass have when it is lifted to a height of 2 meters?

$$PE = mgh$$

$$PE = (25\ \text{kg})(9.8\ \text{m/s}^2)(2\ \text{m})$$

$$PE = 490\ \text{J}$$

KINETIC ENERGY

Energy of a moving body.

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

KE = Kinetic Energy (J) **m** = mass (kg) **v** = velocity (m/s)

How much kinetic energy does a 10 kg object have moving at 10 m/s?

$$KE = 1/2\ mv^2$$
$$KE = (1/2)(10kg)(10\ m/s)^2$$
$$KE = (5kg)(100\ m^2/s^2)$$
$$KE = 500\ J$$

How much kinetic energy does a 10 kg object have moving at 20 m/s?

$$KE = 1/2\ mv^2$$
$$KE = (1/2)(10kg)(20\ m/s)^2$$
$$KE = (5kg)(400\ m^2/s^2)$$
$$KE = 2000\ J$$

The **Conservation of Energy** states that the energy of a system will remain constant, regardless of changes in form.

$$\boxed{E_{before} = E_{after}}$$

For a falling object, the gravitational potential energy at the top of the fall will transform entirely into kinetic energy by the end of the fall, but the **Conservation of Energy** states that the total amount of energy (KE+PE) will remain the same throughout the fall.

PE_{top}

EQUALS

KE_{bottom}