Chapter 3: Nature of Dynamic Forces

At the end of the lesson, students should be able to:

- Define Mass, Force, Torque, Inertia, Work, Power, Energy
- Explain energy conversion, efficiency and heat generated
- State the conservation of energy
- Understand momentum
- Define Impulse
- Understand friction and its importance
- Understand Gears
- Understand aerodynamic designs of cars
- Energy calculation for electric car

3.1 Introduction

Dynamic is concerned with the study of forces and torques and their effect on motion, as opposed to kinematics, which studies the motion of objects without reference to its causes.

Dynamic force can be closely described as amount of acceleration/velocity needed to move an object. The energy from an action increases or decreases by the process.

The two minutes' video from YouTube will clearly demonstrate the difference between static and dynamic forces.

https://www.youtube.com/watch?v=wZCFo3Lcbx8

(a) Mass

The amount of matter contained in an object is known as mass. Mass of an object remains the same at all times and at all places. Mass is a scalar quantity. The SI unit of mass is Kilograms.

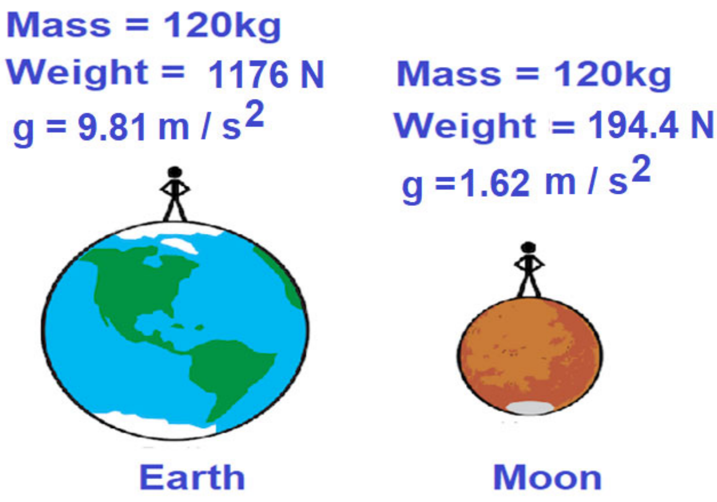


Figure 3:1: Mass is unchanged

Figure 3:1: Mass is unchanged

(b) Force

As stated in chapter 1, a force is a pull or a push. Force can do work.

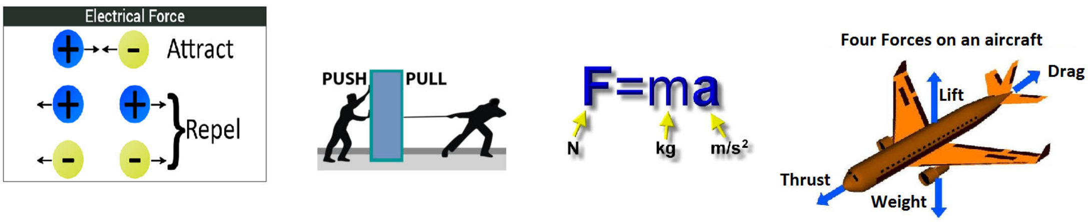
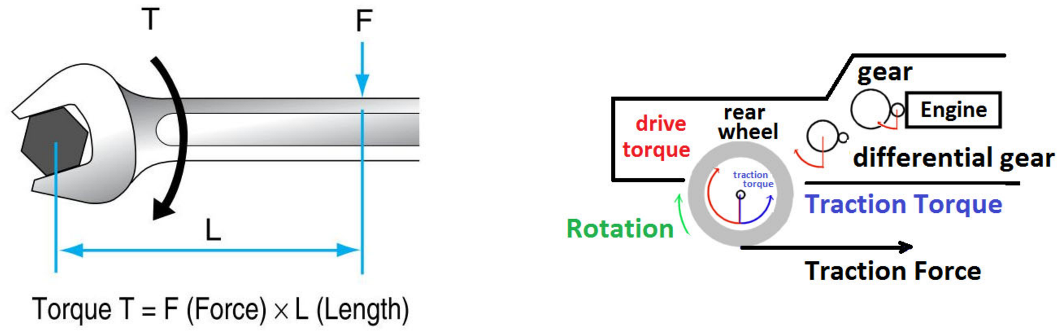


Figure 3.2: Forces

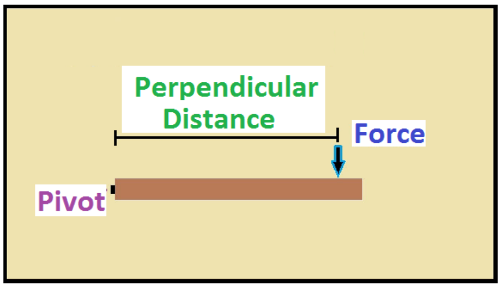
(c) Torque



(a) Torque applied by a spanner

(b) Torque experienced by a car

Figure 3.3: Torque



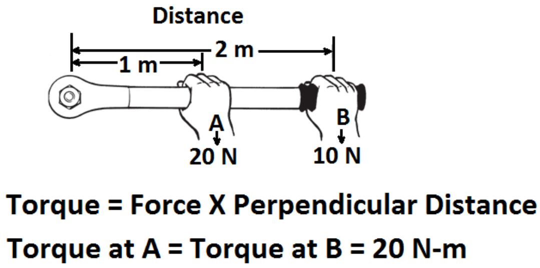


Figure 3.4: Torque = F x Distance in N-m

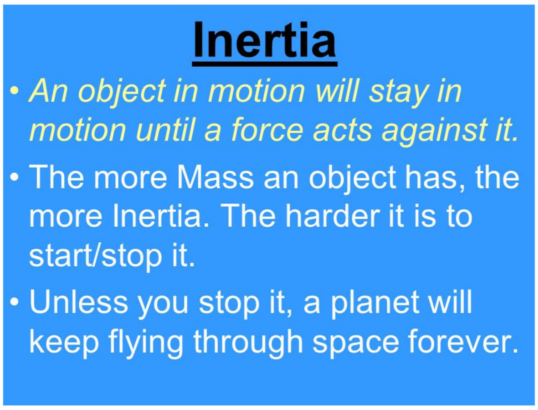
(d) Inertia

Newton's first Law states that an object will remain at rest or in uniform motion in a straight line unless acted upon by an external force. This property of an object is also known as "inertia" i.e. sluggishness or inactivity. Newton's first law is also referred as "law of inertia".

Every object resists change in velocity.

A body moves with acceleration only when it is acted by external net force. The amount of acceleration i.e. rate of change in velocity for a given net force is different for different mass of the bodies.

For example, a car travelling at 100 km per hour will not stop immediately when you let go of the accelerator. Due to inertia, the car will continue to move until frictional force or when it crashes into an object and stops.



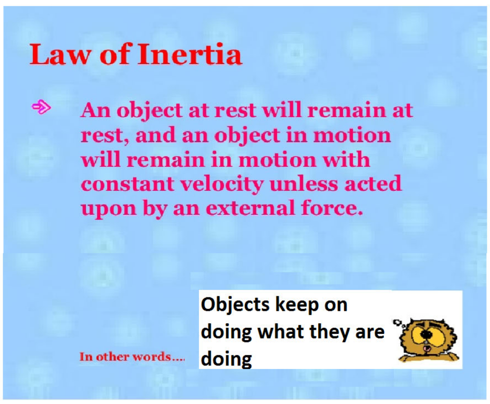


Figure 3.5: Inertia

https://www.youtube.com/watch?v=YbWjx3LUc0U&list=PLmdFyQYShrjcoTLhPodQGjtZKPKlWc3Vp&index=12

(e) Work

Work is a common term, which is widely used in our daily life as a measure of human effort in completing a task. In physics, work involves displacement (not distance). Second, work is done by the component of external force in the direction of displacement.

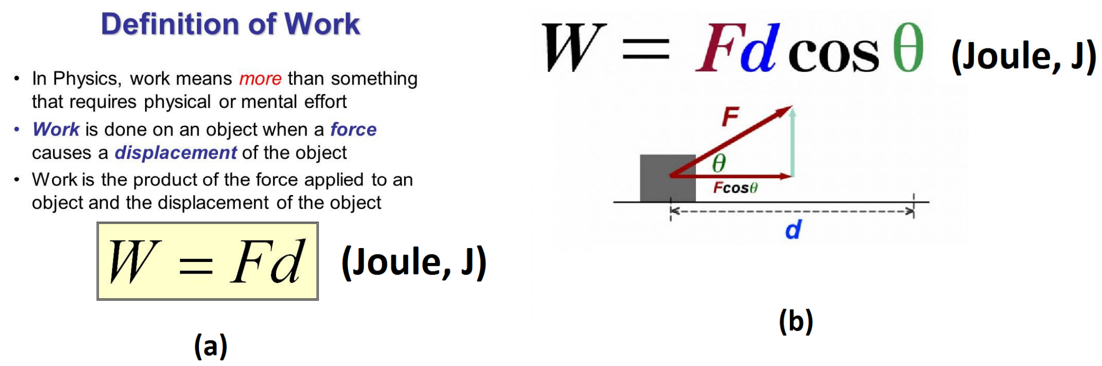


Figure 3.6: Work

https://www.youtube.com/watch?v=zVRH9d5PW8g

(i) Work by a constant force

When applied force on the particle is constant, then work is defined as the product of two quantities (i) scalar component of force in the direction of displacement and (ii) magnitude of displacement. Work is a scalar. From Figure 3.6,

$$W = Fd\cos\theta \quad \text{(N-m or Joule, J)}$$

Work involves two vector quantities: force and displacement. However, work itself is a signed scalar quantity. Sign of work may be either positive or negative, depending on the angle between force and displacement vectors. Alternatively, if the component of force is in the direction of displacement, then work is positive; otherwise negative.

(ii) Work done by a system of forces

The particle under consideration may be subjected to more than one external force. In that case, if we have to find the work by the system of force, then we can adopt either of two approaches:

(i) Approach 1 : Determine the net (resultant) force. Then, compute the work.

$F = \sum F_i$

$W = F\ r \cos\theta$

(ii) Approach 2 : Compute work by each individual external force. Then, sum the works to compute total work.

$W_i = F_i\ r_i \cos\theta_i$

$W = \sum W_i$

Either of two methods yield the same result.

Example 3.1

A force of 250N is used to push a 70 kg crate a distance of 3 m across a level warehouse floor.

(a) How much work is done?
(b) What is the change in crate's potential energy?

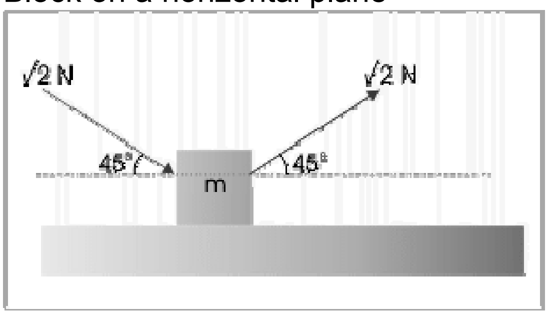
(a) W= 250 x 3 =750 J

(b) No change in potential energy as the crate moves horizontally.

Example 3.2

A block moves by 10 m on a smooth horizontal surface. The forces acting on the block are as shown in the Figure 3.7. Find the work done (J) by the force on the block.

Block on a horizontal plane



The net force on the object is: $2\sqrt{2}\cos 45 = 2N$

Work done = 2 x 10 = 20 J

Figure 3.7

Example 3.3

A particle moves from point A to B along x - axis of a coordinate system. The force on the particle during the motion varies with displacement in x-direction as shown in the Figure 3.9 below. Find the work done by the force.

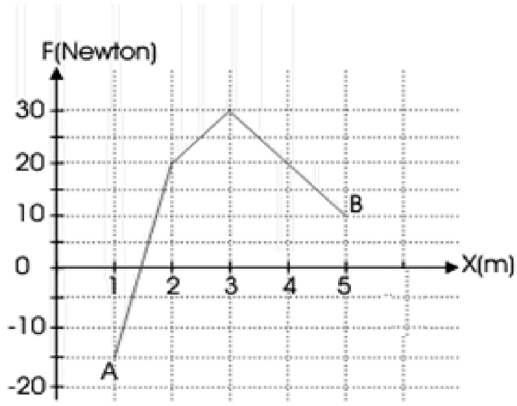


Figure 3.9: Work by Variable Force

The work done by the force is the area between plot and x-axis.

Area above x-axis is :

(½ x 0.5 x 20) + (½ x 1x 50) + (½ x 2x 40) = 70 Sq. units

Area below x-axis is : (½ x 0.5 x 15) = 3.75 Square units

Therefore, net area is (70 – 3.75) = 66.25 Sq. units.

Therefore work done by the force =Net area = 66.25 J

(f) Power

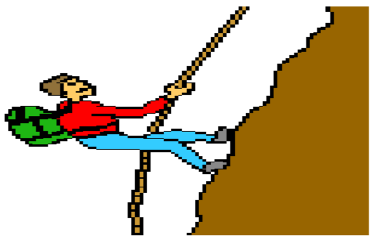
Power is the rate of doing work or the rate of using energy.

$$\text{Power} = \frac{\text{Workdone}}{\text{Time taken}} = \frac{\text{Force X Displacement}}{\text{Time taken}} \qquad \text{(Watts, W)}$$

$$= \text{Force X} \frac{\text{Displacement}}{\text{Time taken}} \qquad \text{(Watts, W)}$$

$$= \text{Force X Velocity} \qquad \text{(Watts, W)}$$

$$= \frac{\text{Energy Transferred (Joule, J)}}{\text{Time taken}} \qquad \text{(Watts, W)}$$



Rock climbers do a lot of work at a slow rate. Hence, their power is small.

Figure 3.10: Power

3.2 Energy, Energy Conversion, Efficiency and Heat

Energy is the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, solar, wind, light, heat, mechanical, gravitational, electrical, sound, or atomic energy and so on. Each form can be converted or changed into the other forms. This process is called energy conversion.

Total Input Energy = Useful Energy + Energy converted to other form + Energy Wasted

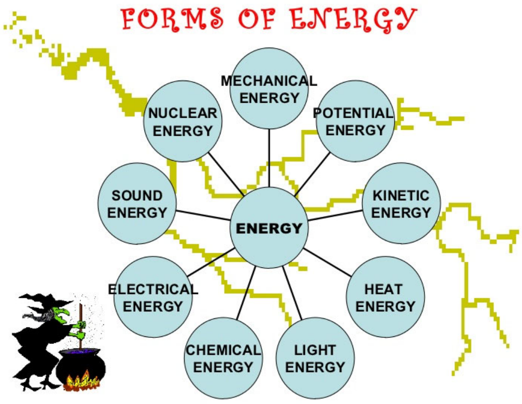


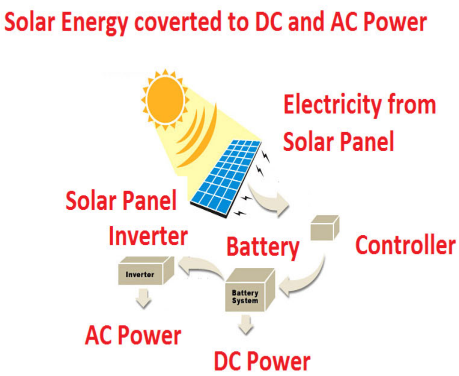
Figure 3.11 : Different types of Energies

https://www.youtube.com/watch?v=H6D_ViW0Ch4

(a) Energy transformation or conversion

The process of converting energy from one form into another is called energy transformation or conversion. In physics, energy is a quantity that provides the capacity to perform work (e.g. lifting an object).

In another example, an internal combustion engine of a car burns gasoline to create pressure that pushes the pistons; thus, performing work in order to accelerate your vehicle, ultimately converting the fuel's chemical energy to your vehicle's additional kinetic energy corresponding to its increase in speed.



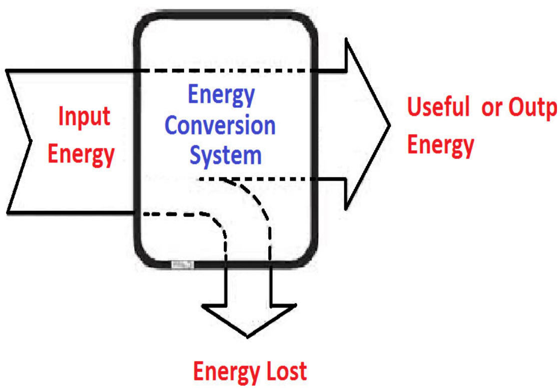


Figure 3.12 : Example of a Typical Energy Conversion

(b) Efficiency

Efficiency is a measure of how much work or energy is conserved in a process. In many processes, work or energy is lost, for example as waste heat or vibration. The efficiency is the energy output, divided by the energy input, and expressed as a percentage. A perfect process would have an efficiency of 100%.

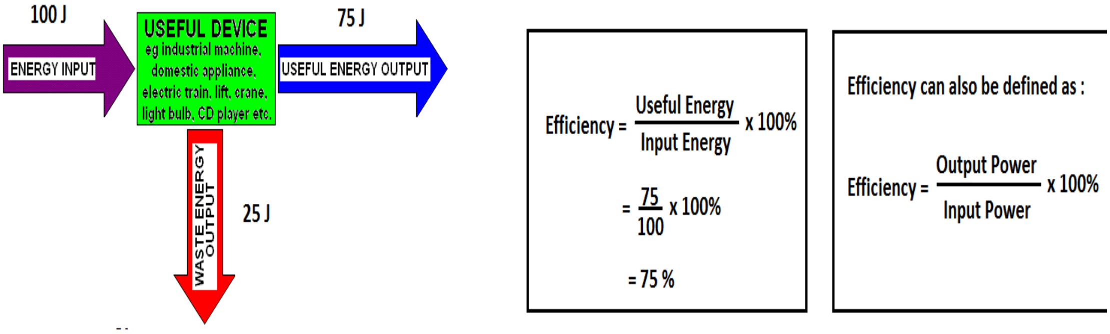


Figure 3.13 : Efficiency

https://www.youtube.com/watch?v=7hcv_mxcA-g

(c) Heat

Heat is a form of energy associated with the movement of atoms and molecules in any material. The higher the temperature of a material, the faster the atoms are moving, and hence the greater the amount of energy present as heat.

Heat is also a form of energy that can be transferred from one object to another when the two objects are at different temperature. Heat is also created at the expense of the loss of other forms of energy. For example, when electricity lights up a bulb, light is useful energy while heat is unwanted or wasted energy.

Temperature is the measure of hotness or coldness of matter. Stated another way, temperature is the average kinetic energy per molecule of a substance.

https://www.youtube.com/watch?v=_5AZwrTkQNA

3.3 Conservation of Energy

Conservation of Energy principle states that "Energy can neither be created nor destroyed". Another approach is to say that the total energy of an isolated system remains constant.

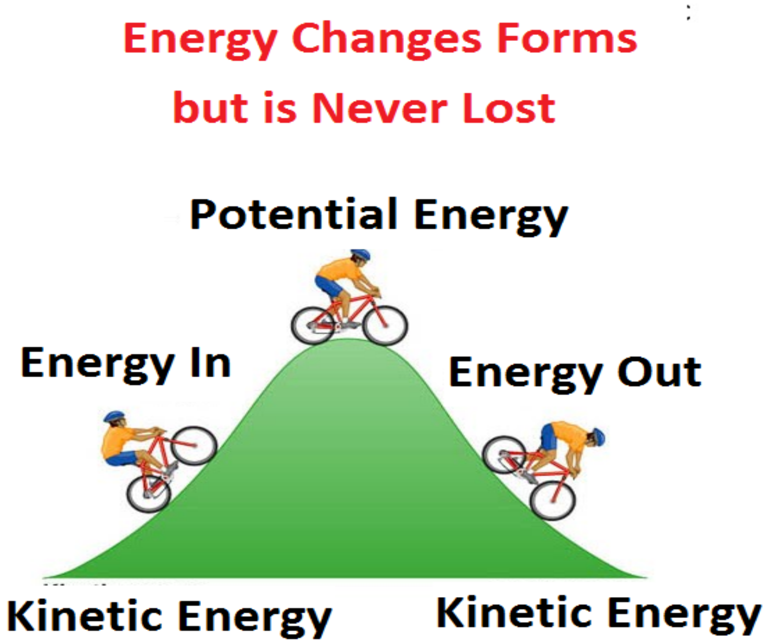


Figure 3.14: Conservation of Energy

https://www.youtube.com/watch?v=OTK9JrKC6EY

(a) Potential Energy

Potential energy is energy which results from position or configuration. An object may have the capacity for doing work as a result of its position in a gravitational field (gravitational potential energy), an electric field (electric potential energy), or a magnetic field (magnetic potential energy). It may have elastic potential energy as a result of a stretched spring or other elastic deformation. Refer to Figure 3.14 and Figure 3.15.

Potential Energy = mgh (mass X gravity x height)

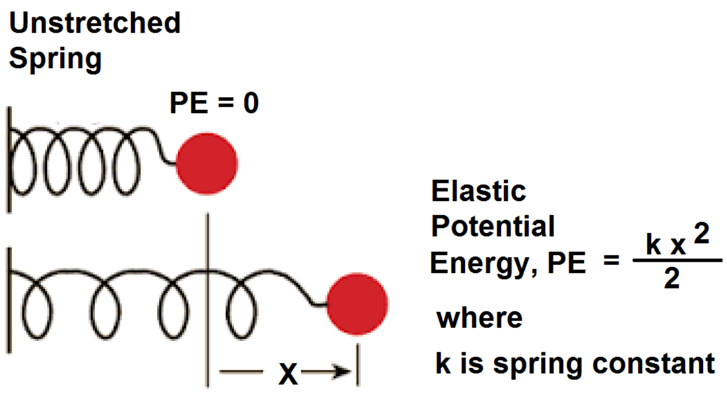


Figure 3.15: Potential Energy

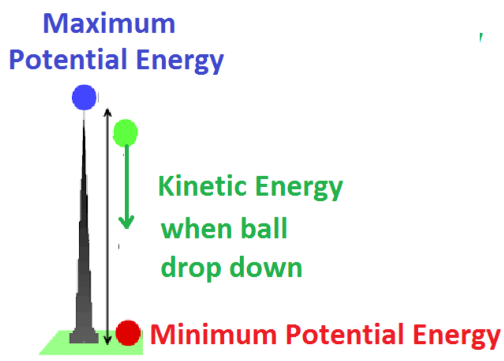


Figure 3.16: Potential Energy

https://www.youtube.com/watch?v=g7u6plfUVy4