May The Forces Be With You

Auburn Mountainview: Physics

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Forces

- Force [v]: A push or pull exerted on any object. (kg m/s^2 = Newtons)
- There are two major types:
  - Contact Forces: Touching the object directly.
    - Friction, Normal, Tensile...
  - Long-Range Forces: No direct contact with an object.
    - Gravity, Magnetism.

Labeling Forces

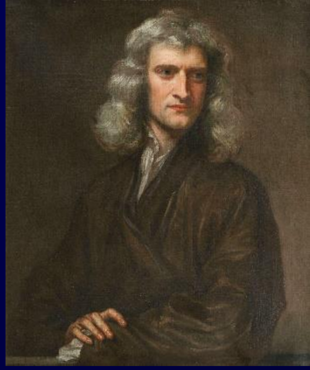
- As a vector, every force must have:
  - Direction: arrows point tail to tip. Algebra: #.##° N/S of E/W
  - Magnitude: longer/thicker. Algebra: #.##-N
  - Labels: A descriptive label

- Using Pythagorean theorem force(s) may:
  - be broken apart into x/y components.
  - be combined to find a NET (total) force.

Specific Labels for Forces

Forces	Label	Definition	Direction
Normal	F_N	A contact force exerted by a surface back on an object.	Perpendicular away from the surface.
Weight	$F_{E/g}$	A long-range force due to gravitational attraction between two objects.	Straight down toward the center of Earth.
Magnetism	F_m	A long-range force due to attraction or repulsion between two objects.	Either straight toward or away from another magnetic object.
Friction	$F_{kf/sf}$	A contact force that acts to oppose sliding motion between two surfaces.	Parallel to the surface and opposite the direction of motion.
Spring	F_{sp}	A restoring force that pushes or pulls a spring.	Opposite the displacement of the object on the spring.
Tension	F_T	A pull exerted by a *rope* when attached to an object and pulled taught.	Away from an object and parallel to the *rope* at point of contact with object.

1st Law of Motion



- If a pool ball sits on an infinite plane what would happen to it?
- If the same ball is hit (like with a pool cue) what would happen now?
  - What if there was no friction between the ball and table?

1^{st} Law

- Recap for objects…
  - not moving they will not start moving on their own.
  - that are moving they will not slow down on their own.
  - will always resist changing their motion (straight path).

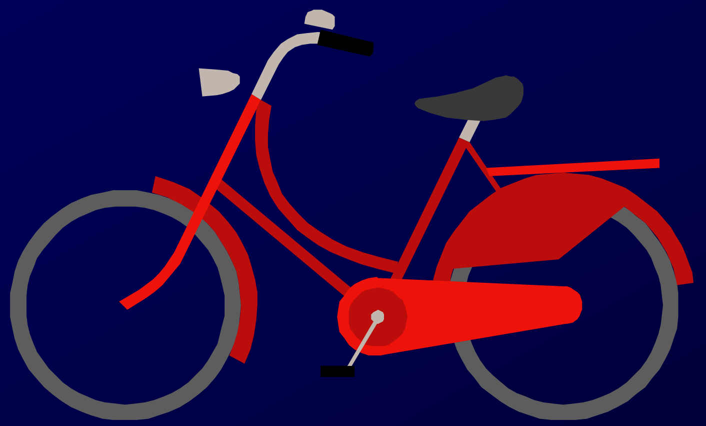
An object in motion stays in motion, an object at rest stays at rest unless acted on by a force.

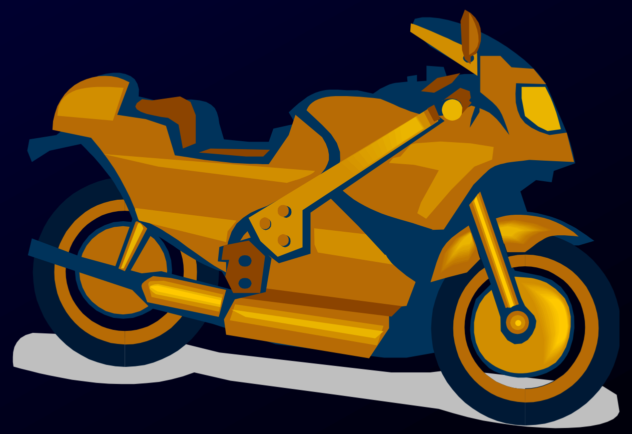
(Law of Inertia)

Inertia

- The tendency of an objects resistance to change.

- Bigger objects have more inertia.
  - Moving/Stopping a bike requires less effort than moving/stopping a motorcycle.





2^{nd} Law of Motion

- Quantifies the relationship between Force, Mass and Acceleration.
  - To accelerate an object a net force must be present.
  - A force must be applied to something (mass).
  - The more the mass the more force needed to accelerate. (Big truck vs. small car.)

2^{nd} Law

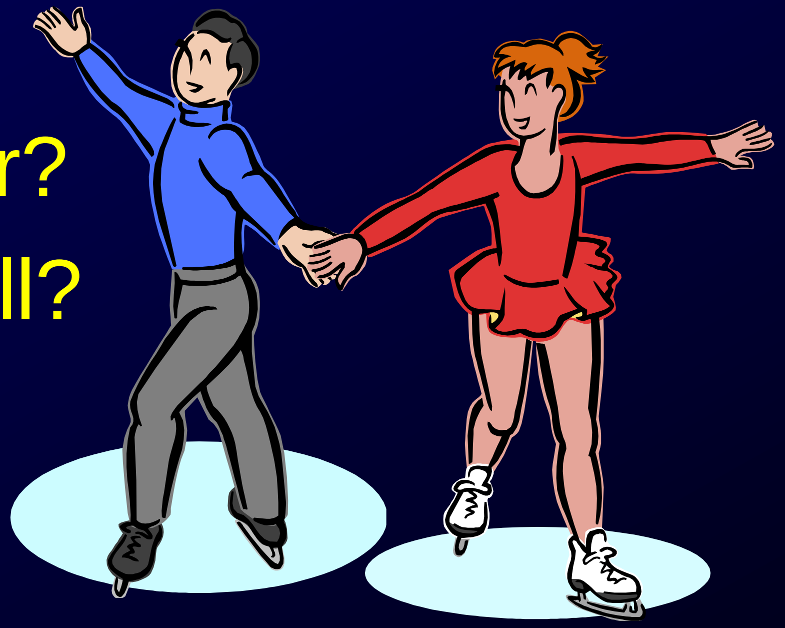
- Newton's second law states:

$$F_{NET}=m \cdot a$$

- Mass: kg
- Acceleration: m/s^2
- F_{NET} [v]: $kg \cdot m/s^2$ → N (Newton)

3rd Law of Motion

- If two ice skaters, who weigh the same, push each other, what happens?
  - What if one skater is much heavier?
  - What if the skater pushes off a wall?
- Newton's third law states:



For every action there is an equal yet opposite reaction.

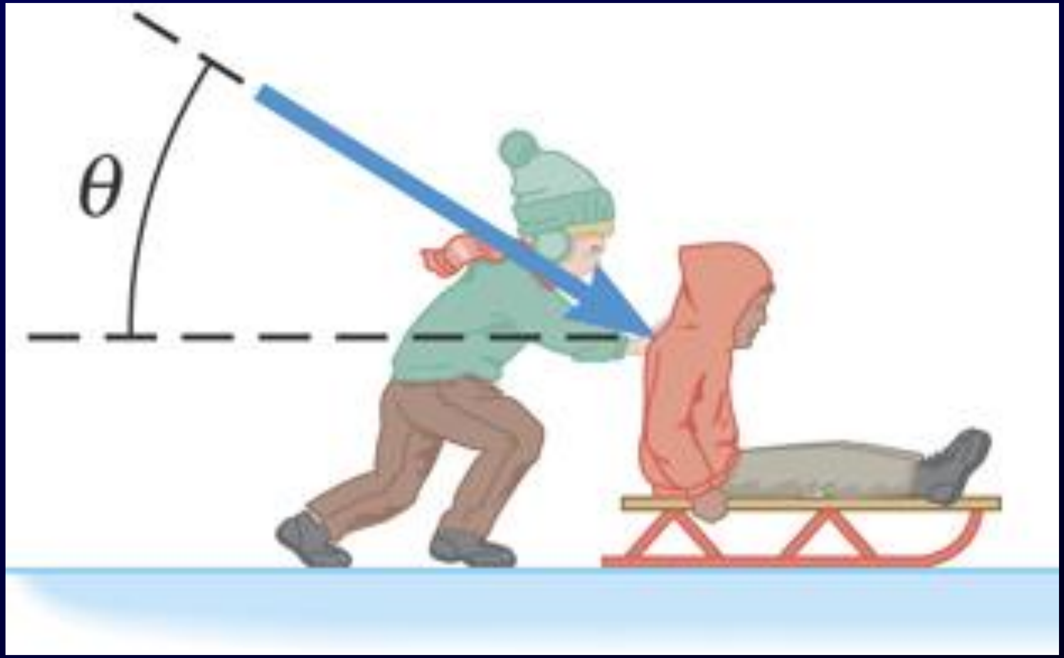
Putting All Three To Use

- When given a situation involving forces, follow the same pattern as before:
  - Draw the situation.
    - Separate out the object being looking at (Free Body Diagram).
  - Draw given and perpetual forces (like gravity).
    - If needed break down into x/y components.
  - Use formulas (Old kinematic + New F=ma)
    - Always ask is there any… motion? a? F_{NET}?
  - Solve for all other forces (balance)
  - Ask: Does this drawing make sense?

Free Body Diagram Example

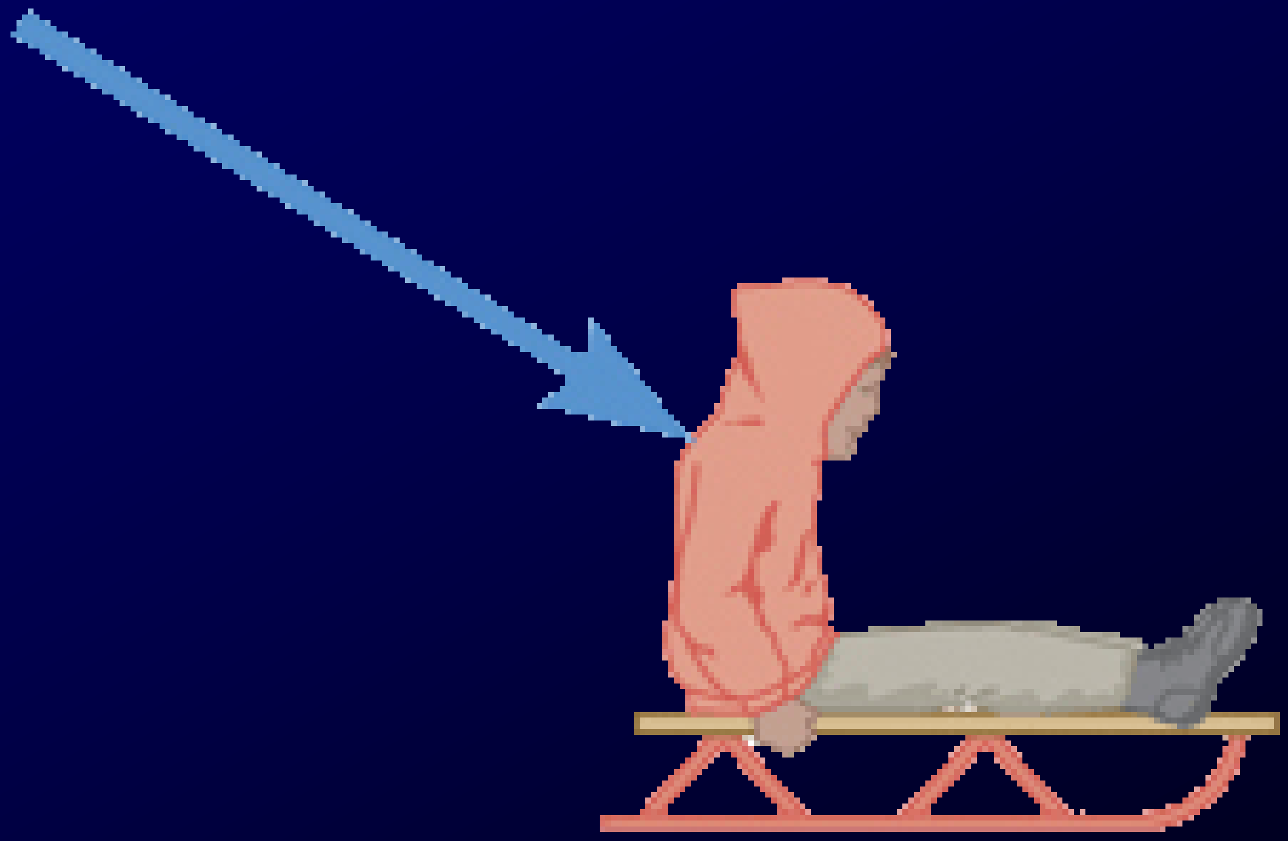
- The boy in blue pushes another boy on a sled at a 30° downward angle with the horizon so that he maintains a constant velocity. What are the forces on the boy_{red} ?

1) Draw the situation



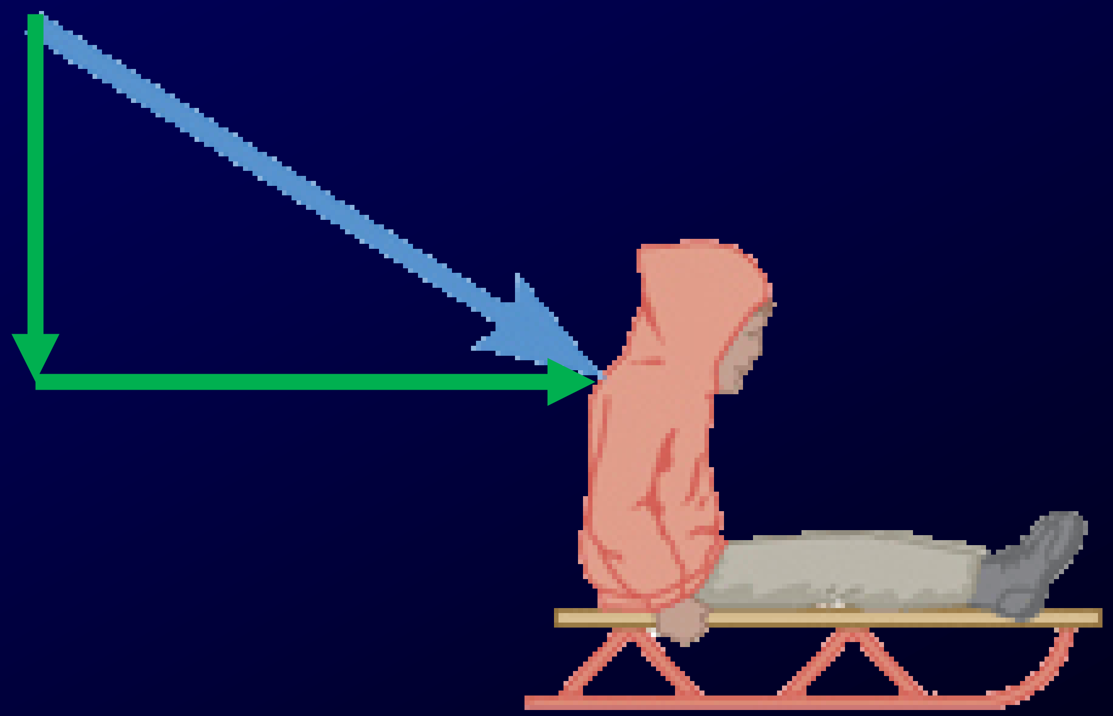
Free Body Diagram Cont.

Separate the object (also called a free body diagram).



Free Body Diagram Cont.

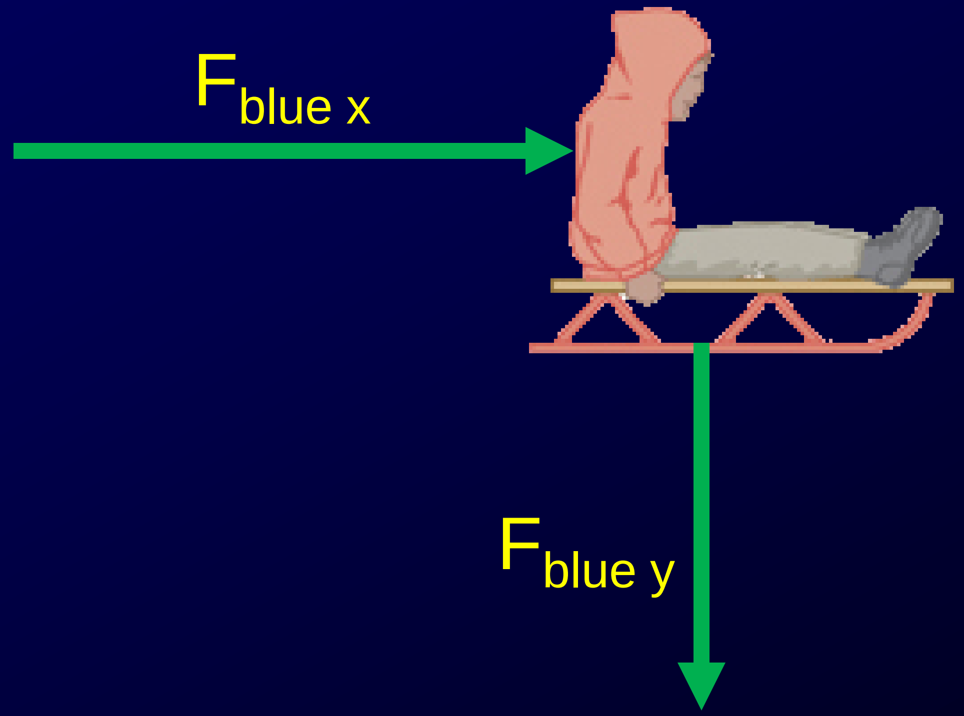
Vectors at an angle often need to be broken apart so that there is a parallel and perpendicular component to the surface. Traditionally and in this case: E-W.



Free Body Diagram Cont.

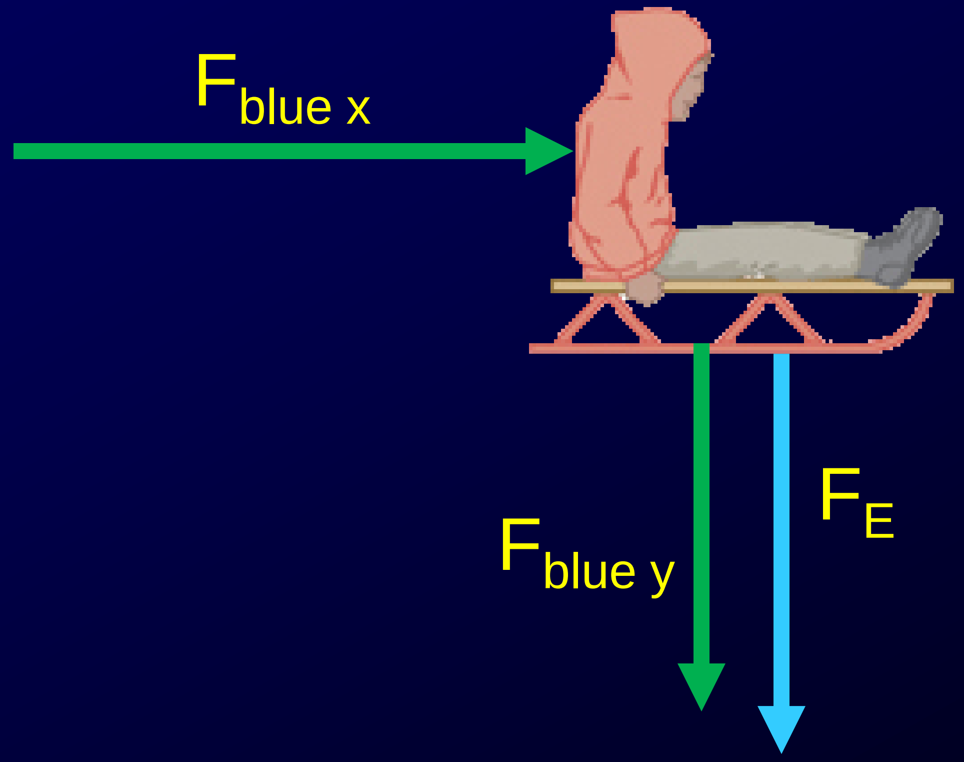
Draw and Label all given vectors.

Remember these two vectors are temporary for the real push of the boy in blue



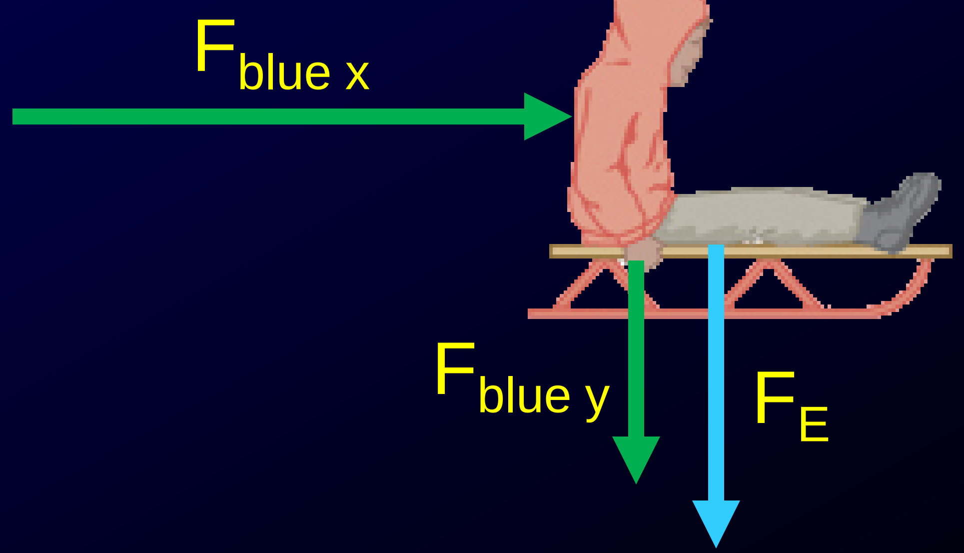
Free Body Diagram Cont.

Add any perpetual vectors like weight (Force of Earth).



Free Body Diagram Cont.

- The problem stated that the boy was being pushed at a constant velocity ($v=k \therefore a=0$).
- Since $F_{NET}=ma$… $F_{NET}= 0$ ($F_{NET}=m\cdot 0$)
- All Forces must balance to equal 0.
- Add action/reaction pairs.

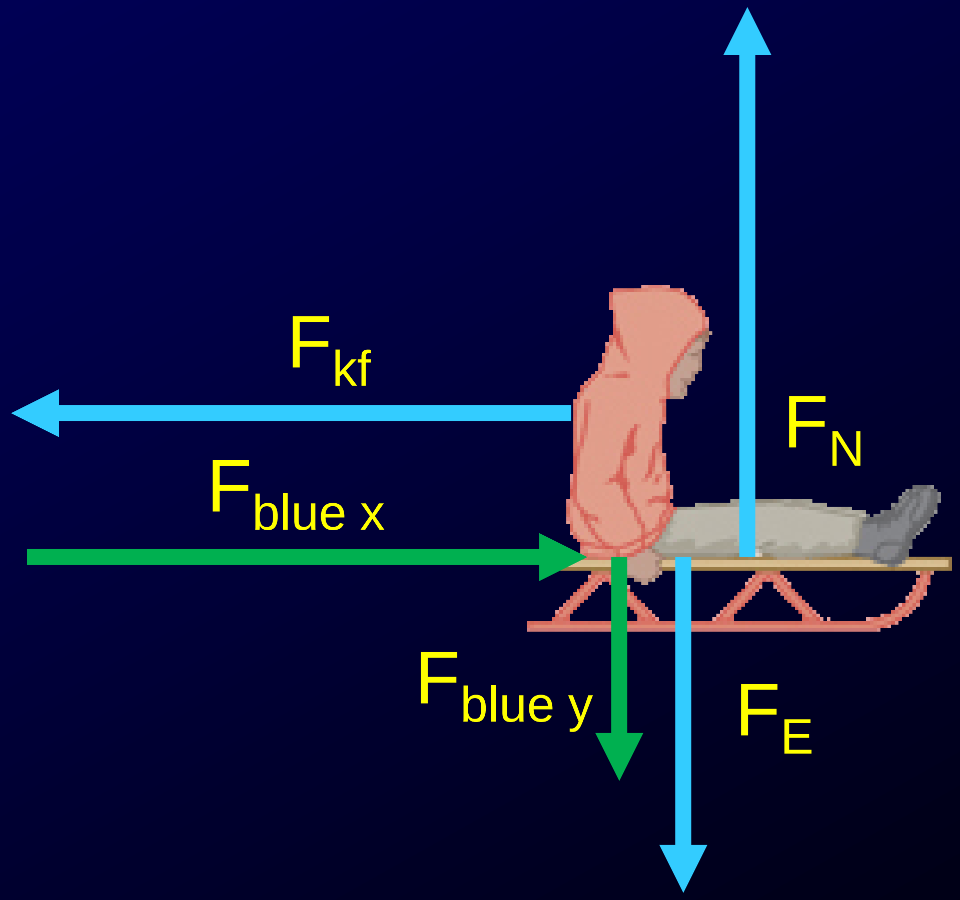


Free Body Diagram Cont.

- Common reaction pairs:
  - Push/Pull ↔ Friction:

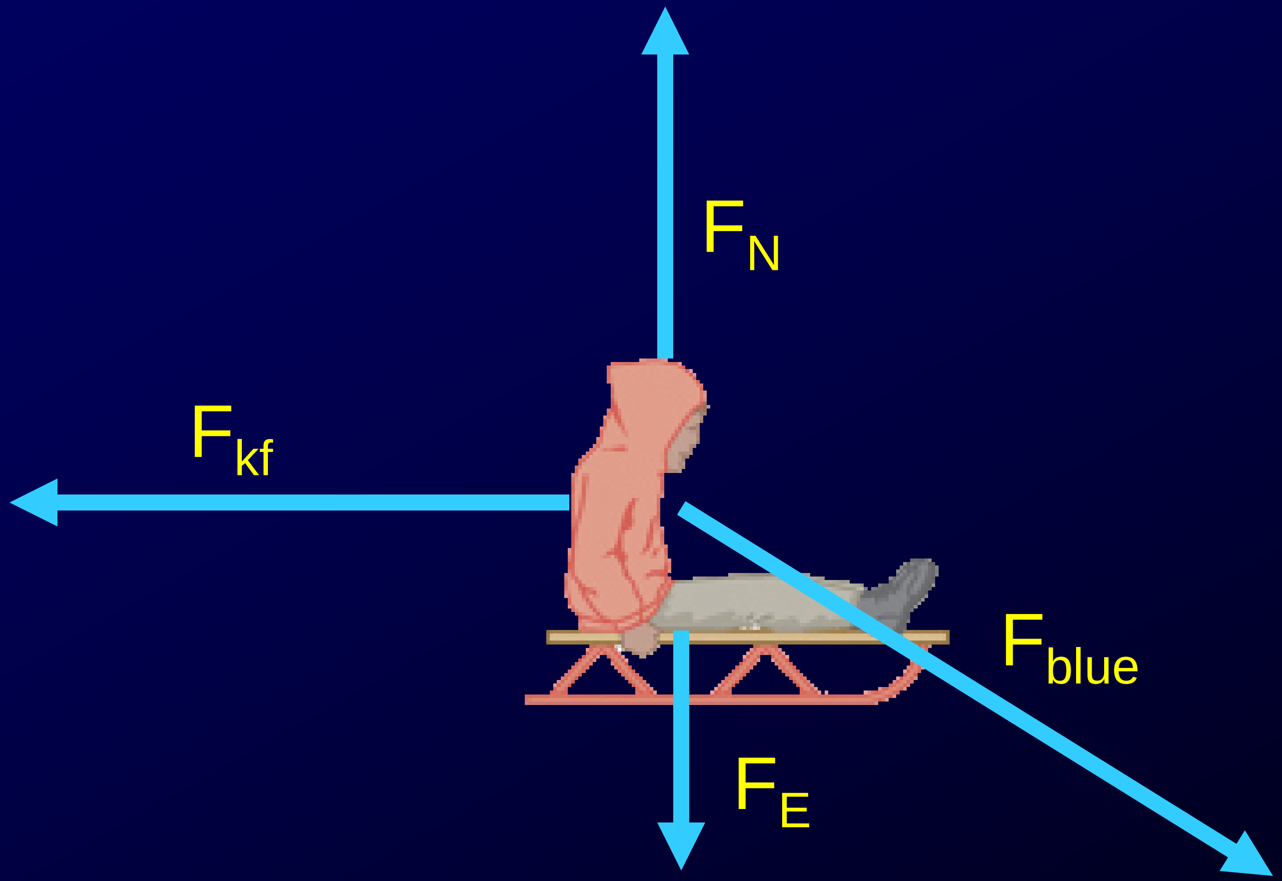
    Always parallel to surface and opposite direction of travel.
  - Into Surface ↔ Normal Force:

    Always perpendicular and out of surface.



Free Body Diagram Cont.

- Any forces at an angle that were broken apart must be put it back together in final diagram.

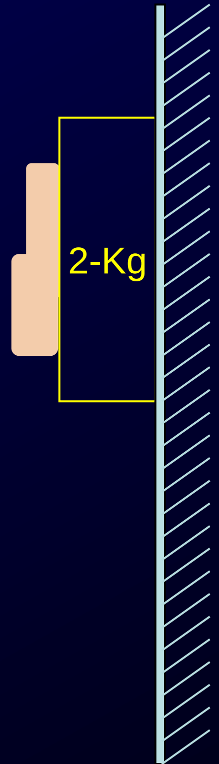


Another word about Gravity

- In the last example the force due to gravity was used.
- This force is applied for all objects normally on or above any planet (normally Earth).
  - The object does not need to be touching the planet
  - This force always points to the center of the planet.
  - This Force should be written as either F_E or F_g.
- If $F=ma$ then $F_E=mg$ ($g_E=9.8\ m/s^2$)

Algebra Example I

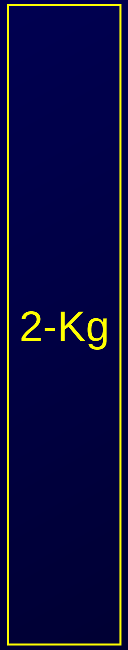
- A hand is holding a book (2.00-kg) against the wall with a force of 5.00-N. The book is not moving.
  - Draw and label all force vectors.
  - GUESS: Picture first:



These lines represent an immovable object

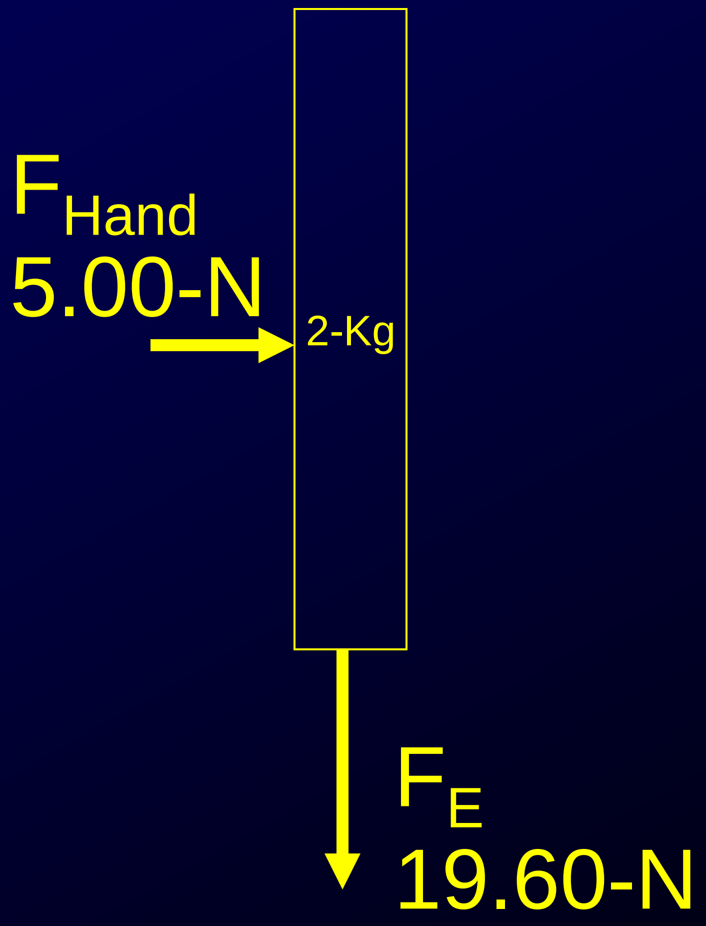
Algebra Example I

- Separate the object:



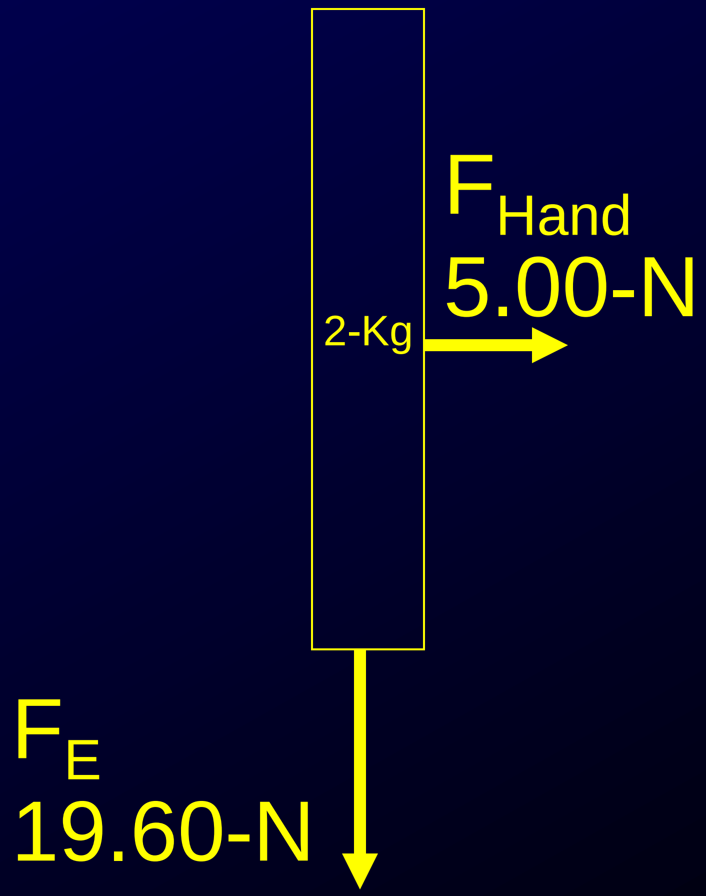
Algebra Example I

- Label given forces first.
- Label perpetual forces.
  - $F_E = mg$
  - $F_E = 2\text{-kg} \times 9.8\ m/s^2$
  - $F_E = 19.60\text{-N}$



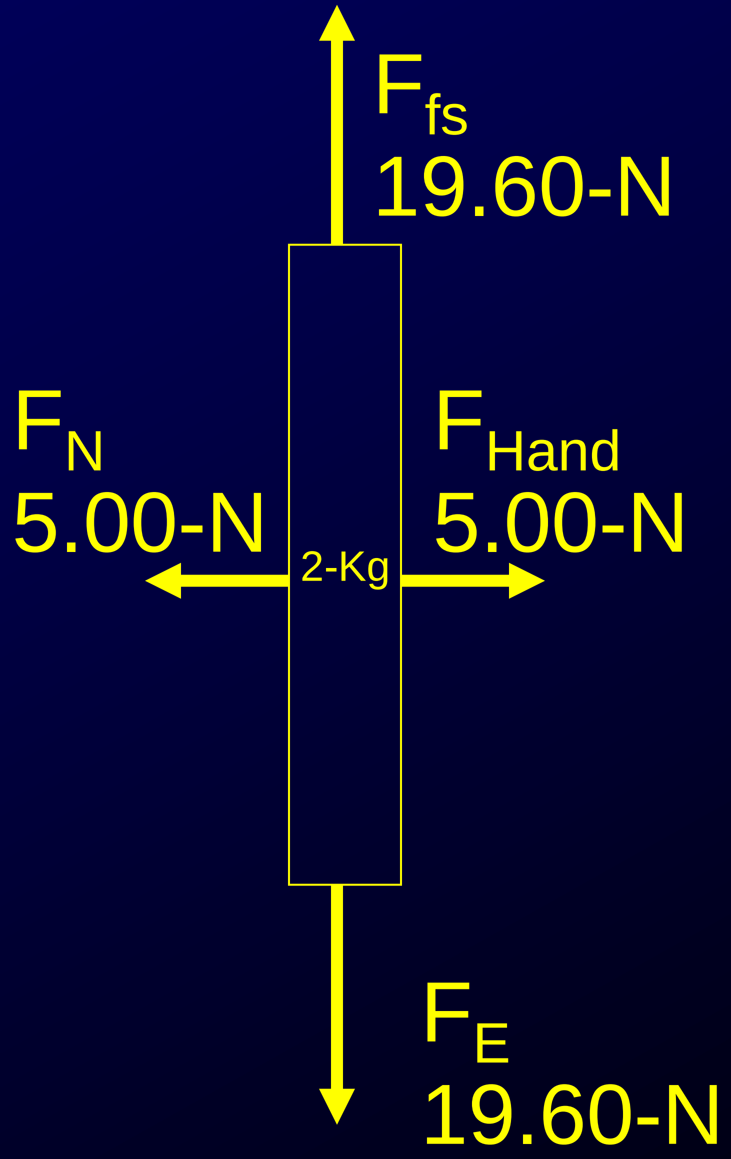
Algebra Example I

- Solve for F_{NET}?
  - Stated: at rest (v = a= 0)
  - Sum of all Forces = 0
  - Must add reaction pairs.

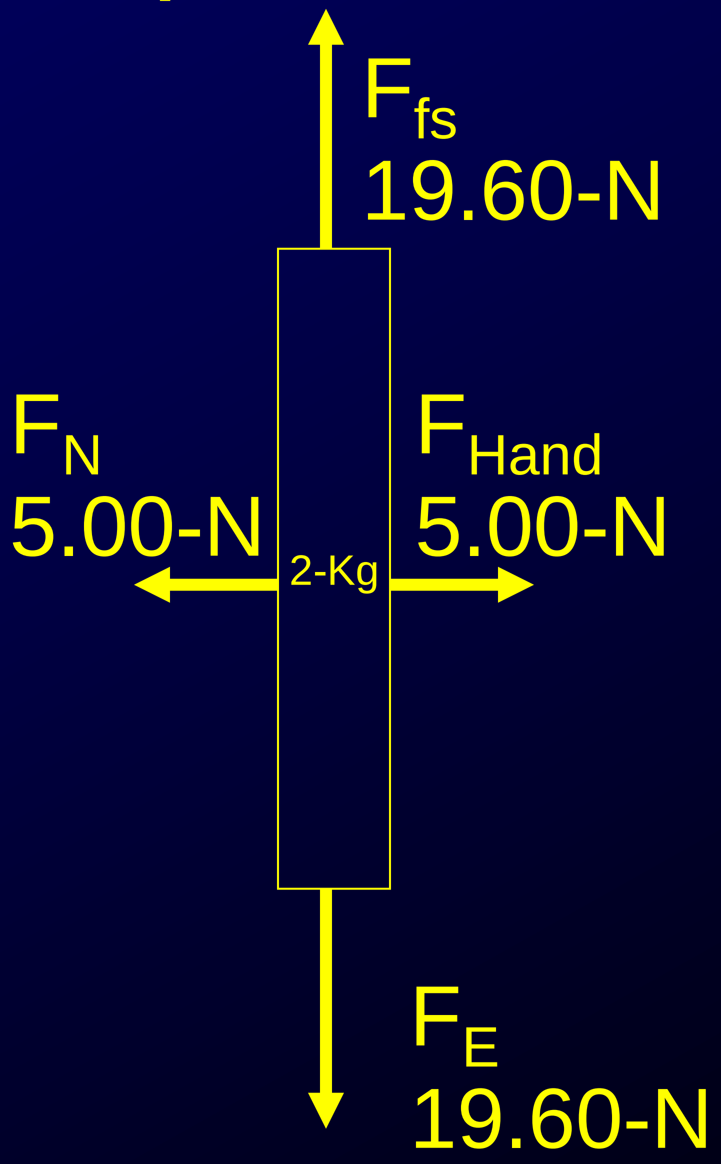


Algebra Example I

- Action-Reaction Pairs.



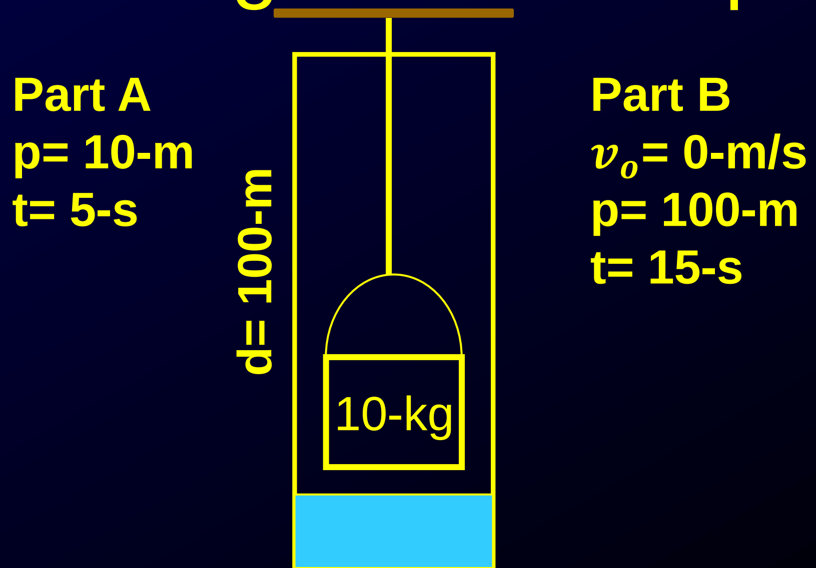
Algebra Example I



- Ask: Does this make sense?
- This is an example of a Normal Force on the x-axis (traditionally Normal is on the y axis).

Algebra Example II

- A bucket of water (10.00-kg) is being pulled up a well 100.00-m deep. The bucket is pulled up 10.00 meters every 5.00 seconds.
  A. Draw and label all force vectors.
- The same bucket then starts from rest and gets to the top of the well in 15.00-seconds
  B. What is the F_{NET}?
  C. Draw and label all force vectors.



Algebra Example II

- Solve for F_{NET}

A) $\bar{v}$ = 2-m/s

∴

a = 0-m/s^2

∴

F_{NET} = 0-N

B) p = v_ot + .5at^2

100-m = .5a(15-s)^2

a = 200-m/225-s^2

a = .89-m/s^2

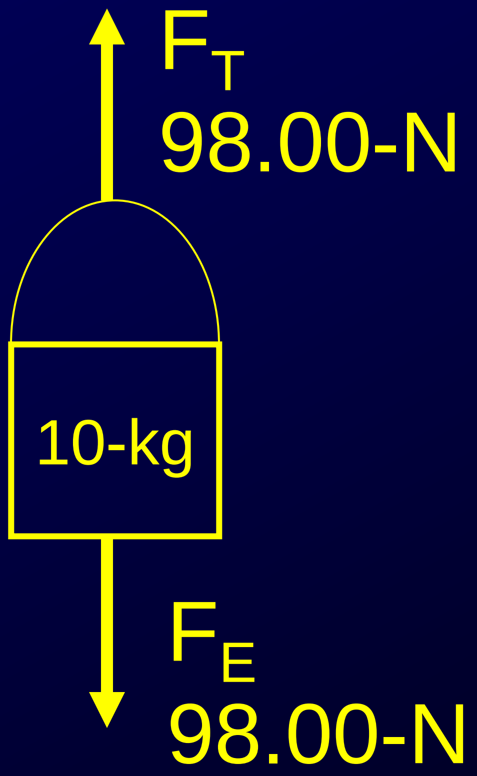
F_{NET} = ma

F_{NET} = 10-kg x a

F_{NET} = 8.89-N

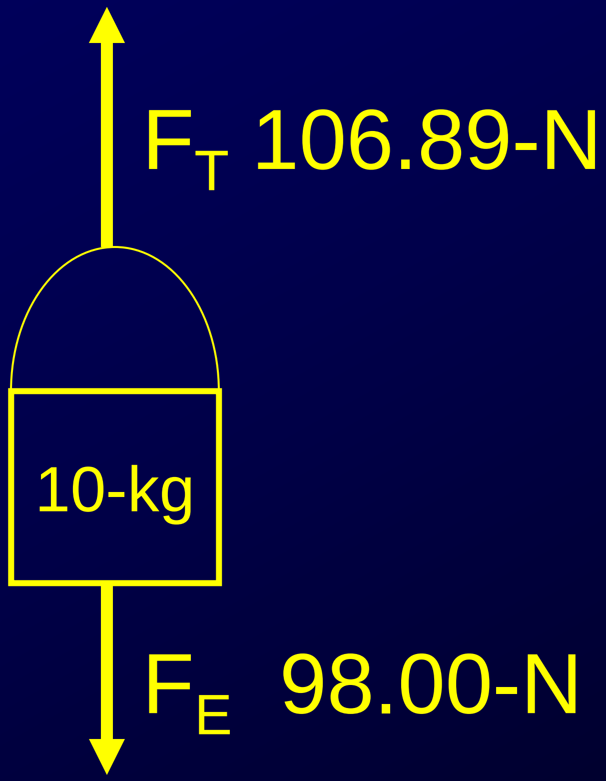
Algebra Example II: Part A

- Label given forces first:
  - While you *could* label the force of the rope as F_r, it is more appropriate to label it as F_T for tension.



Algebra Example II: Part B

- F_{NET}=ma. Also remember that $F_{NET} = \Sigma F_{x\ or\ y}$
  - Since the F_E did not change (same mass) the tension does.

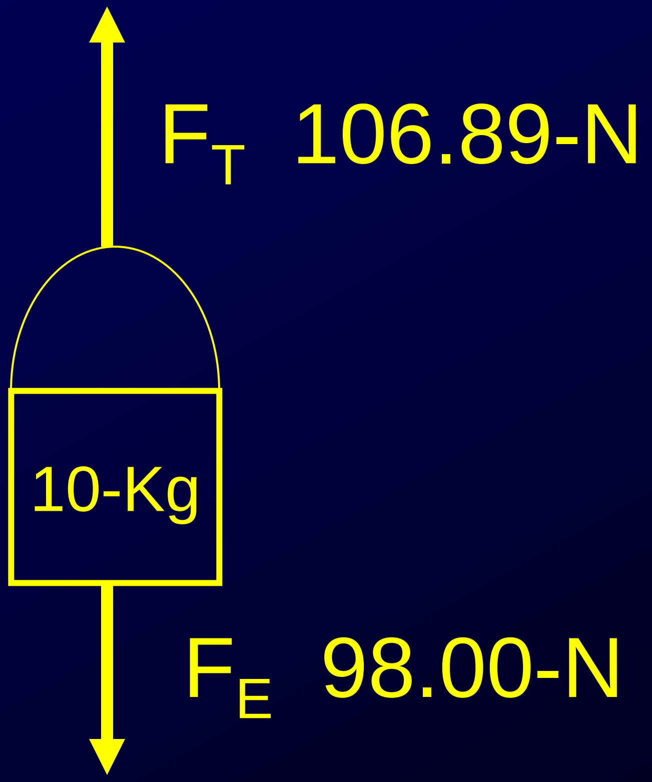


$$F_{NET} = F_T + F_E$$

$$8.89\text{-N} = F_T - 98.00\text{-N}$$

$$F_T = 106.89\text{-N}$$

Algebra Example II: Part B



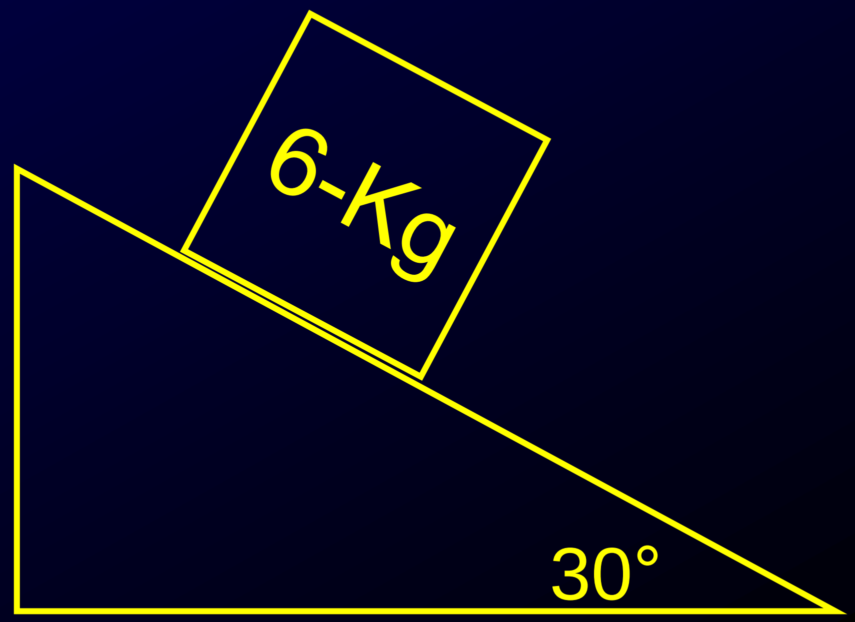
- Ask: Does this make sense?
- This is an example of an unbalanced force combined with no Normal force.

Algebra Example III

- A metal block (6.00-kg) rests on a steel ramp with an elevation of 30.00° to the horizontal.
  A. Draw and label all force vectors.
- Later the object accelerates down the ramp at 3-m/s^2.
  B. What is the F_{NET}?
  C. Draw and label all force vectors.

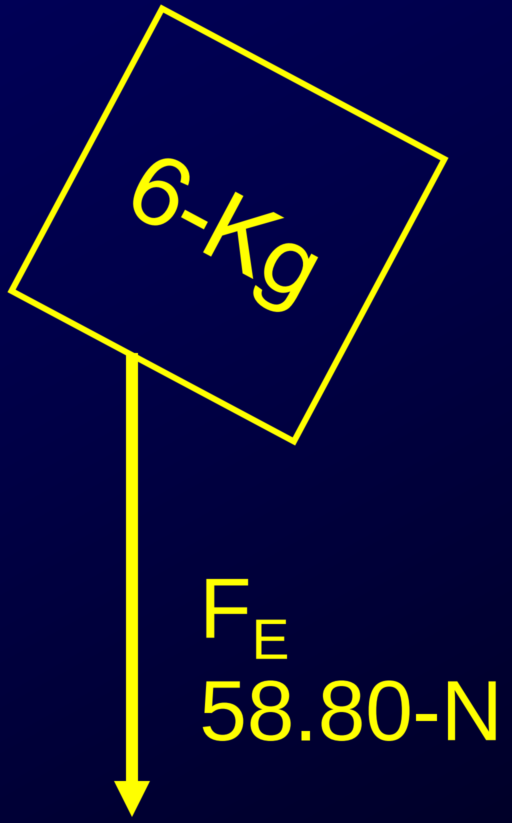
A) $a = 0\text{-m/s}^2$

B) $a = 3\text{-m/s}^2$



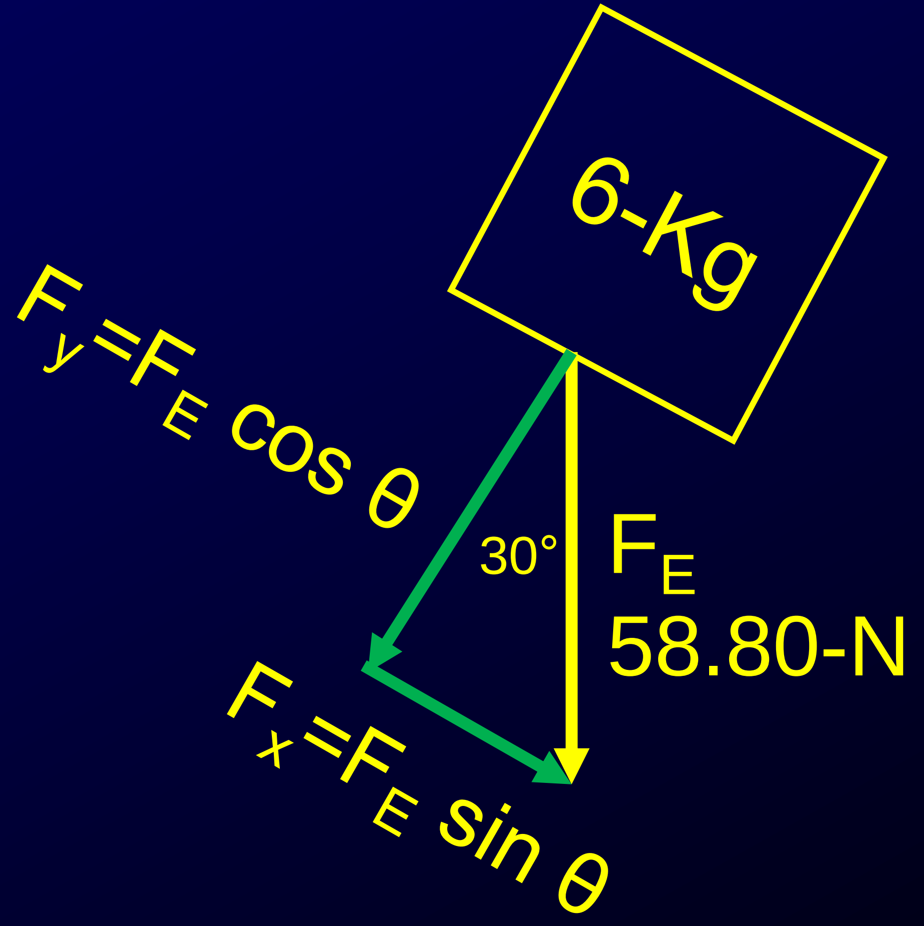
Algebra Example III: Part A

- Separate the system.
- Label given and perpetual forces.



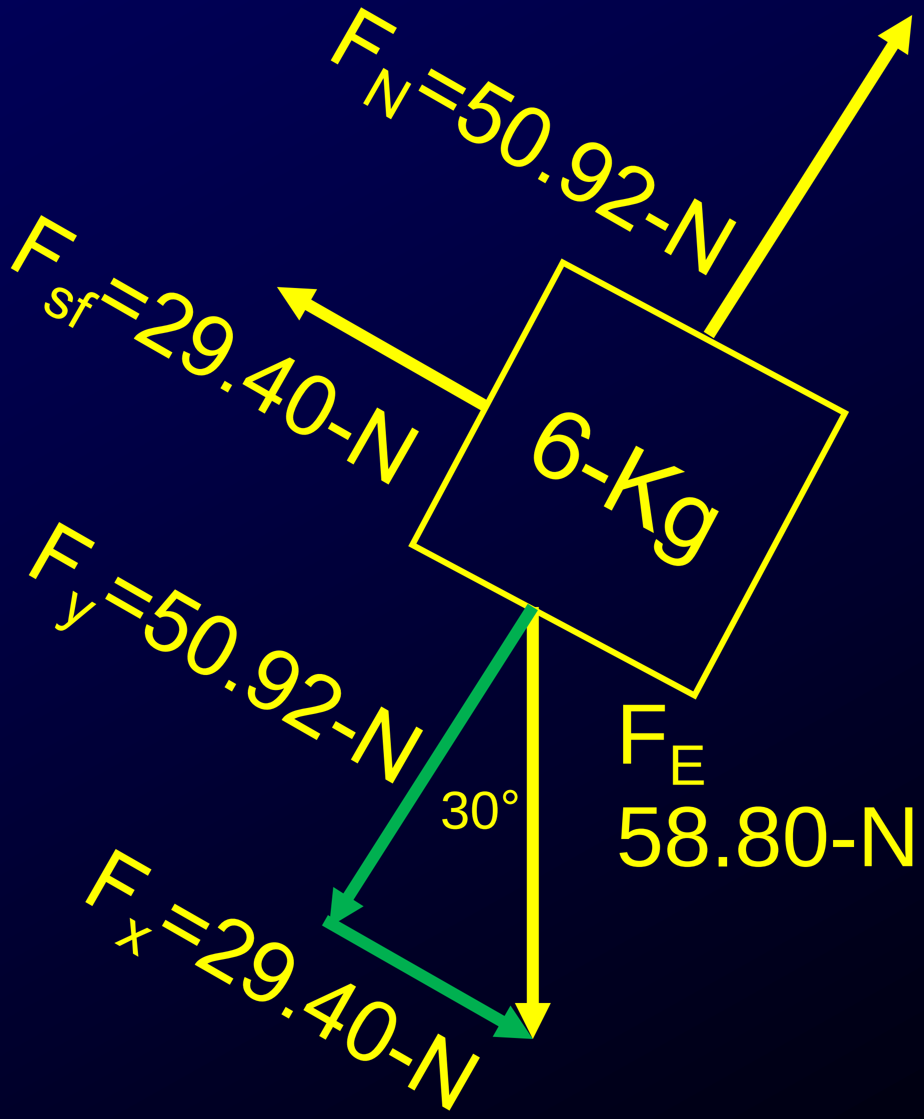
Algebra Example III: Part A

- Since the weight (F_E) is not perpendicular to the surface break it apart.
- Rember balancing forces (fr and N) are parallel or perpendicular to the surface.



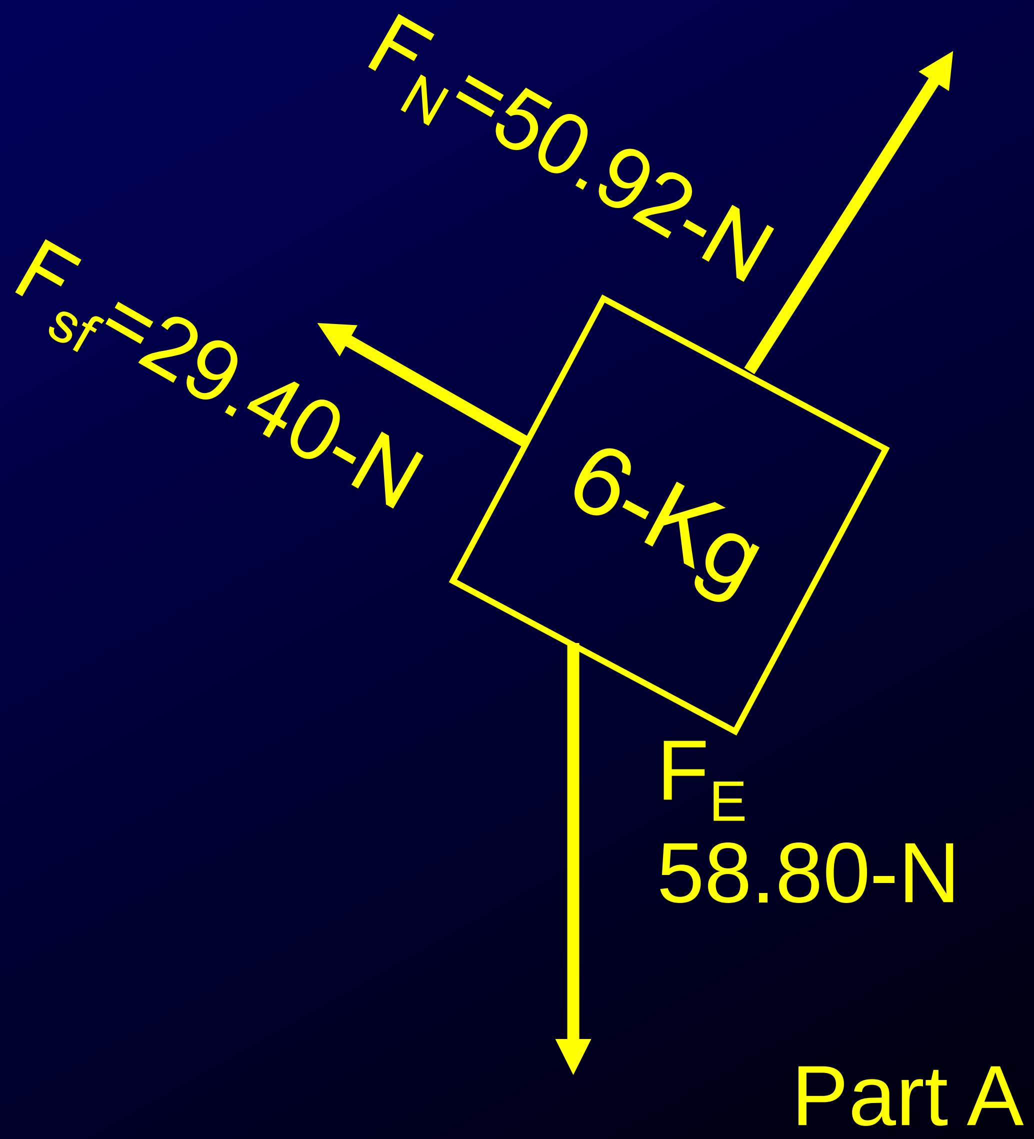
Algebra Example III: Part A

- Action-Reaction Pairs.



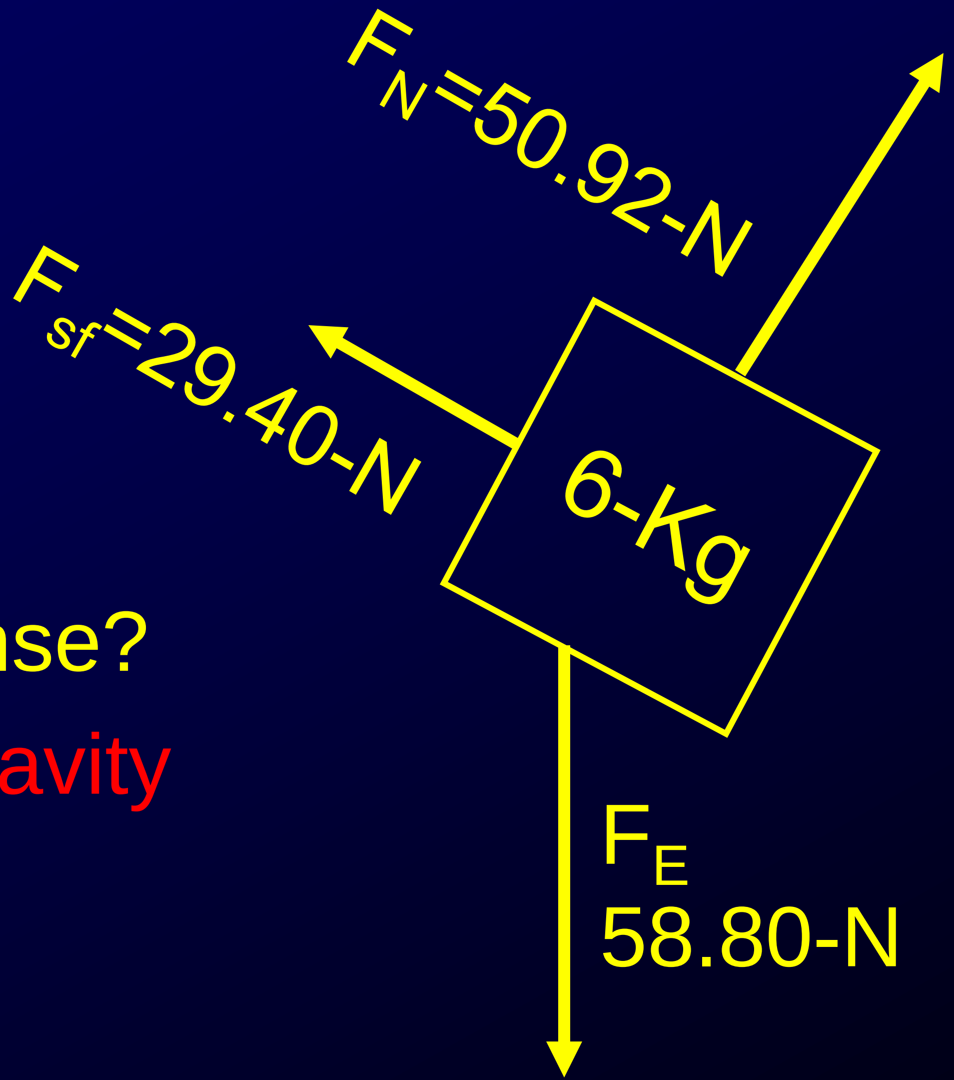
Algebra Example III: Part A

- Component vectors must be put back together at the end.



Algebra Example III: Part A

- Ask: Does this make sense?
- This is an example of Gravity off axis.



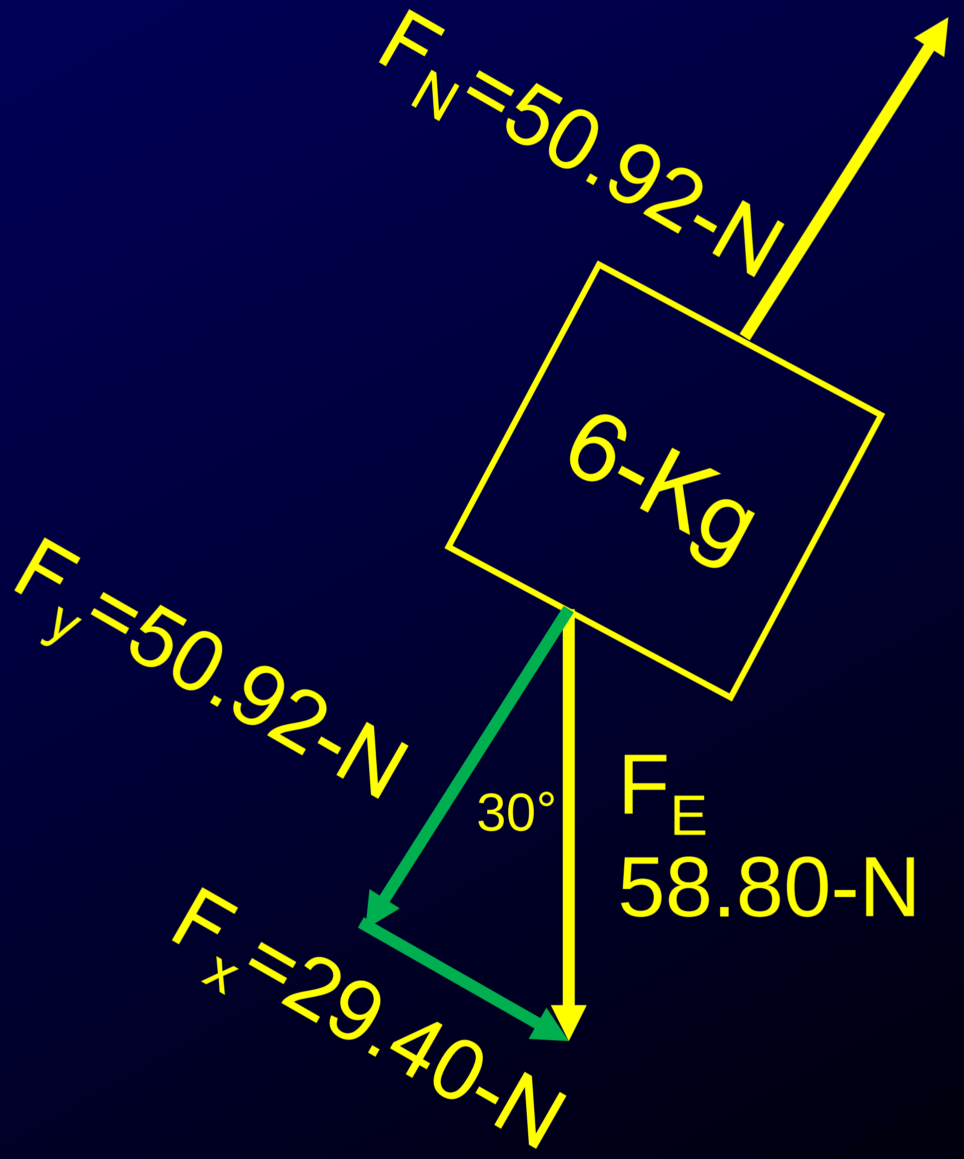
Algebra Example III: Part B

- To solve part B+C solve:

  $F_{NET} = ma$

  $F_{NET} = 6.00\text{-kg} \times 3.00\text{-m/s}^2$

  $F_{NET} = 18.00\text{-N}$



Algebra Example III: Part B

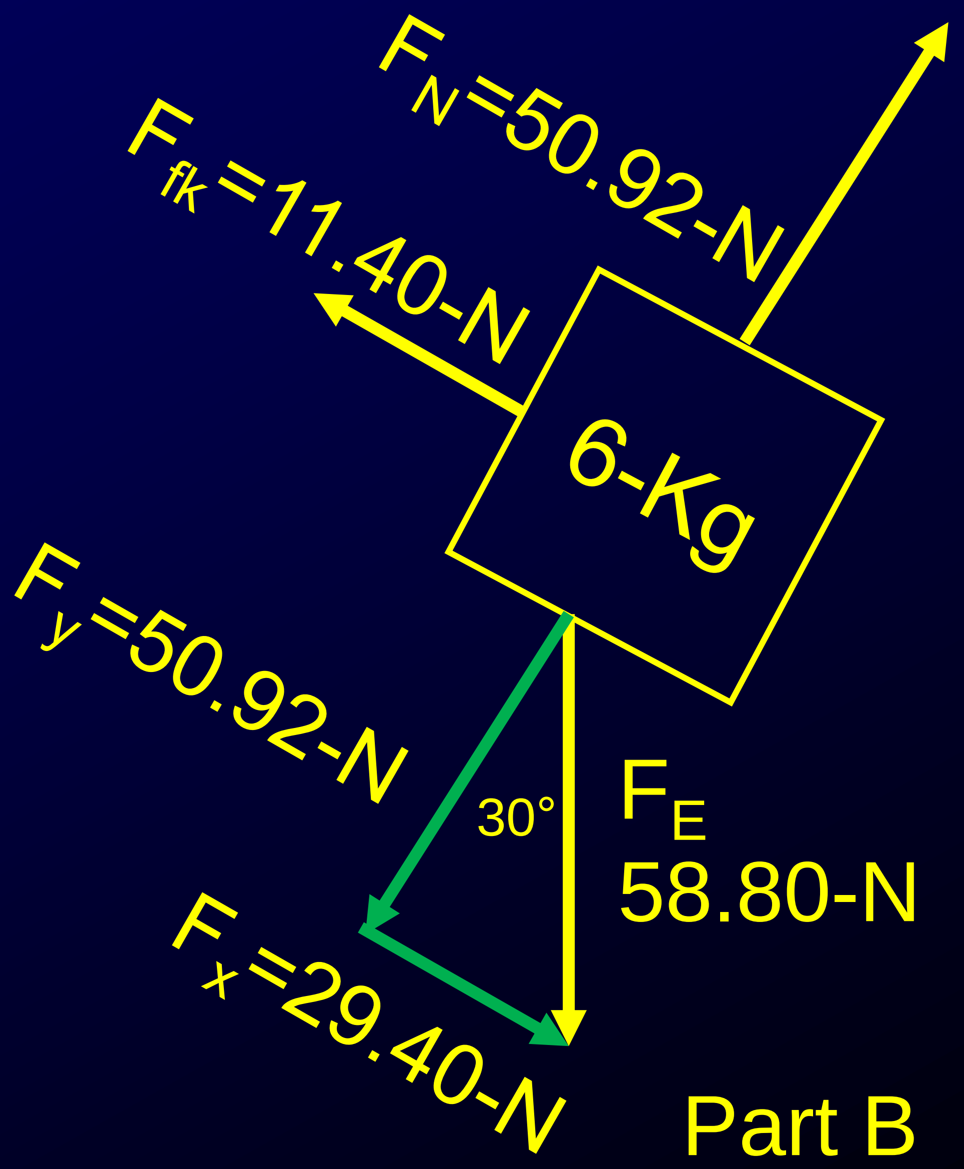
- Gravity does change so the friction must (and can) change.

$F_{NET} = \Sigma F$

$F_{NET} = F_x + F_{fk}$

$18.00\text{-N} = 29.40\text{-N} + F_{fk}$

$F_{fk} = -11.40\text{-N}$



Algebra Example III: Part B

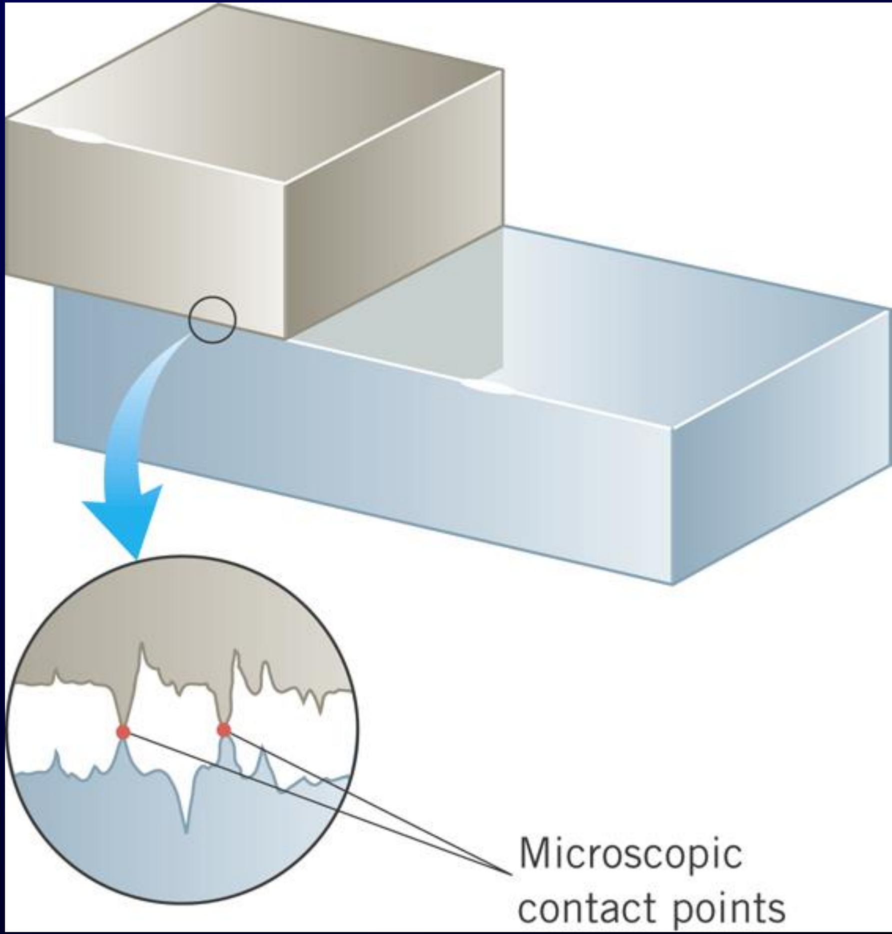
- Ask: Does this make sense?
- This is an example of an unbalanced force combined with Gravity off axis.

Looking at Friction

- In the last problem friction was used two ways.
  - Static Friction: $F_{sf}=\mu_s F_N$ ($F_{static} > F_{kinetic}$)
    - When solving for Static Friction this will be the max possible.
      - Balanced reaction pairs will always be used.
  - Kinetic Friction: $F_{kf}=\mu_k F_N$
    - This will always be constant!
      - F_{kf} less than opposition force? Object will speed up (a=+).
      - F_{kf} equal to opposition force? Object will have constant v (a=0).
      - F_{kf} bigger than opposition force? Object will slow down to 0 (a=-).

The coefficients of friction (μ)

- All interfaces have, a static and a kinetic coefficient.
- The coefficients are a ratio based on how ‘smooth’ the surfaces are.
  - All surfaces have contact points.
  - The more jagged the contact points the higher the coefficient ($0<\mu<1$).
    - 0 = 0% or perfectly smooth
    - 1 = 100% or perfectly sticky



Friction Problem I

- On a steel freighter a forklift slides a 2000.00-kg steel shipping container across the deck.
  A. What was the minimum force needed to start moving the container?
  B. How much force is needed to accelerate the container across the floor at 2.00-m/s^2?

Friction Problem I

- Draw the situation, separate the object.

2000-kg

Part A

v = 0-m/s

a = 0-m/s^2

2000-kg

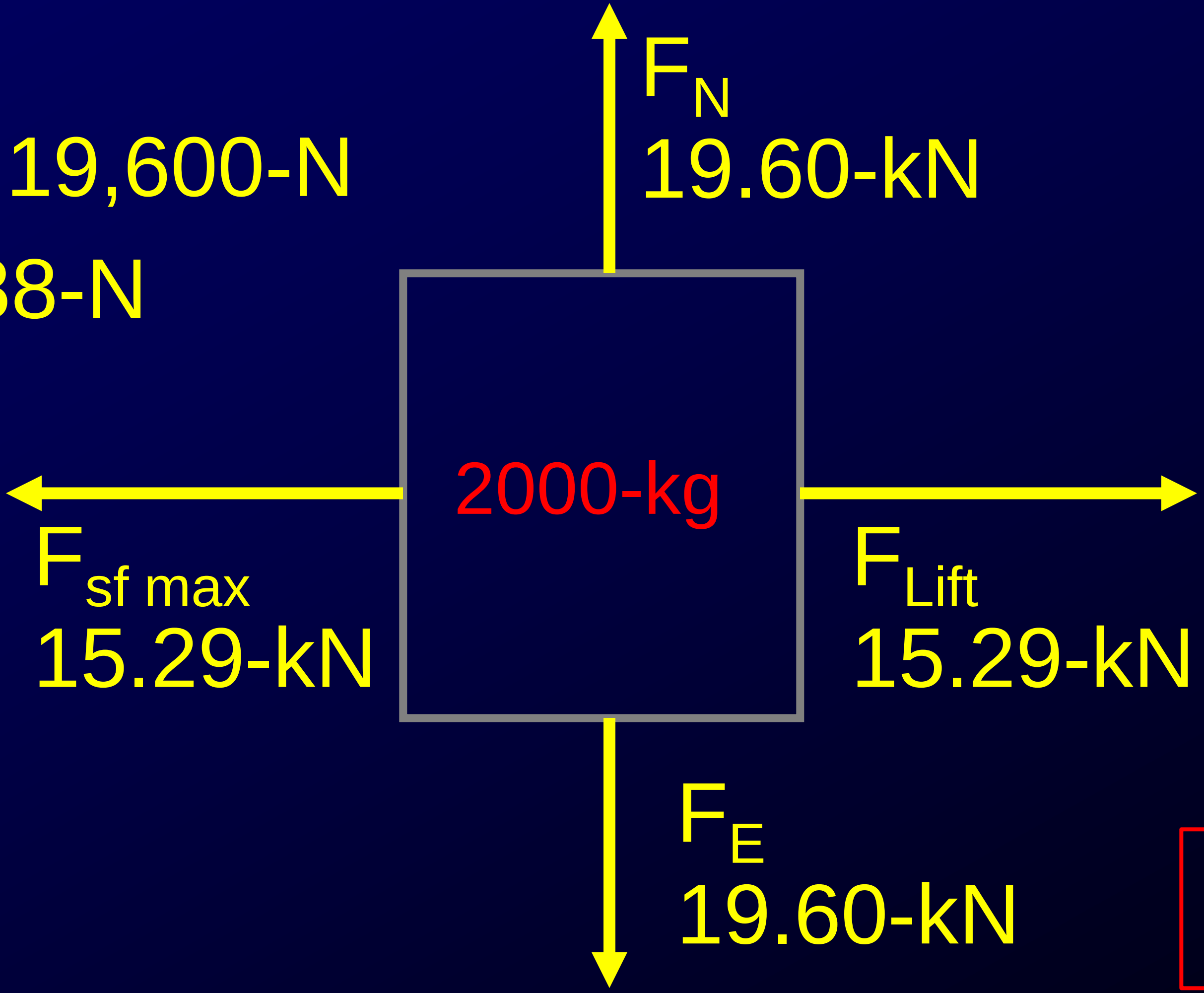
Part B

v = +

a = 2-m/s^2

Friction Problem I: Part A

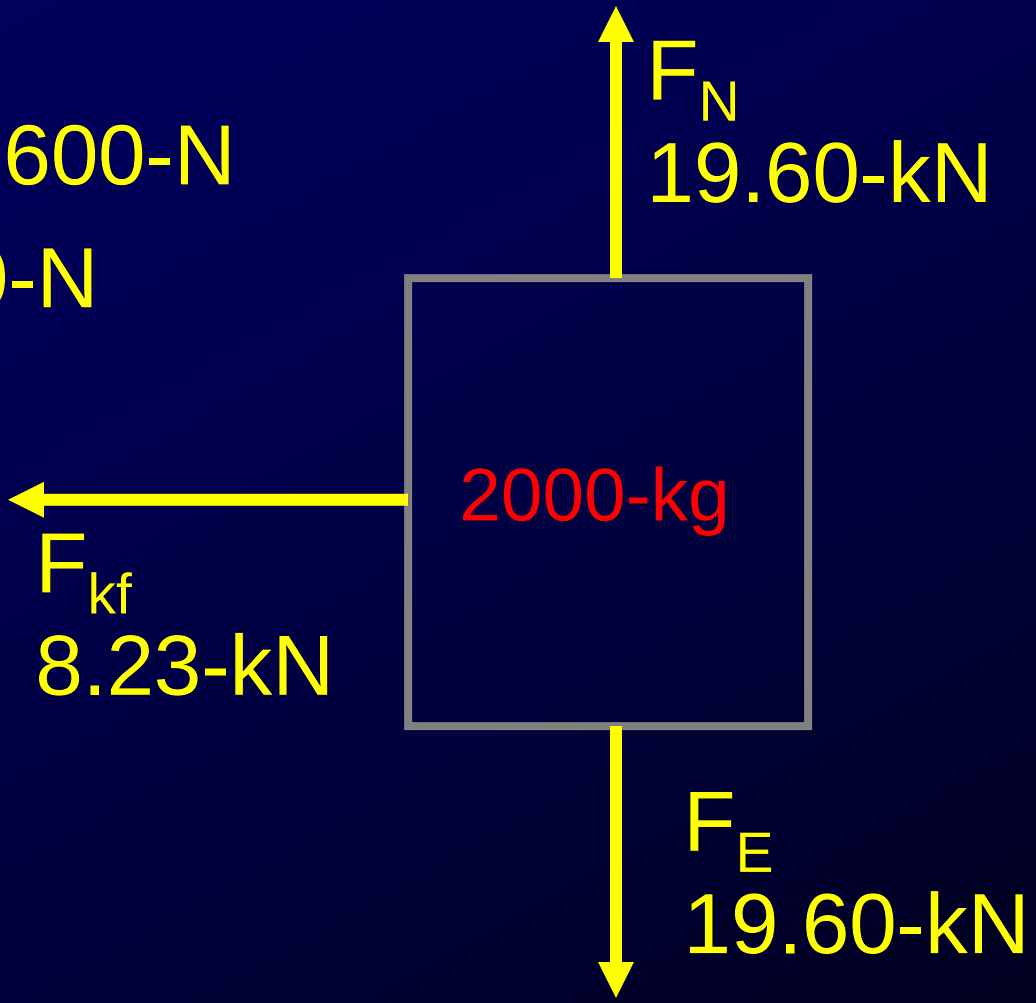
- The coefficient of static friction of steel to steel is .78.
- $F_{sf\ max} = \mu_s F_N$
- $F_{sf\ max}$ = .78 x 19,600-N
- $F_{sf\ max}$ = 15,288-N



$F_{lift} > 1.53 \times 10^4$-N

Friction Problem I: Part B

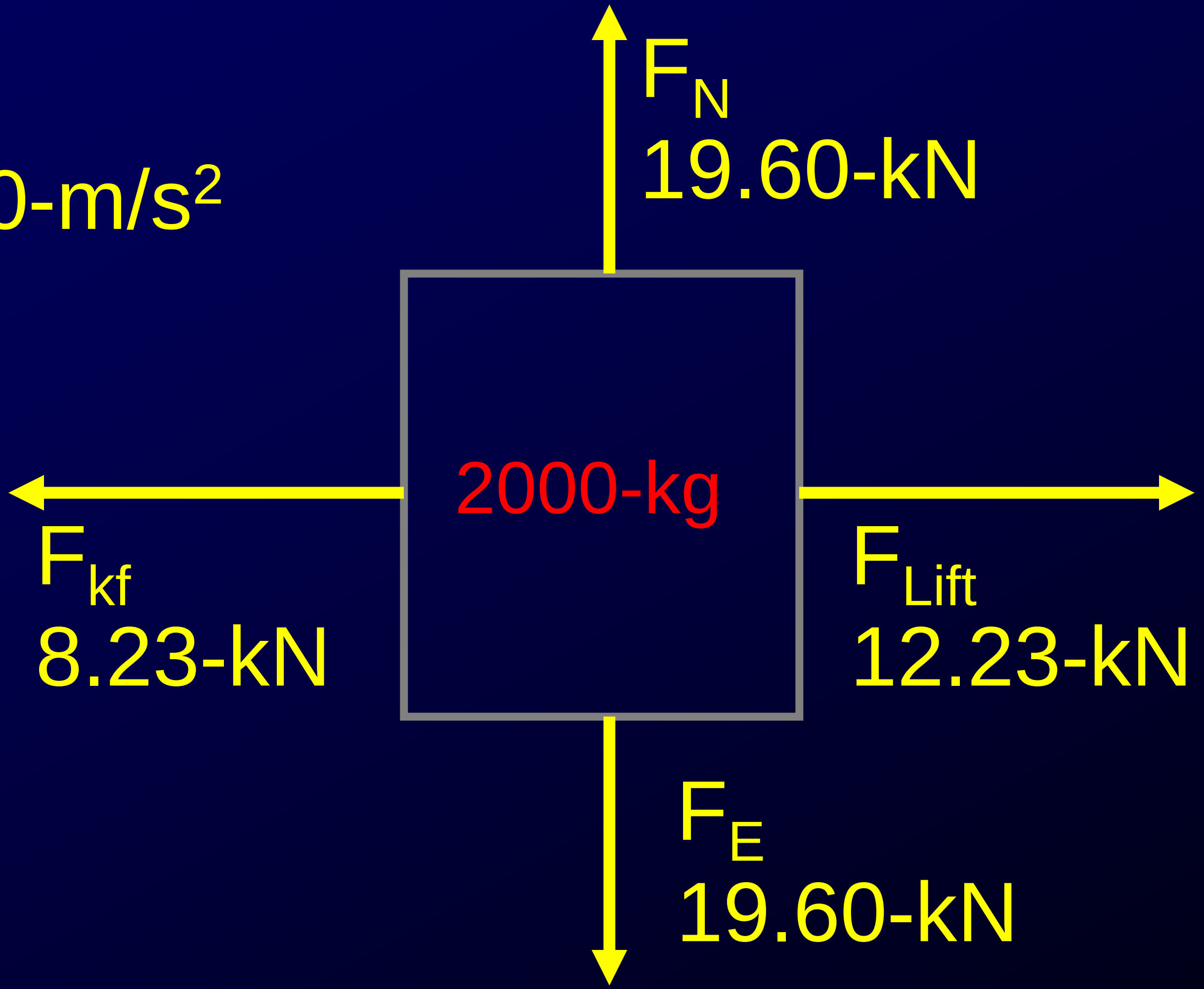
- The coefficient of kinetic friction of steel to steel is .42.
- $F_{kf} = \mu_k F_N$
- $F_{kf} = .42 \times 19{,}600\text{-N}$
- $F_{kf} = 8{,}232.00\text{-N}$



Friction Problem I: Part B

- $F_{NET} = ma$
- $F_{NET} = 2000.00\text{-kg} \times 2.00\text{-m/s}^2$
- $F_{NET} = 4000\text{-N}$

- $F_{NET} = \Sigma F$
- $F_{NET} = F_{lift} + F_k$
- $4.00\text{-kN} = F_{lift} - 8.23\text{-kN}$
- $F_{lift} = 12232\text{-N}$

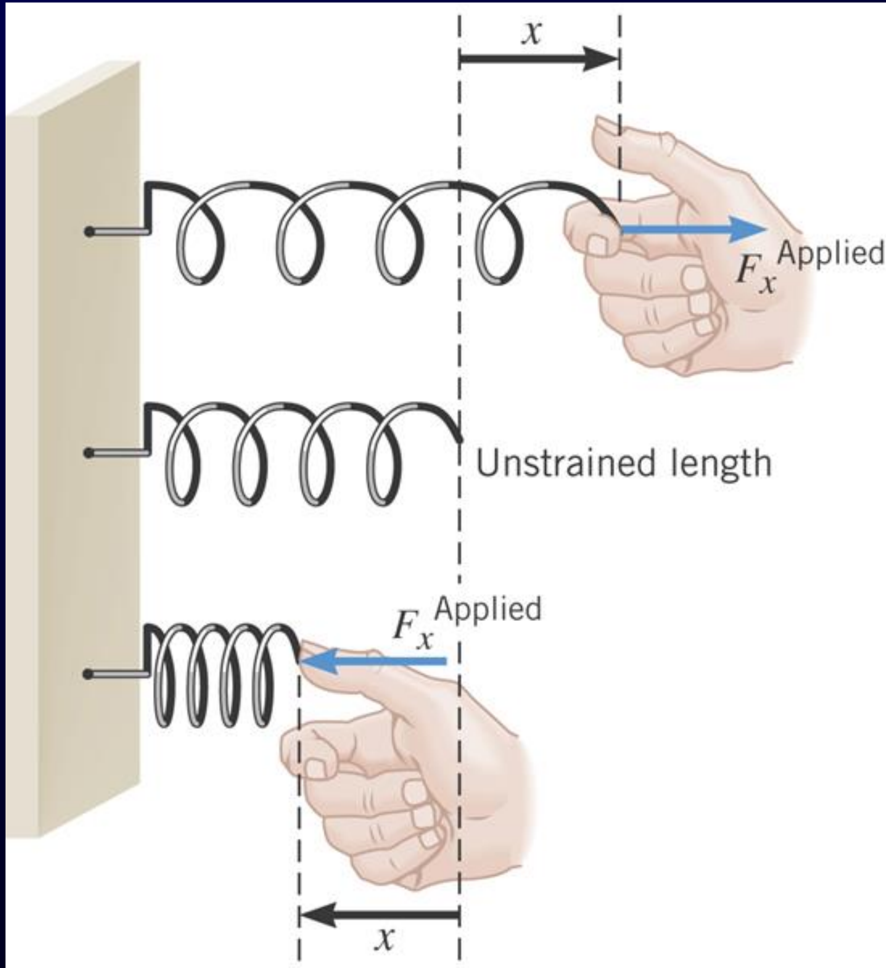


$F_{lift} = 1.22 \times 10^4\text{-N}$

Spring/Elastic Forces

- An Ideal Spring when pulled or pushed will move a set distance as given by:

Hooke's Law: $F_s = kx$



F = Force applied to the spring

k = spring constant (N/m)

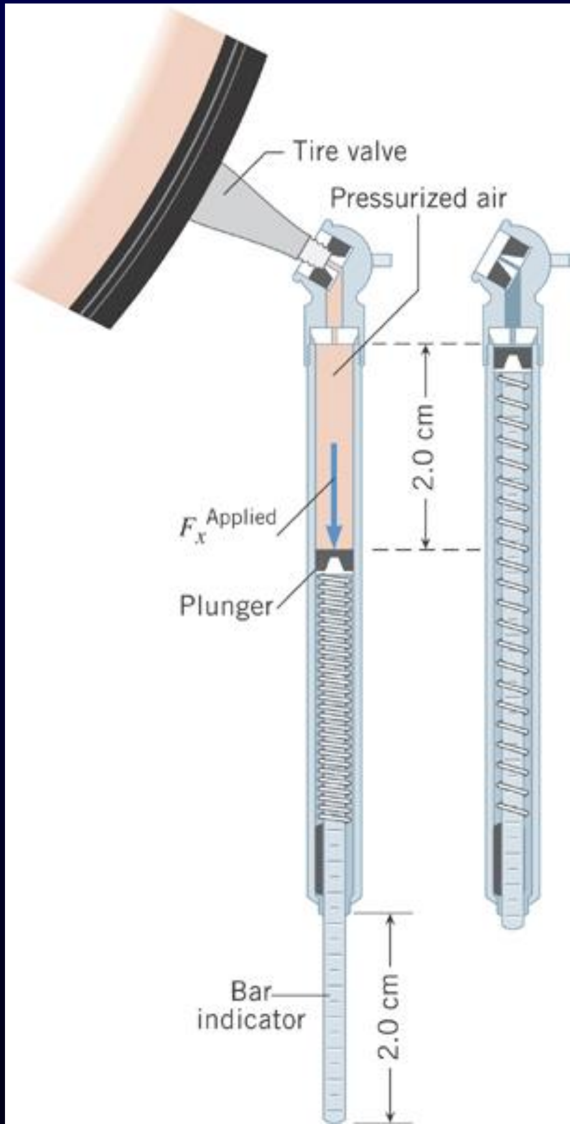
Varies by material, thickness, coil

x = distance from equilibrium

This only applies if the spring is not over stretched.

Spring Example I

- To measure a tires pressure, air in a tire pushes against a plunger attached to a spring (k=320.00-N/m). The plunger extends 2.00-cm. What force does the air in the tire apply to the spring?



Spring Example I

- Just plug and chug.

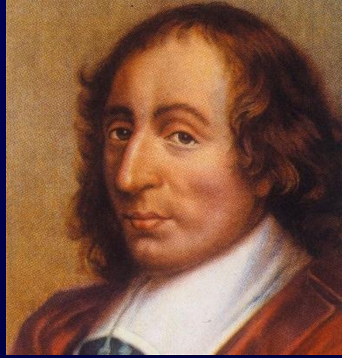
F = x
k = 320-N/m
x= .020-m

$$F_s = kx$$

$$F_s = 320 - \frac{N}{m} \cdot .02 - m$$

$$F_s = 6.40 - N$$

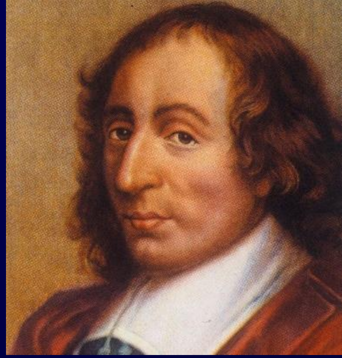
Pressure



- Pressure [v]: How much force is applied to an object over its area.

$$P = F/A \ (N/m^2 = \text{Pascals})$$

- Living at the bottom of the atmosphere we have air pressing on us from every direction.
  - Atmospheric Pressure (Sea Level)= 1.013×10^5 Pa.



Going Deeper

- In water as a diver swims deeper, more pressure is exerted on him.
  - More water weight is on top of him.
- For liquids, the difference in Pressures is:

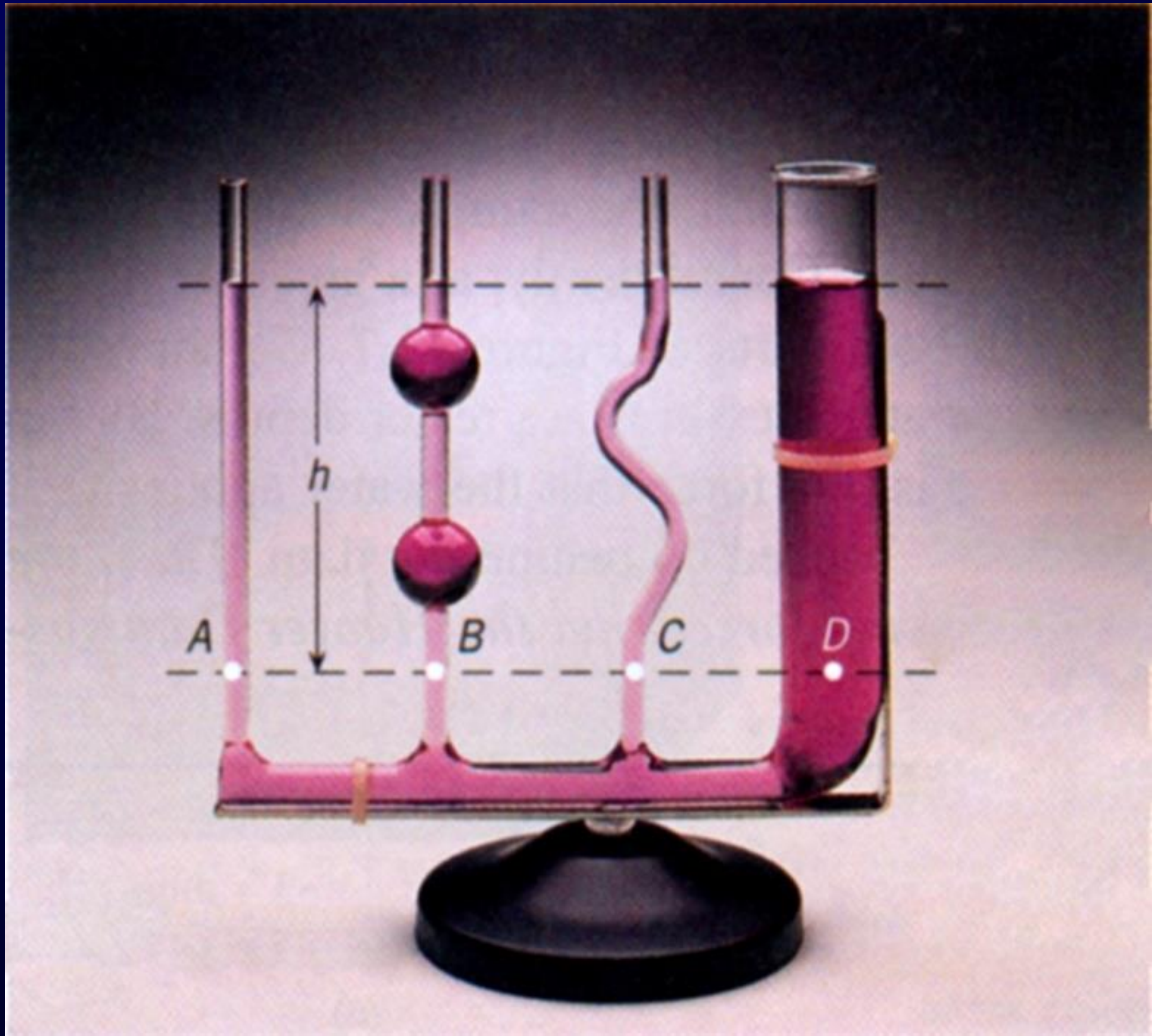
$$\Delta P = \rho g h \qquad \text{or} \qquad P_2 = P_1 + \rho g h$$

This is also known as Pascal's Law.

Conceptual Question

- Sort the Pressure on Points A,B,C,D in order from greatest to least.

- Because each point is at the same depth, the pressure is the same for all!!!



Example 1

- Calculate the difference in pressure for a human whose heart is 1.53-m above his foot (ignoring the flow of the blood).

$$\Delta P = \rho g h$$

$$\Delta P = 1606 - \frac{kg}{m^3} \cdot 9.8 - \frac{m}{s^2} \cdot 1.53 - m$$

$$\Delta P = 15893 - \frac{N}{m^2}$$

P_1 =
P_2 =
ρ = 1060-kg/m^3
g = 9.8-m/s^2
h = 1.53-m

$$\Delta P = 1.59x10^4 - Pa$$

Gravity (and Magnetism)

- Recall Gravity and Magnetism are both forces that act at a distance.
  - Gravity is between two objects with mass and always towards.
  - Magnetism is between two charged objects and can be either towards or away from the two objects.

Gravity and Magnetism

$$F_M = k \frac{q_1 q_2}{d^2}$$

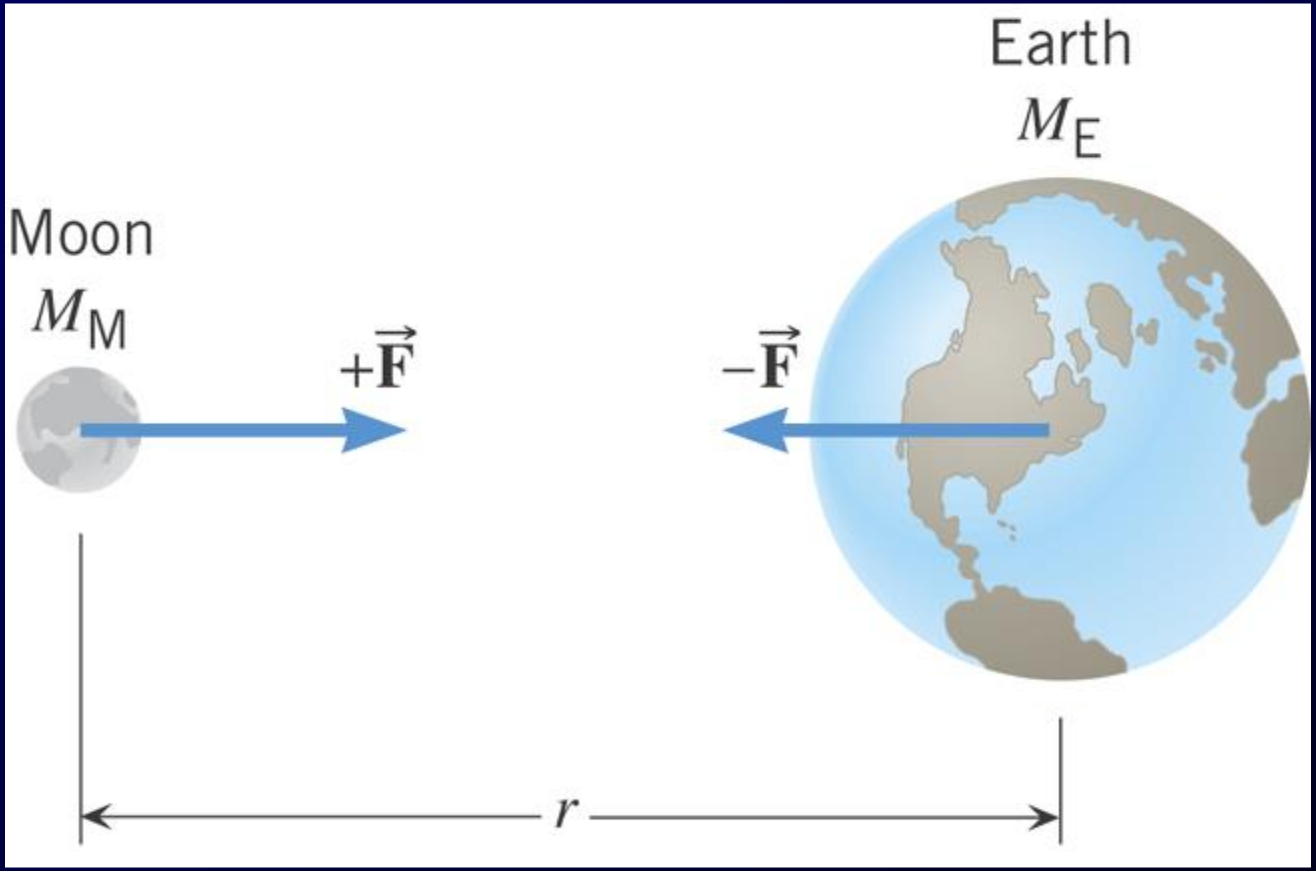
$$F_G = G \frac{m_1 m_2}{r^2}$$

- k→ Electrostatic constant 8.988 x 10^9 $N \cdot m^2/C^2$
- q→ Net charge of object (in Coulombs C)
- d→ distance between two particles (in meters m).

- G→ Universal gravitational constant 6.673 x 10^{-11} $N \cdot m^2/kg^2$
- m→ mass of object (in kilograms kg).
- r→ distance between two objects (in meters m).

Gravity Example I

- Find the attractive gravitational force between the moon and Earth.



Gravity Example I

$$F_G = G\,\frac{m_E m_m}{r^2}$$

G = 6.673 x 10^{-11}-N·m^2/kg^2
m_E = 5.974 x 10^{24}-kg
m_m = 7.348 x 10^{22}-kg
r = 384,440-m

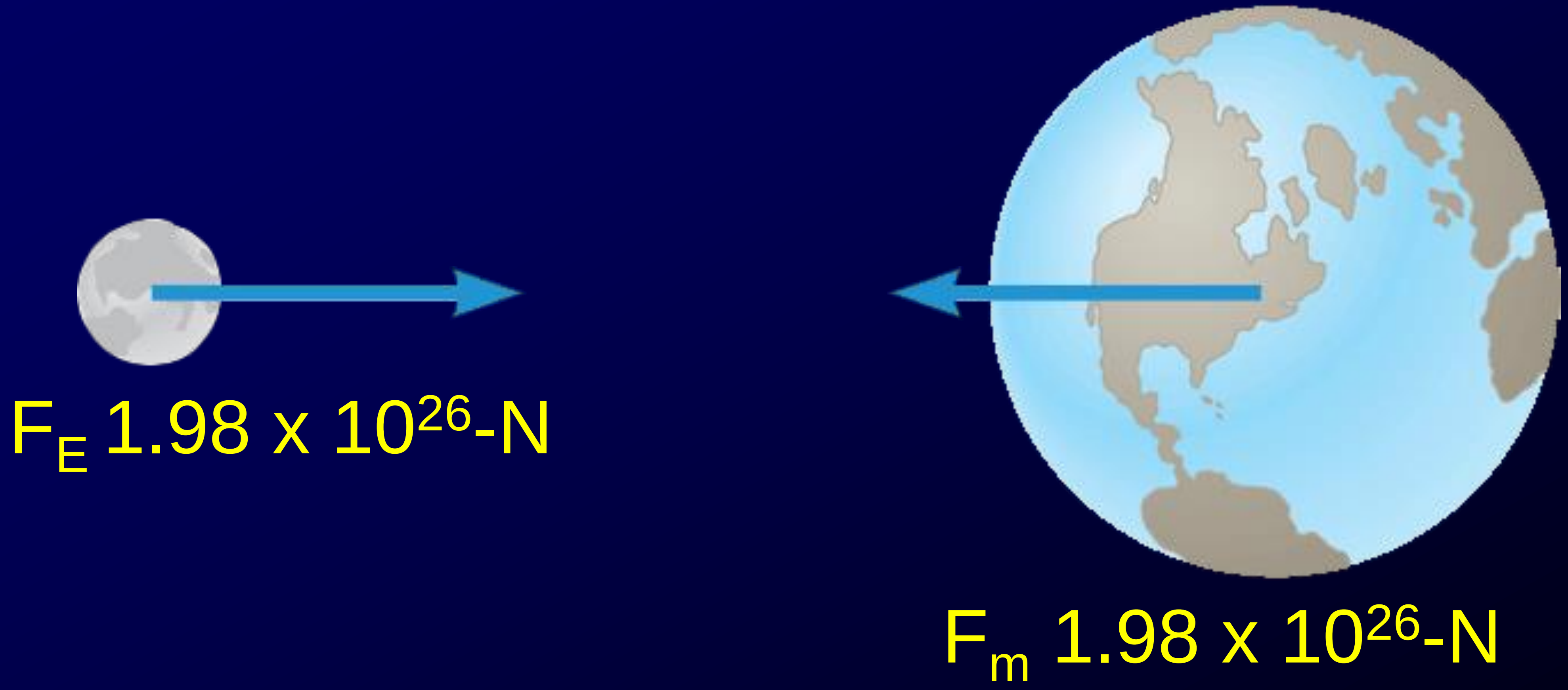
$$F_G = 6.673x10^{-11} - \frac{Nm^2}{kg^2}\,\frac{5.974x10^{24} - kg \cdot 7.348x10^{22} - kg}{(38440 - m)^2}$$

$$F_G = \frac{292.9x10^{24+22-11}}{1.478x10^{11}} - N$$

$$F_G = 1.982x10^{26} - N$$

$$F_G = 1.98x10^{26} - N$$

Gravity Example I



Gravity Example II

- Find the attractive gravitational force between two classmates (55.00-kg and 77.00-kg) sitting next to each other (.61-m).

$$F_G = G\,\frac{m_E m_m}{r^2}$$

$G = 6.673 \text{ x } 10^{-11}\text{-N}\cdot\text{m}^2/\text{kg}^2$

$m_b = 55\text{-kg}$

$m_g = 77\text{-kg}$

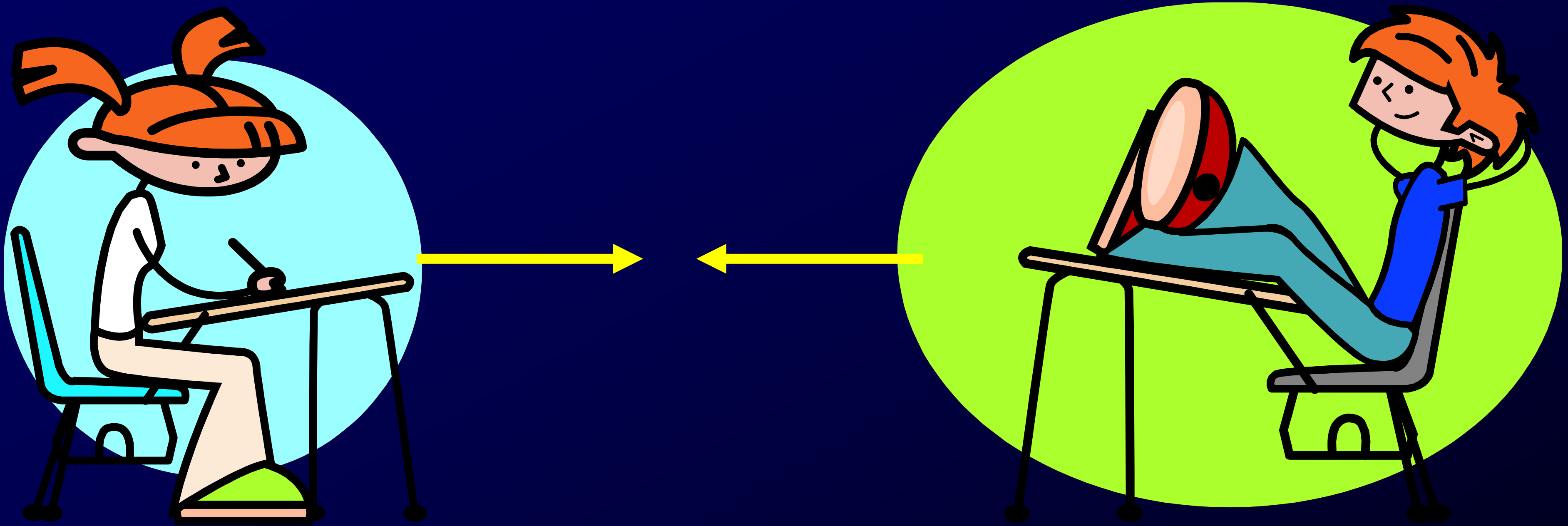
$r = .61\text{-m}$

$$F_G = 6.673x10^{-11} - \frac{Nm^2}{kg^2}\frac{55 - kg \cdot 77 - kg}{(.61 - m)^2}$$

$$F_G = \frac{28260.155x10^{-11}}{3.721x10^{-1}} - N$$

$$F_G = 7.59x10^{-7} - N$$

Gravity Example II



F_{stu1} 7.59 x 10^{-7}-N

F_{stu2} 7.59 x 10^{-7}-N

Gravity Example III

- Find your proportional weight on the moon.
  - This can approximate the acceleration due to gravity on a celestial object.
  - It can also be used to set up a ratio (proportion).
- To Solve:
  - The mass and radius of the moon is needed.
  - Acceleration on earth.
  - Your mass will be irrelevant!

Gravity Example III

$$F_G = G\,\frac{m_{you}m_m}{r_m^2}$$

$G = 6.673 \times 10^{-11}$-N·m^2/kg^2

m_{you} =

$m_m = 7.348 \times 10^{22}$-kg

$r_m = 1.737 \times 10^6$-m

$$F_G = 6.673x10^{-11} - \frac{Nm^2}{kg^2}\frac{m_{you}\cdot 7.348x10^{22} - kg}{(1.737x10^6 - m)^2}$$

$$F_G = \frac{49.03x10^{22-11}}{3.017169x10^{12}} - \frac{N}{kg}\cdot m_{you}$$

$$\frac{N}{kg} = \frac{kg\,\frac{m}{s^2}}{kg}$$

$$F_G = 1.625 - \frac{m}{s^2}\cdot m_{you}$$

Gravity Example III

$1.625 - \frac{m}{s^2}$ is the acceleration due to gravity on the moon

$$proportional\ weight = \frac{a_{gm}}{a_{gE}}$$

$$pw = \frac{1.625 - \frac{m}{s^2}}{9.8 - \frac{m}{s^2}}$$

$$pw = .163 \approx \frac{1}{6}$$

Objects on the moon weigh 1/6 of what they do on Earth.