Physics 1

Lecture 10

Sahraei

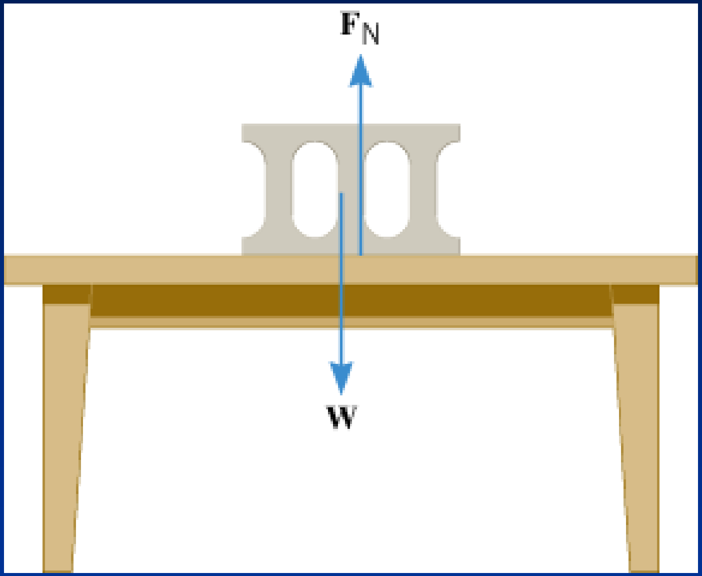
Physics Department, Razi University

http://www.razi.ac.ir/sahraei

Review of Lecture 9

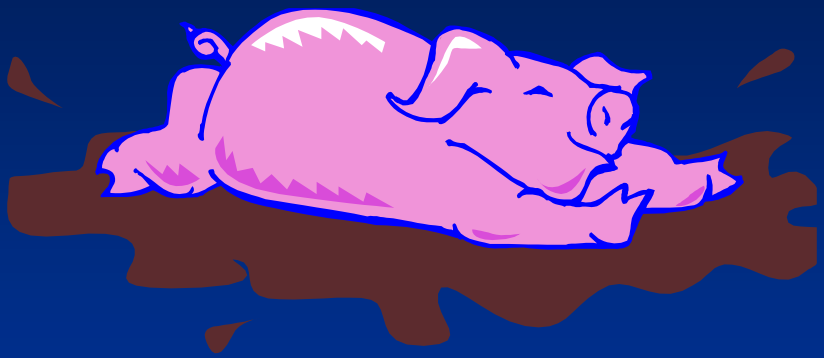
- **What causes acceleration?**
- Force is an interaction between **<u>TWO</u>** objects.
- **Newton's 1st Law**
  - **Force & Mass**
- **Newton's 2nd Law**
- **Some particular forces**
  - **The Normal Force & Friction**
- **Newton's 3rd Law**

Particular Forces (Normal)



The normal force F_N is one component of the force that a surface exerts on an object with which it is in contact, namely, the component that is perpendicular to the surface.

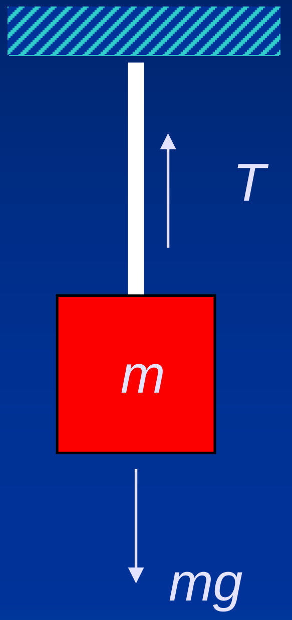
Particular Forces (Friction)



A force that acts in a direction opposite to the motion of two surfaces in contact with each other.

Particular Forces (Tension)

- The force of pull supplied by strings, ropes or chains is called the ***tension force***:
- The tension force is always directed *along the length* of the thing doing the pulling (string, rope, chain).



$$T = mg$$

Particular Forces (Gravitation)

- We have already encountered a particular acceleration – that associated with gravity
- So we can now compute the force that gravity exerts on an object.
- Substituting *g* for *a* in our equation (and aligning our y axis to be vertically upward), we can see that:

$$-F_{\mathrm{g}} = m(-g)$$

- So we can say that:

$$W = F_g = mg$$

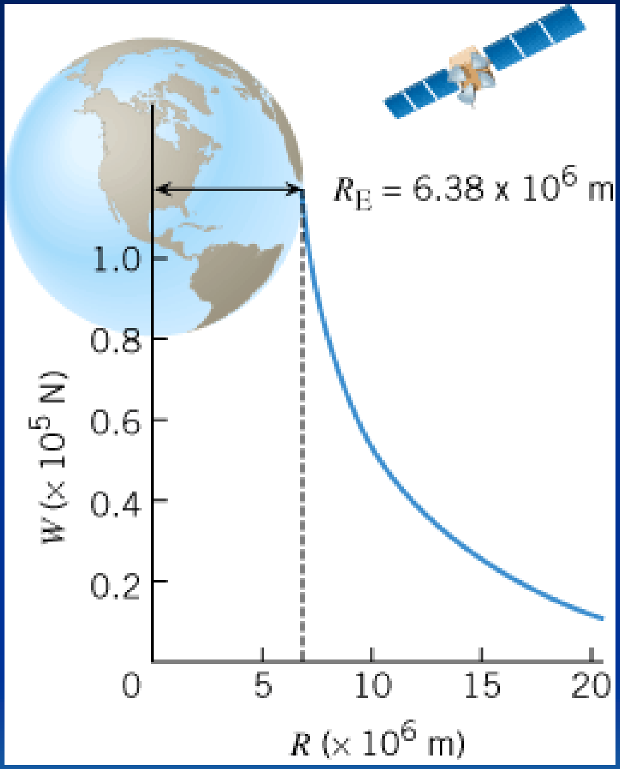
- From this we can see that a body’s weight is directly proportional to it’s mass – with the constant of proportionality being the acceleration of gravity (‘*g*’ for the earth)

- Bear in mind that weight and mass are not the same thing.

- A body that weighs 71 N on earth (~7.25 kg) would only weigh 12 N on the moon.

- This is because while the mass of the body didn't change in going from the earth to the moon, the acceleration of gravity ('*g*') on the moon is only 1.7 m/s^2.

The Hubble Space Telescope



Weight and Mass

- **Mass - A term used to quantify/measure inertia.**
  - **Has SI units of kilogram.**
  - **The amount of a substance.**
  - **The quantity of matter.**
  - **Scalar**

- **Weight - Force exerted on an object while it is under the influence of a gravitational field.**
  - **Vector**

$$\vec{W} = m\vec{g}$$

Using Newton's 2nd Law to Solve Problems

1) Identify the object.

2) Identify all forces acting on the object

-Pushes or Pulls -Frictional forces -Tension in a string
-Gravitational Force - "Normal forces"

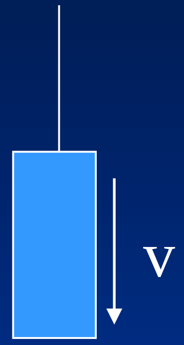
3) Choose a suitable coordinate system.

4) Draw a "Free-body Diagram"

-draw the body as a dot, show all forces acting <u>on that object</u> as vectors pointing in the correct direction and magnitude. **Show the direction of the acceleration.**

5) Translate the free -body diagram into an algebraic expression based on Newton's second law.

Example 1: Consider an elevator moving downward and speeding up with an acceleration of 2 m/s^2. The mass of the elevator is 100 kg. Ignore air resistance.
What is the tension in the cable?

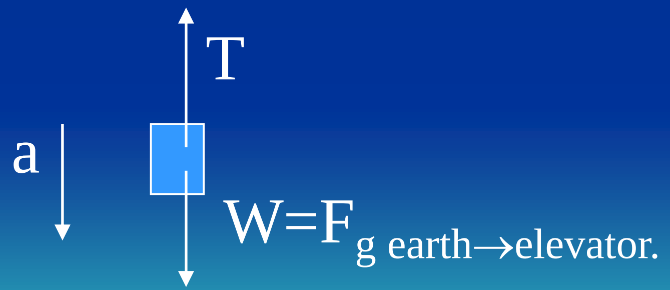


1) Identify body: elevator

2) Identify Forces: Tension in cable, weight of the elevator

3) Chose coordinate system: Let up be the +y direction and down –y. Then :

4) Draw free-body diagram

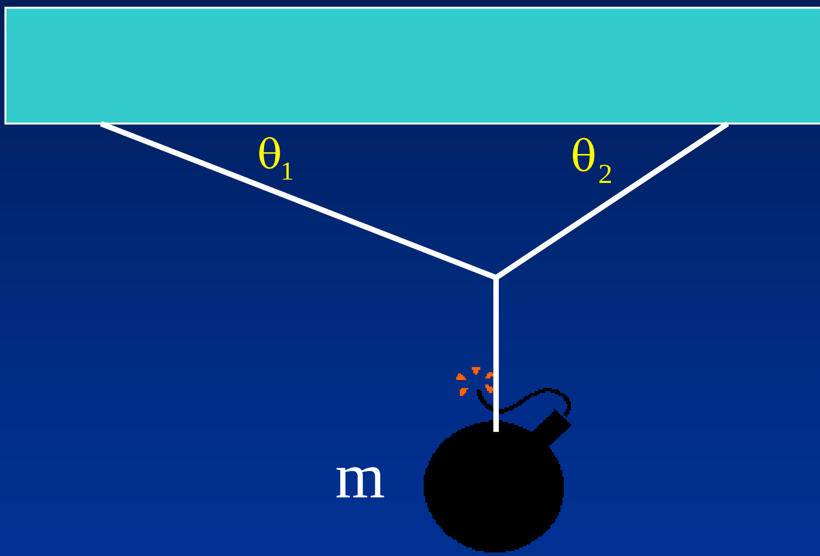


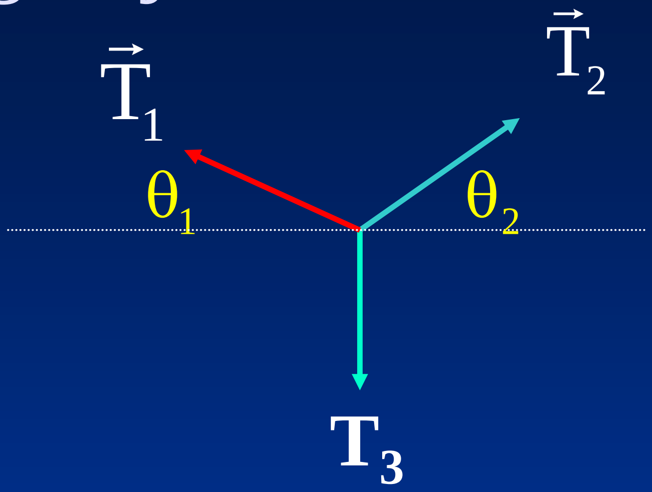
5) Translate the FBD into an algebraic expression. T-W = m(-a)

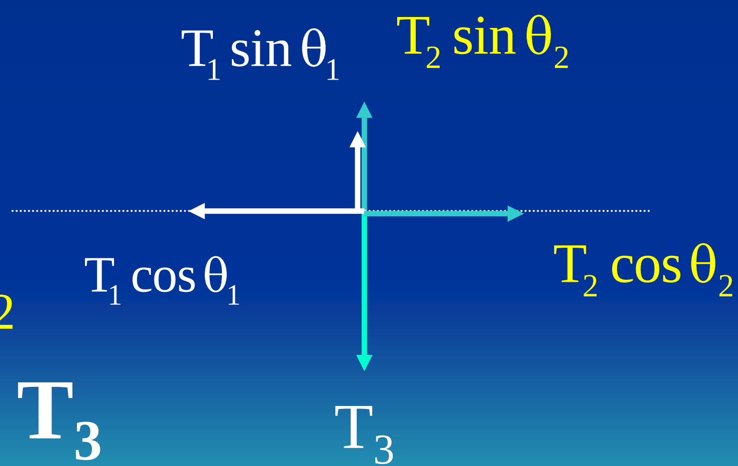
T-(100 kg)(9.8 m/s^2) = (100 kg)(-2 m/s^2)

Note: No negative sign

Example 2 – Hanging Objects







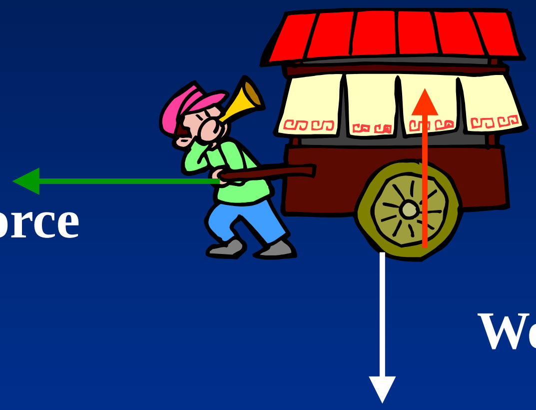
$$\sum \vec{F} = m\vec{a} = 0$$

$$\sum F_x = 0 = -T_1 \cos\theta_1 + T_2 \cos\theta_2$$

$$\sum F_y = 0 = T_1 \sin\theta_1 + T_2 \sin\theta_2 - \mathbf{T_3}$$

$$T_3 - mg = ma_y = 0 \rightarrow T_3 = mg$$

Example 3: Free-body diagram for the hot dog cart (neglecting friction):



"Normal" force (⊥ to surface of contact) $\vec{F}_N$

Pulling force $\vec{F}_{p1}$

$\vec{F}_W$ Weight of cart

Effect of all 3 forces acting on the cart same as effect of a <u>single force</u> equal to vector sum of individual forces

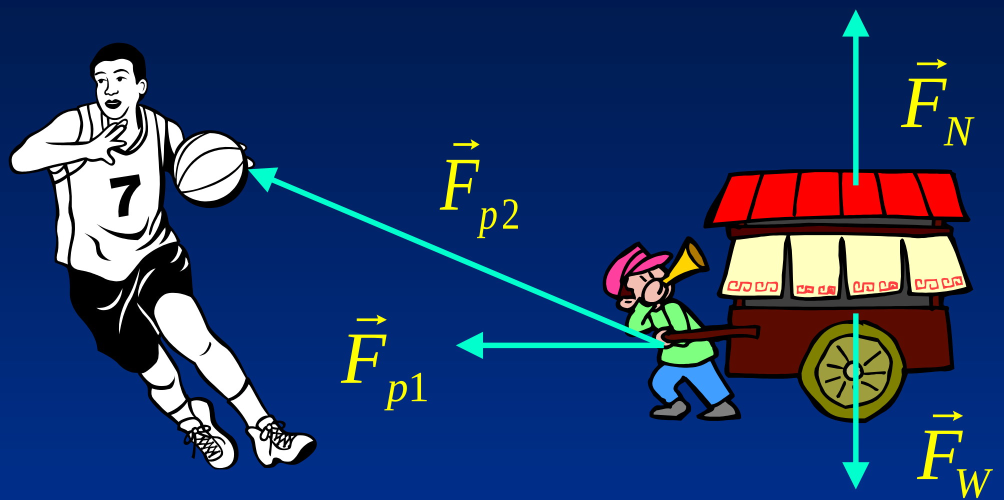
Total (net) force = vector sum of individual forces = $\vec{F}_{net}$

$$\vec{F}_{net} = \vec{F}_{p1} + \vec{F}_w + \vec{F}_N = \sum \vec{F}$$

Since cart does not move up or down, sum of vertical forces must be zero (same effect as no vertical forces):

$$\vec{F}_{net} = \vec{F}_{p1}$$

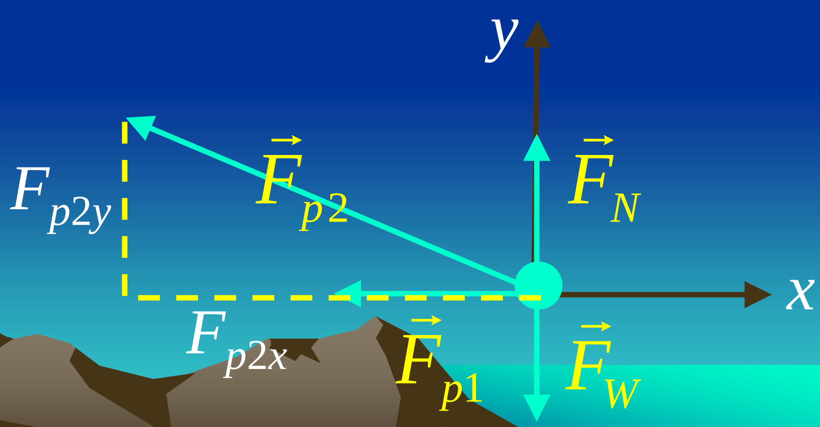
Example 4: Suppose we add a 2nd pulling force:



Easier to add forces if we use the <u>components</u> of each force.

Any force can be replaced by its component vectors, acting at the same point.

Set up coordinate system & determine vector components:



● = hot dog cart

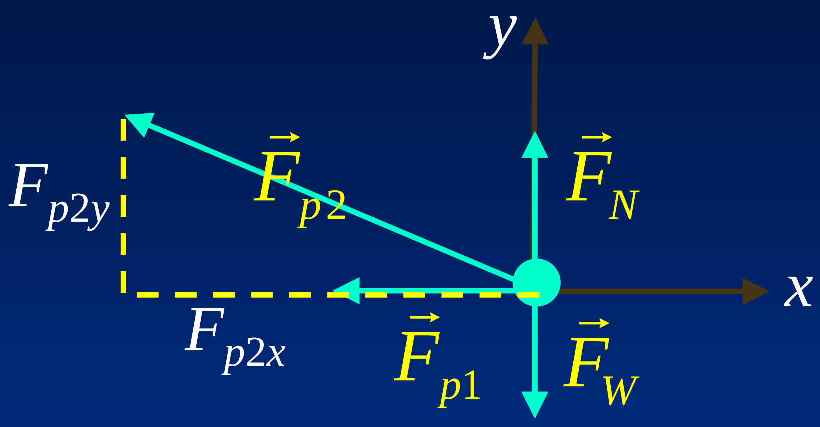
$$F_{net\,x} = \sum F_x$$

$$F_{net\,x} = -F_{p1} - F_{p2}\cos\theta$$

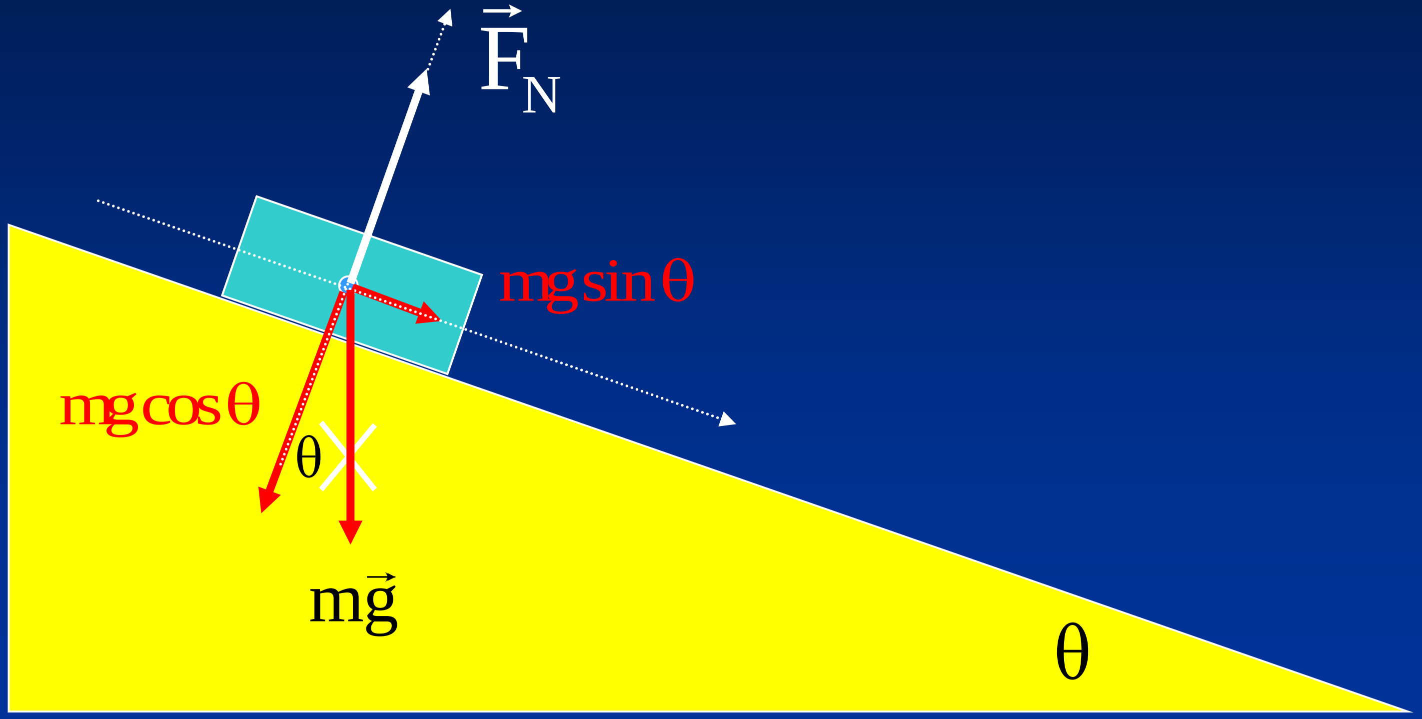
$$F_{net\,y} = \sum F_y$$

$$F_{net\,y} = F_{p2}\sin\theta + F_N - F_W$$

$$\left|\vec{F}_{net}\right| = \sqrt{\left(F_{net\,x}\right)^2 + \left(F_{net\,y}\right)^2}$$



Example 5: Block on a smooth incline plane

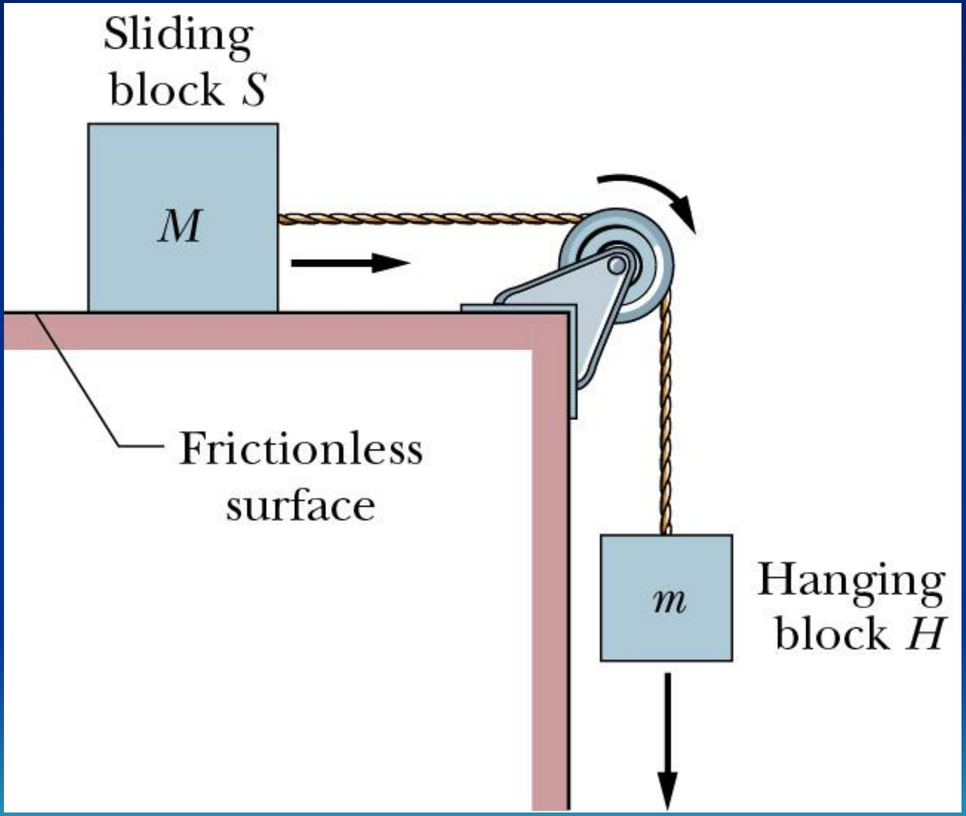


$$\sum F_y = 0 = F_N - mg\cos\theta$$

$$\sum F_x = ma = mg\sin\theta$$

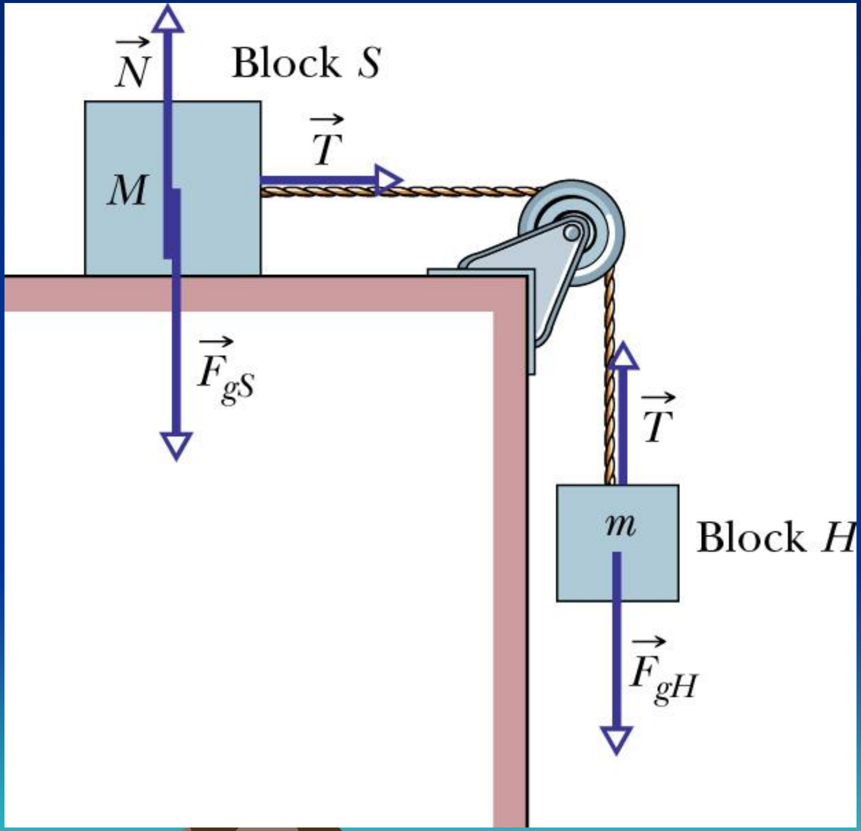
Example 6

- **Find:**
  - **The acceleration of the sliding & hanging blocks.**
  - **The tension in the cord.**



Example 7

- We will start by examining the forces on the bodies in our system:
  - The sliding block,
  - The cord, and
  - The hanging block



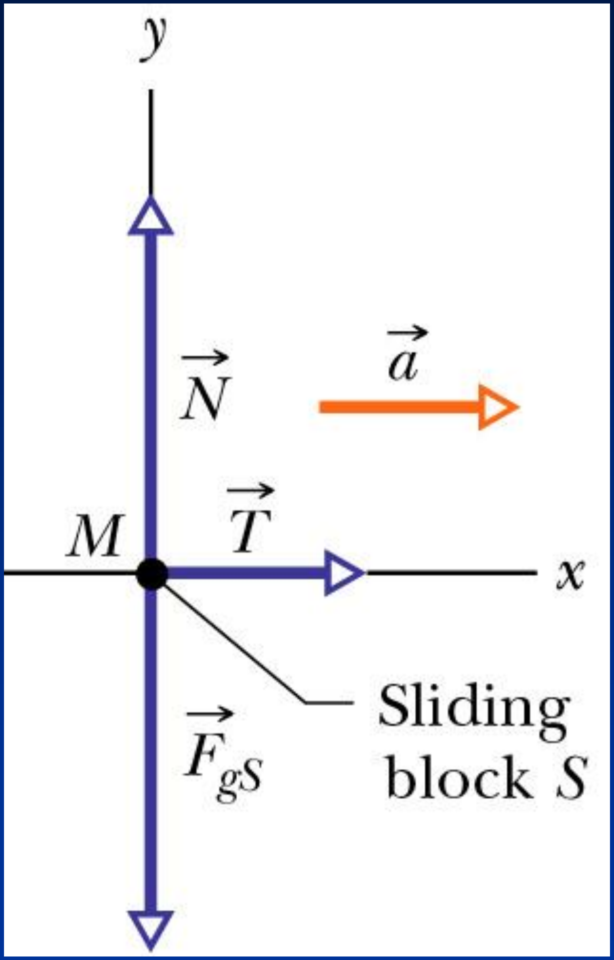
- Now let's look at the free-body diagram for the sliding block

$$F_{net,x} = Ma_x$$
$$F_{net,y} = Ma_y$$

$$N - F_{gS} = 0$$

block is not accelerating in the *y* direction

$$F_{net,x} = T = Ma_x = Ma$$



***a_x* must also equal |*a*| as the rope is under tension (and we assume doesn't stretch)**

- **And the hanging block…**

$$T - F_{gH} = ma_y$$

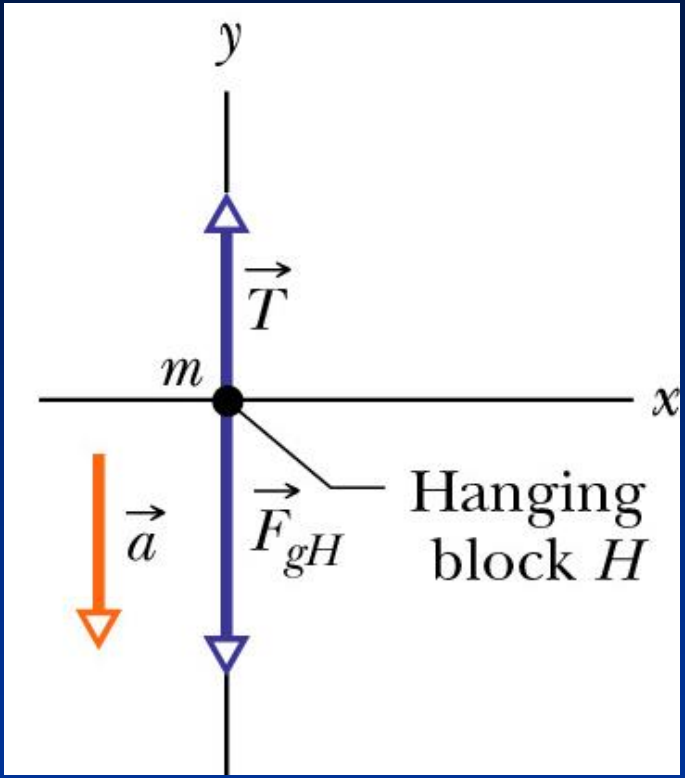
$$T - mg = -ma$$

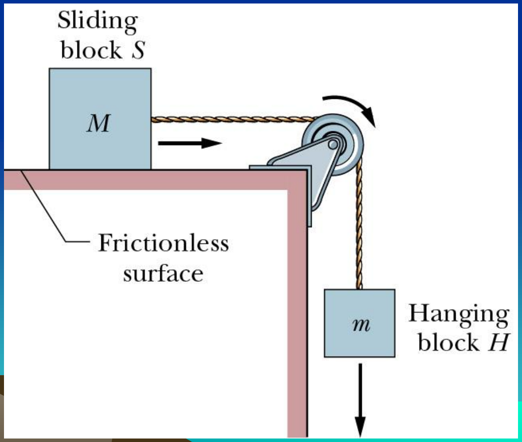
I have substituted –*a* for a_y

$$T = Ma$$

$$a = \frac{m}{M+m} g$$

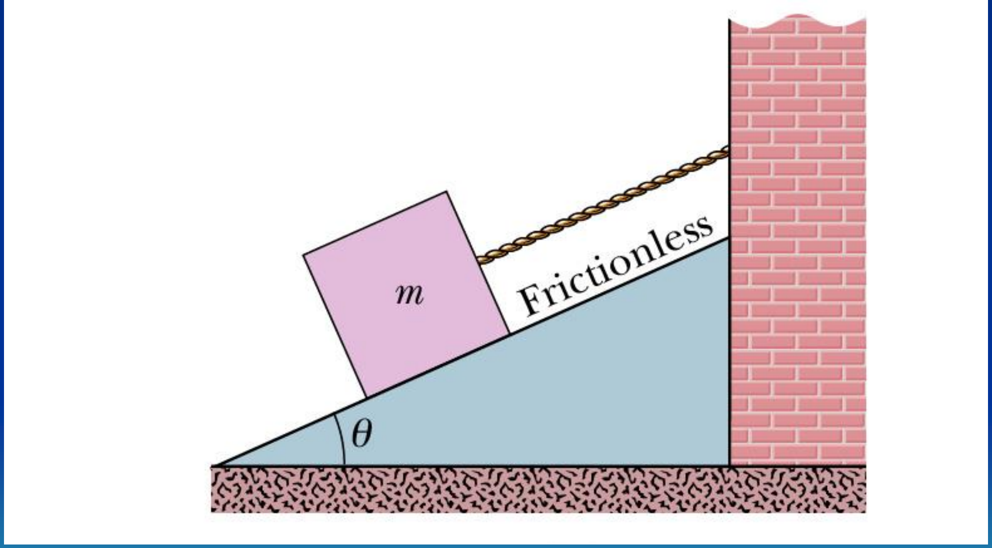
$$T = \frac{Mm}{M+m} g$$

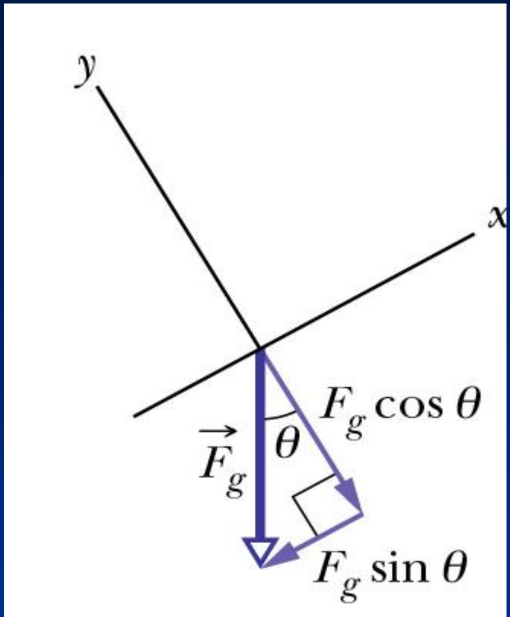


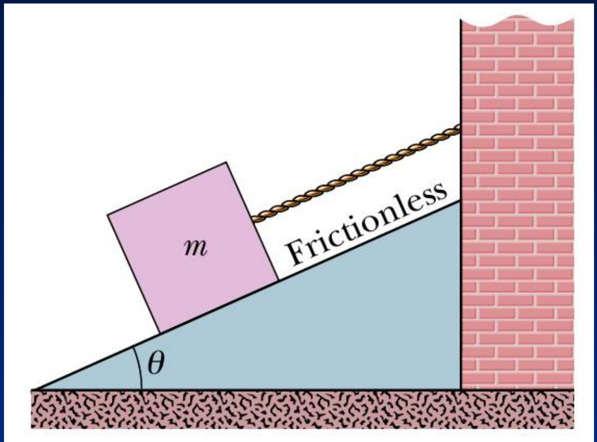


Example 8

- What is the force on the block from the cord, and the normal force on the block from the plane?

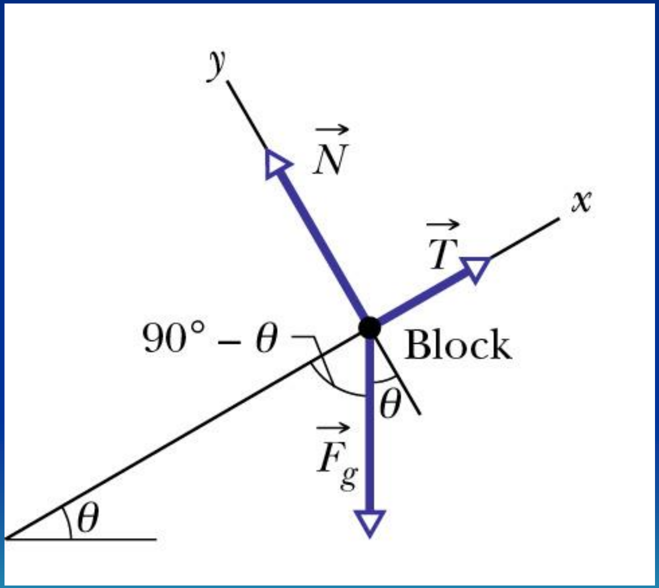




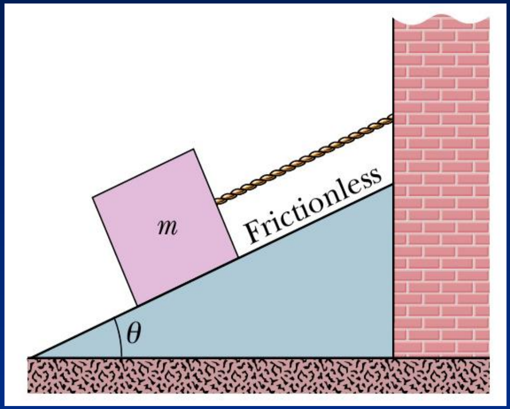


$$\begin{cases} F_x = T - mg\sin\theta = ma_x = 0 \\ F_y = N - mg\cos\theta = ma_y = 0 \end{cases}$$

$$\begin{cases} T = mg\sin\theta \\ N = mg\cos\theta \end{cases}$$



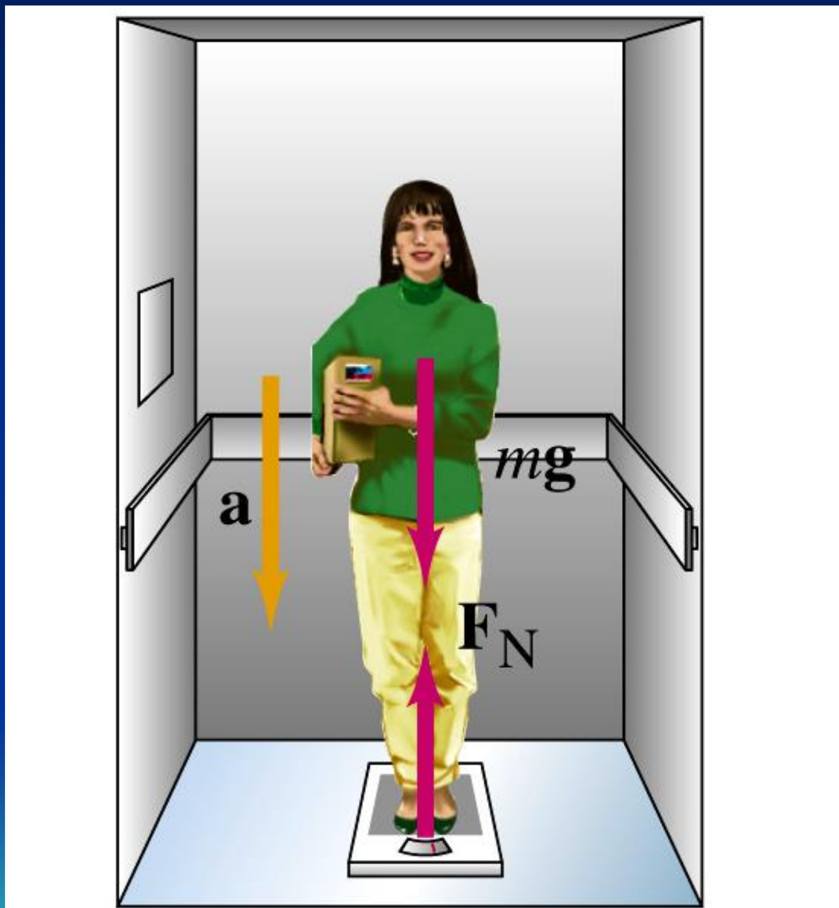
If we cut the cord, does the block accelerate? If so, what is its acceleration?



$$\begin{cases} F_x = T - mg\sin\theta = ma_x \\ F_y = N - mg\cos\theta = ma_y \end{cases}$$

$$\begin{cases} N = mg\sin\theta \\ a_x = -g\sin\theta \end{cases}$$

Example 9: Inside the elevator (non-inertial frame)



While moving up at constant velocity:

$$\sum F_y = F_N - mg = 0$$

Scale reads correctly

While slowing down:

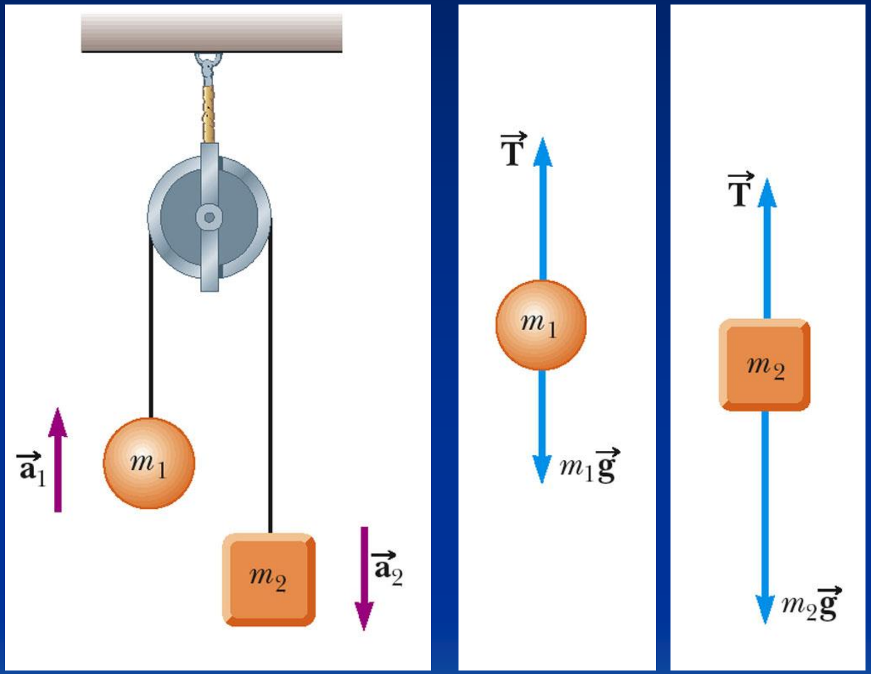
$$\sum F_y = F_N - mg = -ma$$

Scale reads light!

While speeding up:

$$\sum F_y = F_N - mg = \mathbf{ma}$$

Example 10: Atwood's Machine:



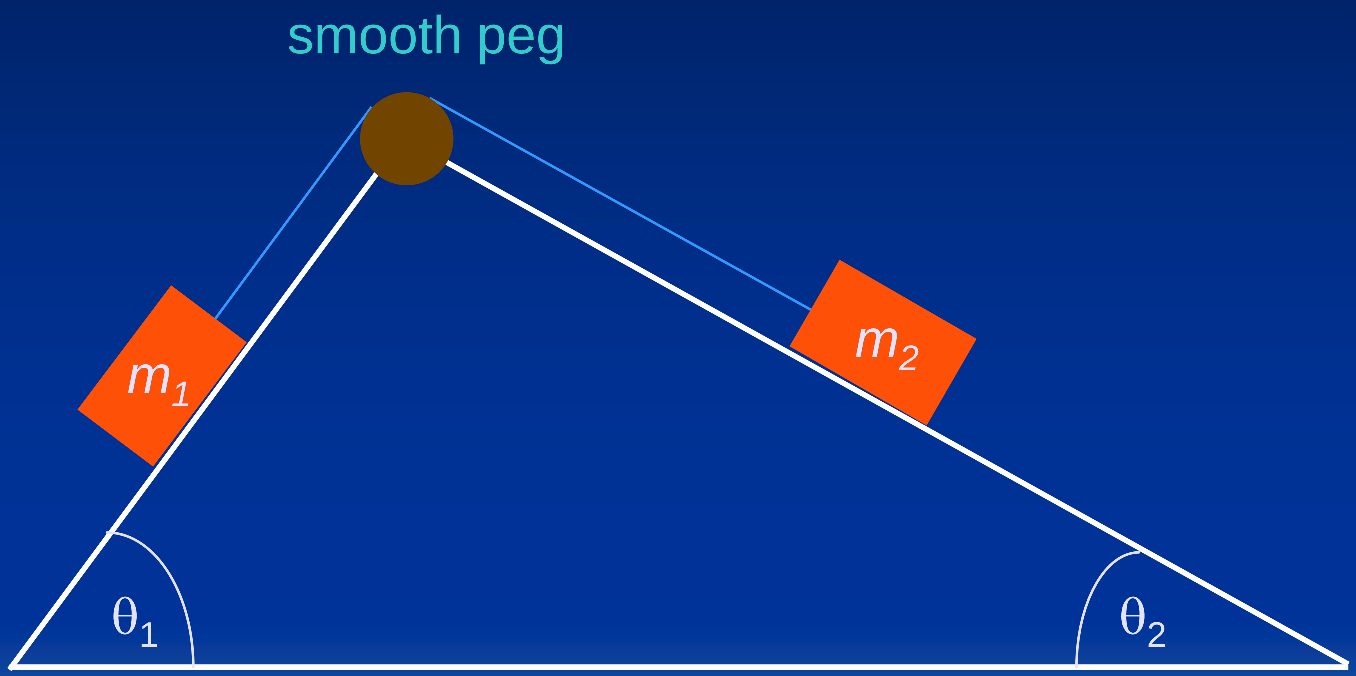
$$\sum F_y = T - m_1 g = m_1 a$$

$$\sum F_y = T - m_2 g = -m_2 a$$

$$a = \frac{m_2 - m_1}{m_2 + m_1} g$$

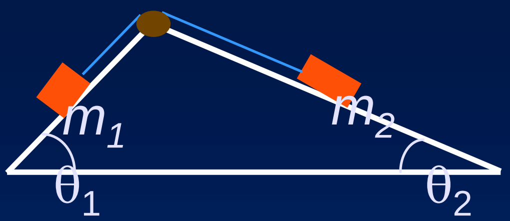
$$T = \frac{2 m_1 m_2}{m_1 + m_2} g$$

Attached bodies on two inclined planes



All surfaces frictionless

How will the bodies move?

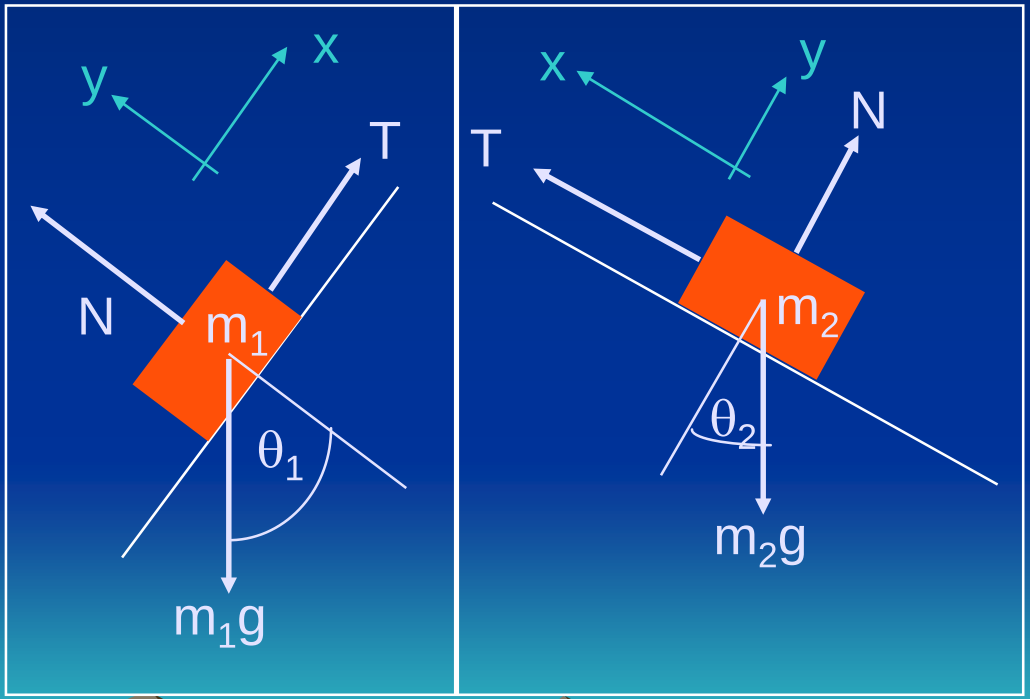


From the free body diagrams for each body, and the chosen coordinate system for each block, we can apply Newton's Second Law:

Taking "*x*" components:

1) $T - m_1 g \sin\theta_1 = m_1 a$

2) $T - m_2 g \sin\theta_2 = -m_2 a$



Using the constraints, solve the equations.

$T - m_1 g \sin\theta_1 = m_1 a$ (a)

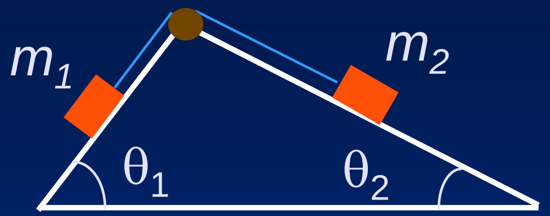
$T - m_2 g \sin\theta_2 = -m_2 a$ (b)

Subtracting *(a)* from *(b)* gives:

$m_2 g \sin\theta_2 - m_1 g \sin\theta_1 = (m_1 + m_2) a$

$$a = \left(\frac{m_2 \sin\theta_2 - m_1 \sin\theta_1}{m_2 + m_1} \right) g$$

$$T = \frac{m_1 m_2 (\sin\theta_1 + \sin\theta_2)}{m_1 + m_2}$$

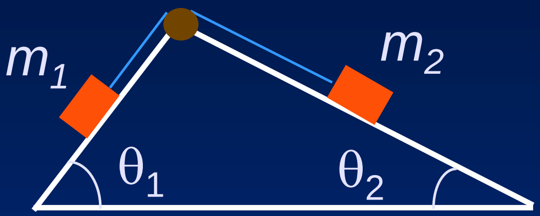


$$a = \frac{m_2 \sin\theta_2 - m_1 \sin\theta_1}{m_1 + m_2} g$$

Special Case 1:

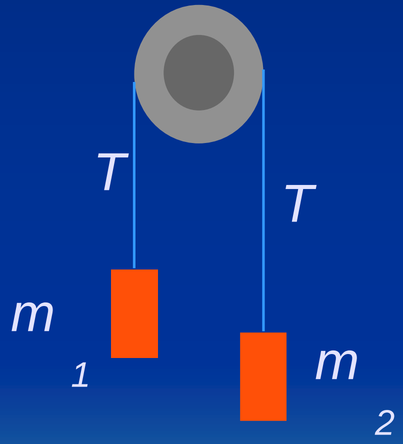
Boring

If θ_1 = 0 and θ_2 = 0, *a = 0*.



$$a = \frac{m_2 \sin\theta_2 - m_1 \sin\theta_1}{m_1 + m_2} g$$

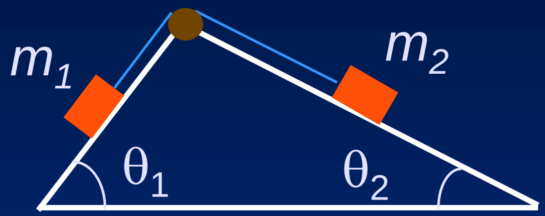
Special Case 2:



Atwood's Machine

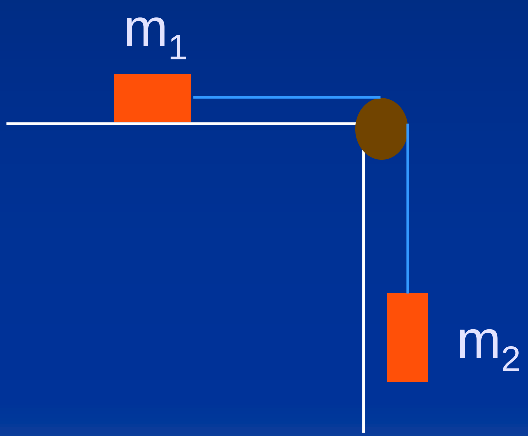
If θ_1 = 90 and θ_2 = 90,

$$a = \frac{(m_2 - m_1)}{(m_1 + m_2)} g$$



$$a = \frac{m_2 \sin\theta_2 - m_1 \sin\theta_1}{m_1 + m_2} g$$

Special Case 3:



Lab configuration

If $\theta_1 = 0$ and $\theta_2 = 90$,

$$a = \frac{m_2}{(m_1 + m_2)} g$$