Physics 207, Lecture 10, Oct. 8

Agenda
- Exam I
- Newton's Third Law
- Pulleys and tension revisited

Assignment:
- MP Problem Set 4A due Oct. 10,Wednesday, 11:59 PM
- For Wednesday, read Chapter 9
- MP Problem Set 5 (Chapters 8 & 9) available soon

Exam I results

- Exams should be returned in your next discussion section
- Regrades: Write down, on a separate sheet, what you want regraded and why.
- With only 110 scores tallied:

Mean: 67.0 Median: 67 Std. Dev.: 14.5
Range: High 97 Low 25
Solution posted later today on http://my.wisc.edu
Tentative (only 130 scores)
87-100 A
77- 86 A/B
67- 76 B
57- 66 B/C
40- 56 C
30- 39 D
Below 30 F

Newton's Laws

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

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)

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 ($\mathbf{F}_{1,2}$)

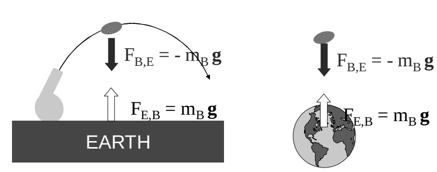
$\mathbf{F}_{1,2} = -\mathbf{F}_{2,1}$

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) !

Example (non-contact)

Consider the forces on an object undergoing projectile motion

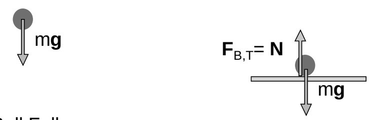


Example

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

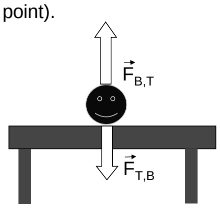


Ball Falls

For Static Situation
N = mg

Normal Forces

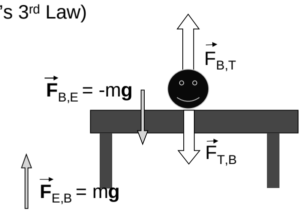
Certain forces act to keep an object in place.
These have what ever force needed to balance all others (until a breaking point).



Main goal at this point : Identify force pairs and apply Newton's third law

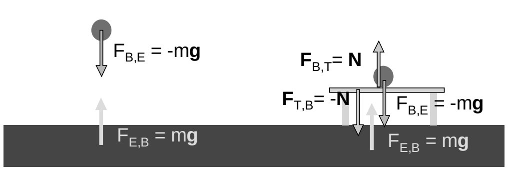
Force Pairs

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)



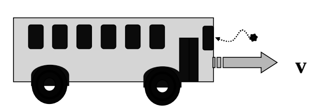
Example

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



Lecture 10, *Exercise 1*
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,

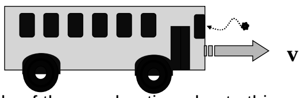
- ✗ A. greater than
- ✓ B. equal to
- ✗ C. less than

that exerted by the fly on the bus.

Lecture 10, *Exercise 2*
Newton's Third Law

Same scenario but now we examine the accelerations

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



The magnitude of the acceleration, due to this collision, of the bus is

- ✗ A. greater than
- ✗ B. equal to
- ✓ C. less than

that of the fly.

Lecture 10, *Exercises 2*
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 $\mathbf{a} = \mathbf{F}_{net}/m$.

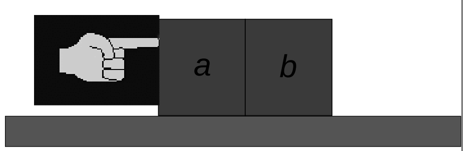
So $\mathbf{F}_{b,f} = -\mathbf{F}_{f,b} = \mathbf{F}_0$

but $|\mathbf{a}_{bus}| = |\mathbf{F}_0 / m_{bus}| \ll |\mathbf{a}_{fly}| = |\mathbf{F}_0/m_{fly}|$

Answer for acceleration is (C)

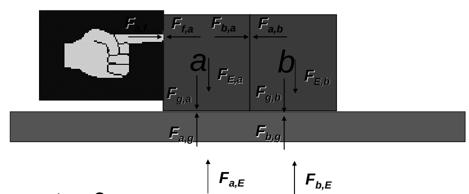
Lecture 10, *Exercise 3*
Newton's 3rd Law

- 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
- ✗ D. Something else

Lecture 10, *Exercise 3*
Solution:



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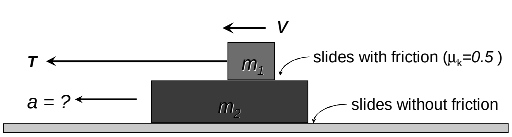
Lecture 10, *Example*
Friction and Motion

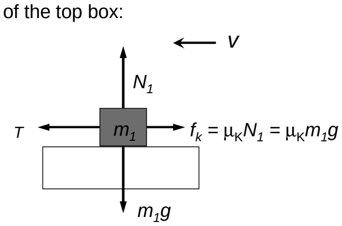
- A box of mass $m_1 = 1$ kg is being pulled by a horizontal string having tension $T = 40$ N. It slides with friction ($\mu_k = 0.5$) on top of a second box having mass $m_2 = 2$ kg, which in turn slides on a smooth (frictionless) surface.
  - ❖ What is the acceleration of the second box ?
  - ❖ But first, what is force on mass 2?

(A) a = 0 N (B) a = 5 N (C) a = 20 N (D) can't tell



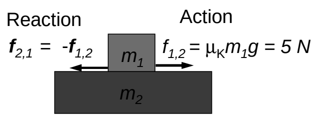
Lecture 10, *Example*
Solution

- First draw FBD of the top box:



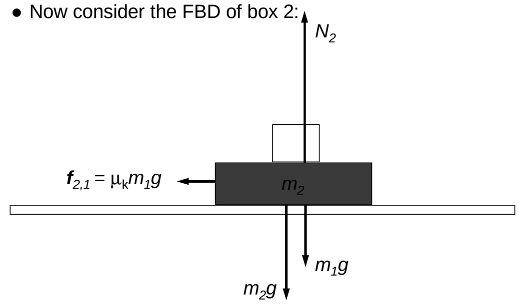
Lecture 10, *Example*
Solution

- Newtons 3rd law says the force *box 2 exerts on box 1* is equal and opposite to the force *box 1 exerts on box 2*.
  - As we just saw, this force is due to friction:



Lecture 10, *Example*
Solution

- Now consider the FBD of box 2:

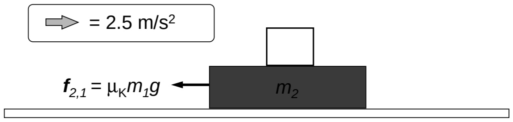


Lecture 10, *Example*
Solution

- Finally, solve $F_x = ma$ in the horizontal direction:

$\Rightarrow$ $\mu_K m_1 g = m_2 a$ $\Rightarrow$ $a = \dfrac{m_1 \mu_k g}{m_2} = \dfrac{5\ \text{N}}{2\ \text{kg}}$

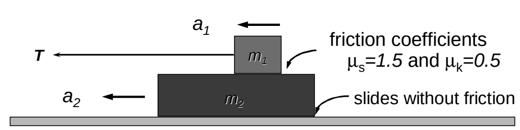
$\Rightarrow$ = 2.5 m/s^2



Lecture 10, *Example*
Friction and Motion, Replay

- A box of mass $m_1 = 1\ kg$, initially at rest, is now pulled by a horizontal string having tension $T = 10\ N$. This box (1) is on top of a second box of mass $m_2 = 2\ kg$. The static and kinetic coefficients of friction between the 2 boxes are $\mu_s = 1.5$ and $\mu_k = 0.5$. The second box can slide freely (frictionless) on an smooth surface.

Compare the acceleration of box 1 to the acceleration of box 2 ?

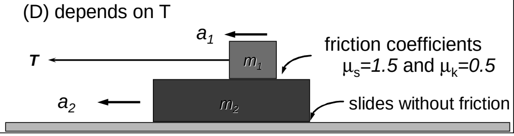


Lecture 10, *Example*
Friction and Motion, Replay in the static case

- A box of mass $m_1 = 1\ kg$, initially at rest, is now pulled by a horizontal string having tension $T = 10\ N$. This box (1) is on top of a second box of mass $m_2 = 2\ kg$. The static and kinetic coefficients of friction between the 2 boxes are $\mu_s = 1.5$ and $\mu_k = 0.5$. The second box can slide freely on an smooth surface (frictionless).

If there is no slippage then maximum frictional force between 1 & 2 is

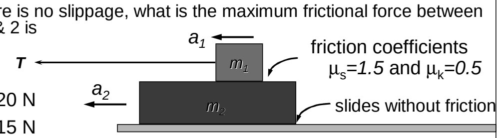
(A) 20 N
(B) 15 N
(C) 5 N
(D) depends on T



Lecture 10, *Exercise 4*
Friction and Motion, Replay in the static case

- A box of mass $m_1 = 1\ kg$, initially at rest, is now pulled by a horizontal string having tension $T = 10\ N$. This box (1) is on top of a second box of mass $m_2 = 2\ kg$. The static and kinetic coefficients of friction between the 2 boxes are $\mu_s = 1.5$ and $\mu_k = 0.5$. The second box can slide freely on an smooth surface (frictionless).

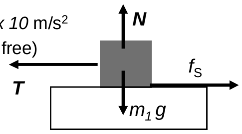
If there is no slippage, what is the maximum frictional force between 1 & 2 is



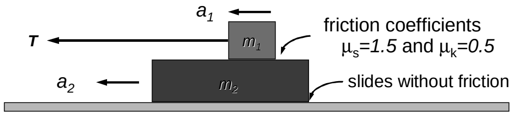
A. 20 N
B. 15 N
C. 5 N
D. depends on T

Lecture 10, *Exercise 4*
Friction and Motion

$f_S \le \mu_S N = \mu_S m_1 g = 1.5 \times 1$ kg x 10 m/s^2
which is 15 N (so m_2 can't break free)



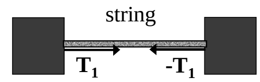
f_s = 10 N and the acceleration of box 1 is
Acceleration of box 2 equals that of box 1, with $|a| = |T| / (m_1+m_2)$ and the frictional force f is $m_2 a$
(Notice that if T were raised to 15 N then it would break free)



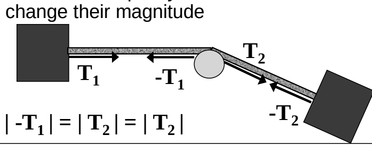
Moving forces around

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

Newton's 3rd of action/reaction to justifies



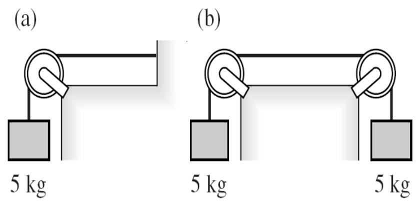
- Massless, frictionless pulleys: Reorient force direction but do not change their magnitude



$| T_1 | = | -T_1 | = | T_2 | = | T_2 |$

Lecture 10, *Exercise 5*
Tension example

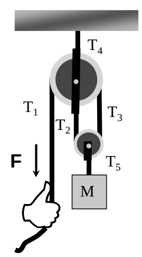
Compare the strings below in settings (a) and (b) and their tensions.



- ✗ A. $T_a = ½ T_b$
- ✗ B. $T_a = 2 T_b$
- ✗ C. $T_a = T_b$
- ✗ D. Correct answer is not given

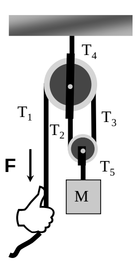
Example with pulley

- A mass M is held in place by a force **F**. Find the tension in each segment of the rope and the magnitude of **F**.
  - ❖ Assume the pulleys are massless and frictionless.
  - ❖ Assume the rope is massless.
- The action of a massless frictionless pulley is to change the direction of a tension.



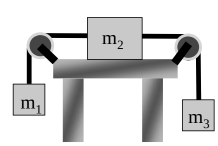
Example with pulley

- A mass M is held in place by a force **F**. Find the tension in each segment of the rope and the magnitude of **F**.
  - ❖ Assume the pulleys are massless and frictionless.
  - ❖ Assume the rope is massless.
- The action of a massless frictionless pulley is to change the direction of a tension.
- Here $F = T_1 = T_2 = T_3$
- Equilibrium means Σ **F** = 0 for x, y & z
- For example: y-dir ma = 0 = $T_2 + T_3 - T_5$ and ma = 0 = $T_5 - Mg$
- So $T_5 = Mg = T_2 + T_3 = 2F \rightarrow T = Mg/2$



Example
Another setting

Three blocks are connected on the table as shown. The table has a coefficient of kinetic friction of μ_K=0.40, the masses are m_1 = 4.0 kg, m_2 = 1.0 kg and m_3 = 2.0 kg.

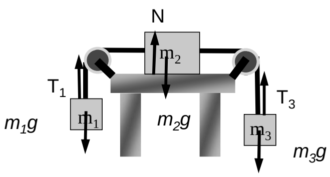


(A) What is the magnitude and direction of acceleration on the three blocks ?

(B) What is the tension on the two cords ?

Another example with a pulley

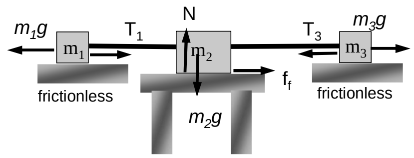
Three blocks are connected on the table as shown. The table has a coefficient of kinetic friction of μ_K=0.40, the masses are m_1 = 4.0 kg, m_2 = 1.0 kg and m_3 = 2.0 kg.



(A) FBD (except for friction)
(B) So what about friction ?

Problem recast as 1D motion

Three blocks are connected on the table as shown. The center table has a coefficient of kinetic friction of μ_K=0.40, the masses are m_1 = 4.0 kg, m_2 = 1.0 kg and m_3 = 2.0 kg.



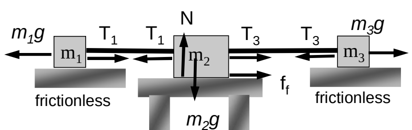
$m_1g > m_3g$ and $m_1g > (\mu_k m_2g + m_3g)$

and friction opposes motion (starting with v = 0)

so f_f is to the right and a is to the left (negative)

Problem recast as 1D motion

Three blocks are connected on the table as shown. The center table has a coefficient of kinetic friction of μ_K=0.40, the masses are m_1 = 4.0 kg, m_2 = 1.0 kg and m_3 = 2.0 kg.



x-dir: 1. $\Sigma F_x = m_2a = \mu_k m_2g - T_1 + T_3$

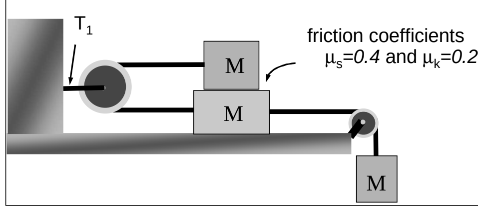
$m_3a = m_3g - T_3$

$m_1a = -m_1g + T_1$

Add all three: $(m_1 + m_2 + m_3)\, a = \mu_k m_2g + m_3g - m_1g$

Another example with friction and pulley

- Three 1 kg masses are connected by two strings as shown below. There is friction, , between the stacked masses but the table top is frictionless.
- Assume the pulleys are massless and frictionless.
- What is T_1 ?



Physics 207, Lecture 10, Oct. 8

Assignment:

- MP Problem Set 4A due Oct. 10,Wednesday, 11:59 PM
- For Wednesday, read Chapter 9 (Impulse and Momentum)
- MP Problem Set 5 (Chapters 8 & 9) available soon