Physics 207 – Lecture 10

### 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, \( \mathbf{F}_{\text{NET}} = \sum \mathbf{F} = m\mathbf{a} \)

**Law 3:** Forces occur in pairs, \( \mathbf{F}_{A \rightarrow B} = -\mathbf{F}_{B \rightarrow A} \)

(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.

\[ \sum \mathbf{F} = \mathbf{F}_{\text{NET}} = m\mathbf{a} \]

- This expression is vector expression: \( \mathbf{F}_x, \mathbf{F}_y, \mathbf{F}_z \)

- 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 (\( \mathbf{F}_{1 \rightarrow 2} \)) then object 2 exerts an equal and opposite force on object 1 (\( \mathbf{F}_{2 \rightarrow 1} \))

\[ \mathbf{F}_{1 \rightarrow 2} = -\mathbf{F}_{2 \rightarrow 1} \]

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

Consider the following two cases (a falling ball and ball on table),
Compare and contrast Free Body Diagram and
Action-Reaction Force Pair sketch

Normal Forces

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

Normal forces

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)

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.

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,
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, 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, 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 ($\mu = 0.5$) 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, 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 $F_{\text{net}} = ma$ or $a = F_{\text{net}}/m$.
So $F_{a,b} = F_{b,a}$
but $|a_{\text{bus}}| = |F_{b,a}/m_{\text{bus}}| < \epsilon \Rightarrow |a_{\text{fly}}| = |F_{a,b}/m_{\text{fly}}|

Answer for acceleration is (C)

Lecture 10, Example
Solution
- First draw FBD of the top box:

\[
\begin{align*}
T & \quad V \\
F_{\text{f,friction}} & \quad m_1 \quad N_1 \\
\mu_1 N_1 & \quad m_1 g \\
\mu_0 N & \quad \text{slides with friction ($\mu = 0.5$)} \\
\mu_0 N & \quad \text{slides without friction}
\end{align*}
\]
Lecture 10, Example

Solution

- Newton's 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:

\[ f_{1,2} = -f_{2,1} \]

\[ f_{1,2} = \mu_k m_1 g = 5 \text{ N} \]

Action

Reaction

Lecture 10, Example

Solution

- Finally, solve \( F_x = ma \) in the horizontal direction:

\[ m_2 f_{2,1} = \mu_k m_1 g \]

\[ \Rightarrow a = \frac{m_1 g}{m_2} = \frac{5 \text{ N}}{2 \text{ kg}} = 2.5 \text{ m/s}^2 \]

Lecture 10, Example

Friction and Motion, Replay

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

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

friction coefficients \( \mu_s = 1.5 \) and \( \mu_k = 0.5 \)

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

\( T = 10 \text{ N} \) and the acceleration of box 1 is
\( a = |T|/\left(m_1 + m_2\right) \)

(Notice that if \( T \) were raised to 15 N then it would break free)

\( f_s = \mu_s N \leq 1.5 \times 1 \text{ kg} \times 10 \text{ m/s}^2 \)
which is 15 N (so \( m_2 \) can't break free)

\( \mu_s = 1.5 \) and \( \mu_k = 0.5 \)

slides without friction

Lecture 10, Exercise 5

Tension example

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

(a) \( T_a = 1/2 T_b \)
(b) \( T_a = 2 T_b \)
(c) \( T_a = T_b \)
(d) Correct answer is not given

Example with pulley

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

Three blocks are connected on the table as shown. The table has a coefficient of friction of \( \mu = 0.40 \), the masses are \( m_1 = 4.0 \text{ kg} \), \( m_2 = 1.0 \text{ kg} \) and \( m_3 = 2.0 \text{ kg} \).

(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 $\mu_k=0.40$, the masses are $m_1=4.0 \text{ kg}$, $m_2=1.0 \text{ kg}$ and $m_3=2.0 \text{ kg}$.

(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 $\mu_k=0.40$, the masses are $m_1=4.0 \text{ kg}$, $m_2=1.0 \text{ kg}$ and $m_3=2.0 \text{ kg}$.

$mg > m_2g$ and $m_3g > (\mu_k m_2 g + m_3 g)$
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 $\mu_k=0.40$, the masses are $m_1=4.0 \text{ kg}$, $m_2=1.0 \text{ kg}$ and $m_3=2.0 \text{ kg}$.

$x$-dir: 1. $\sum F_x = m_2 a = \mu_k m_2 g - T_1 + T_3$

$m_3 a = m_3 g - T_3$

$m_1 a = -m_1 g + T_1$

Add all three: $(m_1 + m_2 + m_3) a = \mu_k m_2 g + m_3 g - m_1 g$

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