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.

\[ \sum F = F_{\text{NET}} = ma \]

- This expression is a vector expression: \( F_x, F_y, F_z \)
- Units:
  - The metric unit of force is kg \( \text{m/s}^2 \) = 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/s²

No net force \( \Rightarrow \) No acceleration

\[ \sum F = \vec{F}_{\text{NET}} = ma = 0 \]
\[ \sum F_x = 0 \]
\[ \sum F_y = 0 \]

(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 the 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. \( P + C = W \)

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Lecture 5, Example
Gravity and Normal Forces
A woman in an elevator is accelerating upwards

\[ \sum F = -mg + N = ma \]
\[ N = mg + ma = m(g + a) \]

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

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Important notes

- Contact forces are conditional, they are not necessarily constant
- The SI units of force are Newtons with 1 N= 1 kg m/s²

Now recall

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

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Lecture 5, Exercise 2
Elevator physics
A 100 kg or 1000 N person (\( g = 10 \text{ m/s}² \)) 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

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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

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

**Free Body Diagram**

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

Horizontal:
- \( T \cos \theta = \text{constant} \)
- \( T \sin \theta = \text{constant} \)

Vertical:
- \( m g - T \sin \theta = \text{constant} \)
- \( T \cos \theta = \text{constant} \)

**Moving forces around**

- Massless, inflexible strings: Translate forces and reverse their direction but do not change their magnitude (we really need Newton’s 3rd law to justify this).
- Massless, frictionless pulleys: Reorient force direction but do not change their magnitude.

**Lecture 5, Exercise 4**

**A rope trick**

- You are going to pull two blocks (\( m_1 = 4 \text{ kg} \) and \( m_2 = 6 \text{ kg} \)) at constant acceleration (\( a = 2.5 \text{ m/s}^2 \)) on a horizontal frictionless floor, as shown below.
- The rope connecting the two blocks can stand tension of only \( T_{\text{max}} = 9.0 \text{ N} \). Would the rope break?
- Step 1: How many FBDs would you draw:
  - (A) 0
  - (B) 1
  - (C) 2
  - (D) 3

- You are going to pull two blocks (\( m_1 = 4 \text{ kg} \) and \( m_2 = 6 \text{ kg} \)) at constant acceleration (\( a = 2.5 \text{ m/s}^2 \)) on a horizontal frictionless floor, as shown below.
- The rope connecting the two blocks can stand tension of only \( T_{\text{max}} = 9.0 \text{ N} \). Would the rope break?
- How many FBDs would you draw? (There is no “correct” answer.)

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**Lecture 5, Exercise 5**

**A rope trick**

- For A, N T
- For B, N -T

- Would the rope break?
  - A. yes
  - B. no
  - C. can’t tell

4 kg rope 6 kg force body diagrams.

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- \(a = 2.5 \text{ m/s}^2\)
- \(T_{\text{max}} = 9.0 \text{ N}\)

**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/s²).

- 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 fish scale.

- What force does the fish scale now read?

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**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 hanging mass
  - One around the massless pulley (even though massless we can treat as an “object”)
  - One around the scale

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

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**Scale Problem**

- \(\sum F_y = 0\) in all cases
- Note: W is scale weight
  - 1: \(0 = -2T + T'\)
  - 2: \(0 = T - mg\) \(\Rightarrow T = mg\)
  - 3: \(0 = T' - W - T'\) (not useful here)
- Substituting 2 into 1 yields \(T' = 2mg = 20 \text{ N}\)
  - (We start with 10 N but end with 20 N)

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**Lecture 5 Recap, Sept. 19**

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

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**Frictionless inclined plane...**

- Use a FBD and consider \(x\) and \(y\) components separately:
  - \(F_x: m_a = mg \sin \theta \quad \Rightarrow \quad a_x = g \sin \theta\)
  - \(F_y: m_a = 0 = N - mg \cos \theta \quad \Rightarrow \quad \vec{N} = mg \cos \theta\)
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Angles of the inclined plane

\[ \theta + \varphi = 90^\circ \]

Forces at different angles

Case 1: Downward angled force with friction
Case 2: Upwards angled force with friction
Cases 3, 4: Up against the wall

Questions:
- What happens to the normal force?
- What happens to the frictional force?

Forces at different angles

Case 1: 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?

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?

\[ \frac{50}{2} = 25 \text{ s} \]
\[ \frac{50}{1} = 50 \text{ s} \]
\[ \frac{50}{\sqrt{3}} = 29 \text{ s} \]
\[ \frac{50}{\sqrt{2}} = 35 \text{ s} \]

Solution

The time taken to swim straight across is \( \frac{\text{distance across}}{\text{v}_y} \). 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 \((\mu > 0)\) and given a brief push. It motion thereafter is down the plane with a constant speed.

If a similar block (same \(\mu\)) 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

\[ F_{\text{TOT,x}} = 2mg \sin \theta - \mu N = ma = 0 \] (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 \( \sqrt{3} \) m/s
- The time to get across is \( \frac{50 \text{ m}}{\sqrt{3} \text{ m/s}} = 29 \text{ s} \)

Answer (c)