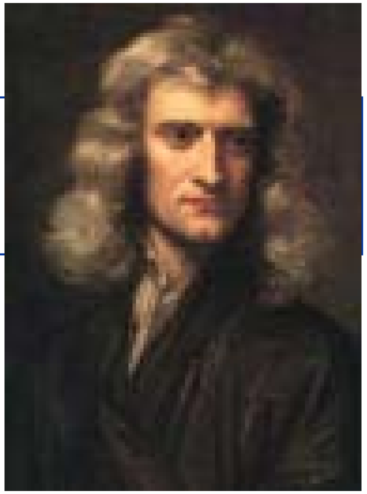
Chapter 4: Forces

- What is a force? Identifying forces.
- What is the connection between force and motion?
- How are forces related when two objects interact?
- Application –
  - **different forces (field forces, contact forces)**
  - **different situations**

Dynamics



Isaac Newton
1642-1727

Sir Isaac Newton asked:

If there is acceleration, what happens to motion?
In fact, when is there motion?

Newton's three laws of motion

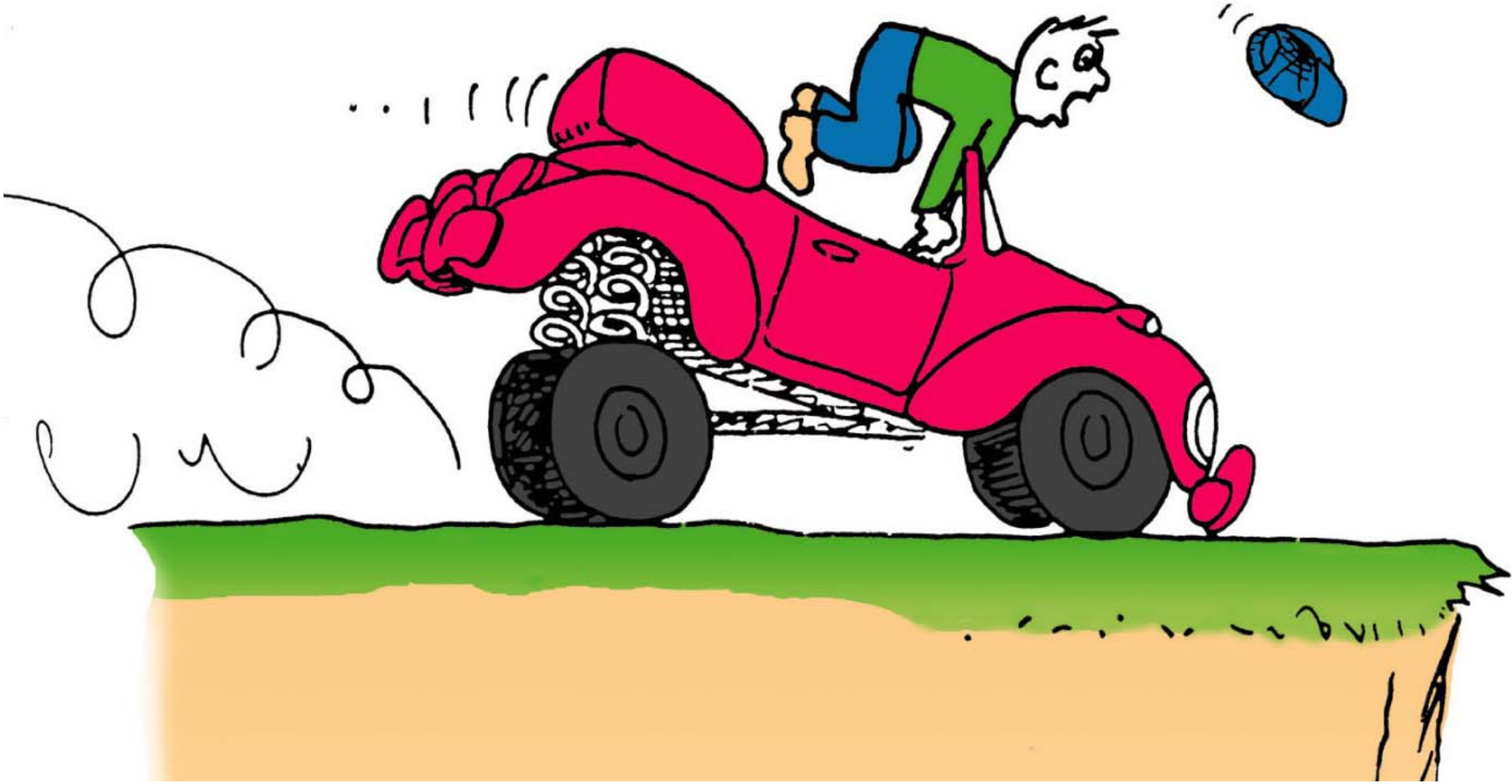
Newton’s First Law

(or law of INERTIA)

“Every object continues in a state of rest or in a state of motion in a straight line at constant speed, unless it is compelled to change that state by forces exerted on it”

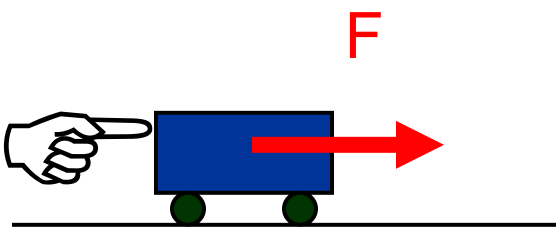
Simply stated, the motion remains ***unchanged*** unless there is a force present.

Inertia: if moving, it keeps on moving!!

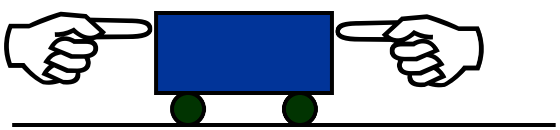


Newton's First Law of Motion

- An object continues in a state of *rest* **or** in a state of motion at a *constant speed along a straight line*, unless compelled to change that state by a ***NET*** force.



Net Force ≠ 0



Net Force = 0

Newton's Second Law

"The acceleration produced by a net force on an object is directly proportional to the force and inversely proportional to the object's mass"

The **net** force is the total sum of all forces on the object.

Newton's second law

Acceleration ~ $\dfrac{\text{net force}}{\text{mass}}$

Net force is a vector

$$a = \frac{F}{m}$$

acceleration is a vector

1 Newton = kg • m/s^2

$$F = ma$$

Question 0

A hockey puck (m=0.2kg) is dragged by a force of 10N. What is its acceleration?

1. $10 m/s^2$
2. $0.2 m/s^2$
3. $50 m/s^2$

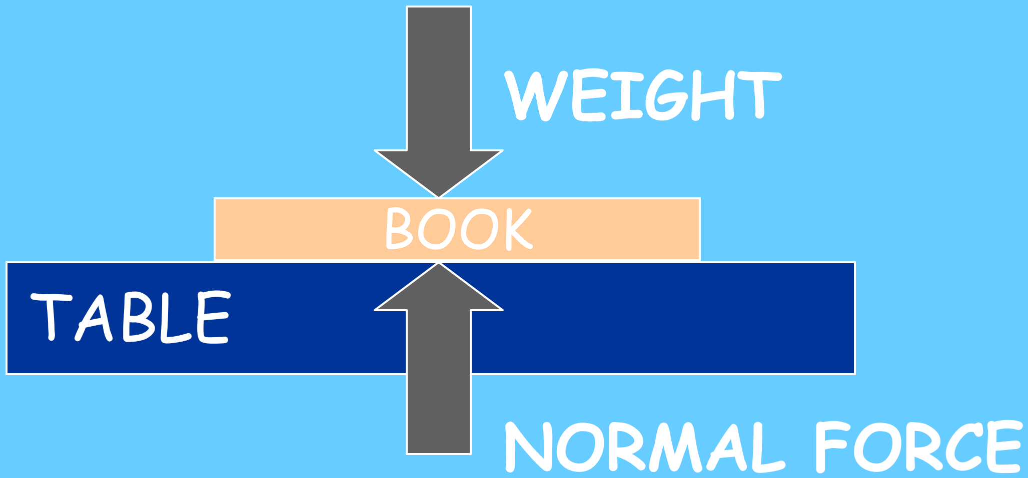
and its direction? Same as the force's!

If there is no net force?

→acceleration is zero

→ velocity is constant!!

$$a = \frac{F}{m} = 0$$



$$a = 0$$

EQUILIBRIUM!!

If there is no net force?

velocity is constant

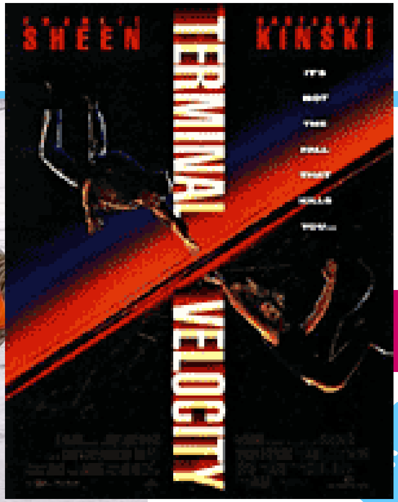
$$F = 0 = \text{Weight} - \text{Drag}$$

→ terminal velocity

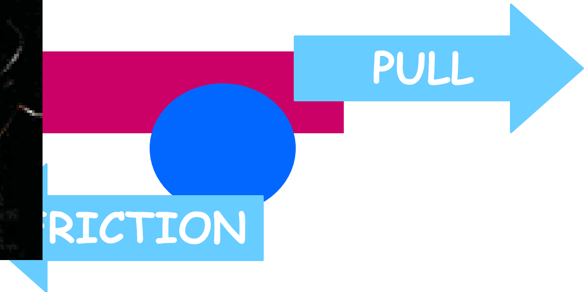
Net Force =0

Drag

Weight



Force =0



Question 1: You push with a 20-N horizontal force on a 2-kg mass resting on a horizontal surface against a horizontal frictional force of 12N. What is the acceleration of the mass?

1. Cannot tell from this information.
2. 10 m/s^2
3. 6.0 m/s^2
4. 4.0 m/s^2

$$a=(F-F_{fr})/m=4 m/s^2$$

Newton's Second Law of Motion

When a *net external* force acts on an object of mass *m*, the acceleration **a** that results is directly proportional to the net force and has a magnitude that is inversely proportional to the mass. The direction of the acceleration is the same as the direction of the net force.

$$\vec{a} = \frac{\vec{F}_{NET}}{m}$$

$$\boxed{\vec{F}_{NET} = m\vec{a}}$$

Mass – measure of *inertia* (kg)

Vectors!

$$a_x = \frac{F_{NET,x}}{m} \qquad a_y = \frac{F_{NET,y}}{m}$$

Lab #2: Forces and Equilibrium

- Equilibrium: forces balanced, ***acceleration = 0***
- If a=0, forces are balanced
- Weight: Force due to gravity: F_g = mass*g
- Balance forces: both in x and y

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

$$\sum F_x = 0$$

$$\sum F_y = 0$$

Reminders

- **For specific questions on LonCapa problems, you can use "Send Message" resource. Try to be SPECIFIC and CLEAR on you question.**

- **RQ#5 due tomorrow 10am**
- **HW#3 due *today* 6/26, 11:59pm.**
- **HW#4 due Sunday 7/01, 11:59pm**

- **Lab sessions:**
- **<u>PRINT OUT</u> Lab Report before going to labs**
  - Download lab report from LONCAPA website
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- **CAPA sessions: Clippinger 036, M-Th, 1-5pm**

- **EXAM 1: Next Thursday (06/29).**
  - Topics: Chapters 1 and 2 **(including related Lab material)**

You and a friend are sliding a large 100-kg box across the floor. Your friend pulls to the right with a force of 250N. You push to the right with a force of 300N. The frictional force of the floor opposes the motion with a force of 500N. What is the acceleration of the box?

(1) 0.5 m/s^2 to the left
(2) 0.5 m/s^2 to the right
(3) 1.0 m/s^2 to the left
(4) 1.0 m/s^2 to the right
(5) 2.0 m/s^2 to the left
(6) 2.0 m/s^2 to the right
(7) 5.5 m/s^2 to the left
(8) 5.5 m/s^2 to the right
(9) 10.5 m/s^2 to the left
(0) 10.5 m/s^2 to the right

Net force 50N to the right

$a = F/m$

You and a friend are sliding a large 100-kg box across the floor. Your friend pulls to the right with a force of 250N. The frictional force of the floor opposes the motion with a force of 500N. The box has an acceleration of 1.0m/s^2 to the right. What is the force that you exert on the box?

(1) 100N to the left

(2) 100N to the right

(3) 300N to the left

(4) 300N to the right

(5) 350N to the left

(6) 350N to the right

(7) 450N to the left

(8) 450N to the right

Net Force is 100N to right (m*a).

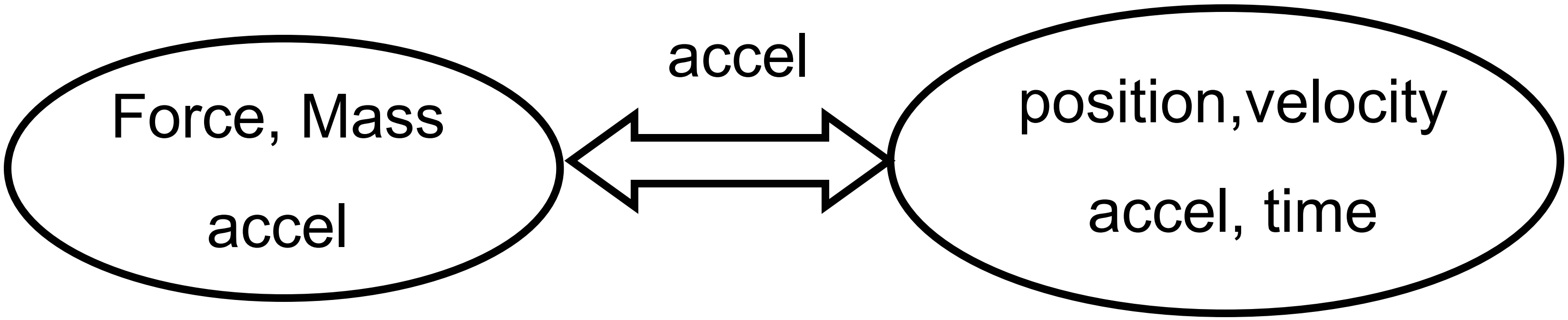
100N = F + 250N – 500N

You and a friend are pulling a large 100-kg box across a very *slippery* floor. Your friend pulls to the East with a force of 300N. You pull North with a force of 300N. The force due to friction is negligible (someone iced up the floor). What is the magnitude of the acceleration of the box?

(1) 3 m/s^2 (2) 4.2 m/s^2 (3) 4.5 m/s^2 (4) 6 m/s^2 (5) 12 m/s^2

Net force is 424N 45° North of East. a = F/m

Linking Kinematics and Dynamics



A 550-kg car increases its speed from 20m/s to 40m/s over a flat stretch of road 400m long. What is the average NET horizontal force on the car?

- Want NET force – Find acceleration from kinematic variables
- Given acceleration, find net force
- $a = 1.5\ m/s^2$ $F_{NET} = 825N$

If drag forces on car are 340N, what is the magnitude of the force propelling the car forward?

Newton’s Third Law

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first

OR

For every action there is always an opposed equal reaction

Newton's Third Law of Motion

Whenever one body exerts a force on a second body, the second body exerts an oppositely directed force of equal magnitude on the first body.

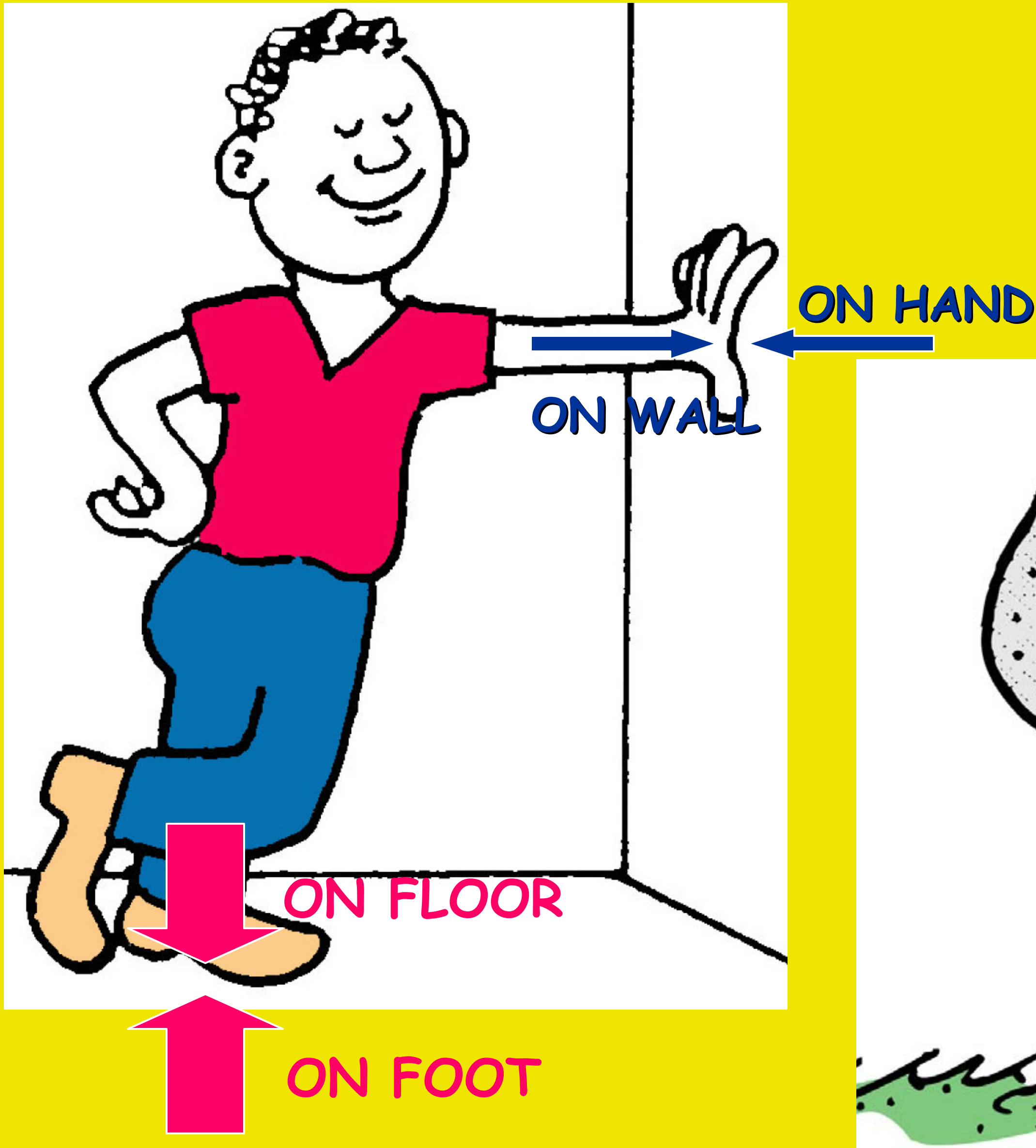
Action/Reaction Pairs (each applied on a ***different*** body)

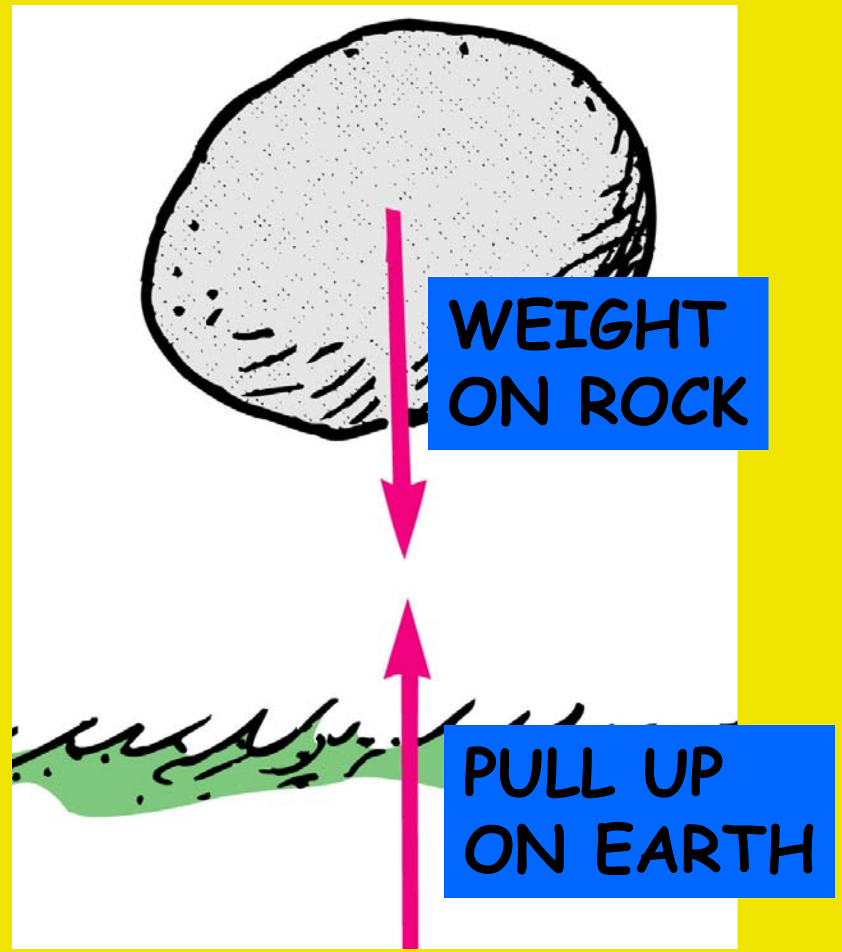
Man presses wall (action).

Normal force on man's arm (reaction)

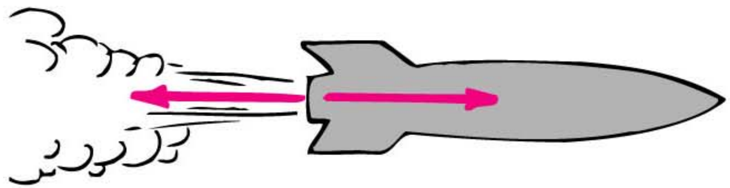
Forces applied: $\sum \vec{F} = 0$

1. On the wall:
   - Push from man's arm
   - base support (keeps it from moving)
2. On the man:
   - Normal from wall
   - Friction

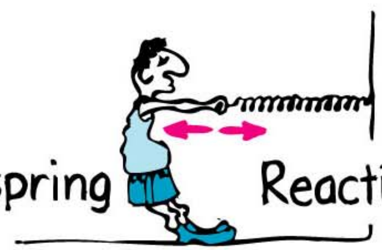

ON HAND
ON WALL
ON FLOOR
ON FOOT


WEIGHT ON ROCK
PULL UP ON EARTH

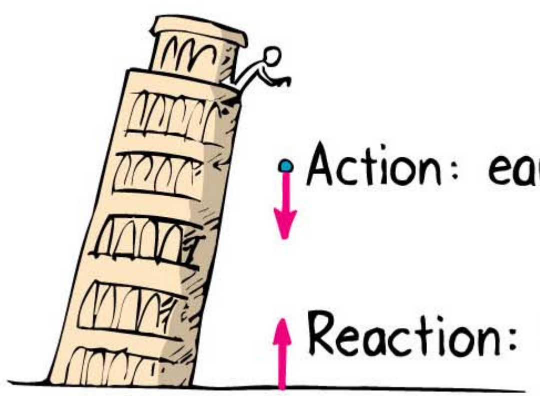
Action: tire pushes on road   Reaction: road pushes on tire



Action: rocket pushes on gas   Reaction: gas pushes on rocket

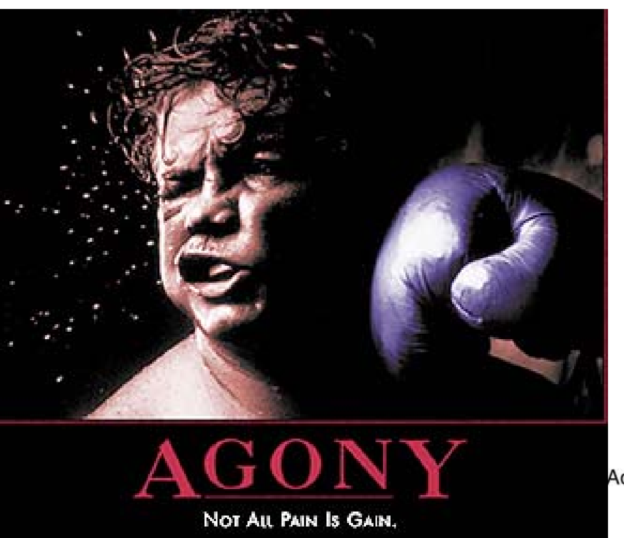


Action: man pulls on spring   Reaction: spring pulls on man



Action: earth pulls on ball

Reaction: ball pulls on earth



You are standing on ice (consider this to be frictionless). Your friend (mass=60kg) pushes you (mass=80kg). Your acceleration is $+1.0 m/s^2$. What is your friend's acceleration?

(1) $0\ m/s^2$

(2) $+0.75\ m/s^2$

(3) $+1.0\ m/s^2$

(4) $+1.33\ m/s^2$

(5) $-0.75\ m/s^2$

(6) $-1.0\ m/s^2$

(7) $-1.33\ m/s^2$

Same magnitude force in opposite direction.

80N in –x direction. $a = F/m$

Two cars are pushed apart by a spring. The blue car is roughly double the mass of the red car.
The magnitude of the force that the blue car exerts on the red car is ________ the magnitude of the force that the red car exerts on the blue car.

1. greater than
2. equal to
3. less than

Fundamental Forces

- Electroweak Force – Electromagnetism and Weak Nuclear Force
- Strong Nuclear Force
- Gravitational Force

This course: Gravitation (fundamental) and non-fundamental electromagnetic-related forces (e.g., the normal force)

Contact and **action-at-a-distance** forces.

Examples:

Contact forces: normal force, friction, …

'***Action-at-a-distance***': Gravitation, magnetism,…

Newton's Law of Universal Gravitation

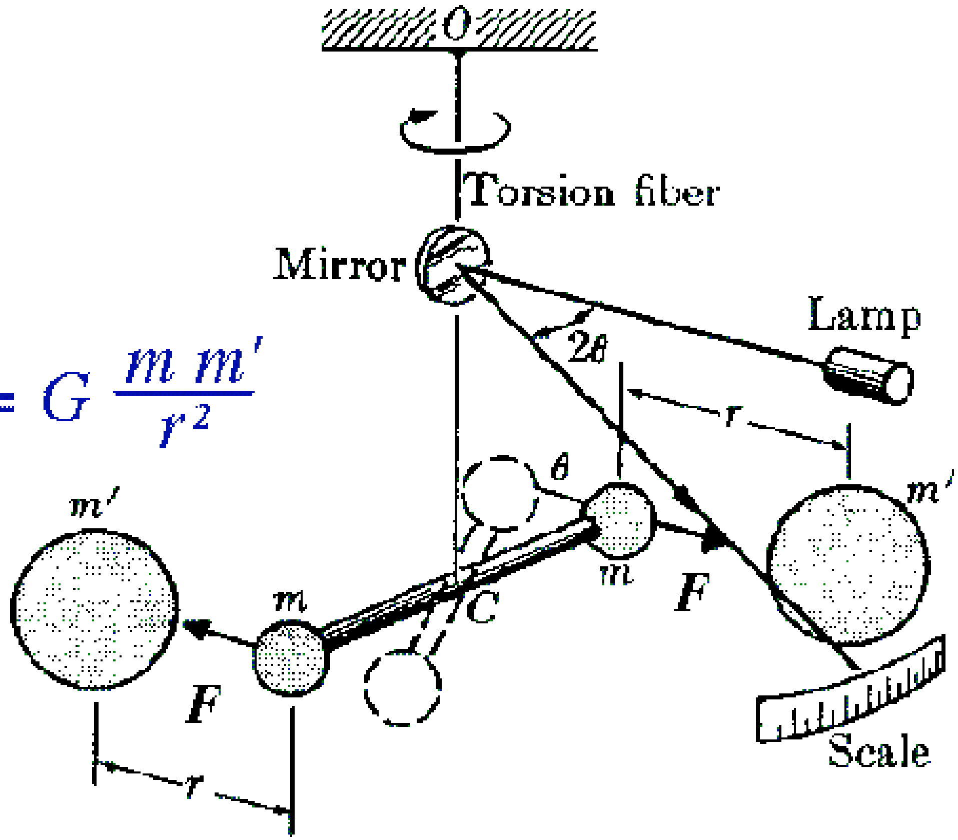
$$F = G\frac{m_1 m_2}{r^2}$$

- Always attractive along line between objects
- G constant
- r is distance between objects
- 'g' at surface of earth:

$$F_{\text{GRAVITY}} = m\left(G\frac{m_{EARTH}}{r^2_{EARTH}}\right) = mg$$

- Gravitational force between ALL objects
- Action-reaction
- Superposition – forces add!

Cavendish measures *G* in 1798



$$F = G\frac{m\,m'}{r^2}$$

$$G = 6.673\times10^{-11}\ \frac{\text{Nm}^2}{\text{kg}^2}$$

What's the earth's mass?

Knowing *G* one can in fact get earth's mass!

$$F = G\frac{m_1 m_2}{d^2}$$

The weight of a 1kg mass is 9.8N and it is at ~6400 km from the earth's center →

$$F = 9.8N = G\frac{m_e \cdot 1kg}{(6400,000m)^2}$$

→ $m_e = 6 \times 10^{24}\ kg$

Consider two situations: an astronaut standing on Earth and on the Moon.

1. The astronaut's mass is greater on Earth.
2. The astronaut's mass is greater on the Moon.
3. The astronaut's mass is the same in both places.

Mass is *independent* of weight

Surfaces

- 'Normal' Force
  - **Always perpendicular to surface**
  - **"Reaction Force" – reacts to applied forces**
- Friction
  - **Always parallel to surface**

What is the magnitude of the normal force of the table on the box?

(1) 100N

(2) 100N + F cosθ

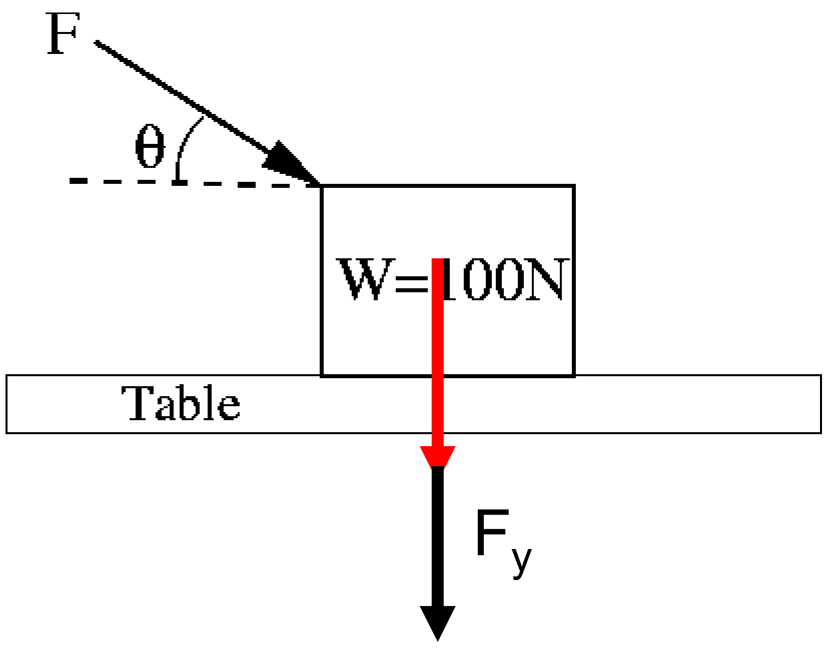
(3) 100N - F cosθ

(4) 100N + F sinθ

(5) 100N - F sinθ

(6) F cosθ

(7) F sinθ



$$\Sigma F_Y = 0 = F_N - 100\ N - F\sin\theta$$

Reminders

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- **HW#4 due Sunday 7/01, 11:59pm**
- **RQ#6 due Monday 7/02 10am.**
- **RQ#7 due Tuesday 7/03 10am.**
- **HW#5 due *Sunday* 7/08, 11:59pm.**

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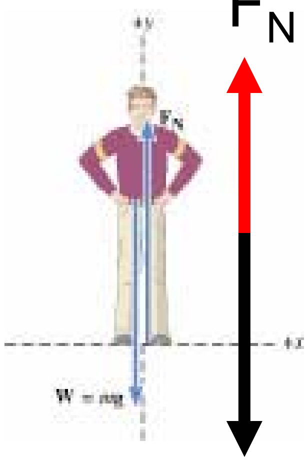
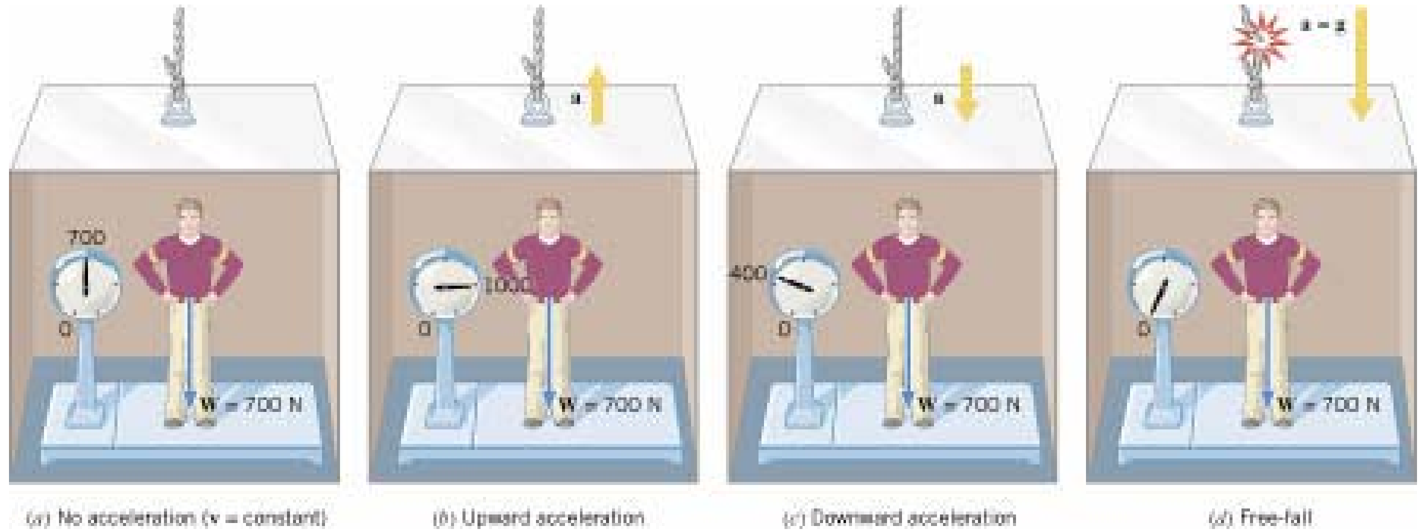
- **EXAM 2: Next Thursday (07/08).**
  - Topics: Chapters 3 and 4 **(including related Lab material)**

Apparent Weight

F_N



W



No acceleration (v=const): $W=F_N$	**a** upward $F_N>W$	**a** downward $F_N<W$	**Free fall (a=g)** $\mathbf{F_N=0}$

$$m\mathbf{a}=F_{NET}=W-F_N$$

- *Normal force not always equal to weight!*
- Bathroom scale reads same as normal force
- Apparent weight is simply the normal force.

You are on an elevator which is accelerating <u>upward</u> at $2.00 m/s^2$. Your mass is 80.0kg, and the elevator has a mass of 500kg. How does the normal force (F_N) compare to your weight (F_g)?

1. normal force > weight
2. normal force = weight
3. normal force < weight

Draw FBD for 'you'. $\Sigma F_y = F_N - F_g = ma_y$

$F_N = F_g + ma_y = mg + ma_y = 80kg*(9.8m/s^2 + 2m/s^2) = 944N$

A cable is used to pull the elevator upward. What is the force of the cable on the elevator?

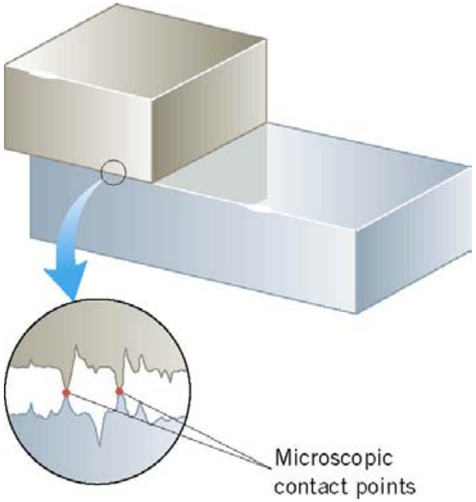
What is the normal force on you if the elevator is traveling at constant velocity upward?

$$\Sigma F_y = F_N - F_g = ma_y = 0$$

Solving problems with Forces

- Draw picture and define axes
- Isolate objects – draw Free Body Diagrams (FBD) for each object
  - **gravity?**
  - **anything else touching object?**
  - **Friction? Direction?**
- Write down sum of forces in each direction
- Solve

Friction



$$F_{Friction} = \mu F_{normal}$$

- *Kinetic* if two surfaces slipping relative to each other

$$F_{Friction,KINETIC} = \mu_{KINETIC} F_{normal}$$

- *Static* if not

$$F_{Friction,STATIC} \leq \mu_{STATIC} F_{normal}$$

μ depends on materials – look up or calculate

- Static Force of Friction "Reaction Force"

A box weighing 10N is moving to the right under the influence of a 10N horizontal force. μ_s=0.4 and μ_k=0.3. What is the magnitude and direction of the frictional force?

(1) 1N to the left

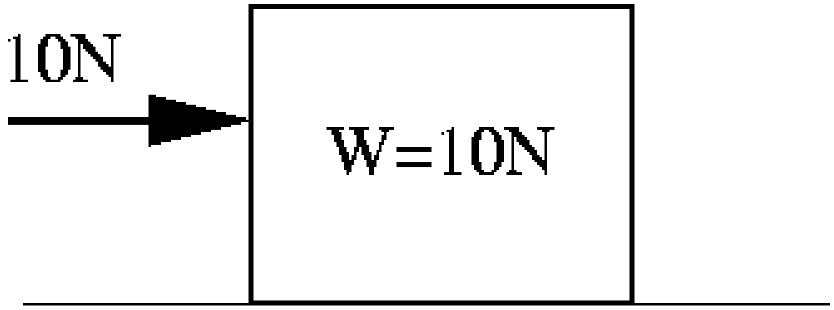
(2) 1N to the right

(3) 3N to the left

(4) 3N to the right

(5) 4N to the left

(6) 4N to the right



Box is moving to right

Moving, so use μ_k.

$$F_f = \mu_k * F_N$$

$$\Sigma F_Y = 0 = F_N - 10\ N$$

$$F_N = 10\ N$$

The 10N force is now applied at an angle downwards. Compare the new acceleration with the previous acceleration (from the horizontal force).

1. Greater than the previous acceleration
2. Same as the previous acceleration
3. Less than the previous acceleration
4. Cannot determine from information given

Normal force increases, friction force increases.

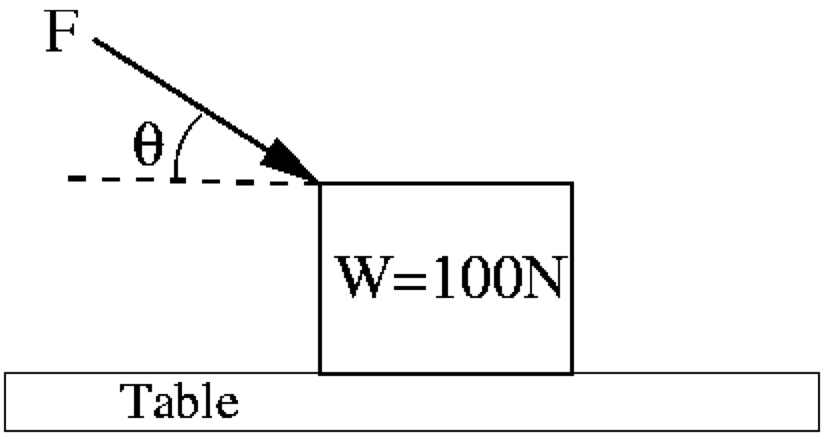
At same time, component of 10N in direction of motion decreases.

Solving problems with Forces

- Draw picture and define axes
- Isolate objects – draw Free Body Diagrams (FBD) for each object
  - **gravity?**
  - **anything else touching object?**
- Write down sum of forces in each direction
- Solve

Example

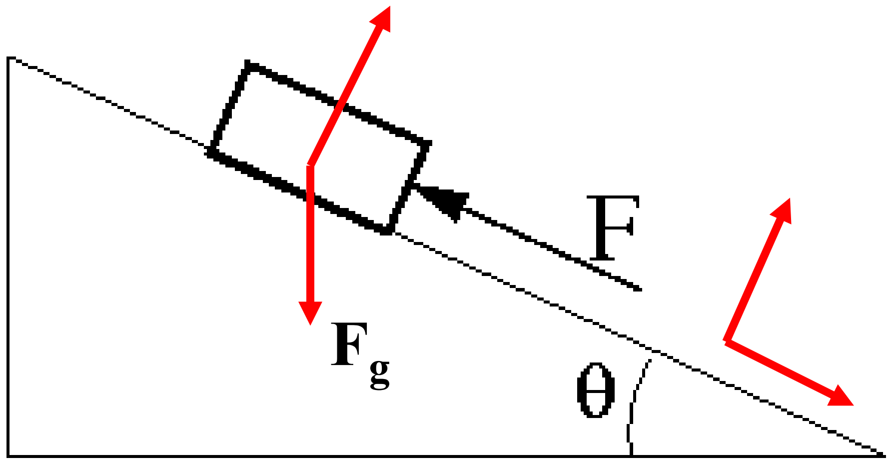
A 100.-N box is being pushed across a floor by a force of 80N which is being applied in a direction 30^o below the horizontal. The coefficients of friction are μ_s=0.4 and μ_k=0.3. What is the acceleration of the box?



$a = 2.68 m/s^2$

Incline

- Gravity downward - has parallel and perpendicular components
- Normal force still perpendicular to surface
- Friction parallel
- Often convenient to tilt coordinate axes



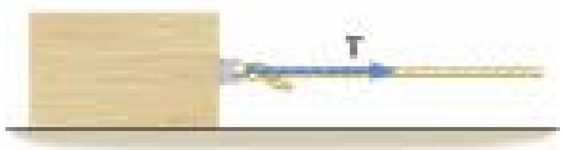
A 30-kg (294-N) crate is sliding down an incline at an angle 30° below the horizontal. The kinetic coefficient of friction is 0.3 between the crate and the ramp. What is the acceleration of the crate?

- Draw picture and define axes
- Isolate objects – draw Free Body Diagrams (FBD) for each object
  - **gravity?**
  - **anything else touching object?**
- Write down sum of forces in each direction
- Solve

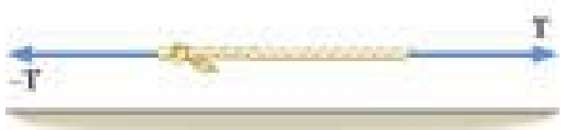
Tension – Ropes/Pulleys

- For now, massless pulley and rope
- Rope can only pull – force in direction of rope
- Tension same in all parts of rope (massless rope)
- Tension – Force rope exerts on other objects
- Magnitude of v and a same for all objects on rope (pulley changes direction).

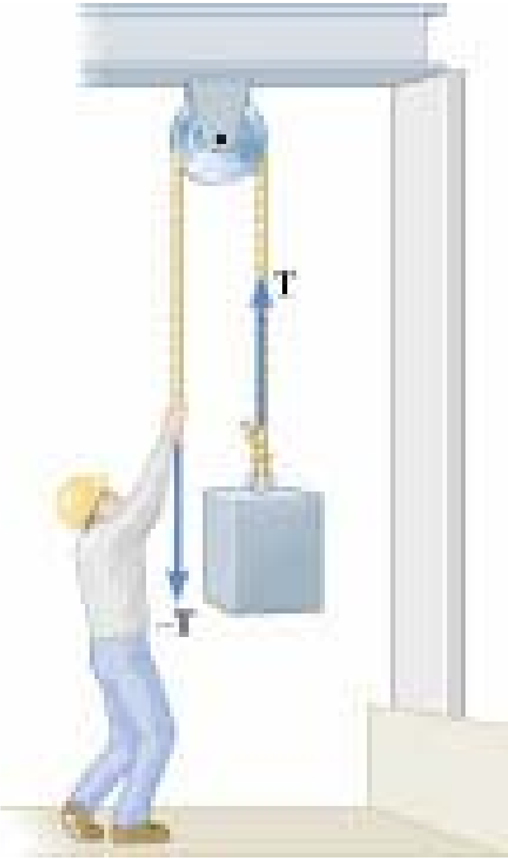
Force T is applied to the rope



Force is transmitted to the box



Rope: equal forces applied to both ends



Force T applied to one end of the rope is always transmitted to the other end.

Two people pull on opposite ends of a massless rope. Each pulls with a force of 40N. What is the tension of the rope?

(1) 0N

(2) 20N

(3) 40N

(4) 80N

Look at one person. Not accelerating. $F_{\text{Person on Rope}} = - F_{\text{rope on person}}$

Force of rope on person is the tension.

Solving problems with Forces

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Friction

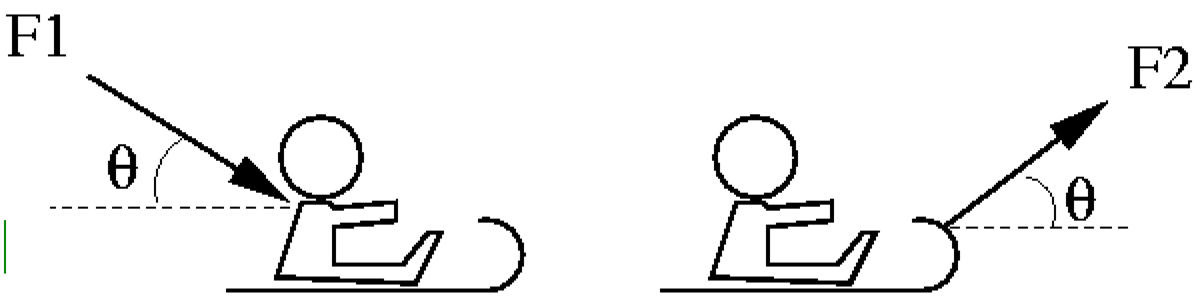
- Direction?
  - **Does it ALWAYS oppose movement?**
  - **What about when you walk?**
  - **What about “Rolling stones”?**

Friction is NOT negligible between the bottom of the sled and the snow. You can either push forward and down at an angle θ or pull up and forward at the same angle. If $F_1=F_2$ and angle are the same, which situation has the greater acceleration?

(1) The push

(2) The pull

(3) Both are equal



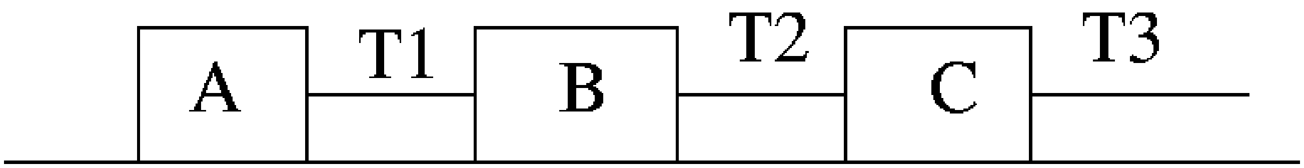
Horizontal component of force same.

Normal force, and therefore frictional force, less in second case.

A crate sits in the back of a pickup track. Assume there is no friction between the truck and the crate and that the crate is not tied down. The truck starts from rest at a stoplight. The crate will:

1. Head towards the front of the truck
2. Head towards the tailgate
3. Stay in the same spot in the back.

Three boxes are accelerating to the right at a rate of 2.0m/s². All 3 have non-zero mass.



How do T_1, T_2, and T_3 relate?

(1) $T_1 = T_2 = T_3$

(2) $T_1 < T_2 < T_3$

(3) $T_3 < T_2 < T_1$

(4) $T_1 < T_2 = T_3$

(5) $T_3 = T_2 < T_1$

(6) $T_1 = T_2 < T_3$

Reminders

- **HW#4: deadline extended to *today*, 11:59pm**

- **RQ#7 due Tuesday 7/03 10am.**
- **HW#5 due *Sunday* 7/08, 11:59pm.**
- **No labs/Capa session this Wed. 07/04**

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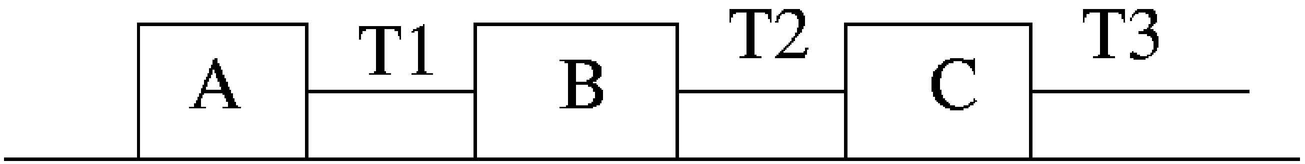
  - Topics: Chapters 3 and 4 **(including related Lab material)**

Example: Three Boxes

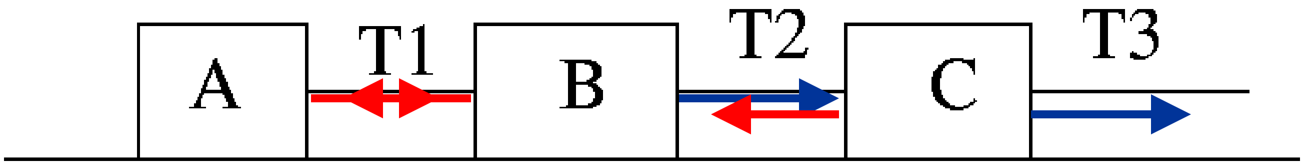


Three boxes are accelerating to the right at a rate of $2.0 m/s^2$ on a smooth surface.

The mass of block A is 2kg and the mass of block B is 1kg. The tension in rope 3 (T3) is 12N.

Find the tensions in the ropes (T1,T2) and the mass of block C.

Solution



Data:

$a=2.0m/s^2$ for all blocks (no friction).

m_A =2kg, m_B=1kg. T_3=12N.

T_1=? T_2=?.

Solution:

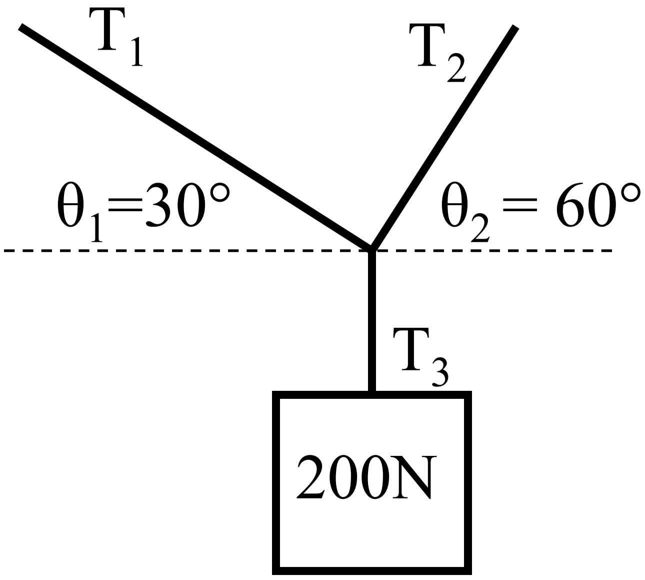
FBD in body A: $F_{NET\ in\ A}=m_A.a=T_1$ $\rightarrow T_1=4N$

FBD in body B: $F_{NET\ in\ B}=m_B.a=T_2-T_1$ $\rightarrow T_2=m_Ba+T_1=2+4=6N$

FBD in body C: $F_{NET\ in\ C}=m_C.a=T_3-T_2$

$2m_c=T_3-T_2=6N \rightarrow m_c=3$ kg

A 200-N box is hanging from a rope. Two ropes attach the box to the ceiling at the angles given. What is the tension in each rope?



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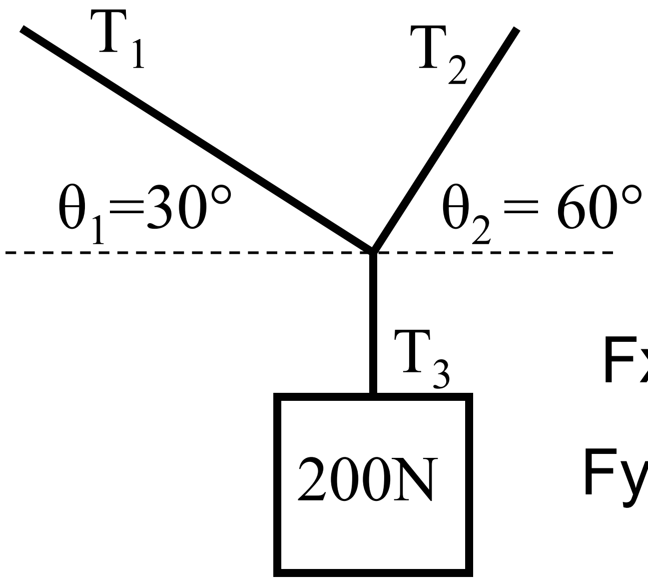


Solution

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

$$T_3 = 200N$$

Fx: $$-T_1 \cos 30 + T_2 \cos 60 = 0$$

Fy: $$-T_3 + T_1 \sin 30 + T_2 \sin 60 = 0$$

$$T_3 = 200N$$

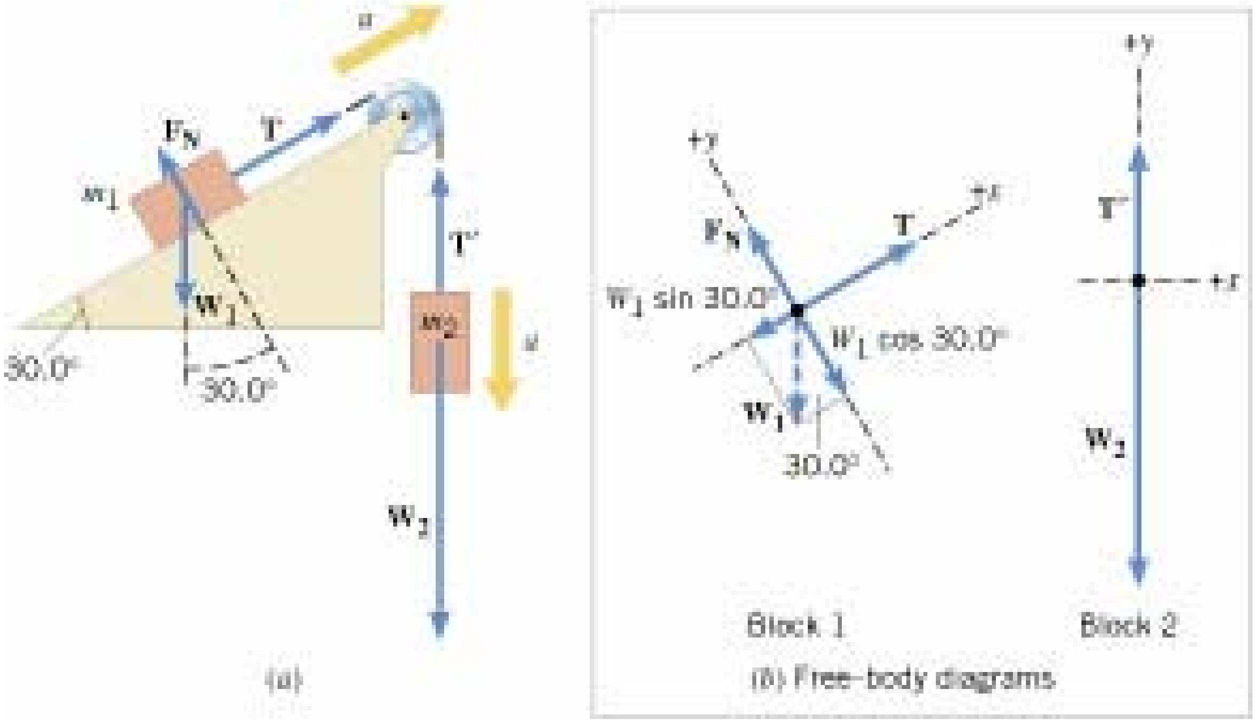
$$\begin{cases} -0.866T_1 + 0.5T_2 = 0 \\ 0.5T_1 + 0.866T_2 = 200 \end{cases}$$

$$T_1 = 100N$$

$$T_2 = 173.2N$$

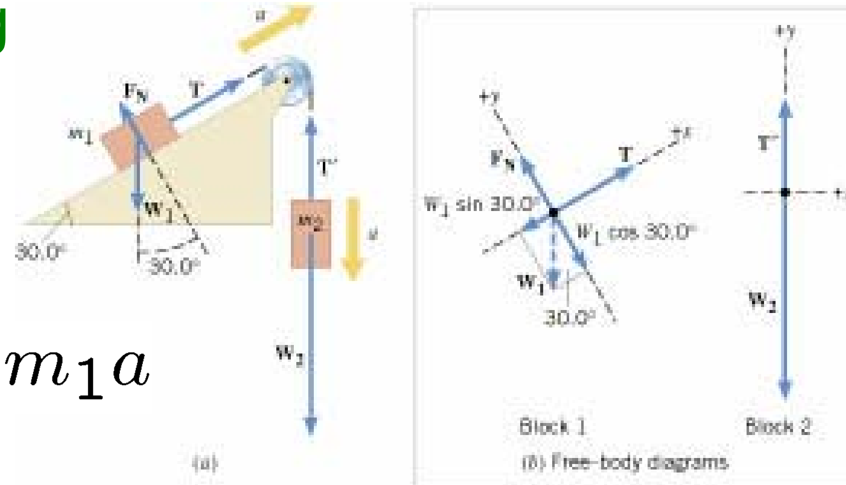
Example: Accelerating Blocks

Block 1 (mass m_1=8.00 kg) is moving on a frictionless 30o incline. This block is connected to block 2 (mass m_2=22 kg) by a massless cord that passes over a massless and frictionless pulley (see Fig.) Find the acceleration *a* on each block and the tension in the cord.



Solution: Accelerating Blocks

m_1=8.00 kg, angle= 30o m_2=22 kg



FBD block 1:

$$\sum F = -W_1 \sin 30 + T = m_1 a$$

FBD block 2:

$$\sum F_y = T' - W_2 = m_2(-a)$$

Massless rope/pulley:

$$\boxed{T = T'}$$

Two equations, two unknwons:

$$\begin{cases} T - 8a = 8 \times 9.8 \times \sin 30 = 39.2N \\ T + 22a = 22 \times 9.8 = 215N \end{cases}$$

T=86.3 N

a=5.89 m/s^2

Chapter 4

g= 9.8 m/s^2 downward

G=6.673x10^{-11} N m^2/kg^2

$$\bar{\vec{v}} = \frac{\vec{r} - \vec{r}_0}{t - t_0} = \frac{\Delta\vec{r}}{\Delta t}$$

$$\bar{\vec{a}} = \frac{\Delta\vec{v}}{\Delta t}$$

$$c^2 = a^2 + b^2$$

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

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

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

$$F_g = mg$$

$$F_{\text{FRICTION}} = \mu F_N$$

$$\sum F_x = ma_x$$

$$\sum F_y = ma_y$$

$$x = v_{x0}t + \frac{1}{2}a_x t^2$$

$$x = \frac{1}{2}(v_{x0} + v_x)t$$

$$v_x = v_{x0} + a_x t$$

$$v_x^2 = v_{x0}^2 + 2a_x x$$