Physics 207 – Lecture 5

Physics 207, Lecture 5, Sept. 19

Agenda:

- Finish Chapter 4 and Chapter 5
  - ❖ Inertial reference frames
  - ❖ Free Body Diagrams
  - ❖ Non-zero net Forces (acceleration)
  - ❖ Friction

Assignment:

- For Monday: Read Chapter 6
- MP Problem Set 2 due tonight(!)
- MP Problem Set 3 due next week

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

Newton's Second Law

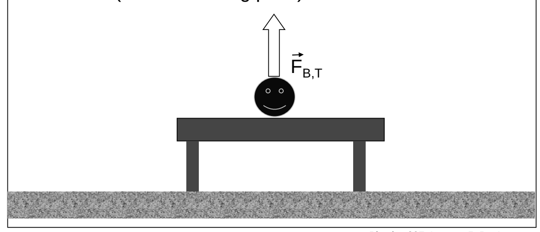
The acceleration of an object is directly proportional to the net force acting upon it. The constant of proportionality is the mass.

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

- 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)

Contact (i.e., normal) Forces

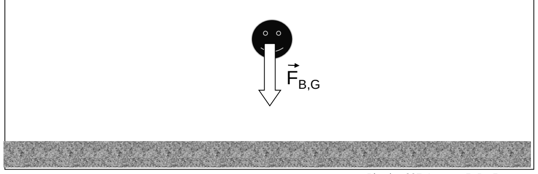
Certain forces act to keep an object in place.
These have what ever force needed to balance all others (until a breaking point).



Non-contact Forces

All objects having mass exhibit a mutually attractive force (i.e., gravity) that is distance dependent

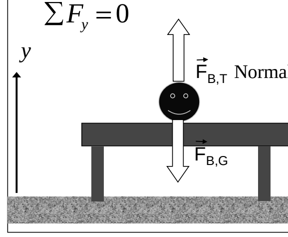
At the Earth's surface this variation is small so little "g" (the associated acceleration) is typically set to 9.80 or 10. m/s^2



No net force ➔ No acceleration

$$\sum \vec{F} = \vec{F}_{\text{net}} = m\vec{a} = 0$$
$$\sum F_x = 0$$
$$\sum F_y = 0$$

(Force vectors are not always drawn at contact points)



Normal force is always $\perp$ to a surface

$$\sum F_y = -mg + N = 0$$
$$N = mg$$

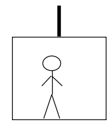
Lecture 5, *Exercise 1* , *Newton's 2nd Law*

A woman is straining to lift a large crate, without success. It is too heavy. We denote the forces on the crate as follows:
P is the upward force being exerted on the crate by the person
C is the contact force on the crate by the floor, and
W is the weight (force of the earth on the crate).
Which of following relationships between these forces is true, while the person is trying unsuccessfully to lift the crate? (Note: force up is positive & down is negative)

✗ *A.* $P + C < W$
✗ *B.* $P + C > W$
✗ *C.* $P = C$
✓ *D.* $P + C = W$

Lecture 5, *Example*
Gravity and Normal Forces

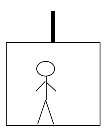
A woman in an elevator is accelerating upwards



The normal force exerted by the elevator on the woman is,
(A) greater than
(B) the same as
(C) less than
the force due to gravity acting on the woman

Lecture 5, *Example*
Gravity and Normal Forces

A woman in an elevator is accelerating upwards



$$\sum F_y = -mg + N = ma$$

$$N = mg + ma = m(g + a)$$

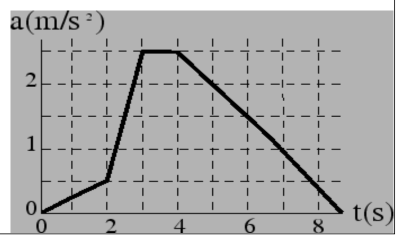
The normal force exerted by the elevator on the woman is,
(A) greater than
(B) the same as
(C) less than
the force due to gravity acting on the woman

Lecture 5, *Exercise 2*
Elevator physics

A 100 kg or 1000 N person ($g = 10$ m/s^2) boards an elevator and goes up three flights. There is a display that tells him his acceleration versus time (shown below).

What is his maximum apparent weight if he is standing on a scale?

✗ A. 1100 N
✗ B. 1200 N
✓ C. 1250 N
✗ D. 750 N



Important notes

- Contact forces are conditional, they are not necessarily constant
- The SI units of force are Newtons with 1 N= 1 kg m/s^2

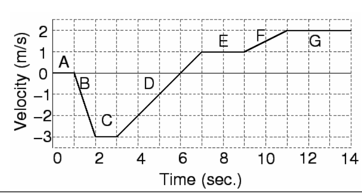
Now recall

- If net force is non-zero & constant then the change in the velocity is simply acceleration times time.

Lecture 5, *Exercise 3*
Newton's Second Law

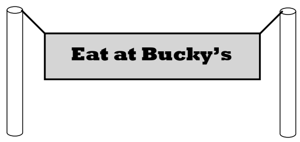
A 10 kg mass undergoes motion along a line with a velocities as given in the figure below. In regards to the stated letters for each region, in which is the magnitude of the force on the mass at its greatest?

✗ A. A
✓ B. B
✗ C. C
✗ D. D
✗ E. E
✗ F. F
✗ G. G



Free Body Diagram

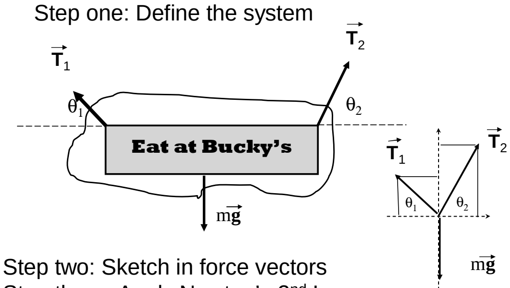
A heavy sign is hung between two poles by a rope at each corner extending to the poles.



What are the forces on the sign and how are they related if the sign is stationary (or moving with constant velocty) in an inertial reference frame ?

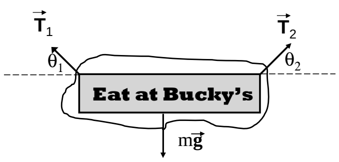
Free Body Diagram

Step one: Define the system



Step two: Sketch in force vectors
Step three: Apply Newton's 2nd Law
(Resolve vectors into appropriate components)

Free Body Diagram



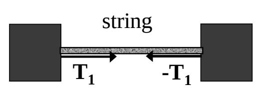
$$\sum \vec{F} = \vec{F}_{NET} = m\vec{a}$$

Vertical :
y-direction $0 = -mg + T_1 \sin\theta_1 + T_2 \sin\theta_2$
Horizontal :
x-direction $0 = -T_1 \cos\theta_1 + T_2 \cos\theta_2$

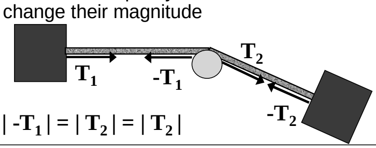
Moving forces around

- Massless, inflexible strings: Translate forces and reverse their direction but do not change their magnitude

(we really need Newton's 3rd of action/reaction to justify this)



- Massless, frictionless pulleys: Reorient force direction but do not change their magnitude



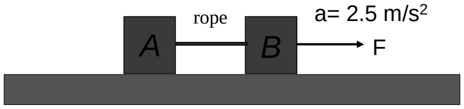
$|\mathbf{T_1}| = |-\mathbf{T_1}| = |\mathbf{T_2}| = |\mathbf{T_2}|$

Lecture 5, Exercise 4
A rope trick

- You are going to pull two blocks ($m_A = 4$ kg and $m_B = 6$ kg) at constant acceleration ($a = 2.5$ m/s^2) on a horizontal frictionless floor, as shown below.

  The rope connecting the two blocks can stand tension of only T = 9.0 N. Would the rope break?
- Step 1: How many FBDs would you draw:

(A) 0 (B) 1 (C) 2 (D) 3

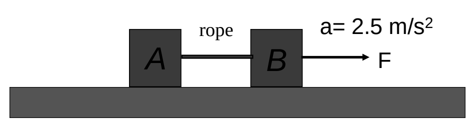


Lecture 5, Exercise 4
A rope trick

- You are going to pull two blocks ($m_A = 4$ kg and $m_B = 6$ kg) at constant acceleration ($a = 2.5$ m/s^2) on a horizontal frictionless floor, as shown below.

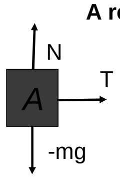
  The rope connecting the two blocks can stand tension of only $T_{max} = 9.0$ N. Would the rope break?
- How many FBDs would you draw: (There is no "correct" answer.)

A. 0
B. 1
C. 2
D. 3

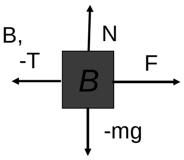


Lecture 5, Exercise 5
A rope trick

- For A,



For B,

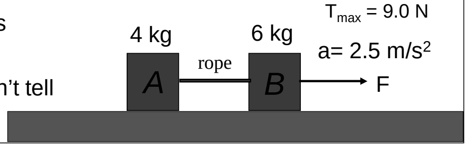


- Would the rope break?

A. yes
B. no
C. can't tell

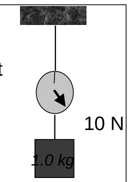
T_{max} = 9.0 N

a= 2.5 m/s^2

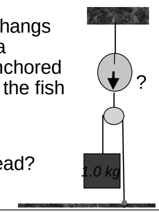


Scale Problem

- You are given a 1.0 kg mass and you hang it directly on a fish scale and it reads 10 N (g is 10 m/s^2).



- Now you use this mass in a second experiment in which the 1.0 kg mass hangs from a massless string passing over a massless, frictionless pulley and is anchored to the floor. The pulley is attached to the fish scale.

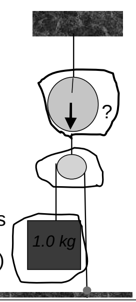


- What force does the fish scale now read?

Scale Problem

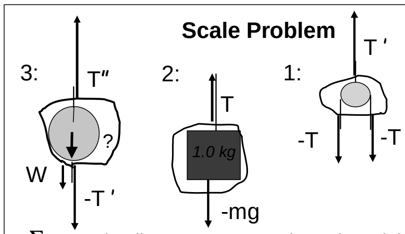
- Step 1: Identify the system(s).

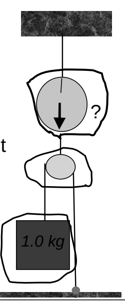
  In this case it is probably best to treat each object as a distinct element and draw three force body diagrams.
  - ❖ One around the scale
  - ❖ One around the massless pulley (even though massless we can treat is as an "object")
  - ❖ One around the hanging mass



- Step 2: Draw the three FBGs. (Because this is a now a one-dimensional problem we need only consider forces in the y-direction.)

Scale Problem





- $\Sigma F_y = 0$ in all cases Note: W is scale weight

  1: 0 = -2T + T ′

  2: 0 = T – mg → T = mg

  3: 0 = T″ – W – T ′ (not useful here)
- Substituting 2 into 1 yields T ′ = 2mg = 20 N

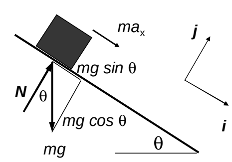
(We start with 10 N but end with 20 N)

Lecture 5 Recap, Sept. 19

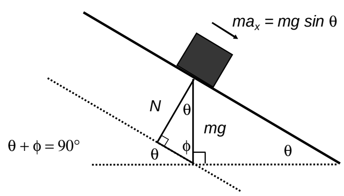
- Assignments:
- For Monday: Read Chapter 6
- MP Problem Set 2 due tonight(!)
- MP Problem Set 3 due next week

Frictionless inclined plane...

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

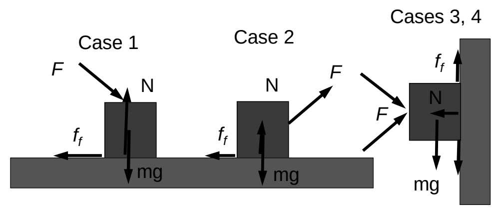


Angles of the inclined plane



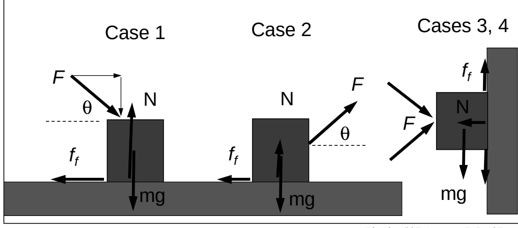
Forces at different angles

Case1: Downward angled force with friction
Case 2: Upwards angled force with friction
Cases 3,4: Up against the wall
Questions: Does it slide?
What happens to the normal force?
What happens to the frictional force?



Forces at different angles

1. Make a Force Body Diagram
2. Choose directions for x, y and z axes
3. Write down Newton's 2nd Law for the x, y and z directions
4. If no acceleration sum of the forces is zero, ma otherwise



Lecture 5, *Chapter 3 reprisal, for home* Relative Motion

- You are swimming across a *50* m wide river in which the current moves at *1* m/s with respect to the shore. Your swimming speed is *2* m/s with respect to the water.

You swim across in such a way that your path is a straight perpendicular line across the river.

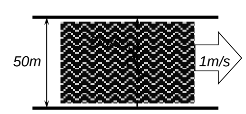
- How many seconds does it take you to get across?

a) $50/2 = 25$ s

b) $50/1 = 50$ s

c) $50/\sqrt{3} = 29$ s

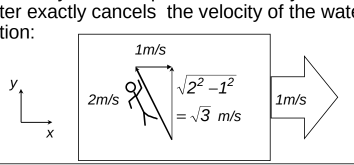
d) $50/\sqrt{2} = 35$ s



Lecture 5, *Chapter 3 reprisal* Solution

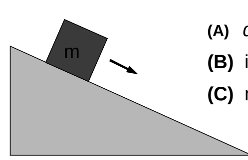
Choose *x* axis along riverbank and *y* axis across river

- The time taken to swim straight across is *(distance across) / (v_y)*
- Since you swim straight across, you must be tilted in the water so that your *x* component of velocity with respect to the water exactly cancels the velocity of the water in the *x* direction:



Lecture 6, *Example* Two-body dynamics

- A block of mass *m*, is placed on a rough inclined plane (μ > 0) and given a brief push. It motion thereafter is down the plane with a constant speed.
  - ❖ If a similar block (same μ) of mass 2*m* were placed on the same incline and given a brief push with v_0 down the block, it will



(A) *decrease its speed*

(B) increase its speed

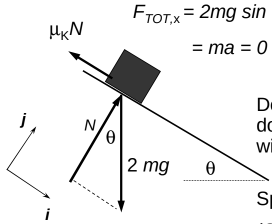
(C) move with constant speed

Lecture 6, *Example* Solution

- Draw FBD and find the total force in the x-direction

$F_{TOT,x} = 2mg \sin\theta - \mu_K\ 2mg \cos\theta = 2\ ma$

$= ma = 0$ (case when just m)



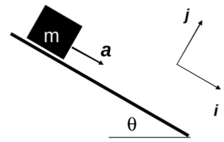
Doubling the mass will simply double both terms…net force will still be zero !

Speed will still be constant !

(C)

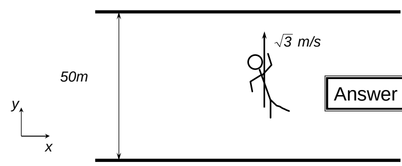
Frictionless inclined plane...

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



Lecture 5, *Exercise 3* Solution

- The *y* component of your velocity with respect to the water is $\sqrt{3}\,\mathrm{m/s}$
  - The time to get across is $\frac{50m}{\sqrt{3}\,m/s} = 29s$



Answer (c)