Example 3.4

(a) How much work is done in raising a 2-kg book from the ground to a height of 1.5 m?
(b) How much potential energy does the book have in its new position?

(a) W = F x d = 2 x 9.8 x1.5 = 29.4 J
(b) P.E. = mgh =2x9.8x 1.5 = 29.4 J

Example 3.5

A man uses a horizontal force of 200N to push a crate up a ramp 8 m long that is 20^0 above the horizontal.

(a) How much work does the man perform?
(b) If the man takes 12 s to push the crate up the ramp, what is his power output in watts?

(a) W = 200 x 8 x cos20° = 1503.51 J

(b) P = energy/time = 1503.51 / 12 = 125.29 W

(a) Kinetic Energy

The kinetic energy of an object is the energy it possesses because of its motion. The kinetic energy of a point mass m is given by

$$\text{Kinetic Energy} = \frac{1}{2} mv^2$$

Kinetic energy quantifies the amount of work the object could do because of its motion. The total mechanical energy of an object is the sum of its kinetic energy and potential energy.

$$\textbf{Total Energy = Kinetic Energy + Potential Energy}$$

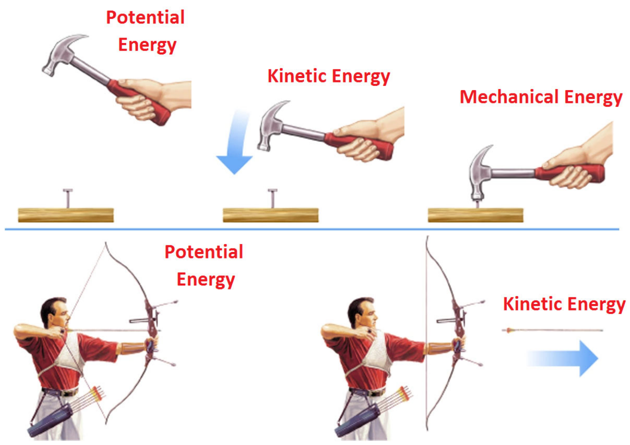

Figure 3.17: Potential and Kinetic Energy

Example 3.6

A cargo weighing 2500 kg broke free from the top of the cargo ramp as shown in Figure 3.18. Ignoring friction, determine the velocity of the cargo the instant it reaches the bottom of the ramp.

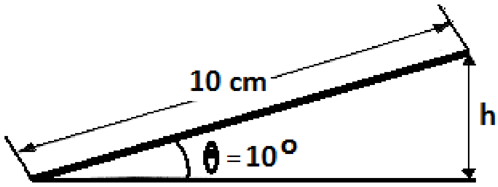

Figure 3.18

h = 10 sin 10 = 1.74 m . P.E. = mgh = 2500 x 9.8 x 1.74 = 42630` J

P.E. = K.E. = (1/2) mv^2

42630 = (1/2) (2500) v^2

Therefore, v = 5.84 m/s

Example 3.7

A hammer with a 1.3 kg head is used to drive a nail into a wooden board. If the hammer is moving at 5m/s when it strikes the nail and the nail moves 1.2 cm into the board, find the average force the hammer exerts on the nail.

K.E. of hammer = work done on the nail

$\frac{1}{2} mv^2 = F \times d$

$(1/2) \times 1.3 \times 5^2 = F \times 1.2 \times 10^{-2}$

F = 1354N

3.4 Understand Momentum

The momentum of a particle is defined as the product of its mass times its velocity. Momentum is a vector. The most common symbol for momentum is p.

Linear momentum **p = mv** kg m/s

The momentum of a system is the vector sum of the momenta of the objects that make up the system. It is subjected to the principle of conservation of momentum.

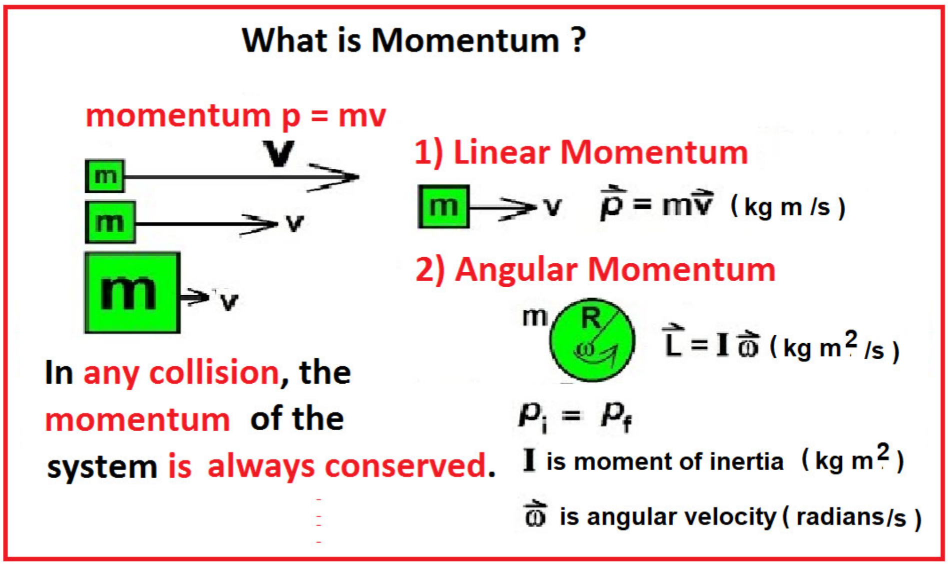

Figure 3.19: Momentum

https://www.youtube.com/watch?v=F8DnNqBhUfQ

Conservation of Momentum

The momentum of an isolated system is a constant. The vector sum of the momenta, p, and mv of all the objects of a system cannot be changed by interactions within the system.

If the momentum of one part of the system is increased, then the momentum of some other part or parts of the same system must decrease, so that the total momentum remains unchanged.

Another way of stating conservation of momentum is:

Initial Momentum = Final momentum.

https://www.youtube.com/watch?v=ZU6rJQTz7FI

Here initial and final refers to before and after collision of objects. See Figure 3.20.

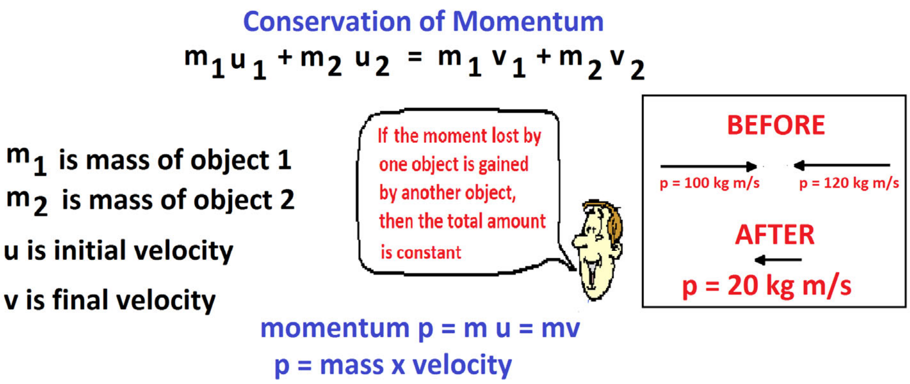

Figure 3.20: Conservation of Momentum

https://www.youtube.com/watch?v=hkaTXiEfTbo (Conservation of momentum video)

Example 3.8

A 16 g mass is moving in the + x direction at 30 cm/s while a 4 g mass is moving in the – x direction at 50cm/s. They collide head on and stick together. Find their velocity after the collision.

Initial momentum = (16 x 30) + (4x (-50)) = 280 g cm/s

Final momentum = (16+ 4) v = 20 v g cm/s.

Therefore, 280 = 20 v

Therefore, v = 14 cm/s in the + x direction.

Example 3.9

A 0.5 kg snowball moving at 20 m/s strikes and sticks to a 70 kg man standing on the frictionless surface of a frozen pond. What is the man's final velocity?

Initial momentum = 0.5 x 20 = 10 kg m/s

Final momentum = (70 + 0.5) x v kg m/s

10 = 70.5 v

Therefore, v = 0.142 m/s

3.5 Impulse of Force

Impulse, I, is a vector quantity **defined** as the product of the force acting on a body and the time interval during which the force is exerted. The unit of **impulse** is the same as the unit of momentum.

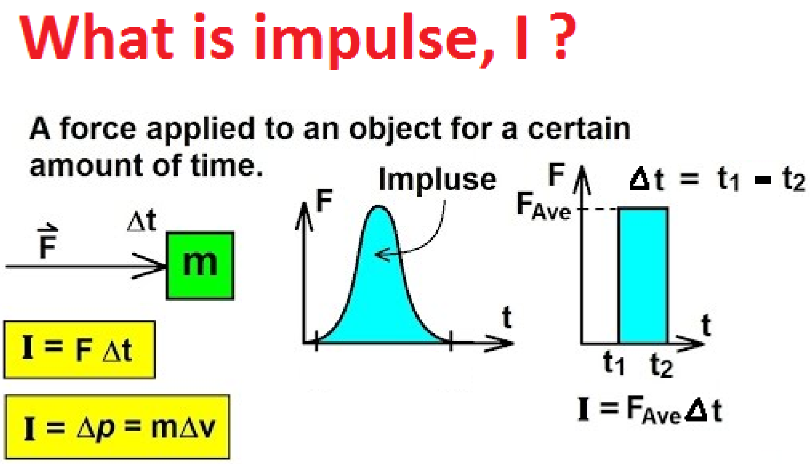

Figure 3.21: Impulse, I

From Newton's second law

$$F_{average} = ma_{average} = m\frac{\Delta v}{\Delta t}$$

$$F_{average} \;\; \Delta t \;\; = \;\; m \; \Delta v$$

Impulse = Change of momentum

https://www.youtube.com/watch?v=E13h1E_Pc00

Example 3.10

A certain solar car has a mass of 500 kg and travelling at velocity of 70 km/hr. Its engines develop a total thrust of 700N. If air resistance is ignored, how long does this solar car takes to reach its velocity starting from rest?

70 km/hr = 70 x 1000/3600 = 19.44 m/s

Change in momentum = 500 (19.44-0) = 9720 kg m/s

Impulse, I = Change in momentum

700 x t = 9720

Therefore, t = (9720 / 700) = 13.89 s.

Example 3.11

A 1200 kg solar car strikes a fence at 10 m/s and comes to a stop in 1 s. What average force acted on the car?

Change in momentum = 1200 (0 – 10) kg m/s = -12000 kg m/s

Impulse = Change in momentum

F x 1 = -12000

Therefore, F = -12000N

The minus sign indicates that the force that acted to stop the car is in the opposite direction to its initial velocity.

Example 3.12

A 0.25 kg ball moving in the + x-direction at 13m/s is hit by a bat. It's final velocity is 19 m/s in the –x-direction. The bat acts on the ball for 0.010 s. Find the average force F exerted on the ball by the bat.

Change in momentum = 0.25 x (-19-13) = - 8 kg m/s

Impulse = Change in momentum

F x 0.010 = -8

F = - 8 / 0.010 = - 800N

3.6 Friction and its importance

Friction is the force that opposes the relative motion between the two surfaces of objects in contact. The surfaces could be solid, liquid or gases. The force of **friction** always acts in the direction opposite to that of the applied force.

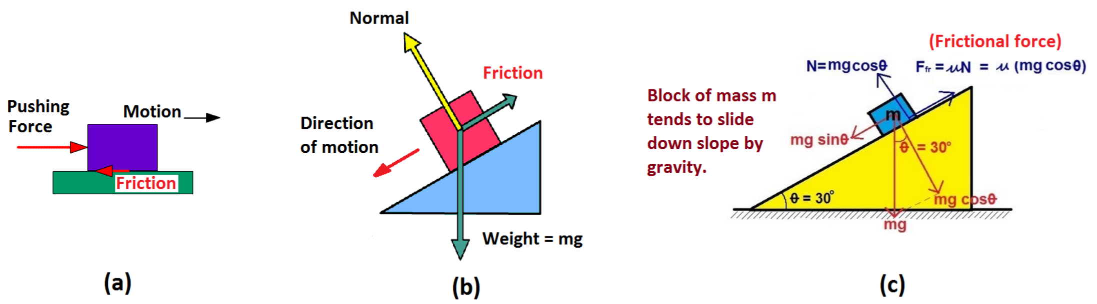

Figure 3.22: Friction resisting motion of an object

https://www.youtube.com/watch?v=n2gQs1mcZHA

Mathematically,

$$\textbf{Friction} = \mu N$$

Where N is the normal force and μ is the coefficient of friction.

There are two coefficients of friction, namely

u_s = coefficient of **static friction**

u_k = coefficient of **kinetic friction**

The frictional force is proportional to the coefficient of friction. However, the amount of force required to move an object starting from rest is usually greater than the force required to keep it moving at constant velocity once it is started. Therefore, two coefficients of friction are sometimes quoted for a given pair of surfaces - a coefficient of static friction and a coefficient of kinetic friction. The force expression above can be called the standard model of surface friction and is dependent upon several assumptions about friction.

Static friction is a force that keeps an object at rest. It must be overcome to start moving the object. Once an object is in motion, it experiences kinetic friction. If a small amount of force is applied to an object, the static friction has an equal magnitude in the opposite direction.

Kinetic friction is a force that acts between moving surfaces. An object that is being moved over a surface will experience a force in the opposite direction as its move. The magnitude of the force depends on the coefficient of kinetic friction between the two kinds of material.

(a) Coefficients of Friction

Friction depends on the coefficient of friction,μ, and the normal force, R. That is , F = μR this case, the normal force, R, is the weight of the block. Typically, there is a significant difference between the coefficients of static friction and kinetic friction as shown in Figure 3.22.

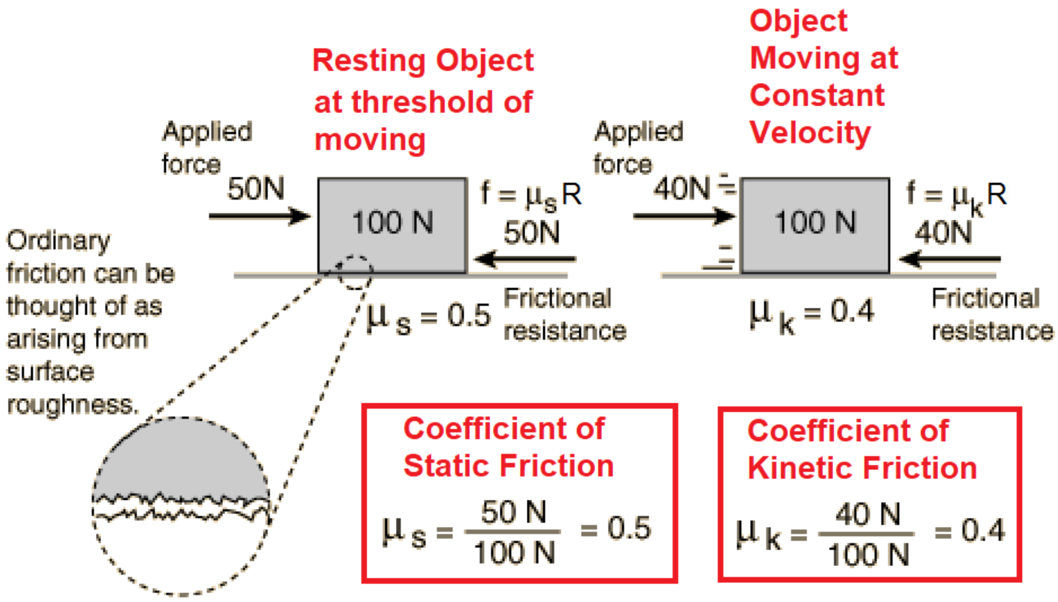

Figure 3.23: Coefficients of static friction and kinetic friction

Note that the static friction coefficient does not characterize static friction in general, but represents the conditions at the threshold of motion only.

(b) Normal Force

Frictional resistance forces are typically proportional to the force that presses the surfaces together. This force that will affect frictional resistance is the component of applied force that acts perpendicular or "normal" to the surfaces, which are in contact, and is typically referred to as the normal force. In many common situations, the normal force is just the weight of the object that is sitting on some surface, but if an object is on an incline or has components of applied force perpendicular to the surface, then it is not equal to the weight. Refer to Figure 3.23.

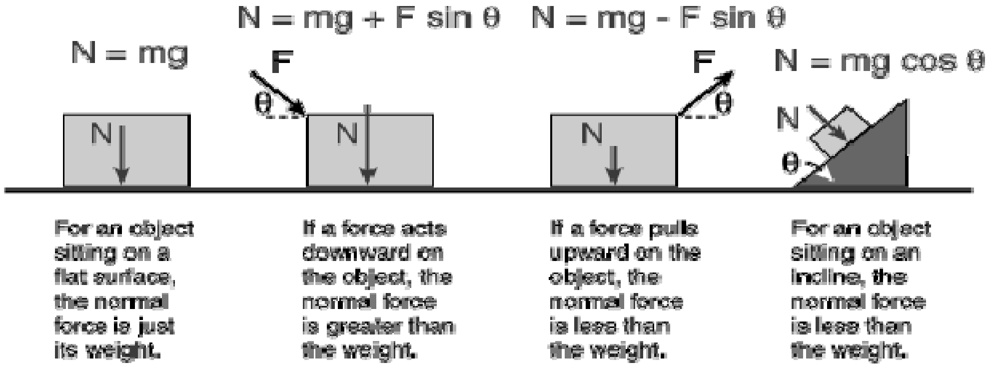

Figure 3.24:Normal Force of an object

The above cases are the commonly encountered situations for objects at rest or in straight-line motion. For curved motion, there are cases like a car on a banked curve where the normal force is determined by the dynamics of the situation. In that case, the normal force depends upon the speed of the car as well as the angle of the bank.

Example 3.13

How much force is needed to keep a 1500 kg car moving at constant velocity on a level concrete road? Assume that the car is moving too slowly for the air resistance to be important, and use μ_k = 0.04.

N = mg = 1500 x 9.8 = 14700N

$f_{friction}$ = μN = 0.04 x 14700 = 588N

Therefore, force needed is 588N.

Example 3.14

A force of 200N is just sufficient to start a 50-kg steel object moving across a wooden floor. Find the coefficient of the static friction.

N = mg = 50 x 9.8 = 490N

F = μN

200 = μ x 490

Therefore, μ = 200 /490 = 0.408

Example 3.15

A 50 kg wooden crate is being pushed across a wooden floor with a force of 200N.

If μ_k = 0.3, find the acceleration of the crate.

N = mg = 50 x 9.8 = 490N

$f_{friction} = \mu N$ = 0.3 x 490 = 147N

Net force acting on the crate = Applied force – Frictional force

= 200N -147N = 53N

53N = 50 kg x a

Therefore, a = 53/50 = 1.06 m /s^2

(c) Importance of Friction

Although you normally hear about trying to reduce or eliminate **friction**, it actually has some **important** uses. Since **friction** is a resistance force that slows down or prevents motion, it is necessary in many applications where you might want to hold items or do things and prevent slipping or sliding.

If a force tries to move an object at rest on a surface, the surface resists this motion with an opposing force of friction. We need friction to walk; if we did not have any friction, everything would be slipping and sliding away.

Friction also produces unnecessary **heat**. For example, car engines become hotter because of friction.

3.7 Understand Gears

There are four principal types of gears:
- **Spur gears**: The simplest type of gears.
- **Helical gears**: The teeth are inclined with respect to the axis.
- **Bevel gears**: The teeth are somehow similar to those of a.
- **Worm gears**: Transmit rotation between.

(a) Spur Gears (b) Helical Gears (c) Bevel Gears (d) Worm Gears

Figure 3.25 : The four Principal Types of Gears

(a) Spur Gears

Spur gears are cylinders or disks with radially projecting teeth that have straight edges and are aligned parallel to the axis of rotation. The **gears** are mounted on to parallel shafts so that the teeth can mesh and transfer motion and power. Sometimes, many spur gears are used at once to create very large gear reductions. With a **gear** reduction, the output speed can be reduced while the torque is increased.

(b) Helical Gears

Helical gears are one type of cylindrical **gears** with slanted teeth. A pair of **helical gears** has the same **helix** angle but the **helix** hand is opposite.

Commonly used in transmissions. They have larger contact ratio and excel in quietness and less vibration and able to transmit large force and carry heavy loads. Hence, they are used in transmission.

(c) Bevel Gears

Bevel gears are gears where the axes of the two shafts intersect and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are most often mounted on shafts that are 90 degrees apart, but can be designed to work at other angles as well. The pitch surface of bevel gears is a cone. Bevel gears are used to change the direction of a shaft's rotation. Bevel gears have teeth that are available in straight, spiral, or hypoid shape. For example, bevel gears are used as the main mechanism for a hand drill. As the handle of the drill is turned in a vertical direction, the bevel gears change the rotation of the chuck to a horizontal rotation.

(d) Worm Gears

A worm drive is a gear arrangement in which a worm meshes with a **worm gear.** The two elements are also called the worm screw and worm wheel. A worm gear system can reduce rotational speed or transmit higher torque. Another major advantage of **worm gear** drive units are that they can transfer motion in 90 degrees.

There are also other types of gears, who are modified from the principal types of gears. Some of them, which we will not study, are shown in Figure 3.25.

(a) Rack and Pinion Gears (b) Screw Gears (c) Herringbone Gears (d) Miter Gears

Figure 3.26: Other Types of Gears

3.8 Understand aerodynamic designs of cars

Automotive aerodynamics is the study of the aerodynamics of road vehicles. Its main goals are reducing drag and wind noise, minimizing noise emission, and preventing undesired lift forces and other causes of aerodynamic instability at high speeds. Air is also considered a fluid in this case.

Cars are getting ever-more aerodynamic. The magic figure is a car’s drag coefficient, Cd. The lower this is, the slipperier through the air it will be.

The less a body ‘drags’ through the air, the less energy it needs to keep it moving. With long-range electric cars on the horizon, and manufacturers under ever-greater pressure to cut the consumption of today’s cars, aerodynamics have never been more important. Examples of aerodynamic cars are:

- 2018 Mercedes-Benz A-Class Hatchback – 0.25 Cd....
- 2018 Ford Focus Saloon – 0.25 Cd....
- 2018 Mercedes-Benz C-Class Saloon – 0.26 Cd....
- 2018 Audi A6 – 0.26 Cd....
- 2014 BMW i8 – 0.26 Cd....
- 2017 Audi A8 – 0.26 Cd....

- 2016 Mazda 3 Saloon – 0.27 Cd....
- 2018 Ford Focus Hatchback – 0.275 Cd.

To improve Cd, designers may make the following changes:

- Round the edges of the front end.
- Tune the grille and fascia openings.
- Tune the wheel openings.
- Place spats (small spoilers) in front of the tires to reduce turbulence.
- Tune the size and shape of the outside mirrors and their attachment arms.

3.9 Energy calculation for electric car

https://www.youtube.com/watch?v=r6RTJd_i6xY

https://www.youtube.com/watch?v=WEGjFjCOWB8

Acknowledgement:

. Images, pictures and photo from Google Images
. Information from Google search and Wikipedia
. Video from YouTube