NEW ZEALAND
MARITIME SCHOOL

STCW 1978 III/2
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MECHANICAL TECHNOLOGY 1

COURSE CODE: 942. 594

ELEMENT 3: DYNAMICS

MASS ACCELERATING FORCE

Chapter 4

Dynamics

4.1 Mass Accelerating a Force

Mass is the quantity of matter possessed by a body and is proportional to the volume and the density of the body. ***Mass*** is a constant quantity, the mass of the body can only be changed by adding on it of taking away from it? The abbreviation for mass is $[m]$and its unit is$[kg]$. Large masses in marine work are common and these measured in *megagrammes*$[Mg.]$.

One Megagrammes =10^3 $\boldsymbol{kilograms}$ and called 1 $\boldsymbol{tonne[t]}$

Mass can be accelerated or retarded by an applied force. When accelerated then this unit is known as force and is called ***Newton***$[N.]$. Hence one newton of force acting on one kilogram of mass will give it acceleration of one meter per second per second. Therefore.

Acceleration force$[\boldsymbol{N}]$**= mass**$[\boldsymbol{kg}]$ $\times$ **acceleration** $\left[\boldsymbol{m/s^2}\right]$

In Symbols: ***F = ma***

This is also known as Newton's first law, because it can be applied to find the downward force acting on an object due to gravity.

4.2 Definition of gravity:

Gravity is that force that pulls the object to the earth. Gravity is proportional to the mass of the body. The acceleration due to gravity is common for all masses of a certain place, but varies from place to place. If a body is allowed to fall freely, it will fall with an acceleration of 9.81 m/s^2

Use ***gravitational*** acceleration, ***g = 9.81 m/s***$^{\mathbf{2}}$for calculation.

Gravitational force = mass x gravitational acceleration

= *mg*

Where ***m*** = mass in ***kg***

g = 9.81 m/ s$^{\mathbf{2}}$

Example*:*

Calculate the force exerted on a mass of 50kg due to gravity.

Solution. Gravitational force = *mg*

= 50 x 9.81

= 490.5 N

Gravitational acceleration is introduced only where gravity is involved.

Determining mass and weight:

All ordinary weighing instruments, i.e. a spring balance, determine the mass of the object. The weight of an object is normally used in engineering. The weight of an object can be determined by using a spring balance that is calibrated in Newton.

Weight $[\boldsymbol{N}]$ **= mass** $[kg] \times \boldsymbol{g}\ [m/s^2]$

Inertia: is the property possessed by matter by which it resist change of motion, and it depends upon its mass, if the mass is already moving it requires a force to change its velocity or to change its direction, again the force required being proportion to the mass.

4.2 Newton's laws of motion:

The laws that connect motion and force are summarized as Newton's 3 laws:

(1) Every body contains in its state of rest, or uniform motion in a straight line, unless acted upon by an external force.

(2) Rate of change of momentum is proportional to the force applied and takes place in the direction in which the force acts.

(3) To every action there is a reaction, equal in magnitude and opposite direction.

Example:

Find the accelerating force required to increase the velocity of a body which has a mass of 20 kg from 30 m/s to 70 m/s in 4 seconds.

Solution:

$$\text{Acceleration} = \frac{\textbf{changeofvelocity}}{\textbf{TimetoChange}}$$

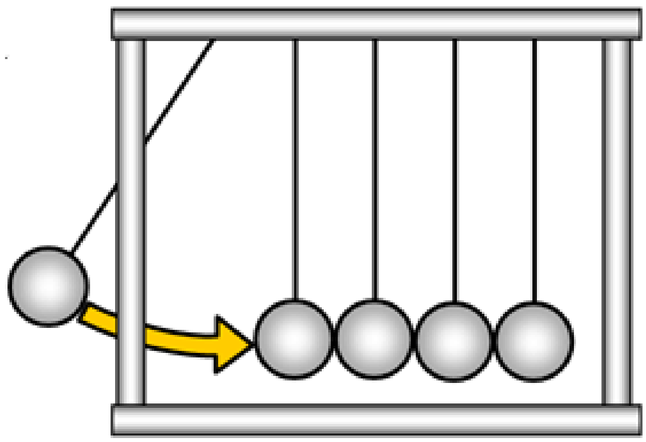
$$= \frac{\mathbf{70-30}}{\mathbf{4}}$$

$$= 10\ m/s^2$$

Acceleration Force [N] = mass [kg] x acceleration [m/s^2]

= 20 x 10 = **200 N Ans.**

4.3 Momentum.



Momentum can be defined as "mass in motion." All objects have mass; so if an object is moving, then it has momentum - it has its mass in motion. The amount of momentum that an object has is dependent upon two variables: how much ***stuff*** is moving and how fast the ***stuff*** is moving. Momentum depends upon the variables ***mass*** and ***velocity***. In terms of an equation, the momentum of an object is equal to the mass of the object times the velocity of the object

Momentum = mass × velocity

In physics, the symbol for the quantity momentum is the lower case "p". Thus, the above equation can be rewritten as

p = m × v

Where ***m*** is the mass and ***v*** is the velocity. The equation illustrates that momentum is directly proportional to an object's mass and directly proportional to the object's velocity.

Express your understanding of the concept and mathematics of momentum by answering the following questions.

*1**. Determine the momentum of***

(i). 60-kg soccer player moving eastward at 9 m/s.

(ii) 1000-kg car moving northward at 20 m/s.

(iii) 40-kg man moving southward at 2 m/s.

Solution:

(i). $p = m \times v$ = 60 kg x 9 m/s

p = 540 kg.m/s, east

(ii). $p = m \times v$ = 1000 kg x 20 m/s

p = 20 000 kg.m/s, north

(iii). $p = m \times v$ = 40 kg x 2 m/s

p = 80 kg.m/s, south

If we substitute for acceleration its value, change of velocity divided by time, we get:

Acceleration Force = $\frac{\mathbf{mass \times change of velocity}}{\mathbf{time}}$

Or this can be written as:

Force × time = Change of momentum.

For a given change of momentum of a body free to move, the applied force varies inversely as the time taken. The product of the force and time is referred to as the ***impulse*** of the force.

Example:

The mass of the head of a hand hammer is 0.8 kg. When moving at 9m/s it strikes a chisel and is brought to rest in $\frac{1}{250}$ ***second. What is the average force of the blow?***

Solution:

Force $= \frac{\mathbf{change of momentum}}{\mathbf{time}}$

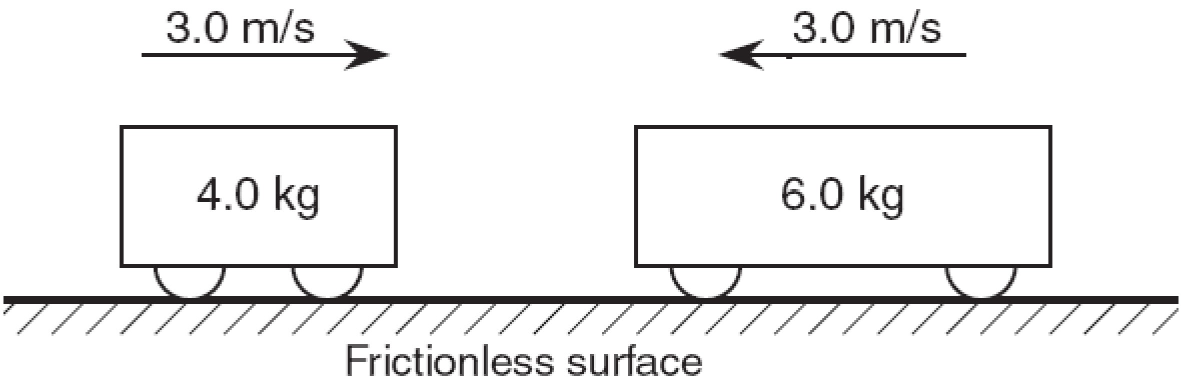
$= \frac{\mathbf{0.8x9}}{\mathbf{1/250}}$

= 0.8 x 9 x 250

= 1800 N *Ans.*

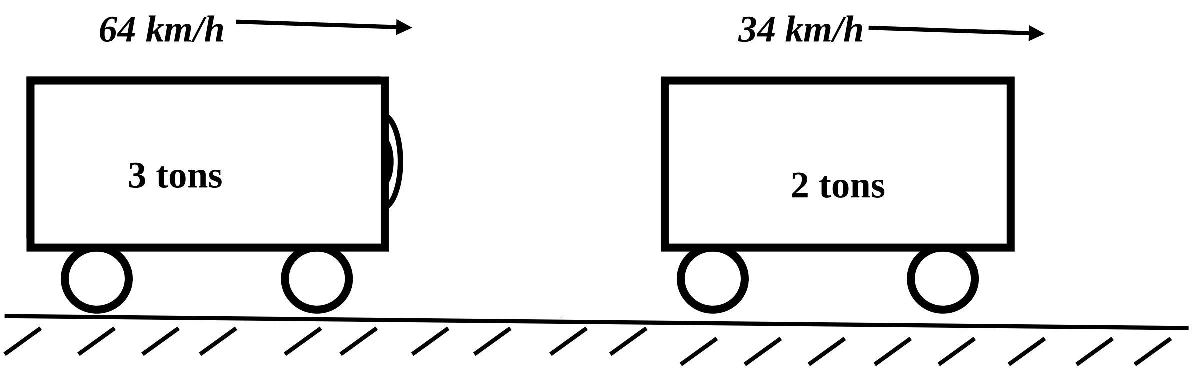
4.4 Conservation of Momentum

When two bodies collide, the force of one body on the other is equal in magnitude and opposite in direction and the time during which the force acts is the same, hence each body receives the same change of momentum.

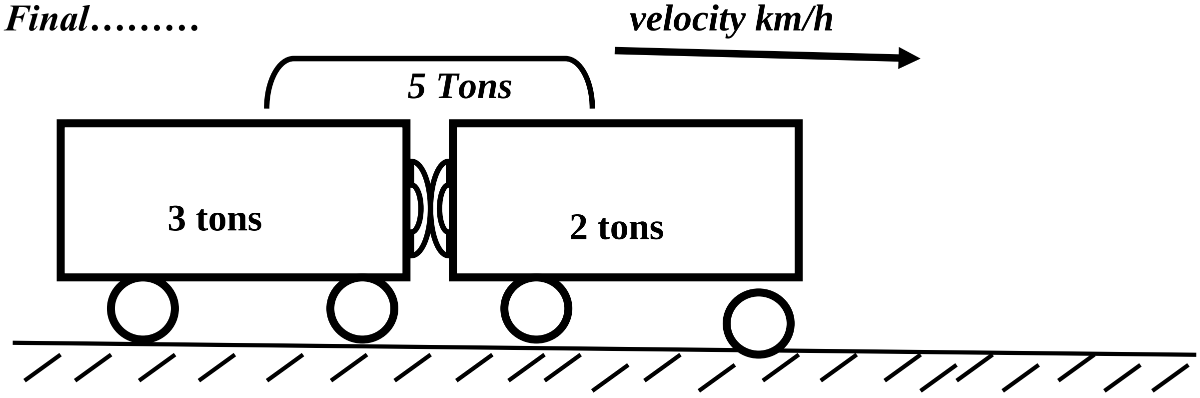


Example: ***A railway truck of mass 3 tons moving at 64 km/h collides with another of 2 tons mass at 34 km/h in the same direction, and they then move together as one unit. Find the velocity of the trucks after impact.***

(a) start………



(b) Final………



Solution (1): ***travelling in the same direction then;***

Momentum before impact = momentum after Impact

$$(3 \times 64) + (2 \times 34) = (3 + 2) \times V$$

$$192 + 68 = 5V$$

V = 52 km/h ans.

Solution (2) : ***if smaller truck was travelling in the opposite direction;***

Momentum before impact = momentum after Impact

$$(3 \times 64) + (2 \times -34) = (3 + 2) \times V$$

$$192 - 68 = 5V$$

V = 24.8 km/hans

Practice Problems – Conservation of Momentum

1. ***A 1.50 kg ball moving at 8.00 m/s south, strikes a 2.00 kg ball moving at 3.00 m/s south. If the velocity of the 2.00 kg ball after the collision is 4.50 m/s south, what is the velocity of the 1.50 kg ball?***

2. ***A 3.0 × 10^5 kg freight car moving at 2.5 m/s east, strikes a stationary 1.5 × 10^5 kg car. If the two cars end up connected to each other, what is their resulting velocity?***

Solution

1. **p (before) = p (after)**
   $ball_1 + ball_2 = ball_1 + ball_2$
   mv + mv = mv + mv
   (1.5) (8) + (2) (3) = (1.5) (v) + (2) (4.5)
   12 + 6 = 1.5 v + 9
   9 = 1.5 v
   v = 6.00 m/s south

2. **car + car = car +car**
   mv + mv = mv
   $(3.0 \times 10^5)\ (2.5) + (1.5 \times 10^5)\ (0) = 4.5 \times 10^5\ v$
   $7.5 \times 10^5 = 4.5 \times 10^5\ v$
   v = 1.7 m/s east

Example*:*

A bullet of mass 0.04 kg. is fired into a freely suspended and stationary block of wood whose mass is 13.6 kg and caused the wood to start moving at 1.9 m/s. Find the initial velocity of the bullet.

Solution:

Let *v* = initial velocity of bullet

Momentum before impact = Momentum after impact.

Mom. of bullet + Mom. of wood = Mom. of (wood and bullet)

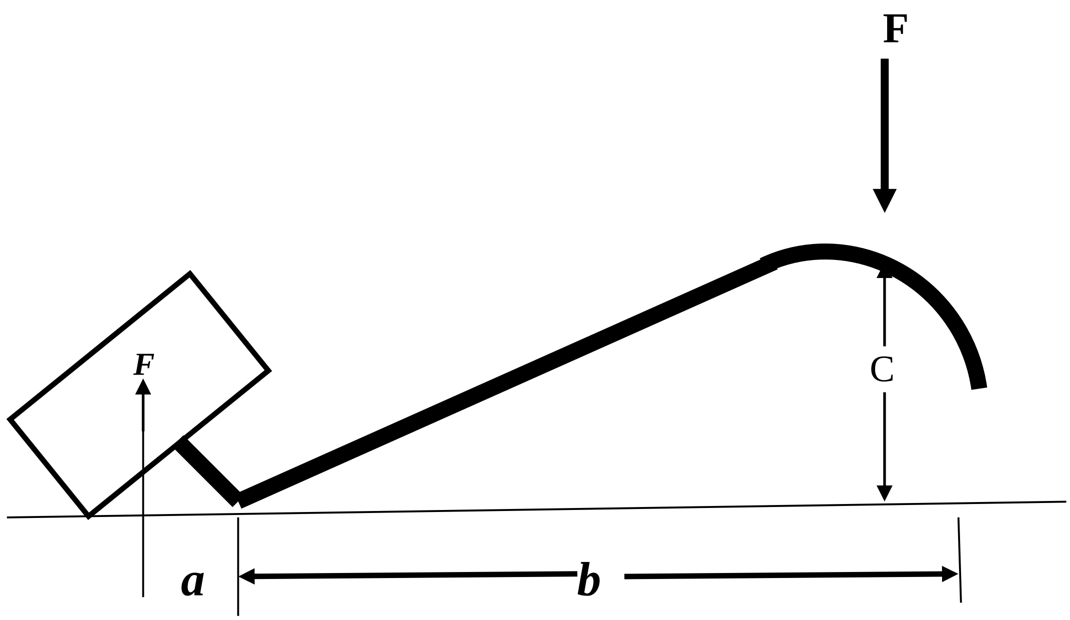
$$0.04 \times V + 13.6 \text{ x } 0 = (\ 0.04 + 13.6\ ) \times 1.9$$

$$V = \frac{13.64\ X\ 1.9}{0.04}$$

= 647.9 m/s Ans

4.5 Turning Moment:

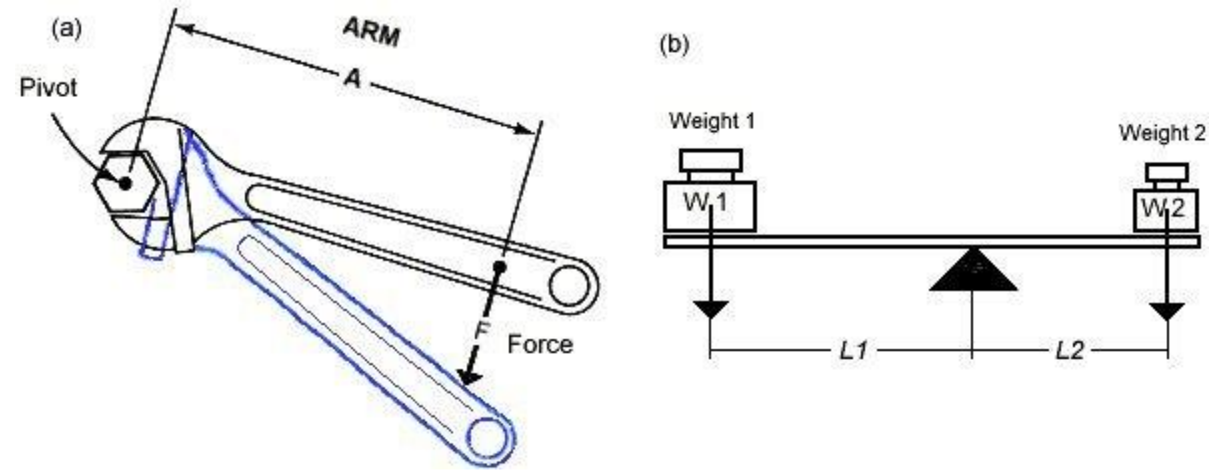
A machine is a device where force is applied at one end in order to obtain (liberate) force at another point. Machines normally make work easier. The force applied is usually called the ***Effort*** and the force overcome by the applied effort, is called the ***Load.***



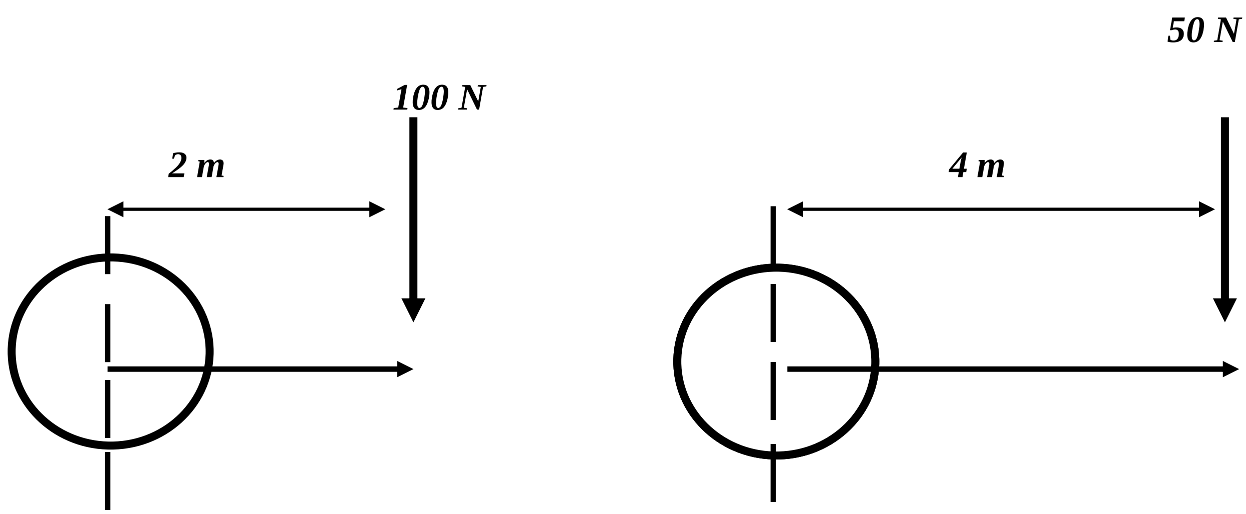
$$\mathbf{F}.\, b = f\, a$$

$$\therefore \quad f = \frac{F\, b}{a}$$

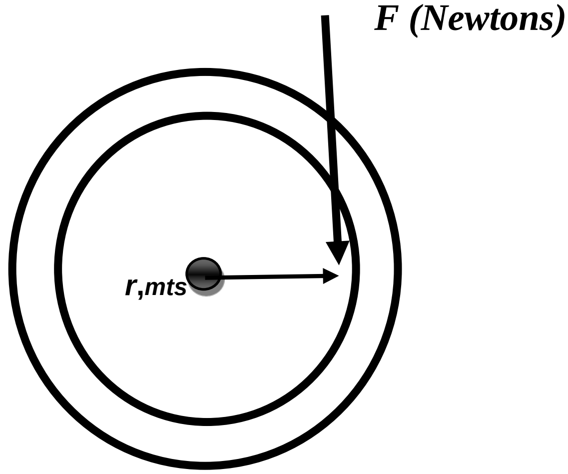
A lever, which consists of a rigid bar that can be turned around a fixed point, is one of the simplest of machines. The fixed point, about which the lever rotates, is called the fulcrum or the turning point. (***As shown above.)***



Assume that a force, as applied to the spanner in the above drawing. It is common knowledge that the full line of the force will tighten the nut when the grip of the spanner is at the end. The next example is when there is a bar placed with an off center support and two weights are placed on either side of different mass to bring it to equilibrium. This turning moment is called the ***moment of force.*** The turning effect of each force, as shown, is in the same direction as the movement of the hands of a clock and that is known as ***clockwise moments.*** If the direction of the forces were inverted then it will be known as ***anti-clockwise moments.***



Consider the turning moment on a rotating body, such as turning a shaft in its bearing, it is usually called *a* ***turning moment or torque.*** Now consider a thin rim of a flywheel of mean radius ***r*** meters. If the tangential force ***F*** **N** is applied to the rim, neglecting frictional resistances, the rim will accelerate and the acceleration can be found from:



Acceleration force = mass x acceleration.

This acceleration, however, is the ***linear acceleration*** of the rim and it has to be converted into terms of angular acceleration.

Now ***F*** **x *L* is the torque applied,** therefore,

Acceleration torque = m $\times \boldsymbol{r^2} \times \boldsymbol{\alpha}$

When a rotating mass is not a thin rim, such as a solid disc wheel, we imagine the whole mass of the wheel to be condensed into a heavy thin rim of such a radius that the whole rotating mass could be considered as concentrated there to have the same effect. This is called the ***Radius of Gyration*** and is represented by ***k*** to avoid confusion with radius of the wheel. Expressed as:

Acceleration torque = $\boldsymbol{mk^2\alpha}$

The mass of a body multiplied by the square of its distance from a given point is called the ***moment of inertia*** of the mass about that point and represented by the letter$\boldsymbol{I}$. $\boldsymbol{m} \times \boldsymbol{k^2}$

From *T* = $\boldsymbol{I\alpha}$ where ***T***= accelerating torque [N m]

I= moment of inertia = $\boldsymbol{mk^2}$ [kgm^2]

$\boldsymbol{\alpha}$= angular acceleration [rad/s^2]

Example.

The mass of a flywheel is 175 kg and its radius of gyration is 380 mm.Find the torque required to attain a speed of 500 rev/min from rest in 30 seconds.

Solution:

Angular acceleration = $\frac{\mathbf{500 \times 2\pi}}{\mathbf{60 \times 30}}$

$= 1.746\ rad/s^2$

Acceleration torque = $\boldsymbol{I\alpha}$

$= mk^2\alpha$

$= 175 \times 0.38^2 \times 1.746$

= **44.12 N m**. *Ans.*

Exercise example:

*1). **Calculate the accelerating force required to increase the velocity of a body of mass 50 kg, from 3m/s to 9m/s in 5 seconds………… (ans. 60 N)***

*2) **Find the extra thrust, in kilonewton, required to increase the speed of a ship 10,000 tones displacement, from 15 to 20 knots in 10 minutes, neglecting the increase of resistance due to increased speed. One knot = 1.852 km/h……….. (ans. 42.86 Kn.)***

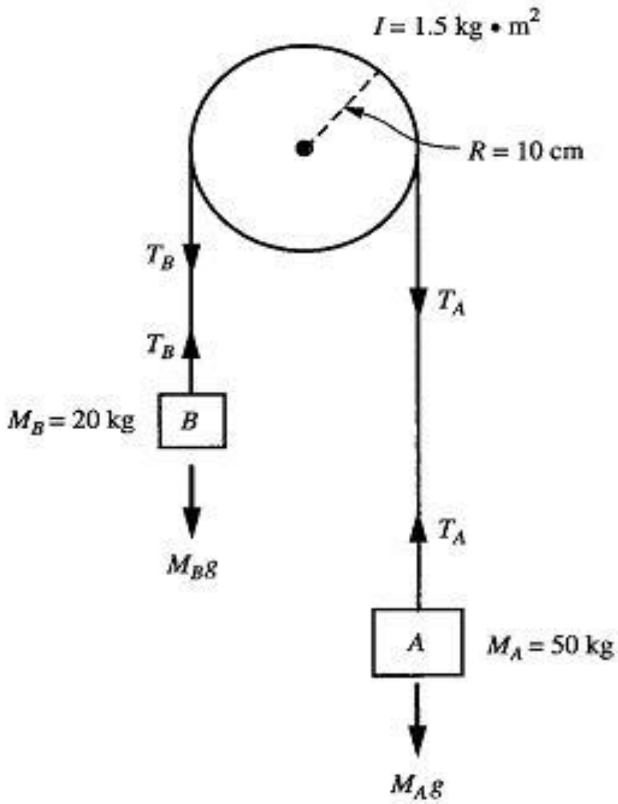
3) Find the average accelerating force required to change the speed and direction of a motor-boat of 5 tons mass from 9 knots North East to 12 knots South East in 2 minutes. One knot = 1.852 km/h. ……(.ans. 321.5 N)

4) A rail- truck of 2 tone mass moving at 10km/h is overtaken on the same line by locomotive of 10 tone mass moving at 16 km/h, and after colliding, the locomotive and truck move on locked together. Find the speed of the two immediately after impact………….(.ans.15km/h.)

5)Find the accelerating torque required to increase the speed of a flywheel from 470 to 700 rev/min in 10 seconds if the mass of the flywheel is 544 kg and its radius of gyration is 0.5m……….(ans. 327.5 Nm.)

4.6 Atwood's Machine.

The Machine below is based on an example upon the principles of Atwood's machine which is based on an experiment for demonstration of **Newton's laws of motion.** The machine consist of a grooved pulley of lightweight material so that the inertia is negligible, mounted on a spindle which runs on top of a tall graduated pillar to which is attached a starting platform near the top and an adjustable stopping buffer near the bottom. There is a cord hung over the pulley that carries a mass on each end, these masses are usually of equal magnitude and a small rider is added to one of them to cause motion. A serious of experiments can be performed by varying the masses.



Example. ***A light flexible cord is hung over a light pulley carried in frictionless bearings. A mass of 2 kg.is hung from one end of the cord and another of 2.1 kg, is hung from the other end, the system is allowed to move from rest. Find (1) the acceleration of the masses, (2) distance moved in 4 seconds, (3) the tension in the cord.***

Solution.

Total mass accelerated = 2.1 + 2 =4.1 kg

Force [N] causing acceleration = (2.1 – 2) × 9.81

= 0.981 N.

Acceleration force = mass × acceleration

Acceleration $= \frac{\textbf{acceleration force}}{\textbf{mass}}$

$= \frac{\mathbf{0.981}}{\mathbf{4.1}}$

= 0.2393 $\boldsymbol{m/s^2}$ Ans. (I)

Velocity after 4 sec. = 0.2393 x 4

= 0.9572 m/s

Average velocity $= \frac{1}{2}$ (0 + 0.9572)

= 0.4786 m/s

Distance = average velocity x time

= 0.4786 x 4

= 1.9144 m Ans. (ii)

Force to accelerate = mass x acceleration

= 2 x 0.2393

= 0.4786 N

Tension in cord = supporting force + accelerating force

= 2 x 9.81 + 0.4786

= 20.0986 N Ans. (iii)