Physics 207, Lecture 6, Sept. 25

Agenda:

- Chapter 4
  - ❖ Frames of reference
- Chapter 5
  - ❖ Newton's Law
  - ❖ Mass
  - ❖ Inertia
  - ❖ Forces (contact and non-contact)
  - ❖ Friction (a external force that opposes motion)
  - ❖ Free Body Diagrams (a very important tool)

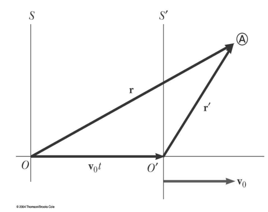
Assignment: For Wednesday read Chapter 6

- WebAssign Problem Set 2 due Wednesday noon
- WebAssign Problem Set 3 available today
- MidTerm Thursday, Oct. 5, Chapters 1-6, 90 minutes, 7-8:45 PM

Relative motion and frames of reference

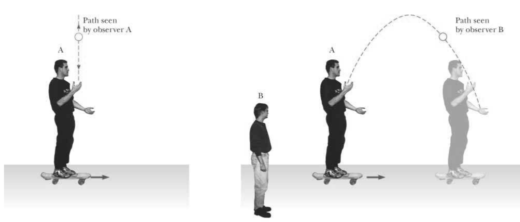
- Reference frame *S* is stationary
- Reference frame *S′* is moving at $\mathbf{v}_o$

  This also means that *S* moves at $-\mathbf{v}_o$ relative to *S′*
- Define time $t = 0$ as that time when the origins coincide



Relative Velocity

- Two observers moving relative to each other generally do not agree on the outcome of an experiment (path)
- For example, observers A and B below see different paths for the ball



Relative Velocity, r, v, a and r′, v′ , a′

- The positions as seen from the two reference frames are related through the velocity

  (remember S is moving at a constant $-v_0$ relative to S′)
  - ❖ $\mathbf{r}' = \mathbf{r} - \mathbf{v}_o\, t$
- The derivative of the position equation will give the velocity equation
  - ❖ $\mathbf{v}' = \mathbf{v} - \mathbf{v}_o = d\,(\mathbf{r} - \mathbf{v}_o\, t)/dt$

Acceleration in Different Frames of Reference

- The derivative of the velocity equation will give the acceleration equation
  - ❖ $\mathbf{v}' = \mathbf{v} - \mathbf{v}_o$
  - ❖ $\mathbf{a}' = \mathbf{a}$
- The acceleration of the particle measured by an observer in one frame of reference is the same as that measured by any other observer moving at a *constant velocity* relative to the first frame.

Monkey and Hunter

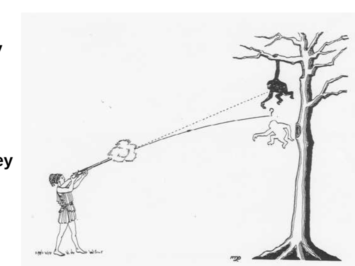
A hunter sees a monkey in a tree, aims his gun at the monkey and fires. At the same instant the monkey lets go. Does the bullet (now the moving frame):

A Go over the monkey

B Hit the monkey

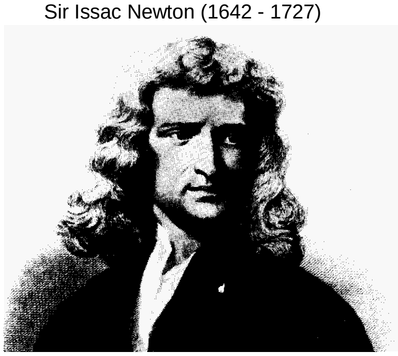
C Go under the monkey

End of Chapter 5



Chapter 6: Newton's Laws and Forces

Sir Issac Newton (1642 - 1727)



See text: Chapter 5

Dynamics

- Principia Mathematica published in 1687. This revolutionary work proposed three "laws" of motion:

Law 1: An object subject to no external forces is at rest or moves with a constant velocity if viewed from an inertial reference frame.

Law 2: For any object, $\mathbf{F}_{NET} = \Sigma \mathbf{F} = m\mathbf{a}$

Law 3: Forces occur in pairs: $\mathbf{F}_{A,B} = -\mathbf{F}_{B,A}$
(For every action there is an equal and opposite reaction.)

Read: Force of B on A

See text: 5-1

Force

- We have a general notion of forces is from everyday life.
- In physics the definition must be precise.
  - ❖A force is *an action which causes a body to accelerate*.
  (Newton's Second Law)

Examples:

Contact Forces	Field Forces (Non-Contact)
(physical contact between objects)	(action at a distance)
Kicking a ball	Moon and Earth

- On a microscopic level, all forces are non-contact

See text: 5-3

Mass

- We have an idea of what mass is from everyday life.
- In physics:
  - ❖mass (in Phys 207) is *a quantity that specifies how much inertia an object has*
  (i.e. a scalar that relates force to acceleration)
  (Newton's First Law)
- Mass is an inherent property of an object.
- Mass and weight are different quantities; weight is usually the magnitude of a gravitational (non-contact) force.

"Pound" (lb) is a definition of weight (i.e., a force), not a mass!

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called ***Inertia***
- ***Mass*** is that property of an object that specifies how much resistance an object exhibits to changes in its velocity

- Mass is an inherent property of an object
- Mass is independent of the object's surroundings
- Mass is independent of the method used to measure it
- Mass is a scalar quantity
- The SI unit of mass is kg

See text: 5-2

Newton's First Law and IRFs

> An object subject to no external forces moves with a constant velocity if viewed from an *inertial reference frame (IRF)*.

If no net force acting on an object, there is no acceleration.

- The above statement can be used to define inertial reference frames.
  - ❖ An IRF is a reference frame that is not accelerating (or rotating) with respect to the "fixed stars".
  - ❖ If one IRF exists, infinitely many exist since they are related by any arbitrary constant velocity vector!
  - ❖ The surface of the Earth may be viewed as an IRF

See text: 5-4

Newton's Second Law

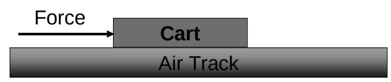
The acceleration of an object is directly proportional to the net force acting upon it. The constant of proportionality is the mass.

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

- This expression is vector expression: F_x, F_y, F_z
- Units
  The metric unit of force is kg m/s^2 = Newtons (N)
  The English unit of force is Pounds (lb)

Lecture 6, *Exercise 1* Newton's Second Law

A constant force is exerted on a cart that is initially at rest on an air table. The force acts for a short period of time and gives the cart a certain final speed.



For a second shot, we apply a force only **half** as large.

To reach the same final speed, how long must the same force force be applied?

(A) 4 x as long (B) 2 x as long (C) 1/2 as long (D) 1/4 as long

Lecture 6, *Exercise 1* Newton's Second Law Solution

F = ma
Since $F_2 = 1/2\ F_1 \Rightarrow a_2 = 1/2\ a_1$

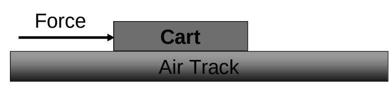
We know that under constant acceleration, $v = a\ \Delta t$

So,
$a_2\ \Delta t_2 = a_1\ \Delta t_1$ we want equal final velocities
$1/2\ a_1 / \Delta t_2 = a_1 / \Delta t_1$ $\Delta t_2 = 2\ \Delta t_1$

(B) 2 x as long

Lecture 6, *Exercise 2* Newton's Second Law

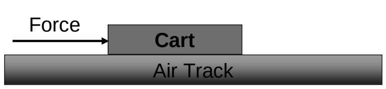
A force of 2 Newtons acts on a cart that is initially at rest on an air table with no air and pushed for 1 second. Because there is no air, the cart stops immediately after I finish pushing. It has traveled a distance, D.



Next, the force of 2 Newtons acts again but is applied for 2 seconds.
The new distance the cart moves relative to D is:

(A) 8 x as far (B) 4 x as far (C) 2 x as far (D) 1/4 as far

Lecture 6, *Exercise 2* Solution



We know that under constant acceleration,
$\Delta x = a\ (\Delta t)^2 / 2$ (when $v_0=0$)

Here $\Delta t_2 = 2\Delta t_1$, $F_2 = F_1 \Rightarrow a_2 = a_1$

$$\frac{\Delta x_2}{\Delta x_1} = \frac{\frac{1}{2} a \Delta t_2^2}{\frac{1}{2} a \Delta t_1^2} = \frac{(2\Delta t_1)^2}{\Delta t_1^2} = 4$$

(B) 4 x as long

See text: 5-6

Newton's Third Law:

If object 1 exerts a force on object 2 ($\mathbf{F}_{2,1}$) then object 2 exerts an equal and opposite force on object 1 ($\mathbf{F}_{1,2}$)

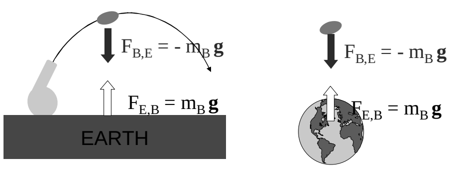
$$\mathbf{F}_{1,2} = -\mathbf{F}_{2,1}$$

For every "action" there is an equal and opposite "reaction"

IMPORTANT:
Newton's 3rd law concerns force pairs which act on two different objects (not on the same object) !

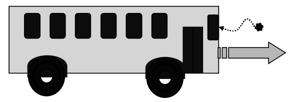
Two Examples (non-contact)

Consider the forces on an object undergoing projectile motion



Lecture 6, *Exercise 3*
Newton's Third Law

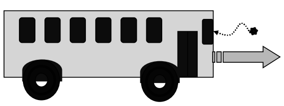
A fly is deformed by hitting the windshield of a speeding bus.



The force exerted by the bus on the fly is,
(A) greater than
(B) the same as
(C) less than
that exerted by the fly on the bus.

Lecture 6, *Exercise 4*
Newton's Third Law

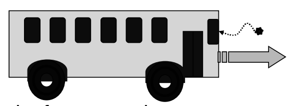
Same scenario but now we examine the accelerations



The magnitude of the acceleration, due to this collision, of the bus
(A) greater than
(B) the same as
(C) less than
that of the fly.

Lecture 6, *Exercises 3&4*
Newton's Third Law
Solution

By Newton's third law these two forces form an interaction pair which are equal (but in opposing directions).



Thus the forces are the same

However, by Newton's second law $\mathbf{F}_{net} = m\mathbf{a}$ or $\mathbf{a} = \mathbf{F}_{net}/m$.
So $\mathbf{F}_{b,\,f} = -\mathbf{F}_{f,\,b} = \mathbf{F}_0$
but $|\mathbf{a}_{bus}| = |\mathbf{F}_0 / m_{bus}| \ll |\mathbf{a}_{fly}| = |\mathbf{F}_0/m_{fly}|$

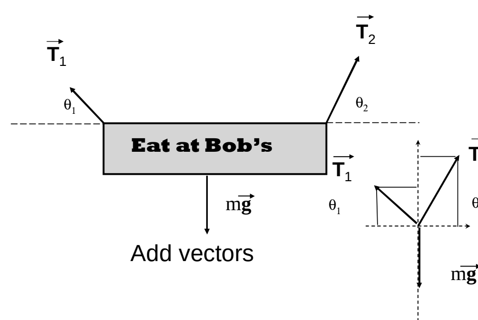
Answer for acceleration is (C)

Free Body Diagram

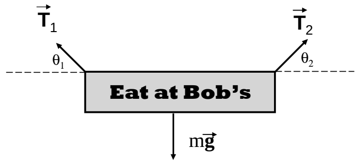
A heavy sign is hung between two poles by a rope at each corner extending to the poles.

What are the forces on the sign?

Free Body Diagram



Free Body Diagram



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

Vertical :

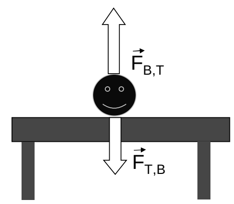
y-direction $0 = -mg + T_1\sin\theta_1 + T_2\sin\theta_2$

Horizontal :

x-direction $0 = -T_1\cos\theta_1 + T_2\cos\theta_2$

Normal Forces

Certain forces act to keep an object in place. These have what ever force needed to balance all others (until a breaking point).

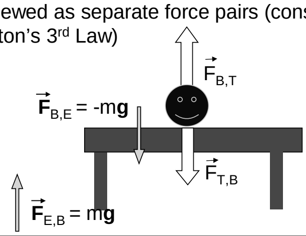


Force Pairs

Newton's 3rd law concerns force pairs:

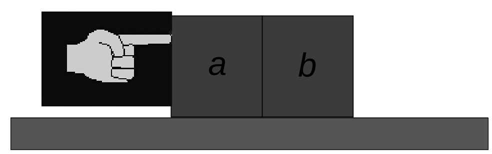
Two members of a force pair cannot act on the same object.

Don't mix gravitational (a non-contact force of the Earth on an object) and normal forces. They must be viewed as separate force pairs (consistent with Newton's 3rd Law)



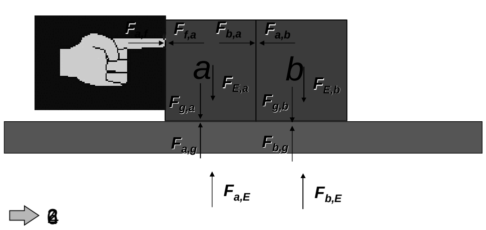
Lecture 6, *Exercise 5*
Newton's 3rd Law

- Two blocks are being pushed by a finger on a horizontal frictionless floor. How many action-reaction force pairs are present in this exercise?



(A) *2* (B) *4* (C) *6*

Lecture 6, *Exercise 5*
Solution:



Example

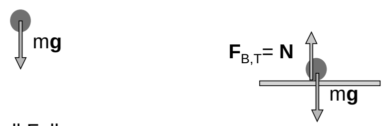
Consider the following two cases (a falling ball and ball on table),

Compare and contrast Free Body Diagram and

Action-Reaction Force Pair sketch

Example

The Free Body Diagram

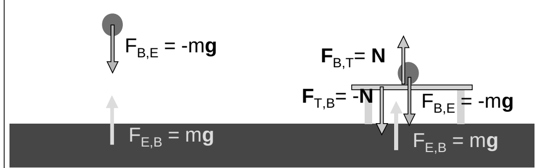


Ball Falls

For Static Situation
N = m**g**

Example

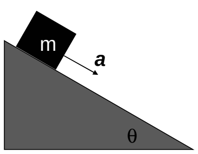
First: Free-body diagram
Second: Action/reaction pair forces



See text: Example 5.7

Exercise: Frictionless inclined plane

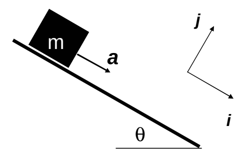
- A block of mass *m* slides down a frictionless ramp that makes angle θ with respect to horizontal. What is its acceleration *a* ?



See text: Example 5.7

Frictionless inclined plane...

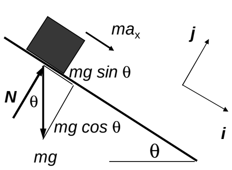
- Define convenient axes parallel and perpendicular to plane:
  - ❖ Acceleration *a* is in *x* direction only (defined as a_x).



See text: Example 5.7

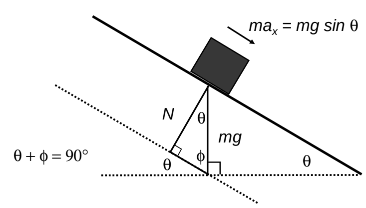
Frictionless inclined plane...

- Use a FBD and consider *x* and *y* components separately:
- F_x ***i***: $ma_x = mg \sin\theta$ ⇨ $a_x = g \sin\theta$
- F_y ***j***: $ma_y = 0 = N - mg \cos\theta$ ⇨ $N = mg \cos\theta$



See text: Example 5.7

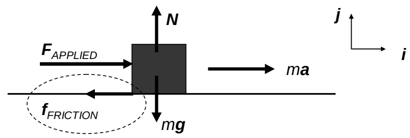
Angles of the inclined plane



See text: 5.8

A special contact force, friction

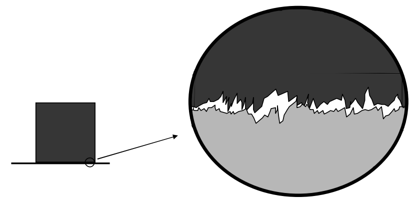
- What does it do?
  - ❖ It opposes motion!
- How do we characterize this in terms we have learned?
  - ❖ Friction results in a force in a direction opposite to the direction of motion (actual or, if static, then implied)!



See text: 5.8

Friction...

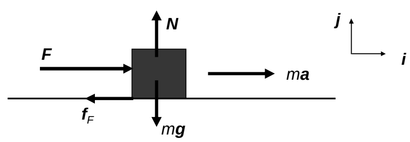
- Friction is caused by the "microscopic" interactions between the two surfaces:



See text: 5.8

Friction...

- Force of friction acts to oppose motion:
  - ❖ Parallel to a surface
  - ❖ Perpendicular to a ***N***ormal force.



See figure 5.17

See text: 6-1

Model for Sliding Friction (with motion)

- The direction of the frictional force vector is perpendicular to the normal force vector ***N***.
- The magnitude of the frictional force vector $|f_K|$ is proportional to the magnitude of the normal force $|N|$.
  - ❖ $|f_K| = \mu_K |N|$ ($= \mu_K | mg |$ in the previous example)
  - ❖ The "heavier" something is, the greater the frictional force
- The constant μ_K is called the "coefficient of kinetic friction".

See text: 6-1

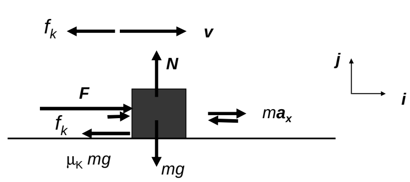
Case study ...

- Dynamics:

x-axis i: $ma_x = F - \mu_K N$

y-axis j: $ma_y = 0 = N - mg$ or $N = mg$

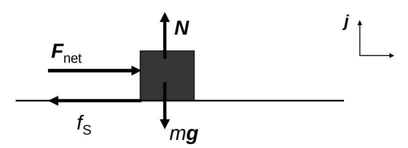
so $F - \mu_K mg = m\,a_x$



See text: Ch 5.8

Static Friction...

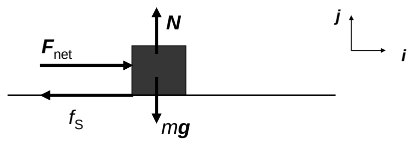
- So far we have considered friction acting when something has a non-zero velocity
  - ❖ We also know that it acts in fixed or "static" systems:
- In these cases, the force provided by friction depends on the forces applied on the system ($f_s \le \mu N$)
- Opposes motion that would occur if μ were zero



See text: Ch 5.8

Static Friction...

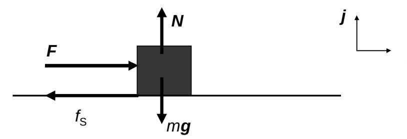
- Just like in the sliding case except $a = 0$.
  - i : $F_{net} - f_S = 0$
  - j : $N = mg$
  - While the block is static: $f_S = F_{net}$ ***(unlike kinetic friction)***



See text: Ch 5.8

Static Friction...

- The maximum possible force that the friction between two objects can provide is $f_{MAX} = \mu_S N$, where μ_s is the "coefficient of static friction".
  - ❖So $f_S \leq \mu_S N$.
  - ❖As one increases F, f_S gets bigger until $f_S = \mu_S N$ and the object "breaks loose" and starts to move.



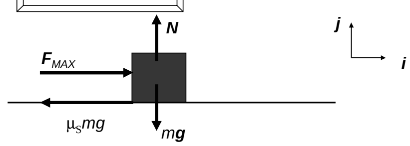
See text: Ch 5.8

Static Friction...

- μ_S is discovered by increasing ***F*** until the block starts to slide:
  - i : $F_{MAX} - \mu_S N = 0$
  - j : $N = mg$

$$\mu_S = F_{MAX} / mg$$

Active Figure



See text: 6-1

Additional comments on Friction:

- Since $f = \mu N$, the force of friction does not depend on the area of the surfaces in contact.
- Logic dictates that $\boxed{\mu_S > \mu_K}$ for any system

Recapping

Sept. 25

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  - ❖ Inertia
  - ❖ Forces (contact and non-contact)
  - ❖ Friction (a external force that opposes motion)
  - ❖ Free Body Diagrams (a very important tool)

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