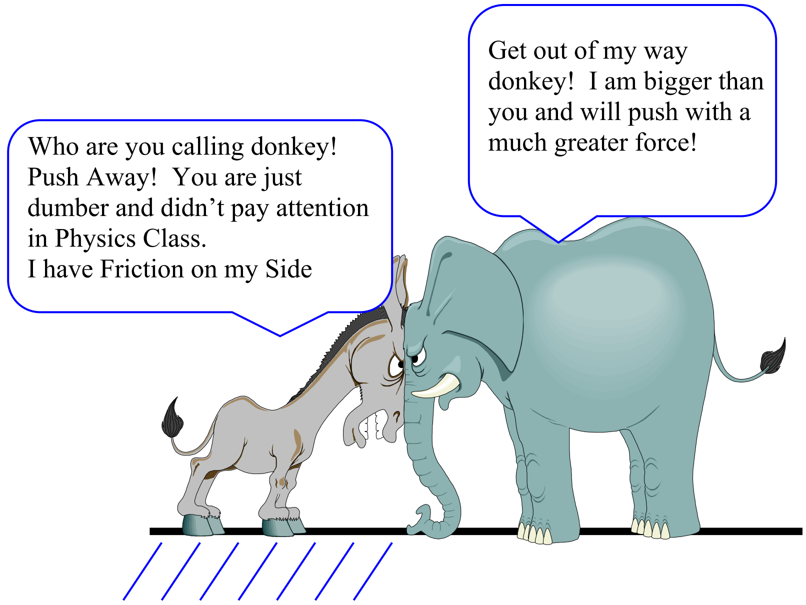
Forces and Newton's Laws



<u>Definitions</u>

<u>Dynamics</u> - The study of WHY things move.

<u>Mass</u> - 1) The amount of matter that makes up an object.
2) The measure of the ***<u>inertia</u>*** of an object.

- Mass is a scalar quantity
- The symbol for mass will be lower case "m"
- The units for mass are as follows:

MKS = kilogram (kg)
CGS = gram (g)
English = slug (slug)

<u>Inertia</u> - An objects tendency to maintain its present state of motion.

- Inertia is <u>quantitative</u>, the numerical value is the mass number for that object.
- If an object is a rest, the object's inertia is a measure of how much it wants to stay at rest.
- If an object is moving with constant velocity, the object's inertia is a measure of how much it wants to maintain its current speed and direction.

(Refer to Newton's Laws for a more complete explanation)

Force - a push or a pull– it is the "thing" that causes accelerations.

Note: This is a very abstract concept. We can never really talk about acceleration without stating the "thing" that caused the acceleration

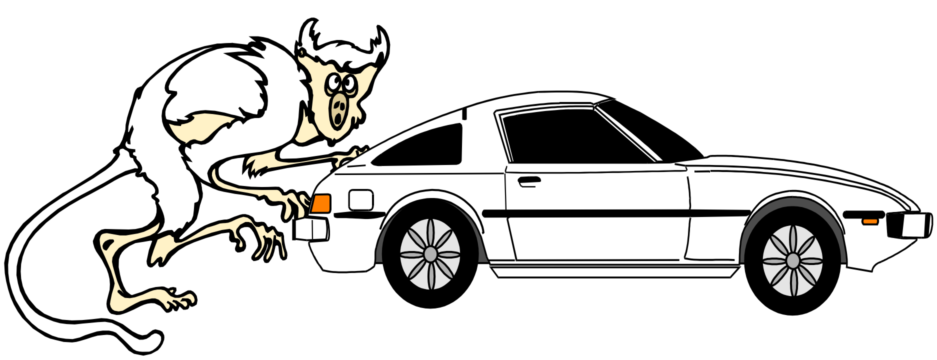
For example: The acceleration due to gravity
The acceleration on the baseball due to the bat
The acceleration of car due to friction!

- When you exert a push or a pull on an object, you say, you are exerting a force on that object.
- A force cannot be seen, it is only known by its *effects* on an object.

(Refer to Newton's Laws for a more complete explanation)

1st Effect – Forces cause accelerations

But, what if a car is stuck in the mud, and a giant monkey pushes (exerting a force) and the car doesn't move (no acceleration). Is he still exerting a force on the car?



2nd Effect – Action-Reaction Law of Motion.

When you push on something, it pushes back at you.

Newton's Three Laws of Motion

1st Law (The law of inertia) – An object will continue in its state of rest or constant velocity (both magnitude and direction) unless acted on by a **NET** force.

- The **NET** Force is defined as *the Sum of* all the force vectors acting on an object. The Greek letter upper case sigma "Σ" means "*the sum of*".
  Therefore, ΣF will mean **NET** force.
- If the Net Force (ΣF) equals zero then Acceleration **Must** also equal zero!
- This is a change from Aristotle's belief that a body's natural state is at rest. Newton shows a body's natural state is whatever state it has at present.

Question

1. Can an object have forces acting on it and NOT be accelerating? Explain your answer.

2. If an object has a zero net force acting on it, does this mean there are no forces acting on the object? Explain your answer.

2^{nd} Law $(F = ma)$ - The acceleration of an object is directly proportional to the **NET** force on it, and inversely proportional to its mass. The direction of the acceleration vector will be in the direction of the **NET** force vector. $a = \frac{\Sigma F}{m}$

- The second law shows from where the units for force are derived.

(Acceleration) (Mass) = Force

MKS $\left(1_{\frac{m}{s^2}}\right)\left(1_{kg}\right) = 1_{Newton} = 1_N$

CGS $\left(1_{\frac{cm}{s^2}}\right)\left(1_g\right) = 1_{dyne}$

English $\left(1_{\frac{ft}{s^2}}\right)\left(1_{slug}\right) = 1_{pound} = 1_{lb}$

- The second law also helps to quantify the idea of inertia.

Example:

A Force equal to $+10_N\hat{x}$ is applied to two different masses. m_1 = 10 kg and m_2 = 100 kg

A comparison of the two object's acceleration will show which object has the greater inertia.

$$a_1 = \frac{\Sigma F}{m_1} = \frac{10_N\hat{x}}{10_{kg}} = 1_{\frac{m}{s^2}}\hat{x} \qquad a_2 = \frac{\Sigma F}{m_2} = \frac{10_N\hat{x}}{100_{kg}} = 0.1_{\frac{m}{s^2}}\hat{x}$$

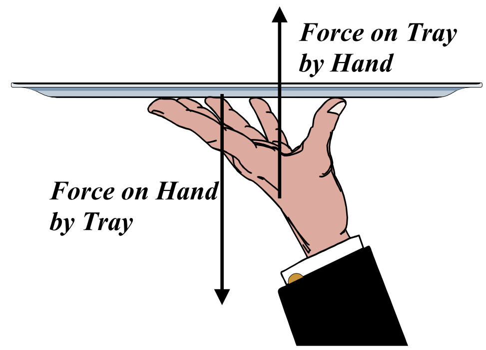
Remember, acceleration is inversely proportion to the inertia of an object. Therefore m_2 must have 10 times more inertia than m_1, because it has 10 time less acceleration.

<u>3^{rd} Law (Action/Reaction forces)</u> – When one object exerts a force on a second object, the second object will exert a force on the first object. The second force will be equal in magnitude but opposite in direction to the first force.

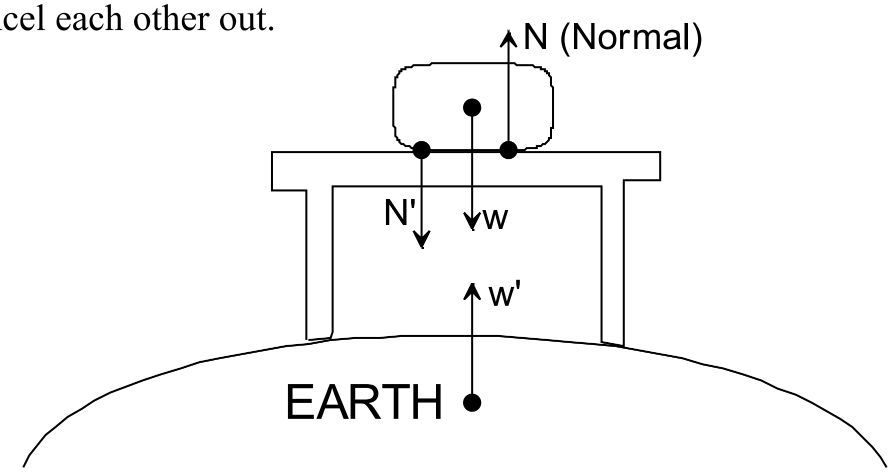
- Forces always come in pairs.
- Using the "**<u>on</u>**" & "**<u>by</u>**" terms

  <u>Action</u> – The force exerted **on** the *tray* **by** the *hand*.

  <u>Reaction</u> – The force exerted **on** the *hand* **by** the *tray*.



Note: the action reaction forces do NOT act on the same object, and therefore can never cancel each other out.



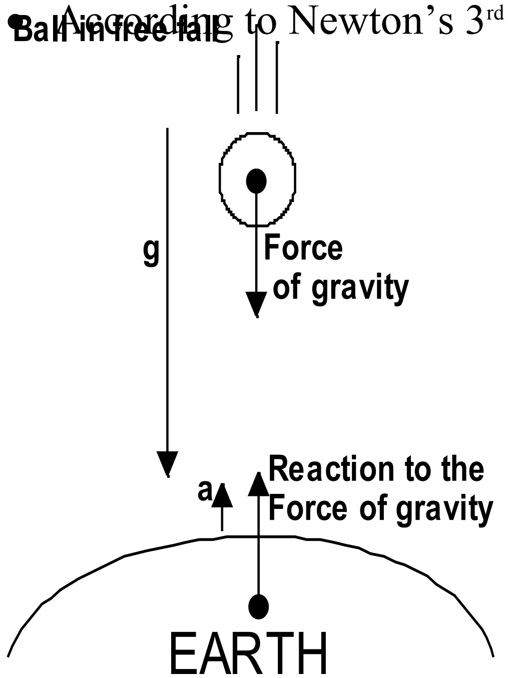
<u>ACTION – REACTION PAIRS</u>

w = weight force, force exerted **<u>on</u>** the block **<u>by</u>** the earth.
w′ = force **<u>on</u>** the earth **<u>by</u>** the block.

N = surface force, force **<u>on</u>** the block **<u>by</u>** the table
N′ = force **<u>on</u>** the table **<u>by</u>** the block

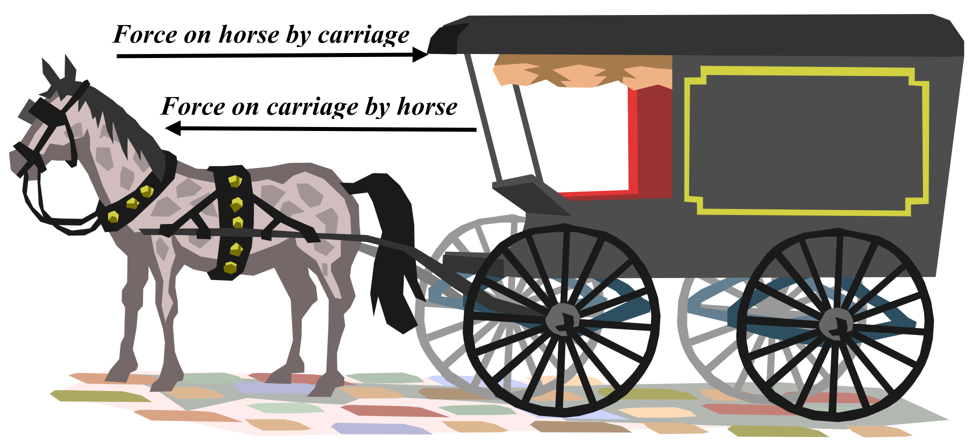
** Common Misconception – the weight and the force normal are an action/reaction pair. ***NOT TRUE!!!*** They are often equal in magnitude and opposite in direction, but they are not an action/reaction pair.

- According to Newton's 3rd Law, when any object falls to the earth there is a force exerted **by** the object **on** the earth.



- Therefore, the earth should accelerate just as the ball does.
- IT DOES!! However, the accelerations are inversely proportional to the masses.

$$m_{earth}a_{earth} = m_{ball}a_{ball}$$



According to legend, a talking horse (we will call him Wilber) learned Newton's laws. When he was told to pull the carriage, he refused; saying that when he pulls on the carriage forward, Newton's 3rd law states the carriage will pull on him with an equal force in the opposite direction. Therefore, the forces would be balanced, and there would be no **NET** force. Wilber then goes on to say that since there is no **NET** force Newton's 1st and 2nd laws state there can be no acceleration. How would you reason with this rather weird horse?

THE FOUR FUNDAMENTAL FORCES

- Scientists have worked very hard to find a commonality between all forces in the universe. They are trying to prove that all forces are components or properties of a single *Grand Unifying Force*. So far the scientists have unsuccessful.
- Instead of one force, they have grouped all forces into four categories.

Important note: All of these forces act at a distance. (No contact at the microscopic level)

1) ***Gravitational Forces***

- Attractive forces that exists between all objects.
- Caused by the interaction between the objects gravitational fields
- Infinite Range, weakest force, Relative force = 10^{-38}

2) ***Electromagnetic Forces***

- Force that exists between all charged particles or particles that demonstrate magnetic properties.
  (Protons, electrons, molecular bonding)
- Force that holds all matter together
- Infinite Range, Relative strength = 10^{-2}

3) ***Strong Nuclear Force***

- The force that holds the nucleus of the atom together.
- Overcomes the natural electromagnetic repulsion of protons
- Range ≤ to the diameter of an atom, Strongest force, Relative strength = 1

4) ***Weak Nuclear Force***

- Force that causes the radioactive decay of some nuclei
- Modern Theory has linked the weak nuclear force with the electromagnetic force with a theory known as *electroweak* theory
- Range ≤ the diameter of an atom, Relative strength = 10^{-6}

Theories such as the *electroweak* theory have recently lead to attempts to complete a ***Grand Unification Theory***; a theory that would tie all the fundamental forces together, as well as revolutionize the study of physics.

COMMON FORCES

Force due to Gravity (A.K.A. "weight force")

$$F_g = (m)(a_g) = (m)(g)$$

Where F_g = weight, m = mass and g = acceleration due to gravity $-9.8_{\frac{m}{s^2}}\,\hat{y}$

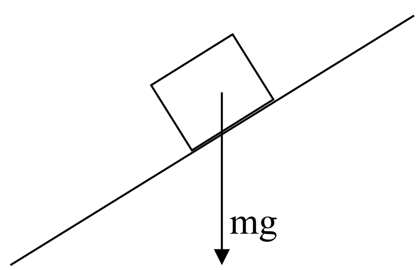
$$F_g = (1.00_{kg})(-9.80_{\frac{m}{s^2}}) = -9.80_N\,\hat{y}$$

Therefore, the weight of 1 kg on the earth is 9.8 Newtons,

$$F_g = (1.00_{kg})(-1.67_{\frac{m}{s^2}}) = -1.67_N\,\hat{y}$$

But only 1.67 Newtons on the moon, where "g" is less.

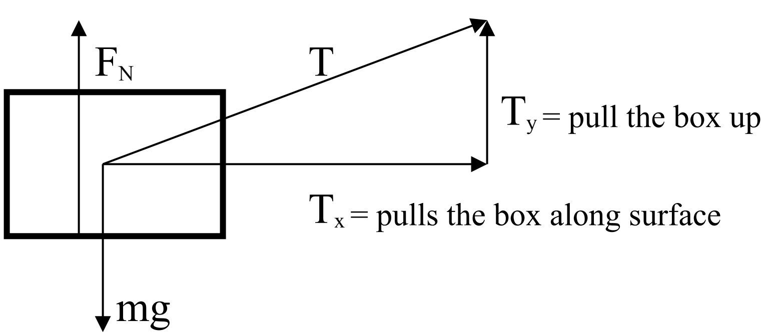
- Force due to gravity always acts straight down, even if the mass is on an incline.

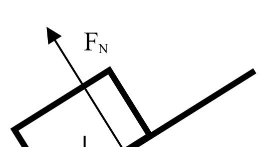


Tension Forces - force of strings, ropes, cables

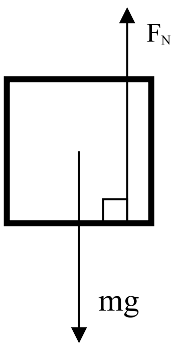
- Tension forces pull, never push
- Tension forces always act along the string
- Tension force is a reactive force

(something must pull on the rope to have tension in the rope)





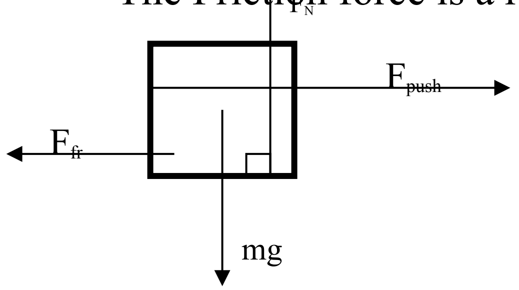
The Normal Force = surface force of a table, the ground, etc. straight up (90°) from the surface.



- The Force Normal, F_N, is reactive, not pro-active
- F_N always acts perpendicular to the surface, even if the mass is on an incline.
- F_N is not always equal to the weight force (mg) – it may be increased or reduced by an third force acting in the vertical plane

Friction – Surface force that acts parallel to the surface and resists the tendency for sliding.

- The Friction force is a reactive force, not pro-active



- only present if F_{push} is present
- $F_{fr} = \mu F_N$

What is μ ?

- Greek Letter “mu”; represents the ***coefficient of friction***

- Numerically the ***coefficient of friction*** is a ratio between two forces
- Unit-less number that characterizes friction between two surfaces
    - Every two surfaces in contact have their own value for μ

- Types of μ
    - μ_s = coefficient of static friction
    - μ_k = coefficient of kinetic friction

Friction (continued)

Experimentally it can be found:

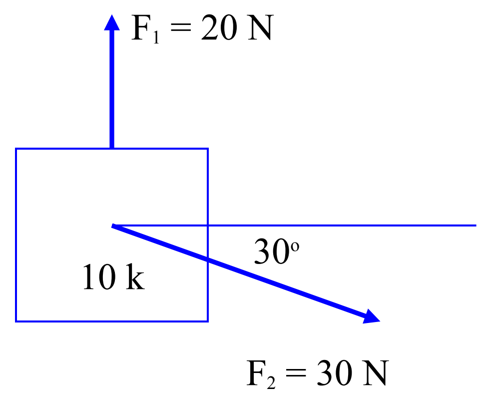
1) $\mu_s > \mu_k$
2) μ_s and μ_k are independent of the surface area in contact

Question: The value for μ is found experimentally. What type of an experiment could you do to calculate μ?

Example: Constant Force Problem
(Sum the Forces Problem)

A 10 kg object is subjected to the two forces F_1 and F_2, as shown below.

a.) Find the acceleration of the object
b.) If the object is at rest at t = 0 how fast is it moving after 3s.?
c.) Find the third force F_3 needed so that the object is in static equilibrium.



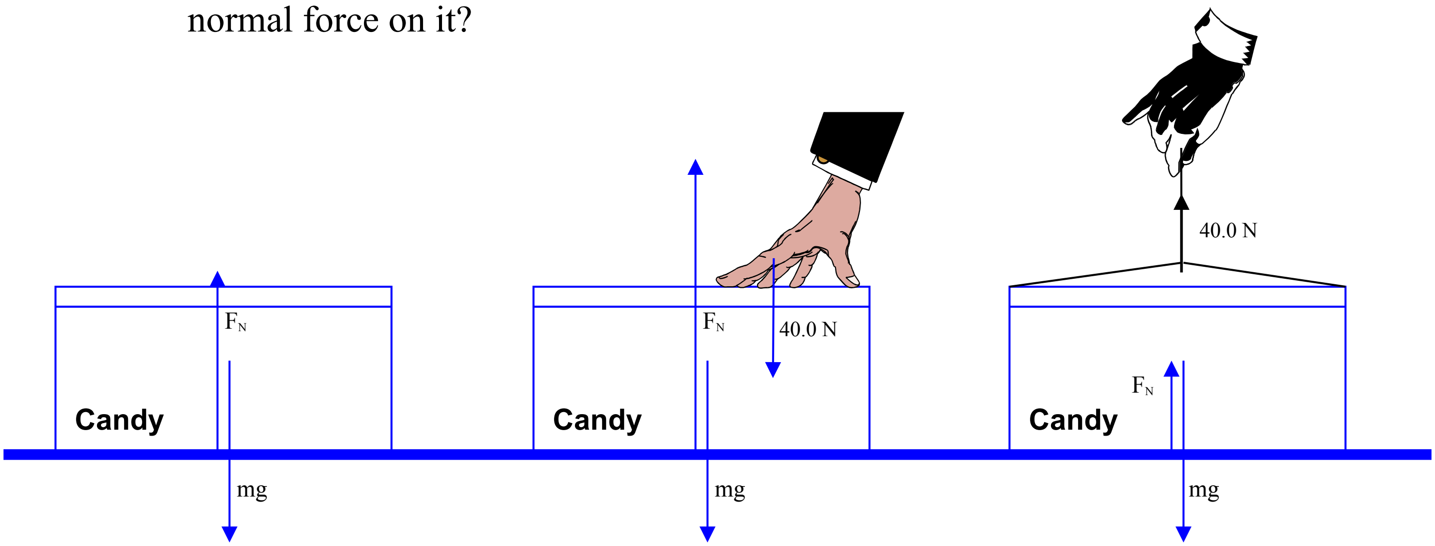
Example: Normal Force Problem

A 10 kg box of chocolates is resting on a smooth (frictionless) horizontal surface of a table.

a.) Determine the weight of the box and the normal force acting on it.

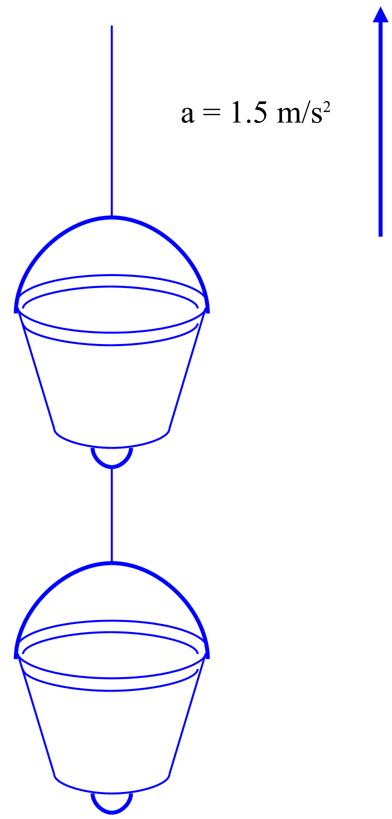
b.) Now you push down on the box with a force of 40 N. Again determine the box's weight and the normal force acting on it.

c.) If you pull upward with a force of 40 N, what is the box's weight and the normal force on it?



Example: Tension Problem

One paint bucket weighting 40 N is hanging from a massless cord from another bucket also weighing 40 N. The two are being pulled upward with an acceleration of 1.5 m/s^2 by a massless cord attached to the upper bucket. Calculate the tension in each cord.



Example: Person pulling on the rope Tension Problem

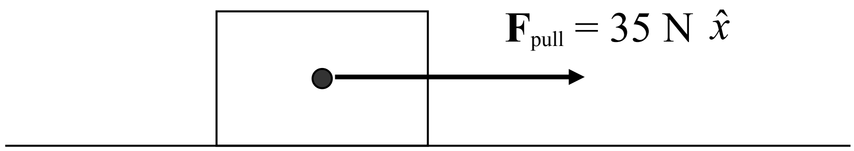
A 75 kg person is accelerating at a rate of 0.5 m/s^2 upward while climbing a rope attached to the ceiling.

a.) Draw a force diagram of the rope showing all of the forces acting on ropes
b.) Draw a force diagram of the person showing all of the forces acting on the person
c.) What force is pulling the person upward?
d.) Calculate the tension force in the rope.

<u>Friction – A closer look.</u>

Recall: $F_{fr} = \mu F_N$

What happens when the frictional force is bigger than the applied force?



m = 6 kg

$\mu_{static} = \mu_{kinetic} = 0.7$

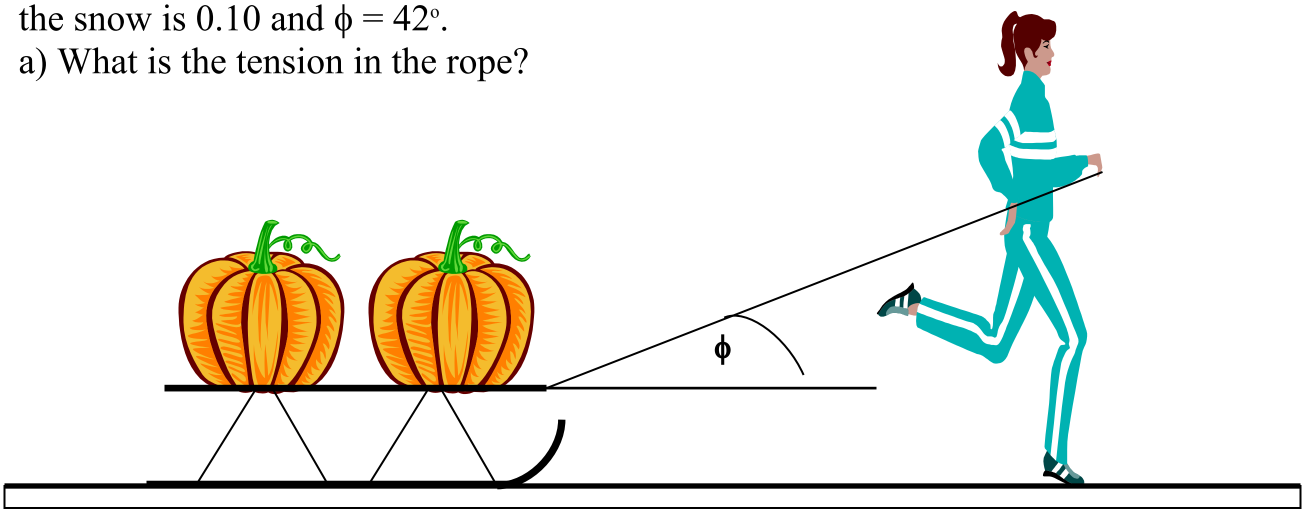
1. Draw a free-body diagram for the block above.

2. Use Newton's 2[nd] law ($\sum F = m\,a$) to calculate the acceleration.

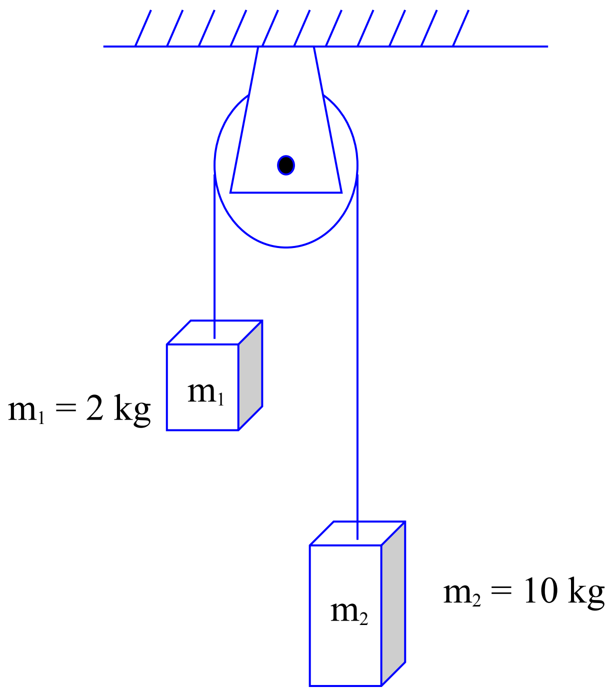
3. What is the frictional force?

Friction and the Normal Force

A woman pulls a loaded sled of mass, m = 75kg, along a horizontal surface at a constant velocity. The coefficient of kinetic friction, μ_k, between the runners and the snow is 0.10 and $\phi = 42^{\circ}$.
a) What is the tension in the rope?



Atwood Machines (Pulleys)



Assumptions
1. Massless, Frictionless Pulley
2. Massless rope that doesn't stretch

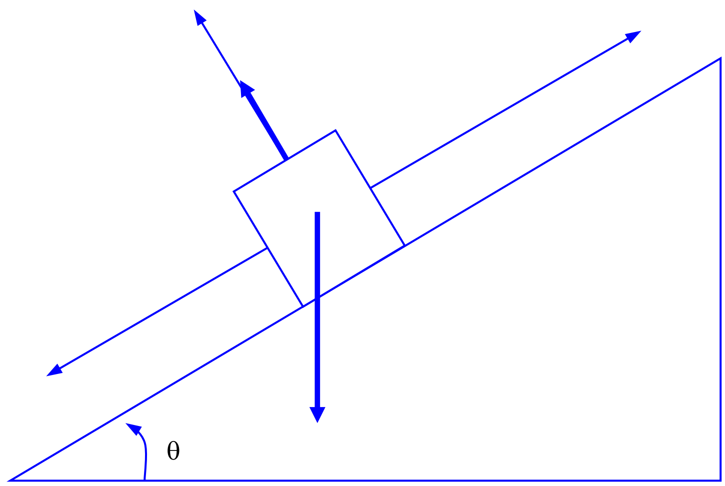
Problem Solving
1. Coupled System Approach

And/Or

2. Individual Force Diagram for each object

Find the tension in the rope and the acceleration of the system

Inclined Plane Problems



Problem Solving

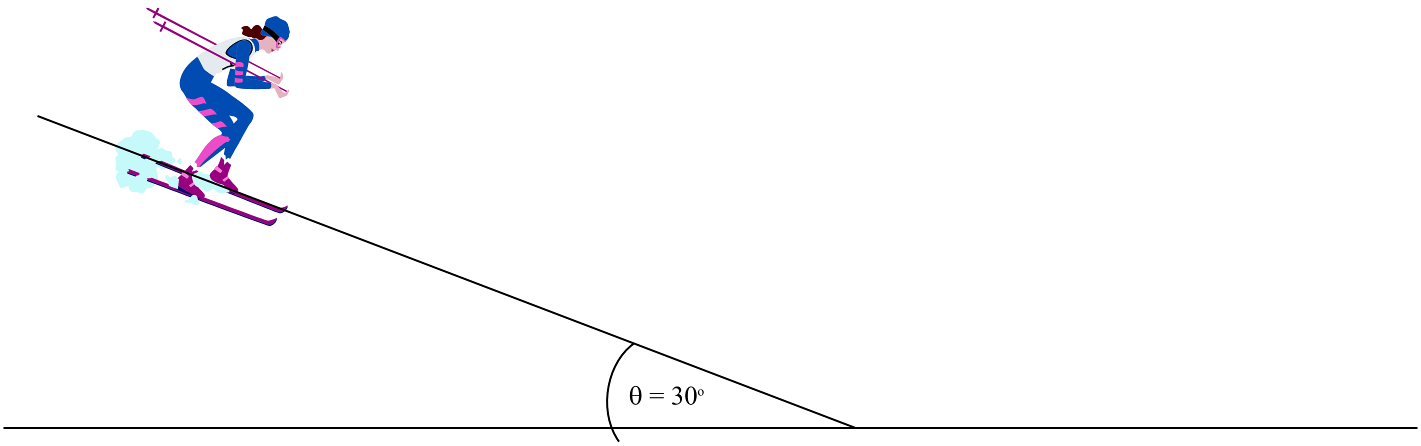
1. Always put the x-y axis so that the y-axis is perpendicular the plane and the x-axis is parallel to the plane (in other words ROTATE THE COORDINATE SYSTEM!)
2. Make sure the weight force (F_g = mg) is straight down
3. Identify all other forces, draw vectors on the rotated x-y axis
4. Use $\Sigma F_x = ma_x$ and $\Sigma F_y = ma_y$ to solve the problems

Example Problem – Incline plane

The skier has just begun descending the 30° slope. Assuming the coefficient of kinetic friction is 0.01, calculate

a) the acceleration of the skier.

b) The speed of the skier after 6.0 s.



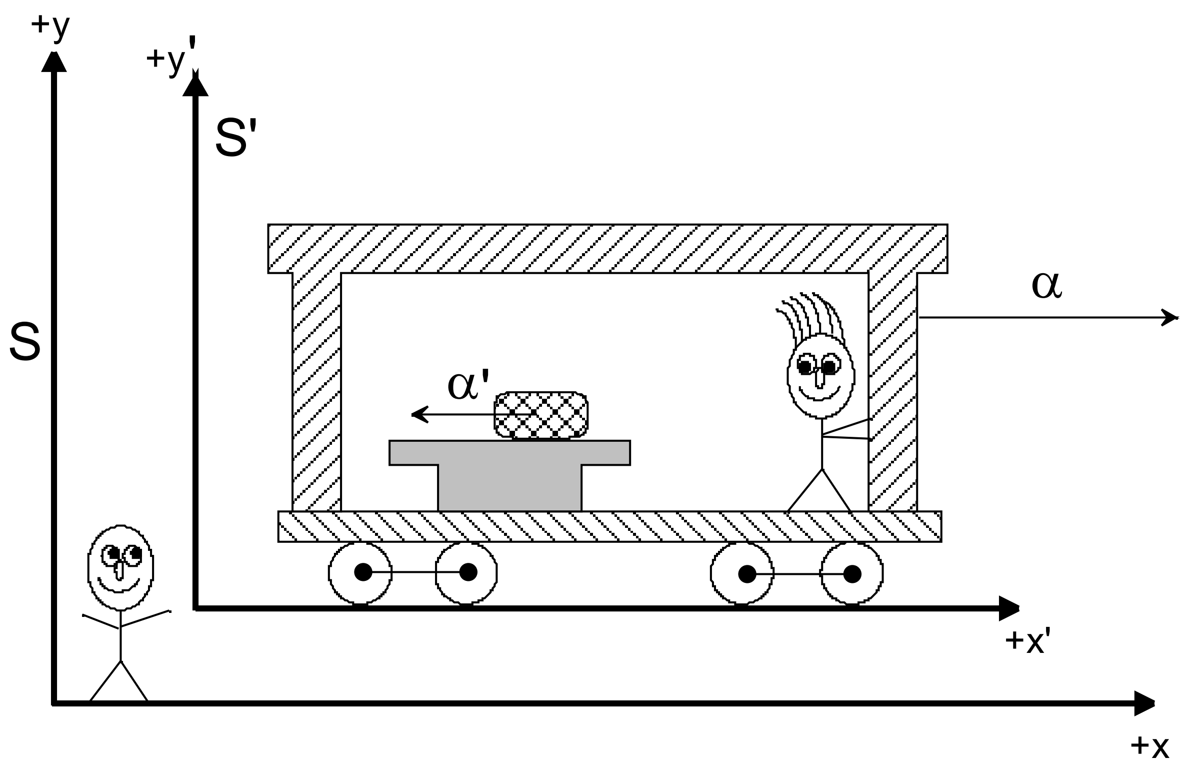
INERTIAL REFERENCE FRAMES

Inertial Reference Frame – Any reference frame in which Newton's Laws Hold.

At Rest ($v = 0$) Is an example of an inertial reference frame. The earth can be considered to be "at rest" relative to object moving on its surface.

Constant Velocity ($\Delta v = 0$) Is another example of an inertial reference frame.
If you are in a reference frame moving with zero acceleration, (constant velocity) your motion can not be detected experimentally.

Consider the case in which S is an inertial reference frame, and S′ is a reference frame accelerating relative to S.

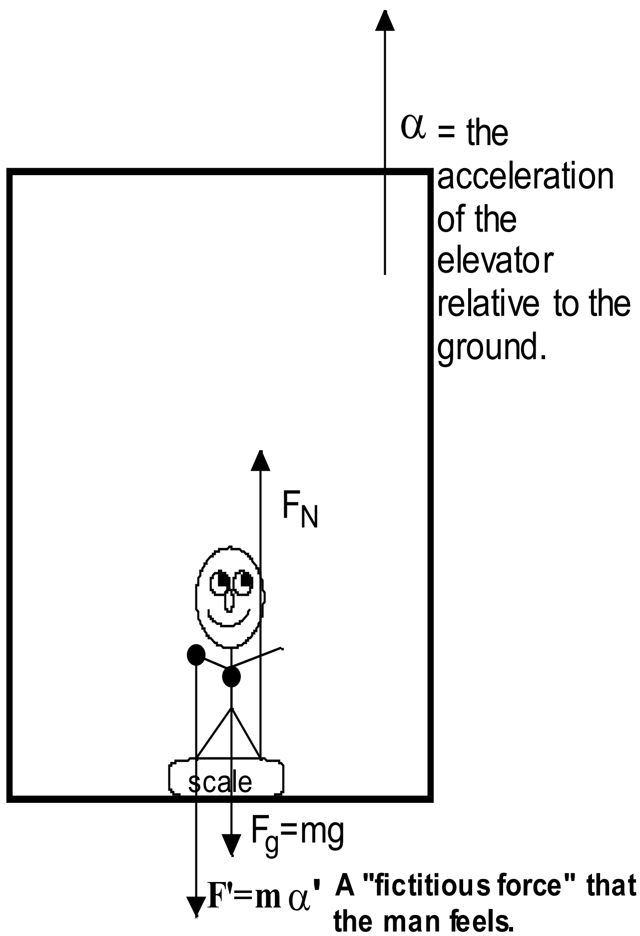


Newton's laws will **not** hold in the railroad car.
In the railroad car, a body at rest on a smooth table does not appear to remain at rest or move with a constant velocity. It appears to accelerate with an acceleration equal to α'.

Accelerating Frames of reference are called ***Non-Inertial*** reference frames.

Example: Non-Inertial Reference Frame

Calculate the "apparent" weight of a 60 kg man in an elevator that is accelerating upward with an acceleration of 2.0 m/s².



From the man's non-inertial reference frame:

$$\sum F = 0 = F_N + mg + F'$$

because the $F_N \neq -mg$, the man believes there must be another force acting (F′).

From an observe in an inertial reference frame:

$$\sum F = m\alpha = F_N + mg$$

the inertial observer can see that the man ***IS*** accelerating, and therefore would find that what the man calls **F′** is equal and opposite to the NET Force.