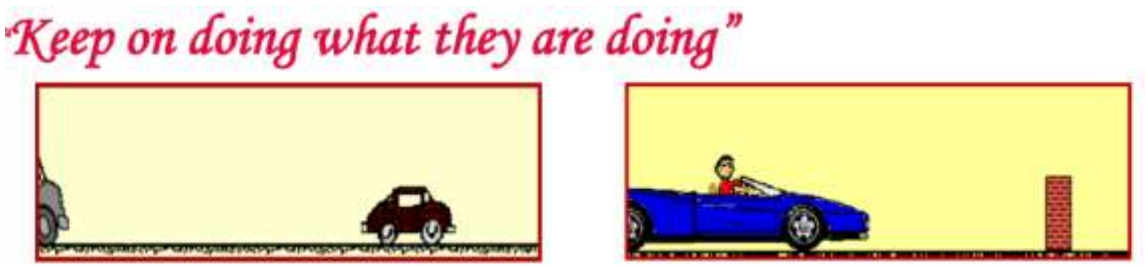
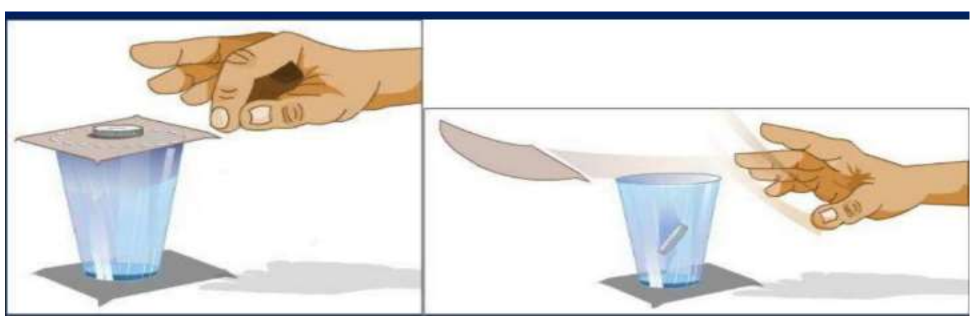
Newton’s Laws of Forces & Motion

1st law (law of inertia)

- It states that an object at rest tends to stay resting, and an object in motion tends to stay in motion with the same **speed & and direction Unless Acted upon by an unbalanced force**

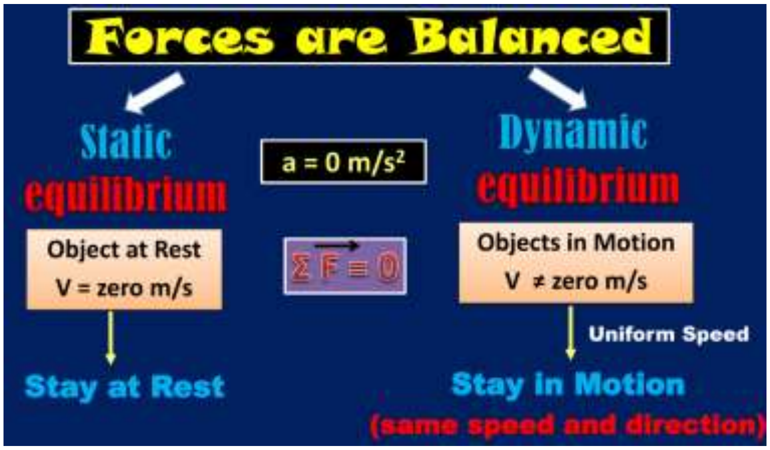


- It was named for **inertia**, the tendency of objects to resist change in their state of motion



you can see that the coin didnt move with the paper because of newton 1st law

- It ties up well with the equilibriums, an object in static equilibrium tends to stay at rest, while an object in dynamic equilibrium tends to stay in motion



- As previously mentioned, balanced forces do not cause a change in motion, because they cancel each other out
- 

  you can see that the sum of the gravitational/weight force is being cancelled by the air resistance, but because the body is already in motion, it will continue to be in motion, it just wont fall faster overtime
- **Momentum (p)** it's the amount of motion

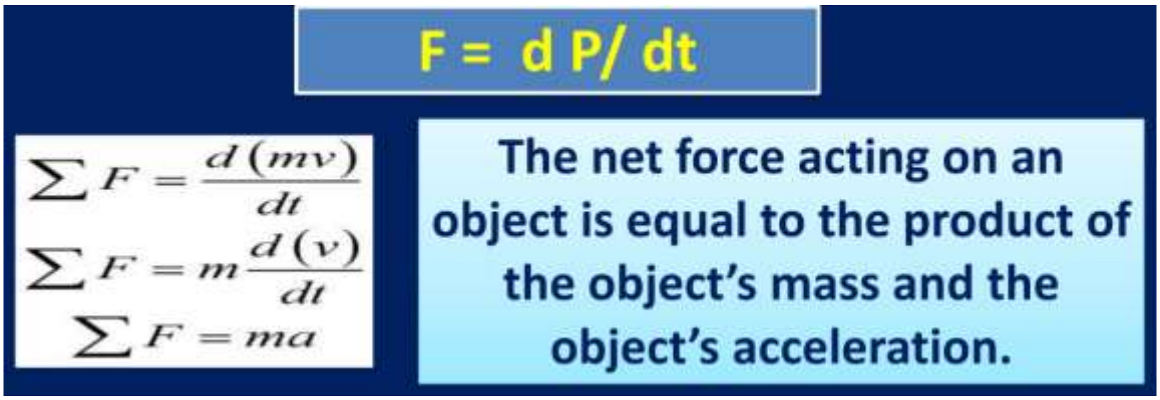
$$P = mv \quad \text{Kg ms}^{-1}$$

the symbol was takin from impetus

momentum meaning the tendency of a moving object to continue

moving in the absence of an applied force
it's like when you're driving and suddenly stop, you get thrown

2nd law

- It states that the **change of momentum (Acceleration)** has a positive relation with force and a negative relationship with the mass
- 

- **An unbalanced force** causes a change, when they act in opposite directions, you can find the **net force (magnitude = difference between two forces, direction = direction of the largest force)**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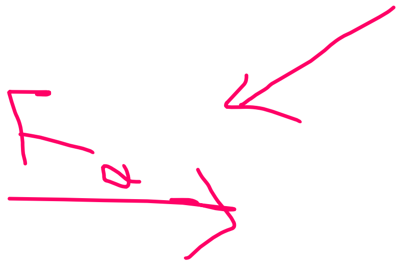
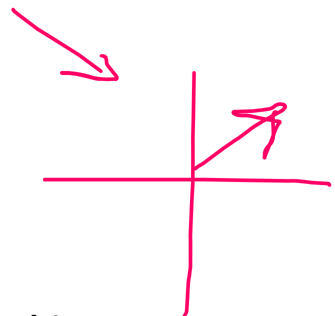
1st law (law of inertia)

- Every action has an opposite reaction

FORCES

They can have **one dimension** or **multiple dimensions**



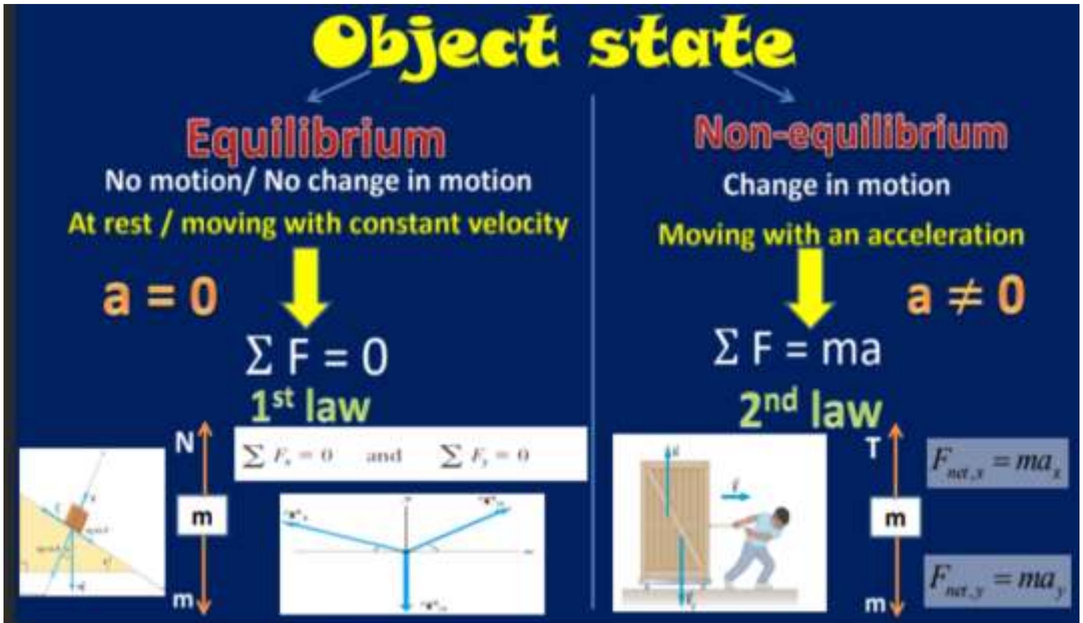


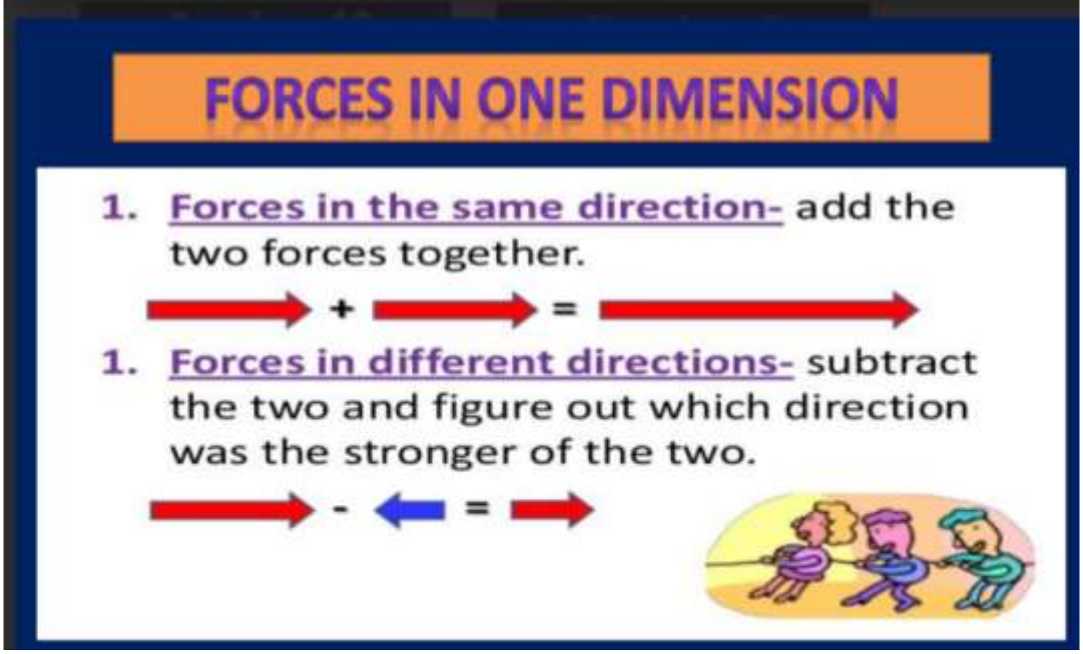
An object can be single **or connected to another object**

Sum of forces (net forces)

Is the vector sum of all forces acting on an object, lets say the net force = force X + force Y

When you combine the equation of Fx and Fy you can determine unknown variables


Object state
Equilibrium
No motion/ No change in motion
At rest / moving with constant velocity
a = 0
Σ F = 0
1st law
N
m
m
Σ Fx = 0 and Σ Fy = 0
Non-equilibrium
Change in motion
Moving with an acceleration
a ≠ 0
Σ F = ma
2nd law
T
m
m
Fnet,x = max
Fnet,y = may


FORCES IN ONE DIMENSION
1. Forces in the same direction- add the two forces together.
+ =
1. Forces in different directions- subtract the two and figure out which direction was the stronger of the two.
- =

Equilibrium vs motion vs change in motion

Equilibrium is a state in which an object is either at rest or moving at a constant velocity in a straight line. Motion is a state in which an object is changing its position over time. Change in motion is a change in the object's velocity.

Equilibrium can be static or dynamic. Static equilibrium is when an object is at rest and the net force acting on it is zero. Dynamic equilibrium is when an object is moving at a constant velocity and the net force acting on it is also zero.

Motion can be uniform or accelerated. Uniform motion is when an object's velocity is constant. Accelerated motion is when an object's velocity is changing.

Change in motion can be caused by an unbalanced force. An unbalanced force is a force that is not cancelled out by other forces.

Force as a vector

A force is a vector quantity, which means that it has both a magnitude and a direction. The magnitude of a force is measured in units such as newtons (N). The direction of a force is indicated by an arrow.

Example:

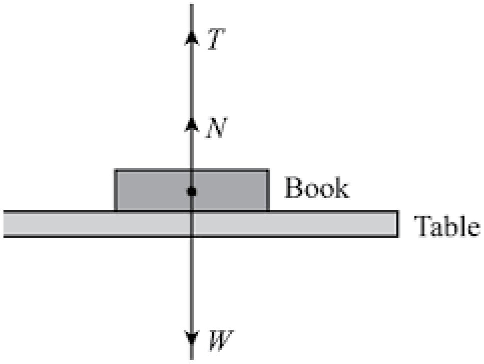
The force of gravity is a vector quantity. It has a magnitude of 9.81 N/kg and points downwards.

Use free-body diagram to determine net force acting on a body via graphical vector addition

A free-body diagram is a diagram that shows all of the forces acting on an object. The forces are represented by arrows, and the direction of the arrow indicates the direction of the force. The magnitude of the force is represented by the length of the arrow.

Example:

The following free-body diagram shows the forces acting on a book sitting on a table:



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freebody diagram of a book sitting on a table

The forces acting on the book are:

- Gravity (Fg)
- Normal force (Fn)

The net force acting on the book is zero, because the book is at rest.

To determine the net force acting on an object using graphical vector addition, we can use the following steps:

1. Draw a free-body diagram of the object.
2. Represent each force as an arrow.
3. Place the arrows tail to tail.
4. Draw the resultant force vector from the tail of the first arrow to the head of the last arrow.

The resultant force vector is the net force acting on the object.

Example:

The following diagram shows how to determine the net force acting on the book sitting on the table using graphical vector addition:

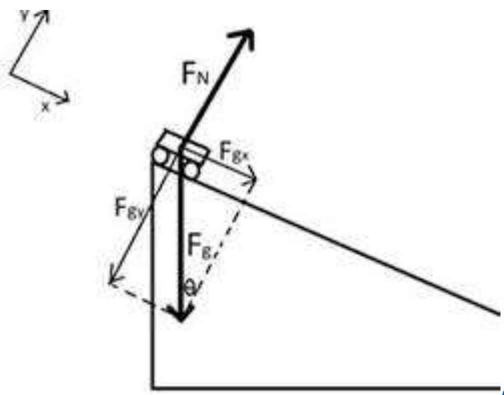

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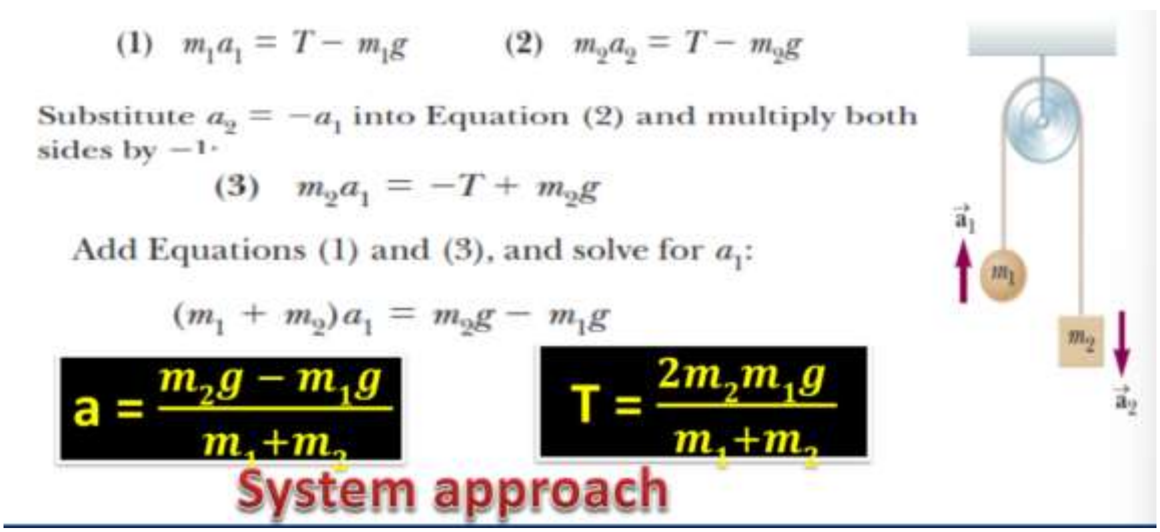
diagram showing how to determine the net force acting on a book sitting on a table using graphical vector addition

The net force vector is shown in blue. It is zero, because the book is at rest.

Determining the net force

Multiple Connected Objects :

1-Atwood's machine

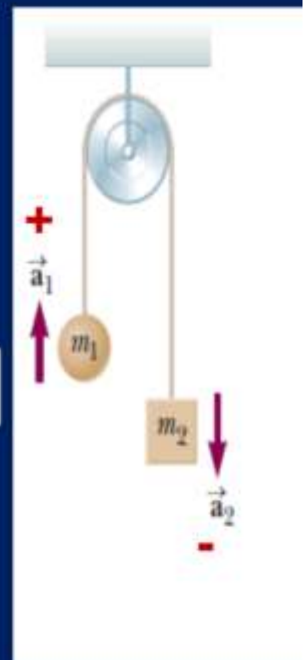


For mass 1 that accelerates upward

$$\Sigma F = T - m_1 g = m_1 a$$
$$T = m_1 g + m_1 a$$
$$\boxed{T = m_1 (g + a)}$$

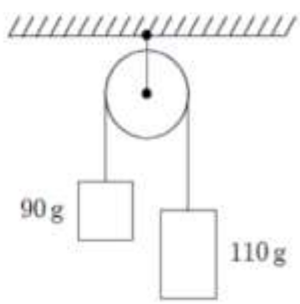
For mass 2 that accelerates downward

$$\Sigma F = T - m_2 g = - m_2 a$$
$$T = m_2 g - m_2 a$$
$$\boxed{T = m_2 (g - a)}$$



you can get the acceleration using the law $\frac{m1g-m2g}{m1+m2}$ or forces/masses

Two blocks are connected by a string and pulley as shown. Assuming that the string and pulley are massless, the magnitude of the acceleration of each block is:

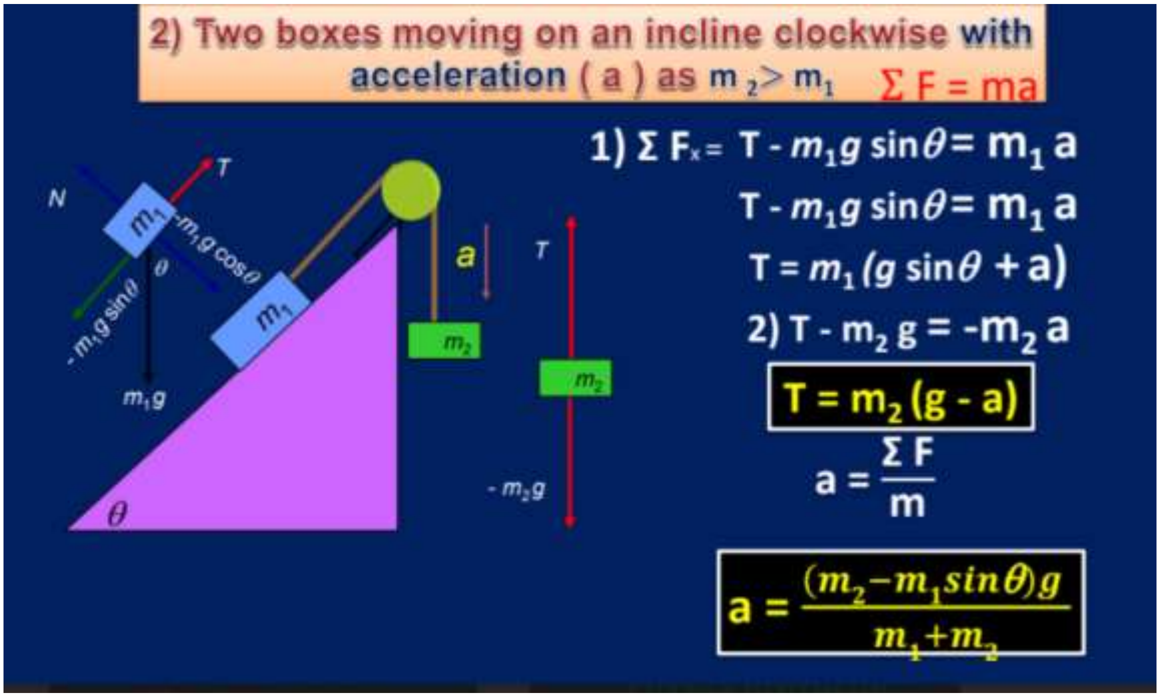


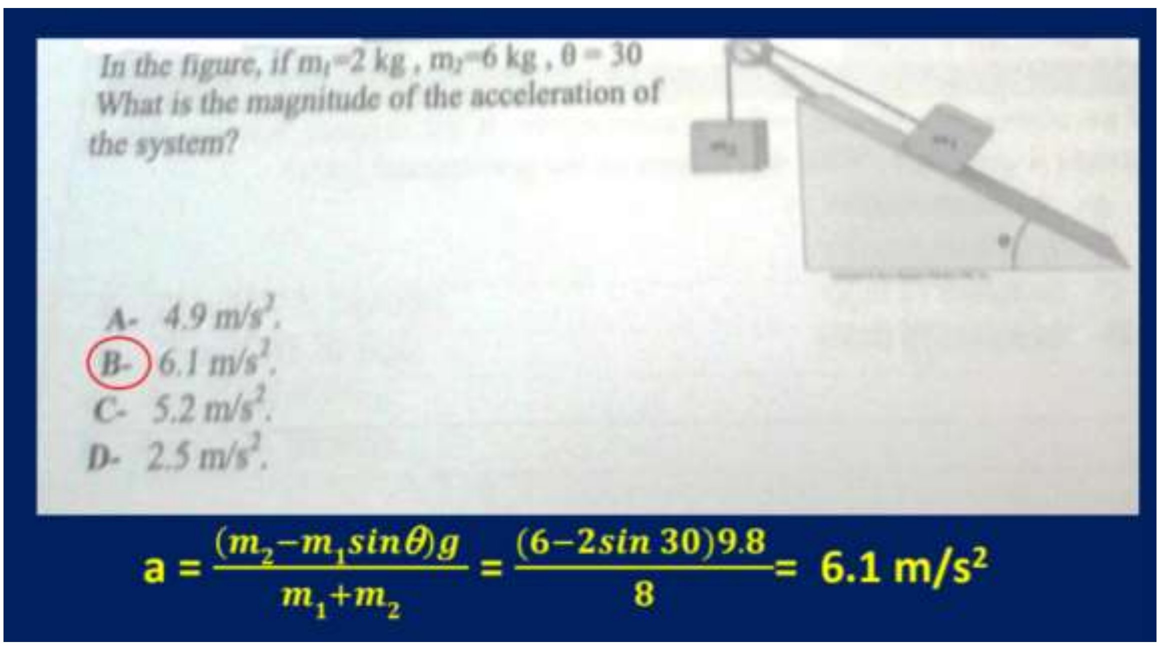
A. $0.049\,\mathrm{m/s^2}$
B. $0.020\,\mathrm{m/s^2}$
C. $0.0098\,\mathrm{m/s^2}$
D. $0.54\,\mathrm{m/s^2}$
E. $0.98\,\mathrm{m/s^2}$

ans: E

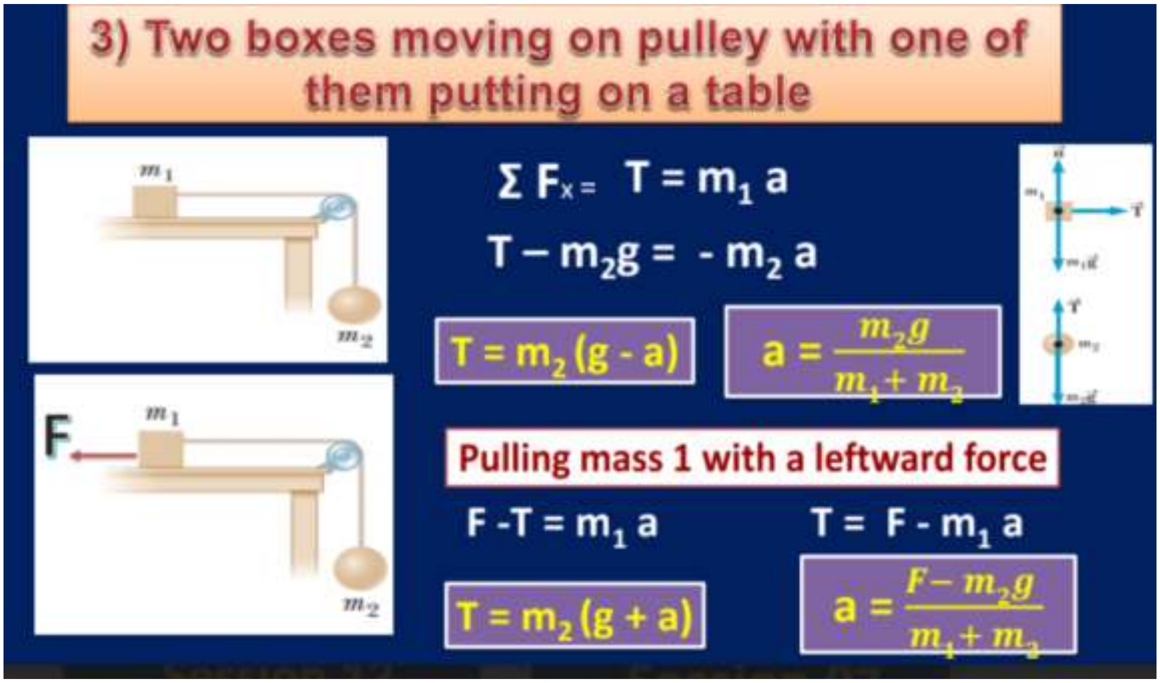
$$a = \frac{m_2 g - m_1 g}{m_1 + m_2} = \frac{(m_2 - m_1)g}{m_1 + m_2} = \frac{(110 - 90)x\,9.8}{200}$$
$$= 0.98\ \mathrm{m/s^2}$$

(2) Pulling on an incline



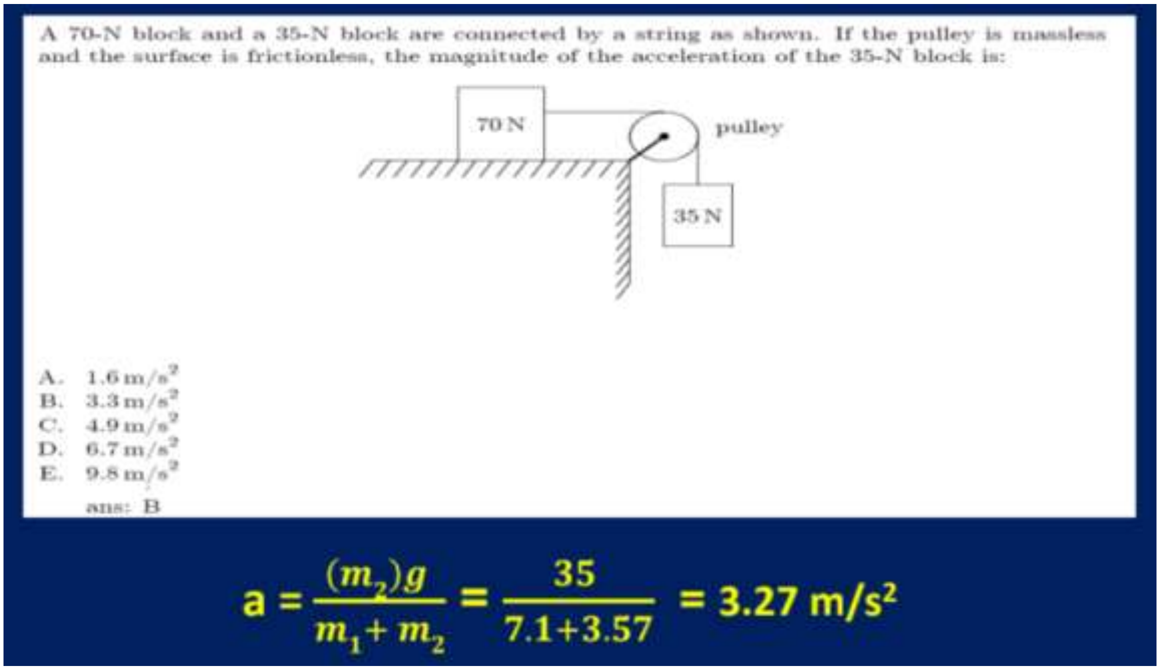


(2) 2 boxes on a pulley



Observation

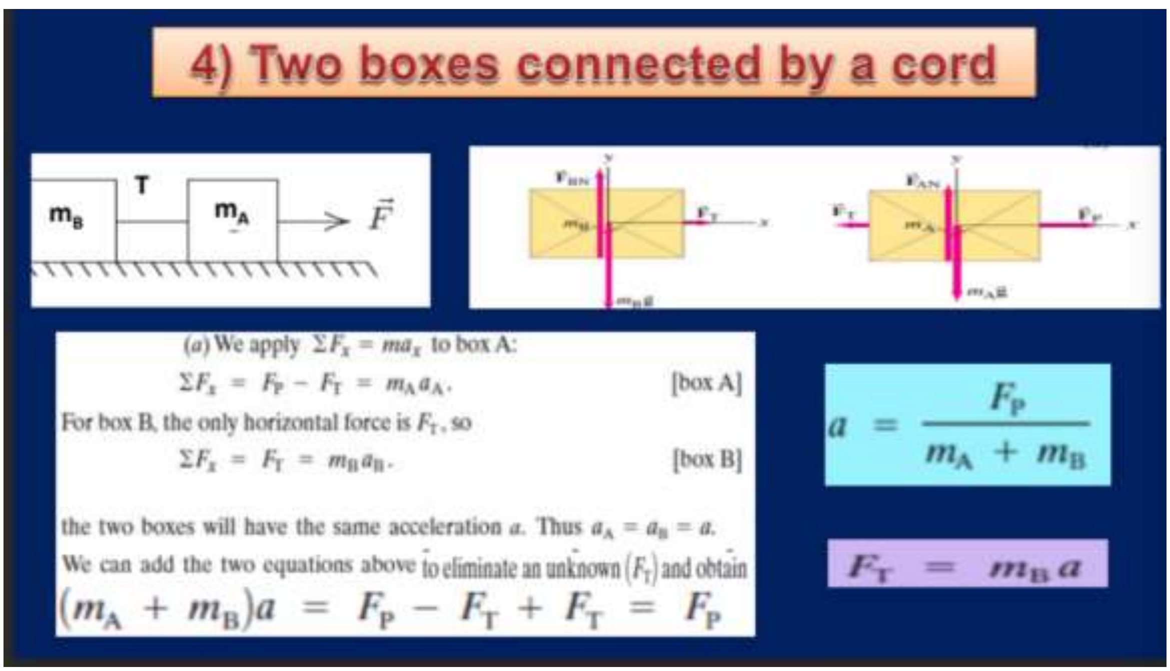
- When there is no leftward force, you would see
  m2 is greater than m1, so it will accelerate downward.
  The tension force is acting upward on m2, so it is countering gravity.
  Therefore, the tension force is negative.
- When there is a leftward force, you would see
  An applied force is acting to the left on m1.
  The net force on m1 is to the left, so it will accelerate to the left.
  The tension force is acting to the right on m1, so it is opposing the applied force.
  Therefore, the tension force is positive.



Observation

-m2 is the 2nd mention

-when they are using newtons instead of grams, cancel G



(5) block storage

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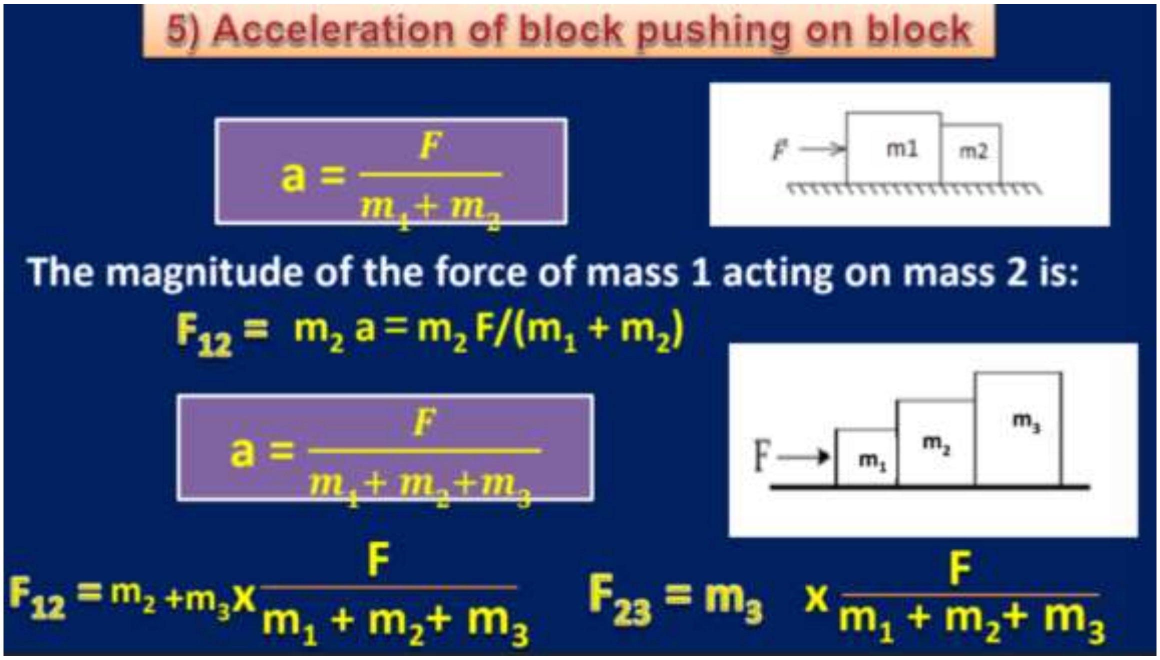
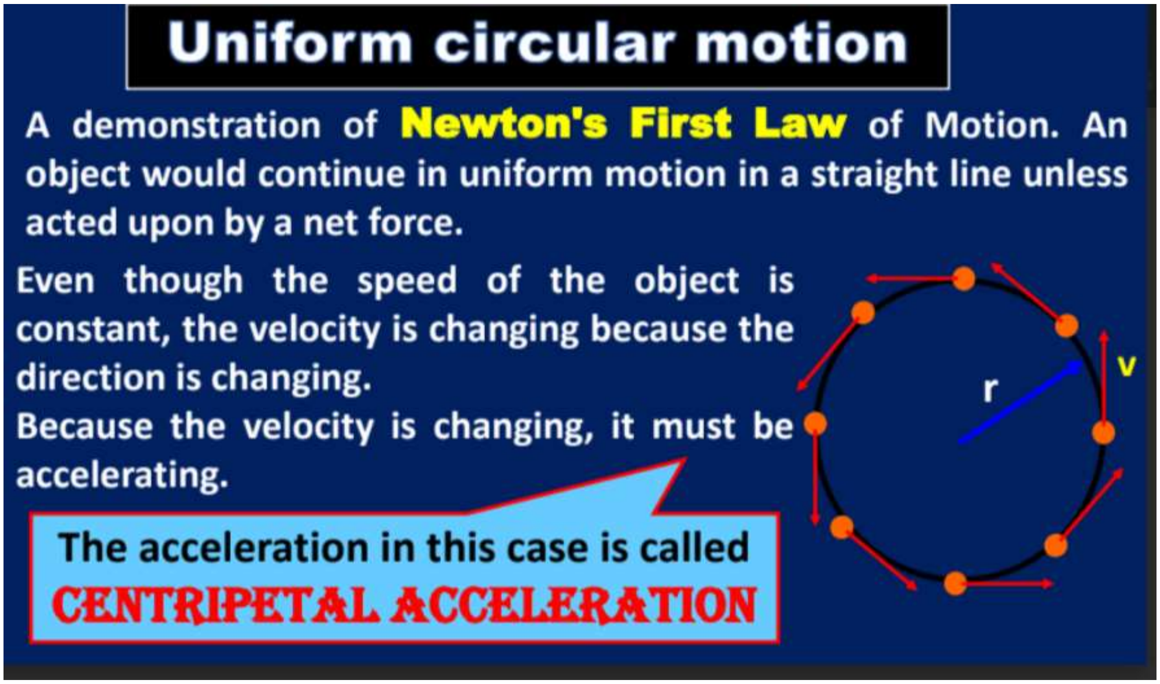
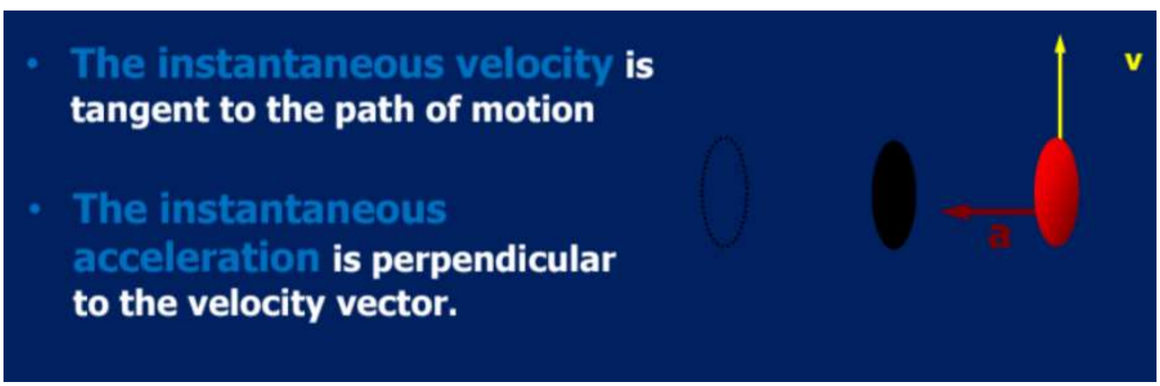


Acceleration = Net force / masses

CIRCULAR MOTION



Anything that goes in a circle at constant speed is undergoing something called **uniform circular motion**

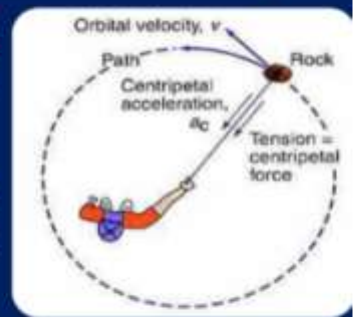


Tangent is the مماس

And perpendicular to the velocity vector is عمودي على المماس

EXAMPLES OF CIRCULAR MOTION

- **EX. 1:** Imagine you have a rock tied to a string and are whirling it around above your head in a horizontal plane.
- If you were to let go of the string, the rock would fly off at a tangent to the circle.



- It is the tension force between the rock and the hand that acts to maintain the circular motion and keep it in orbit.

- **EX. 2: A spacecraft** in orbit around the Earth or any object in circular motion - some force is needed to keep it moving in a circle or accelerate it and that force is directed towards the center of the circle.

- It is the gravitational attraction between the Earth and the spacecraft that acts to maintain the circular motion and keep it in orbit.

Centripetal Force

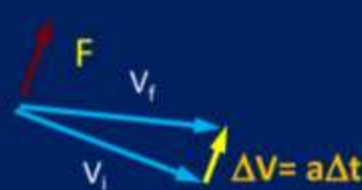
The ball is accelerating, what force makes it accelerate?

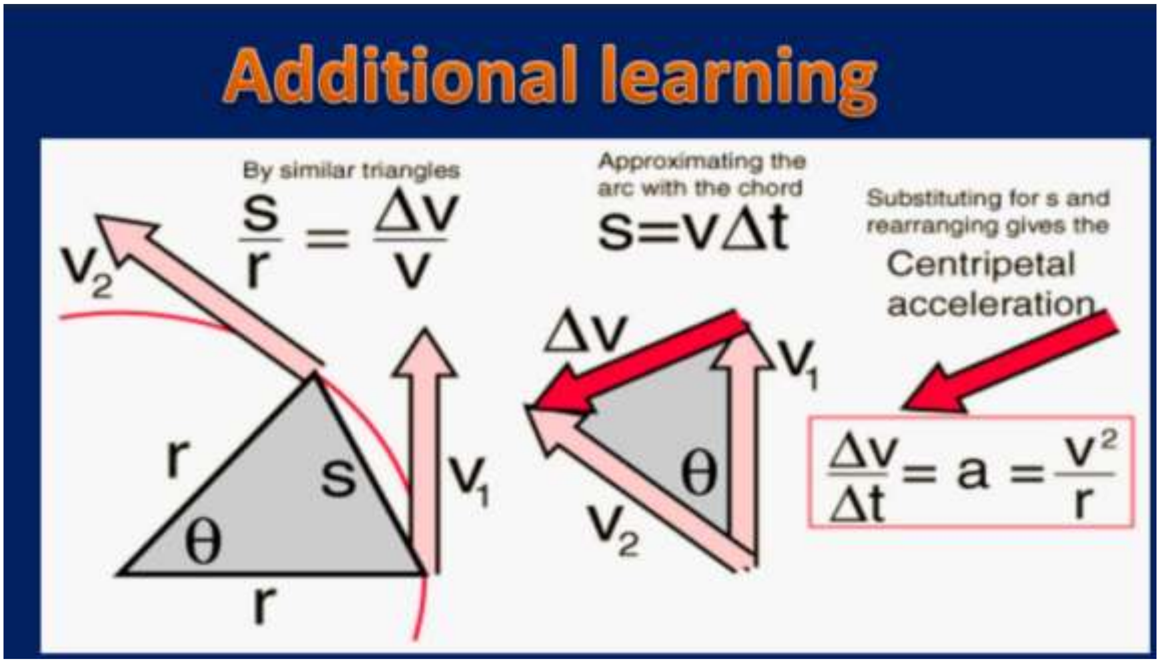
The tension in the string F_T !

- It is always directed back towards the hand at the center of the circle.
- It is called centripetal force and the acceleration called the centripetal acceleration.

- Consider an object moving in a straight line
- A force **F** applied parallel to the direction of motion for a time Δt increases the magnitude of velocity by an amount $a\Delta t$, that change an object's speed but does not change the direction of motion.

- A force **F** applied perpendicular to the direction of motion for a time Δt changes the direction of the velocity vector BUT NOT ITS SPEED (never speeds up or slows down)





The diagram shows two similar triangles. The larger triangle represents the object moving in a circle, and the smaller triangle represents the change in velocity of the object over a small time interval. The two triangles are similar because the angle between the velocity vectors is the same.

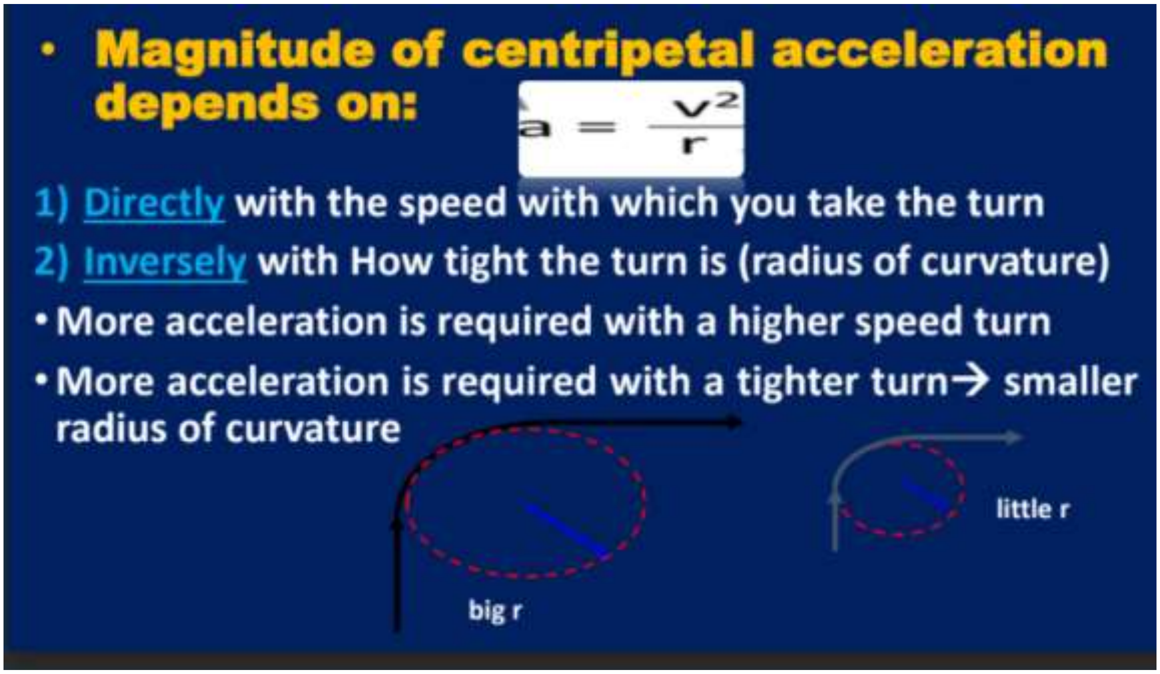
Using the similarity of the triangles, we can derive the following equation for centripetal acceleration:

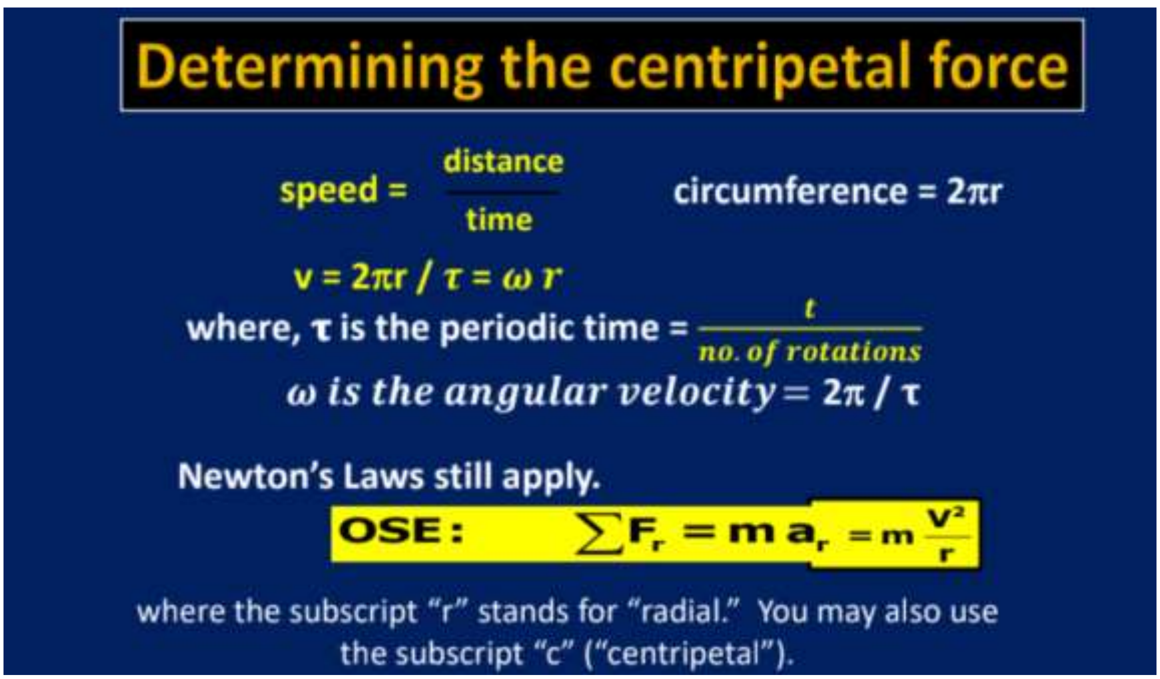
a_c = v^2/r

where:

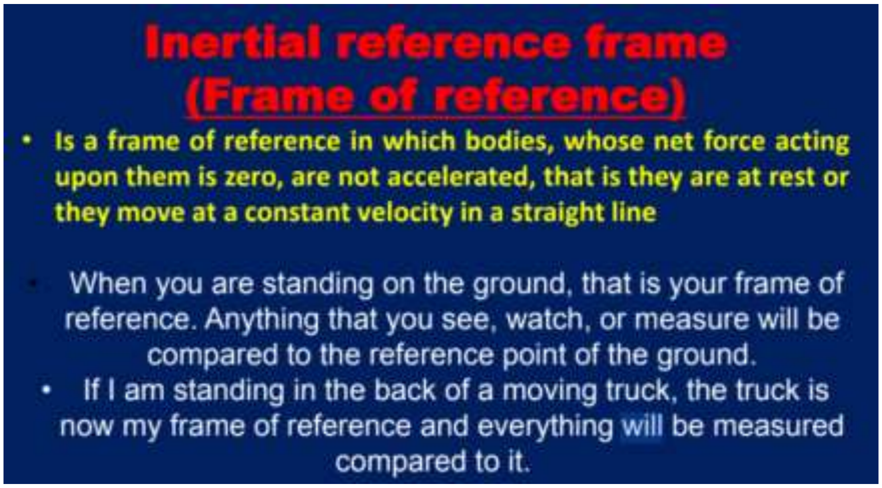
- **a_c is the centripetal acceleration**
- **v is the velocity of the object**
- **r is the radius of the circle**

This equation tells us that the centripetal acceleration is proportional to the square of the velocity and inversely proportional to the radius of the circle. This means that the centripetal acceleration will increase as the velocity increases or as the radius decreases.





Initial Reference Frame (frame of reference)



It’s a frame reference for bodies with acceleration of 0, let’s say it’s a car, so the car isn’t moving because it is the reference

Centripetal motion relations

Velocity (v) = $2\pi r / \tau$

where, r is the circle radius

τ is the periodic time = $\frac{t}{no.\ of\ rotations}$

The Centripetal (Radial) acceleration

$$a_c = \frac{v^2}{r}$$

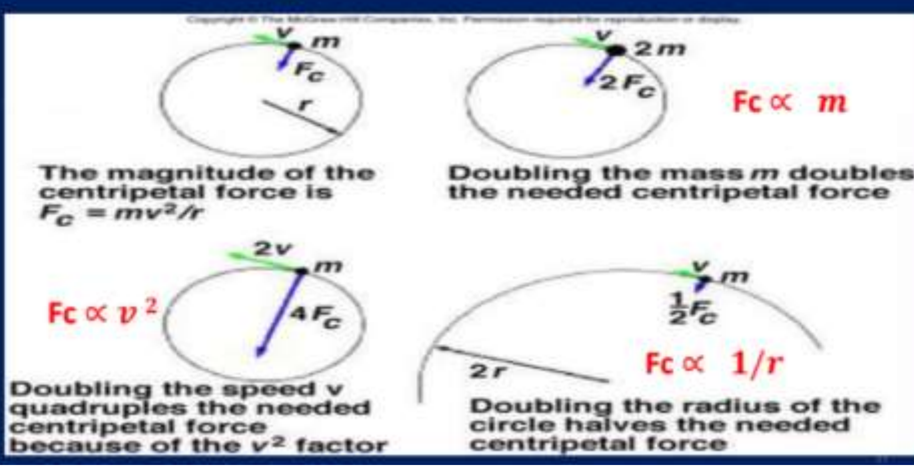
According to Newton's 2nd law

$$\Sigma F_c = m\, a_c$$

The Centripetal force, directed towards the center

$$\Sigma F_c = m\, \frac{v^2}{r}$$

Important relations



Solving circular motion problems

PROBLEM SOLVING

Uniform Circular Motion

1. **Draw a free-body diagram**, showing all the forces acting on each object under consideration. Be sure you can identify the source of each force (tension in a cord, Earth's gravity, friction, normal force, and so on). Don't put in something that doesn't belong (like a centrifugal force).
2. **Determine** which of the forces, or which of their components, act to provide the centripetal acceleration—that is, all the **forces or components that act radially**, toward or away from the center of the circular path. The sum of these forces (or components) provides the centripetal acceleration, $a_R = v^2/r$.
3. **Choose a convenient coordinate system**, preferably with one axis along the acceleration direction.
4. **Apply Newton's second law** to the radial component:

$$\Sigma F_R = ma_R = m\frac{v^2}{r}. \qquad \text{[radial direction]}$$

Note -> **when we are moving in a circle in a vertical motion**

When we are on the highest point, we have the least speed value

And when we are on the lowest point, we have the highest speed value

For the ball to continue moving at the top point, the tension has to be 0, other than that and the ball will fall

And when we are at the lowest point, the tension has to be the max value, other than that and the ball will fly off

EXAMPLE **TIME**

Example 1

Acceleration of a revolving ball

A 150-g ball at the end of a string is revolving uniformly in a horizontal circle of radius 0.600 m. The ball makes 2.00 revolutions in a second. What is its centripetal acceleration?

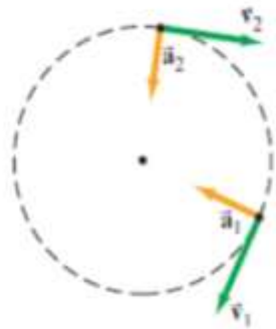
Solution

T = t/ no. of revolution = 1 /2.00 = 0.500 s

$$v = \frac{2\pi r}{T} = \frac{2\pi(0.600\,\text{m})}{(0.500\,\text{s})} = 7.54\,\text{m/s}.$$

The centripetal acceleration† is

$$a_R = \frac{v^2}{r} = \frac{(7.54\,\text{m/s})^2}{(0.600\,\text{m})} = 94.7\,\text{m/s}^2.$$



Example 2

Force on revolving ball (horizontal)

Estimate the force a person must exert on a string attached to a 0.150-kg ball **to make the ball revolve in a horizontal circle of** radius 0.600 m. The ball makes 2.00 revolutions per second. Ignore the string's mass.

SOLUTION We apply Newton's second law to the radial direction, which we assume is horizontal:

$$(\Sigma F)_R = ma_R,$$

where $a_R = v^2/r$ and $v = 2\pi r/T = 2\pi(0.600\,\text{m})/(0.500\,\text{s}) = 7.54\,\text{m/s}$. Thus

$$F_T = m\frac{v^2}{r}$$

$$= (0.150\,\text{kg})\frac{(7.54\,\text{m/s})^2}{(0.600\,\text{m})} \approx 14\,\text{N}.$$

Example 3

Moon's centripetal acceleration

The Moon's nearly circular orbit around the Earth has a radius of about 384,000 km and a period T of 27.3 days. Determine the acceleration of the Moon toward the Earth.

Solution

$$r = 3.84 \times 10^8 \text{ m}$$

$$T = (27.3 \text{ d})(24.0 \text{ h/d})(3600 \text{ s/h}) = 2.36 \times 10^6 \text{ s}.$$

$$a_R = \frac{v^2}{r} = \frac{(2\pi r)^2}{T^2 r} = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2(3.84 \times 10^8 \text{ m})}{(2.36 \times 10^6 \text{ s})^2}$$

$$= 0.00272 \text{ m/s}^2 = 2.72 \times 10^{-3} \text{ m/s}^2.$$

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EXAMPLE 3 OBSERVATION

You would see that instead of giving us a **t** and **number of revolutions**

He gave us the direct **T (time)** but in days, so we turned it into seconds

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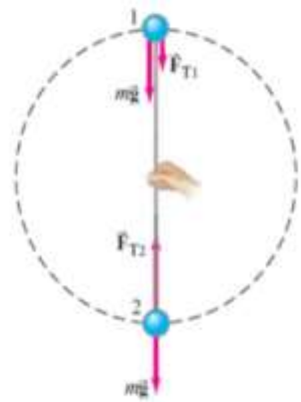
Example 4

Revolving ball (vertical circle)

A 0.150-kg ball on the end of a 1.10-m-long cord (negligible mass) is swung in a *vertical* circle.

(*a*) Determine the minimum speed the ball must have at the top of its arc so that the ball continues moving in a circle.

(*b*) Calculate the tension in the cord at the bottom of the arc, assuming the ball is moving at twice the speed of part (*a*).



SOLUTION (*a*) At the top (point 1), two forces act on the ball: $m\vec{g}$, the force of gravity, and $\vec{F}_{T1}$, the tension force the cord exerts at point 1. Both act downward, and their vector sum acts to give the ball its centripetal acceleration a_R. We apply Newton's second law, for the vertical direction, choosing downward as positive since the acceleration is downward (toward the center):

$$(\Sigma F)_R = ma_R$$

$$F_{T1} + mg = m\frac{v_1^2}{r}. \qquad \text{[at top]}$$

From this equation we can see that the tension force F_{T1} at point 1 will get larger if v_1 (ball's speed at top of circle) is made larger, as expected. But we are asked for the *minimum* speed to keep the ball moving in a circle. The cord will remain taut as long as there is tension in it. But if the tension disappears (because v_1 is too small) the cord can go limp, and the ball will fall out of its circular path. Thus, the minimum speed will occur if $F_{T1} = 0$ (the ball at the topmost point), for which the equation above becomes

$$mg = m\frac{v_1^2}{r}. \qquad \text{[minimum speed at top]}$$

We solve for v_1, keeping an extra digit for use in (*b*):

$$v_1 = \sqrt{gr} = \sqrt{(9.80\ \text{m/s}^2)(1.10\ \text{m})} = 3.283\ \text{m/s} \approx 3.28\ \text{m/s}.$$

This is the minimum speed at the top of the circle if the ball is to continue moving in a circular path.

$$(\Sigma F)_R = ma_R$$

$$F_{T2} - mg = m\frac{v_2^2}{r}. \qquad \text{[at bottom]}$$

The speed v_2 is given as twice that in (*a*), namely 6.566 m/s. We solve for F_{T2}:

$$F_{T2} = m\frac{v_2^2}{r} + mg$$

$$= (0.150\ \text{kg})\frac{(6.566\ \text{m/s})^2}{(1.10\ \text{m})} + (0.150\ \text{kg})(9.80\ \text{m/s}^2) = 7.35\ \text{N}.$$

(a) 1-we define that the forces acting on point 1 is (**mg gravitional mass aka weight)** & **tension force** in the same direction which is down, so we add the two forcesso we came up with the equation of netforce
Netforce = Mg + Ft = m * v^2/r

2-because point 1 is the highest point, the tension has to be 0 for it not to go limb

3-now the equation is **Mass x Gravitational$_{acceleration}$ = Mass * velocity^2 / r**

4-you reverse the equation, subtract the mass from both sides, multiple by r, then get the square root to get the speed

(b) 1-we define that the forces acting on the point are the gravitional force and the tension force which are opposites so we are going to subtract

2-the new equation is **Netforce = Mg + Ft = m * v^2/r**

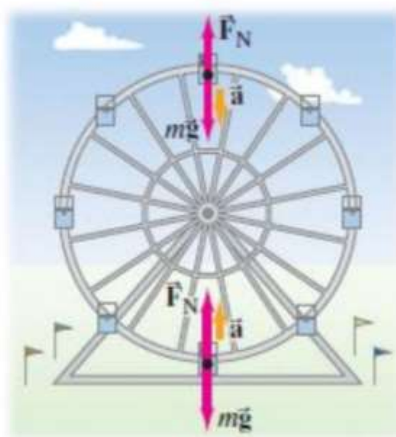
3-we move mg to the other side and continue

Exercise 6:

A rider on a Ferris wheel moves in a vertical circle of radius *r* at constant speed v .

The normal force that the seat exerts on the rider at the top of the wheel is

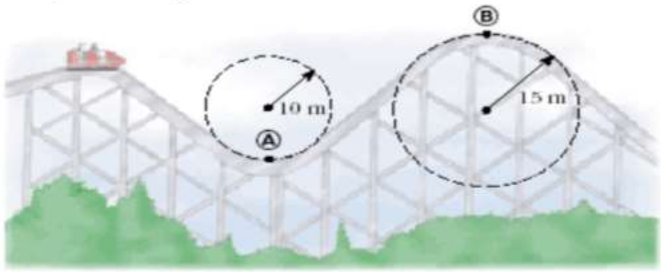
(*a*) less than, (*b*) more than, or (*c*) the same as, **the force the seat exerts at the bottom of the wheel**



Because at the top the velocity is at its lowest therefore the centripetal acceleration is at its lowest therefor the normal force is less

Example 5

A roller-coaster vehicle has a mass of 500 kg when fully loaded with passengers



(a) If the vehicle has a speed of 20.0 m/s at point A, what is the force of the track on the vehicle at this point?

(b) What is the maximum speed the vehicle can have at point B in order for gravity to hold it on the track?

- A roller coaster is a vertical circular track on which cars can move almost without friction.
- When a body moves on a vertical circular track without friction, the forces acting on it are

(1) its weight mg vertically downward

(2) the normal force of the track N towards the center of the track.

- As to move on a circular path **a centripetal force** is required, the resultant of the component of the weight towards center and the normal force will provide this force.

- **When the body is at the lowest point of the track** the normal force N is upward and the weight mg of the body is acting downwards hence their resultant will be **(N - mg)** upward and is providing necessary centripetal force.

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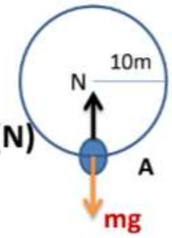
Solution

At the bottom of the circular path



Drawing the FBD for the vehicle at point A

a) Calculating the force of the track on the vehicle (N)

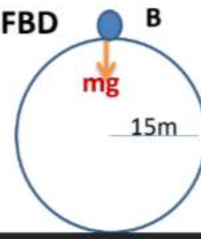
$$\Sigma F_c = m\frac{v^2}{r}$$

$$N - mg = m\frac{v^2}{r}$$

$$N = m\left(\frac{v^2}{r} + g\right) = 500\left(\frac{20^2}{10} + 9.8\right) = 24900\ N = 24.9\ KN$$

At the top of the circular path

b) For maximum speed the vehicle will not be in contact with the track, so we will remove the normal force from the FBD



$$mg = m\frac{v^2}{r}$$

$$v^2 = g\,r$$

$$v = \sqrt{gr} = \sqrt{15\,(9.8)} = 12\ m/s$$

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(1) Because there is no string or tension, the forces acting on the car are gravity and normal

(2) Because we are at the maximum speed, the car would begin to fall off the track so the Fn = 0 because no contact

So it is just Mg = M * v^2 / r

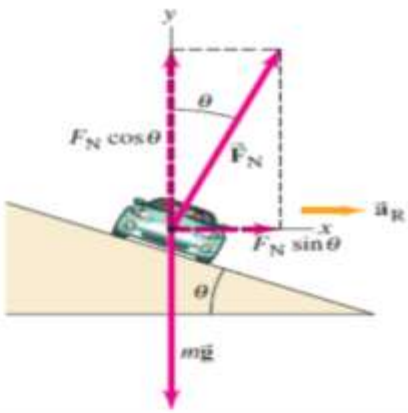
Reverse and subtract the m

Example 7

Banking angle

(a) For a car traveling with speed v around a curve of radius *r*, determine a formula for the angle at which a road should be banked so that no friction is required.

(b) What is this angle for a road which has a curve of radius 50 m with a design speed of 50 km/h?



SOLUTION (*a*) Since there is no vertical motion, $a_y = 0$ and $\Sigma F_y = ma_y$ gives

$$F_N \cos\theta - mg = 0$$

or

$$F_N = \frac{mg}{\cos\theta}.$$

[Note in this case that $F_N \geq mg$ because $\cos\theta \leq 1$.]
We substitute this relation for F_N into the equation for the horizontal motion,

$$F_N \sin\theta = m\frac{v^2}{r},$$

which becomes

$$\frac{mg}{\cos\theta}\sin\theta = m\frac{v^2}{r}$$

or

$$\tan\theta = \frac{v^2}{rg}.$$

This is the formula for the banking angle θ: no friction needed at this speed v.
(*b*) For $r = 50\text{ m}$ and $v = 50\text{ km/h}$ ($= 14\text{ m/s}$),

$$\tan\theta = \frac{(14\text{ m/s})^2}{(50\text{ m})(9.8\text{ m/s}^2)} = 0.40,$$

so $\theta = \tan^{-1}(0.40) = 22°$.

Essential Questions:

How can you design a tall structure that does not blow over in heavy winds?

To answer this question, students need to understand the forces acting on a tall structure and how to design the structure to resist those forces. They need to know about Newton's laws of motion, as well as about wind forces and the strength of materials.

How can you control the direction a large tree will fall when chopping it down?

To answer this question, students need to understand about the forces acting on a tree and how to make a cut that will cause the tree to fall in a desired direction. They also need to know about wedges and felling levers.

Why is it possible that a sheet of paper can be dragged quickly from beneath a heavy body, but the body does not move?

To answer this question, students need to understand about friction and inertia. They need to know that friction is a force that opposes motion and that inertia is the tendency of an object to resist a change in its motion.

Grand Challenge Connections:

Address the exponential population growth and prepare for the impact

The ability to predict and control the motion of objects is essential for designing and building safe and sustainable structures. By understanding the forces that act on objects, we can design structures that can withstand strong winds, earthquakes, and other natural disasters.

Increase efficient use of our land through improved use of arid areas

Arid areas are often windy and have poor soil quality. This makes it difficult to grow crops and build structures in these areas. By understanding the forces that act on objects, we can design more efficient and sustainable ways to use arid land.

How to achieve the stability of the sustainable structure of your capstone project?

The stability of a sustainable structure depends on a number of factors, including the forces acting on it, the strength of the materials used to build it, and the design of the structure. Students can use their knowledge of forces and motion to design a capstone project that is stable and sustainable.