Energy & Conservation Law

Conservation Laws

Always remember nothing is created or destroyed – **everything is transferred from on side to another**

The hour glass or a balance is perfect example.

Linear Momentum - Conservation Law

The total mass in an isolated system is constant

Linear Momentum: The mass of an object times its velocity is linear momentum

$$momentum = m\vec{v}$$

Newtons 2nd Law of motion assumes that the mass is constant. What happens if the mass changes

$$\vec{F} = m.\vec{a}$$

Newtons 2nd Law (other notation)

Linear Momentum: The net external force acting on an object equals the rate of change in its linear momentum

$$\vec{F} = \frac{\Delta(mv)}{\Delta t}$$

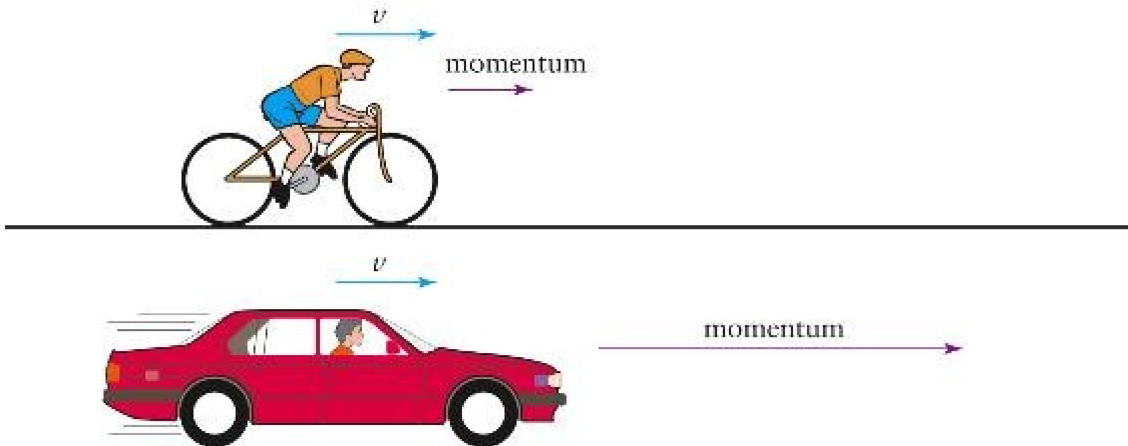
Units: Linear Momentum (kg m/s) or (N.s)

Practice - Momentum

What is the momentum of a bicycle with a mass of 80 kg and a speed of 10 m/s?

What is the momentum of a 1,200 kg car with the same speed?

What should be the speed of the bicycle in order to have this same momentum as the car.



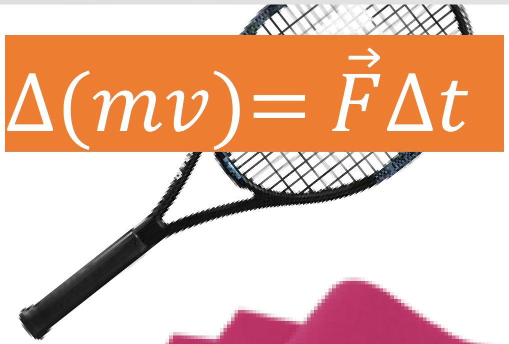
Practice - Momentum

How much higher the momentum of a 4 kg turtle running at 0.5 m/s comparing to a 300 kg horse at rest?

Impulse

Impulse: impulse is defined as the <u>change</u> in momentum.

$$\Delta(mv) = \vec{F}\Delta t$$



A change in momentum can result from a small force acting for a long period of time or large force acting on a small period of time.

What are the units of impulse?

What are the units of momentum?

Do not memorize everything! Understand the basics and solve for the units

Units: Linear Momentum (kg m/s) or (N.s)

Conservation Law

The concept of Conservation laws is so important we dedicated this whole slide to it in red and bold. Conservation laws, nothing is created or destroy things transfer from form to another as such it is simply compares states.

State Before vs State After

Practice - Momentum

Let’s estimate the average force on a golf ball as it is driven off the fairway. The ball’s mass is 0.045 kg, and it leaves the club head with a horizontal speed of, say, 50 m/s. High-speed photographs indicate that the contact time is about 5 milliseconds (0.005 s).

Conservation of Linear Momentum

Law of Conservation of Linear Momentum: The total linear momentum of an isolated system is constant.

For this Law, an isolated system means there are **no outside forces** acting on it. Change in momentum can result from a small force acting for a long period of time or large force acting on a small period of time.

$$Total\ (mv)_{b4} = Total\ (mv)_{aftr}$$

$$\Delta(mv) = \vec{F}\Delta t$$

Collision: Conservation of L. Momentum

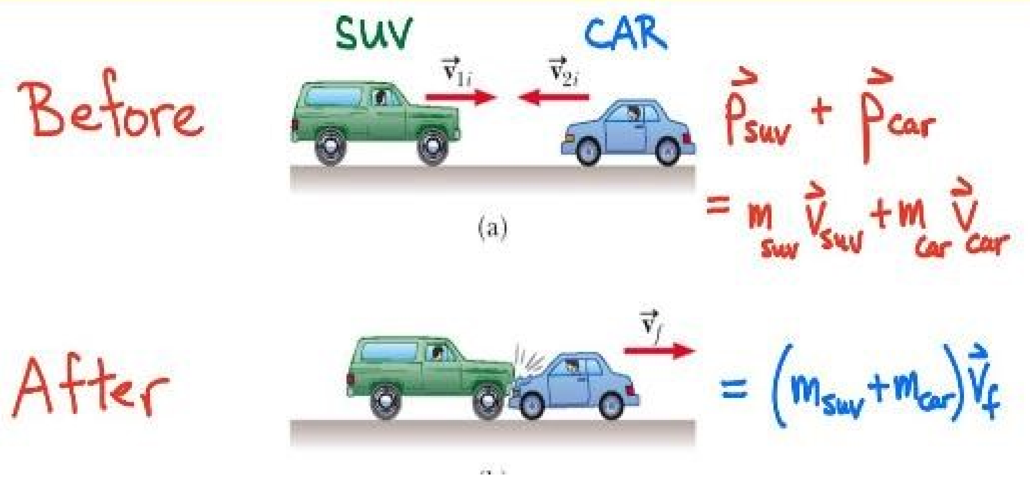
Collision : The total linear momentum of the Objects in a system before the collision is the same as the total linear momentum after the collision.

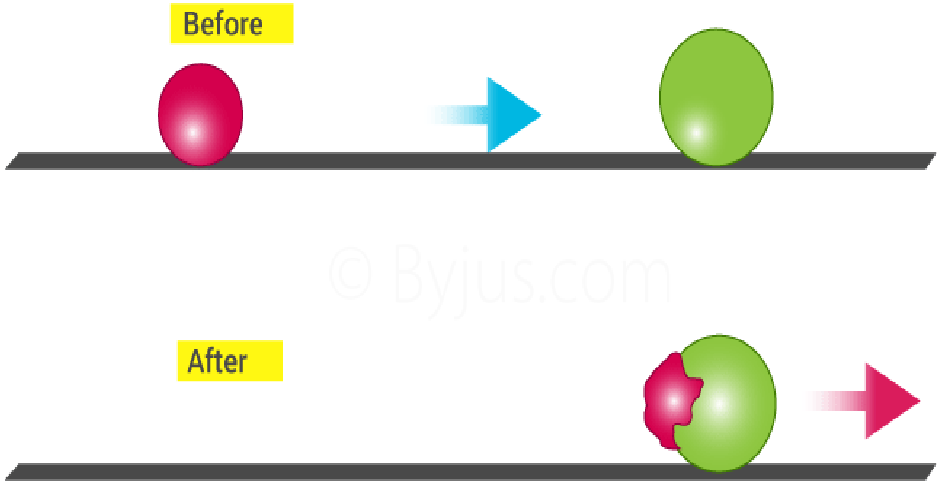
$$Total\ (mv)_{b4} = Total\ (mv)_{aftr}$$

This will be in the exam – Guaranteed!
A common use of the Conservation of Linear Momentum is Collision - based on the fact that nothing is created or lost everything is transformed from one form to another - Conservation Law.

We will limit our discussion to 2 objects in 1-D (same line)

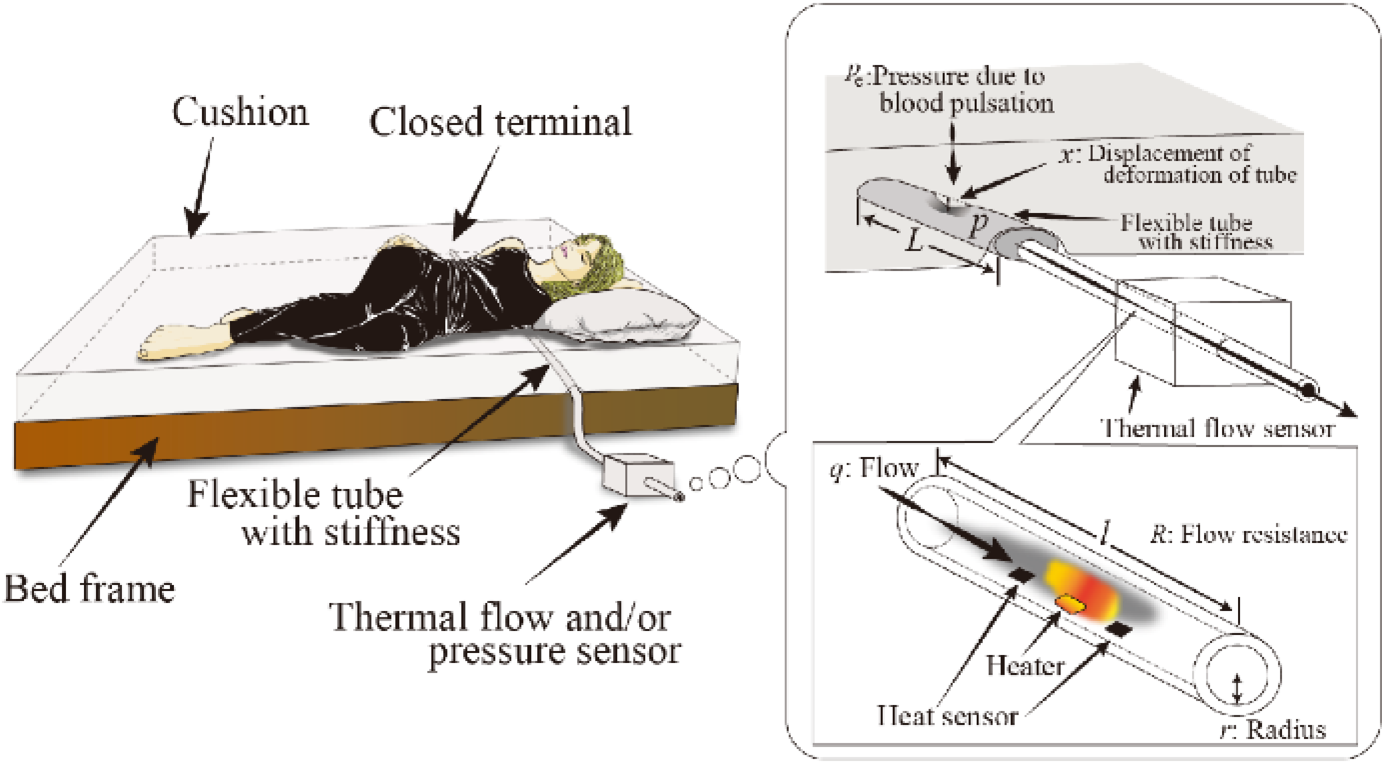
- Elastic
- Non-Elastic





Practice – Collision L. Momentum Conservation Law

BCG! What is a ballistocardiograph & how does it work? A BCG measures movement of the body caused by the heart's contractions. It detects changes in momentum and acceleration of the body as blood is pumped through the heart. This movement is then converted into an electrical signal that can be recorded and analyzed conservation of momentum.



(a) BCG measurement situation

(b) Differential pressure sensor based on the thermal flow measurement method

Practice – Collision L. Momentum Conservation Law

Use conservation of momentum. A 1,000 kg automobile (car 1) runs into the rear of a parked vehicle (car 2) with a mass of 1,500 kilograms. After collision, the cars are hooked with a of speed is 4 m/s.

What was the speed of car 1 just before the collision?

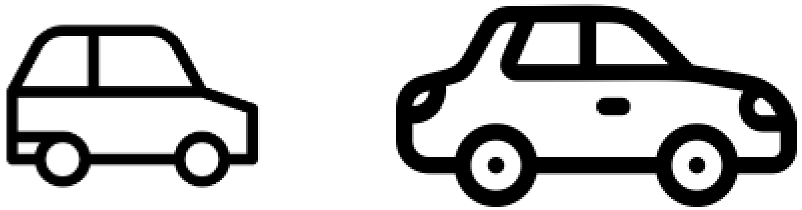
Practice – Collision L. Momentum Conservation Law

A 1,000 kg (car 1) runs into the rear of a parked (car 2) with a mass of 1,500 kilograms. After collision, the hooked cars speed is 4 m/s. What was the speed of car 1 just before the collision?

1 Free Body Diagram

2 Concept / Formula

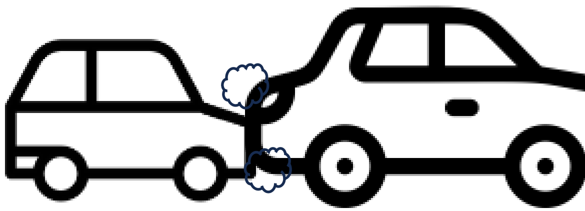
Before



$$Total\ (mv)_{b4} = Total\ (mv)_{aftr}$$

$$(m_{c1}v_{c1})_{b4} + (m_{c2}v_{c2})_{b4} =$$

After



Work

Work : It is the force times the distance moved in the same direction as the force.

$Work = \vec{F}\ d\ \rightarrow$

Note: Work is **not** $\vec{F}\ d$ it is $\vec{F}\ d$ $\rightarrow$ **the force and direction have to be in the same direction path**

We do it every day.

Shouldn’t we include time?

But why we get tired when we work for longer hours?

What are the units of work? Do not remember, solve for it.

Units: N m, Joules (J), Calories (cal), kWh, Btu

Practice – Collision L. Momentum Conservation Law

Because of friction, a constant force of 100 newtons is needed to slide a box at a steady speed across a room. If the box moves 3 meters, how much work is done?

Work

Someone measured the force applied by the women F_w on the fulcrum to lift a rock F_r and found F_w = 2N, and F_r = 6N

Then measured the distance the woman pushed the fulcrum d_w and the height the rock gained d_r and found $d_w = 90cm$, the rock height is $d_r = 30cm$

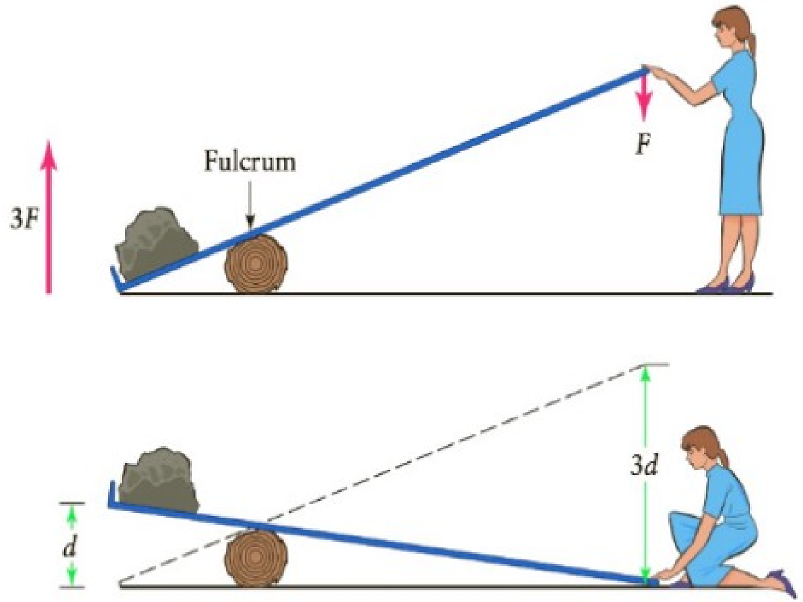
Upon taking the ratios distance, $\frac{d_w}{d_r} = \frac{90cm}{30cm} = 3$ the same ratio was found when applied to force $\frac{F_r}{F_w} = \frac{6N}{2N} = 3$ coincidence?

Let's rewrite and organize $\frac{d_w}{d_r} = \frac{F_r}{F_w}$, Cross multiply

$$F_w * d_w = F_r * d_r$$

Simple experiment like this one gave rise to work, energy formula. Notice the distance and force are parallel.

$$Work = \vec{F}\ \vec{d}$$



Work

Similar to the prior example of the women lifting the rock with a fulcrum

$Work = \vec{F}\, d \;\rightarrow$

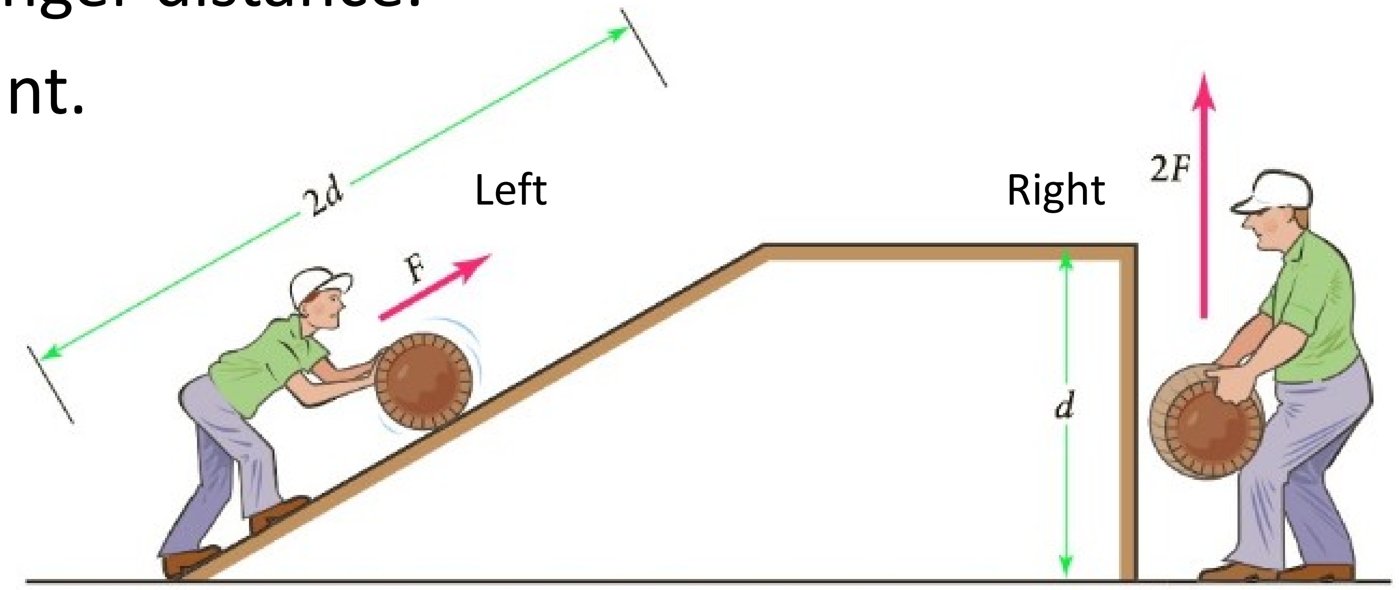
"Coincidentally", the force times the vertical distance on the right hand side is found to be equal to the force times distance along the incline on the left hand side.

$Work = \vec{F}\, d \;\rightarrow$

To right hand the force is greater for a shorter distance

To the left the force is smaller for a longer distance.

The work required for a task is constant.

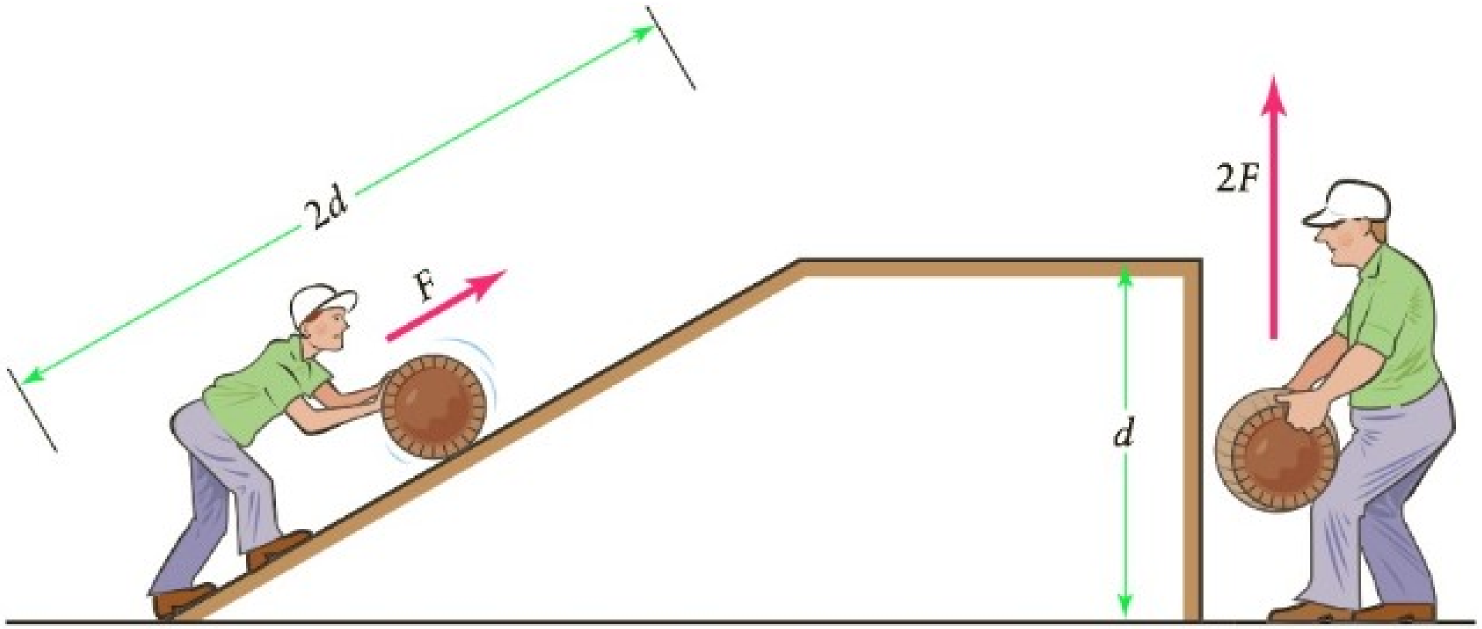


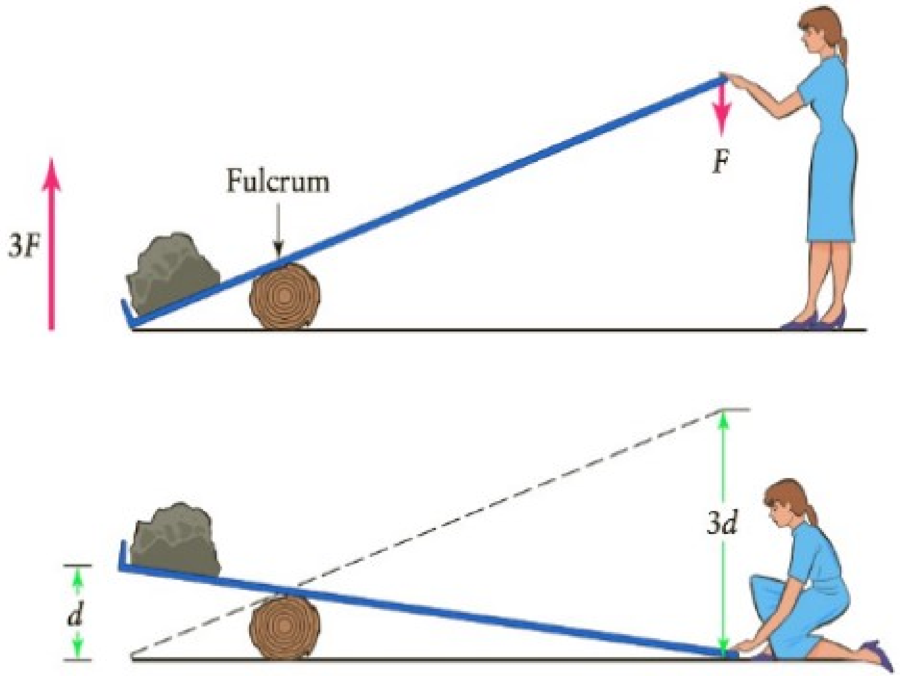
Work

Both events the women with the lifting the rock or operator lifting the barrel, the object have been **raised** (work performed) with respect to ground. Kept unchecked the object will (undo the work performed) **fall down** back the ground.

In order to do or undo work, **energy** is required.

So it is fair to think of **Energy as the ability of something to do work**!





Different Forces Different Work

Work : It is the force times the distance moved in the same direction as the force.

$Work = \vec{F}\,\vec{d}$

Work is the force x **the distance along the force**.

Trap? Since the weight is perpendicular to the path, there appears to be **no work done**.

Think about it. Once that box is lifted sooner or later, it must come down – the work will be undone/recovered or lets say Energy

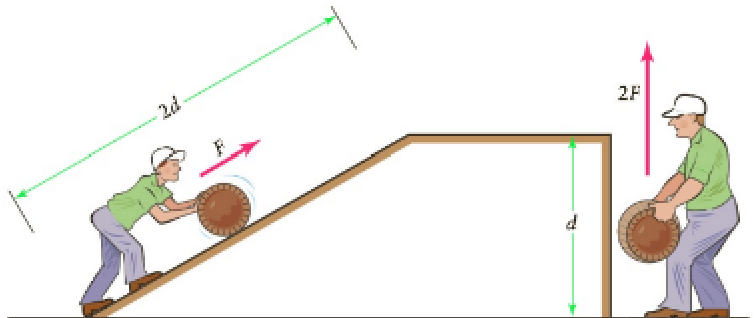
When work is done on a object that object gains Energy

Two (2) Mechanical Energy will be discussed i.e.

- Kinetic Energy
- Potential Energy

Practice – Collision L. Momentum Conservation Law

Let's say that you want to lift a barrel with a mass of 30 kilograms and that the height of the dock is 1.2 meters. How much work would you do lifting the barrel?



Different Forces Different Work

Work : It is the force times the distance moved in the same direction as the force.

$Work = \vec{F}\, d \;\rightarrow$

From prior lectures an object in a free fall experiences the force of gravity $\vec{F} = \overrightarrow{W} = mg$. On free fall as time passed the object travels some distance (d) as such $Work = \vec{F}\, d \;\rightarrow$. Substituting $Work = mg\, d \;\rightarrow$.

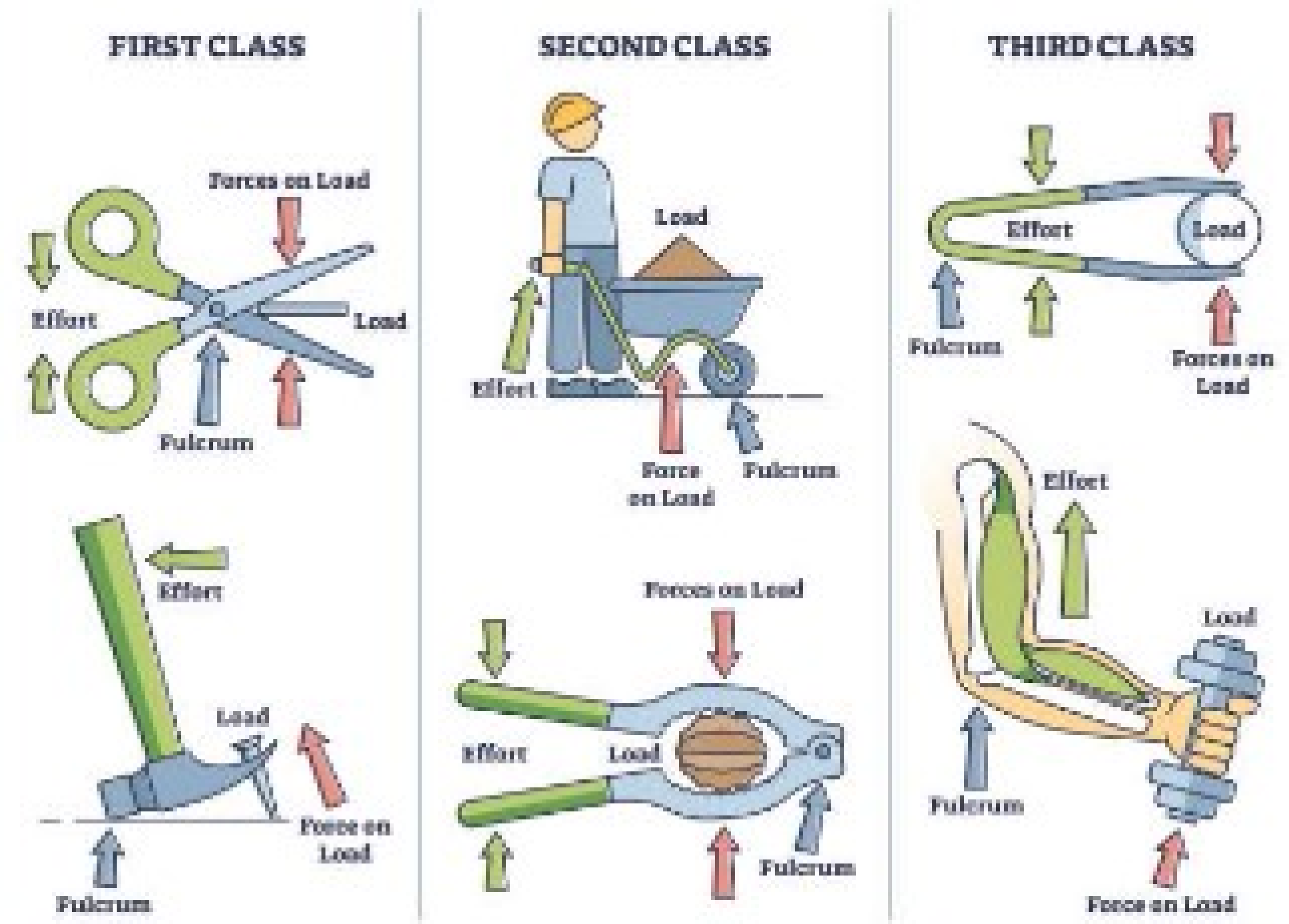
Now we can claim when work is done on an object, in real life, that object gains energy. (and vice versa).

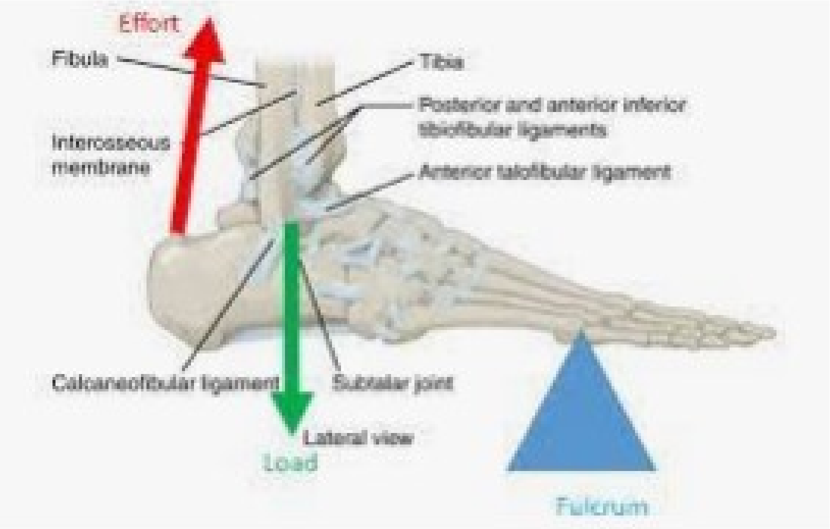
$Work = mgd$

Different Forces Different Work

Work : It is the force times the distance moved in the same direction as the force.

$$Work = \vec{F}\ d\ \rightarrow$$





Mechanical Kinetic Energy

Kinetic Energy : Energy resulting from motion. Energy that an object has because it is moving.

To visually understand kinetic energy is to duplicate the experiment of Emelie de Chatelet. As this professor shows an object free falls on clay leaves a crater.

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

- The more mass the object has the bigger the volume of the crater.
- The higher the object starts the higher the velocity.
- The volume of the crater also increase with the velocity square of the object.

Mechanical Kinetic Energy

Kinetic Energy : Energy resulting from motion. Energy that an object has because it is moving.

The kinetic energy that an object has is equal to the work done when accelerating the object from rest.

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

So another way to determine the amount of work done when accelerating an object is to compute its kinetic energy.

$$Fd \rightarrow = Wh = mgh$$

Also another way to find the kinetic energy associated with a falling object is to calculate the force times the height.

What are the units of Kinetic Energy?

Units: Joules, Calories, N m, BTUs

Practice – Kinetic Energy

In prior example, we used Newton's 2nd law to compute the force needed to accelerate a 1,000-kilogram car from 0 to 27 m/s in 10 seconds. Our answer was F = 2,700 newtons. Using the definition of work, compute how much work is done in this process.

Practice – Kinetic Energy

In the prior example, we computed the work that is done on a 1,000-kilogram car as it accelerates from 0 to 27 m/s. Let's compute the total kinetic energy gained by the car during its acceleration.

Mechanical Potential Energy

Potential Energy : Energy resulting from an object position or orientation. Energy that an object has because it is configuration.

2 common potential Energy

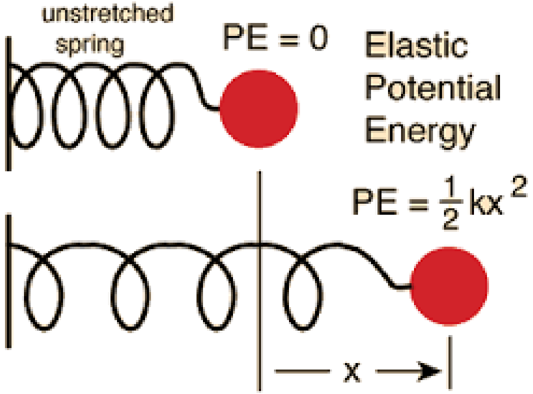
- Potential Energy Due to Gravity

$$PE = Wd \rightarrow = mgd$$

Here it is the weight x the vertical distance – remember the box.

- Potential Energy Due to a spring

Where k is spring constant and d is the displacement.



$$PE_{spring} = \frac{kd^2}{2}$$

Units: Joules, Calories, N m, BTUs

Practice – Potential Energy

In prior problems, a spring with spring constant of 2.4 N/m was stretched from equilibrium by a distance of 0.30 m. How much energy was stored in the spring under these conditions?

Conservation Laws

Always remember nothing is created or destroyed – **everything is transferred from on side to another**

The hour glass or a balance is perfect example.

Conservation of Energy

Conservation of Energy : Energy cannot be created or destroyed, only converted from one form to another. The total energy in an isolated system is constant.

$$E_{Before} = E_{After} = Constant$$

$$E = KE + PE = Constant$$

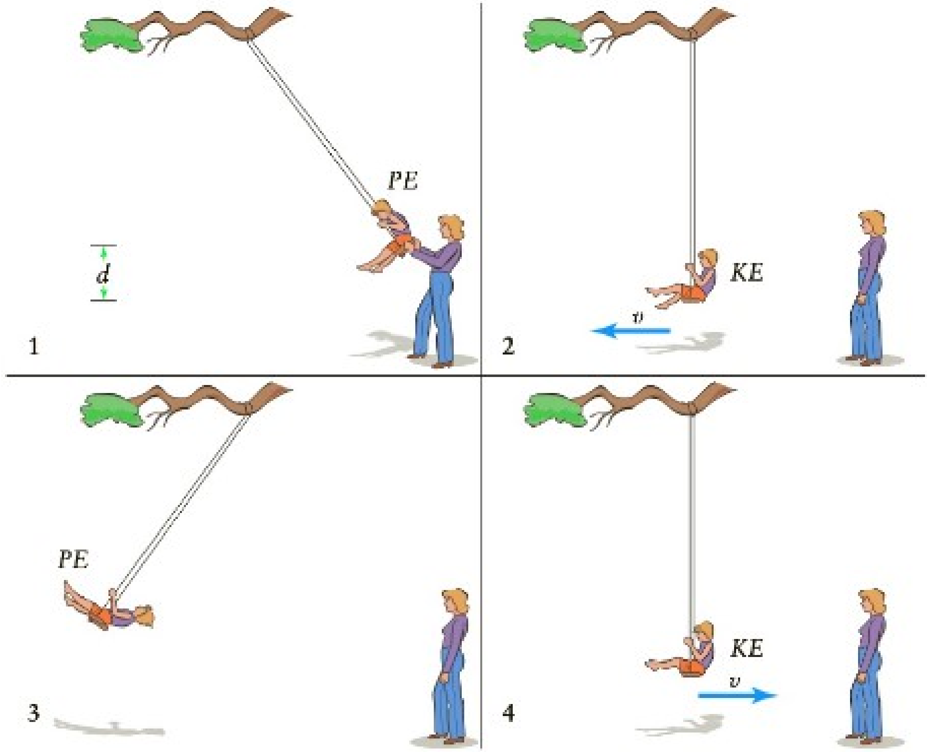
Note: that we have 4 states, applying Conservation of Energy means S1 = S2 = S3 = S4

We take lowest point to be a the reference point.

KE1 + PE1 = KE2 + PE2 = KE3 + PE3 = KE4 + PE4

Note:

State1,V=0, State2,d=0, State3,V=0, State4,d=0



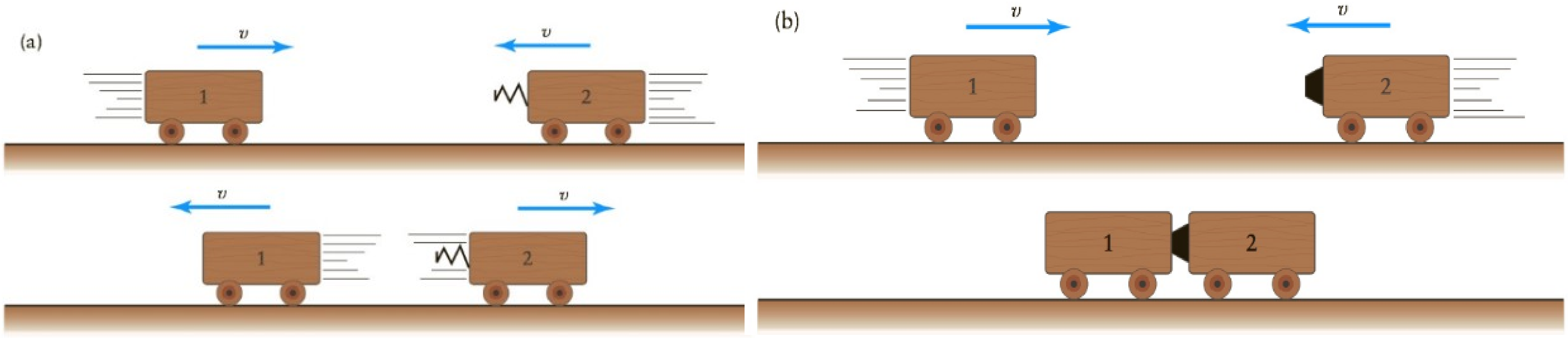
Practice – Potential Energy (lab and Exam)

A child on swing has a speed of 7.7 m/s at the low point of the arc (see sketch). How high will the swing be at the highest point?

Collision: Energy Perspective

Elastic Collision: is one in which the Total KE of the colliding bodies after the collision **equals** the Total KE before the collision.

Inelastic Collision: is one in which the Total KE of the colliding bodies after the collision is **NOT equal** the total KE before the collision. The TKE after could be greater or less than TKE before



Power

Power: The rate of doing work.

The rate at which energy transformed.

$$P = \frac{Work}{\Delta t}$$

Since work and energy are related, the power is either

- Work divided by time, or,
- Energy divided by time

$$P = \frac{Energy}{\Delta t}$$

And so the units follow

Common day terminology could be misleading

Have you ever felt tired and thought you overworked?

It is not because of work it is indeed the work or energy divided by time.

Units: Watts, (J/s)

Practice - Work

In Examples 2.2 and 3.5, we computed the acceleration, force, and work for a 1,000-kilogram car that goes from 0 to 27 m/s in 10 seconds. Let us now determine the required power output of the engine.

Practice - Work

An elevator is able to raise 1,000 kg to a height of 40 m in 15 s. (a) How much work does the elevator do? (b) What is the elevator's power output?

Summary

- **Conservation laws** are powerful tools for analyzing physical systems, particularly those in mechanics. Their main advantage is that it is not necessary to know the details of what is going on in the system at each instant in time to apply them effectively.
- The use of conservation laws is based on a "before-and-after" approach: the total amount of the conserved physical quantity *before* an interaction is equal to the total amount *after* the interaction.
- **Linear momentum, energy,** and **angular momentum** are physical quantities that are defined and used mainly because they are conserved in isolated systems.
- The main application of the **law of conservation of linear momentum** is to collisions. The total linear momentum before a collision equals the total linear momentum after the collision, if the system is isolated. This applies to all collisions, both elastic and inelastic.
- **Work** is done whenever a force acts through a distance in the same direction as the force.
- To be able to do work, a device or a person must have **energy**. The act of doing work involves the transfer of energy from one thing to another, the transformation of energy from one form to another, or both.
- In mechanics, the main forms of energy are **kinetic energy, potential energy,** and **internal energy**. There are many other forms of energy corresponding to different sources of work. Any form of energy can be used to do work if a suitable conversion device is available.

An updated version is pending.