Physics 207, Lecture 7, Sept. 25

Agenda:
- Chapter 5 (Forces and Newton’s Laws)
  - Static Friction
  - Problem exercise
- Chapter 6 (Circular Motion and Other Applications)
  - Kinetic friction (friction force)
  - Friction (a constant force that opposes motion)
  - Uniform and non-uniform circular motion
  - Accelerated Frames
  - Resistive Forces

Assignment:
- WebAssign Problem Set 3 due Tuesday midnight
- MidTerm Thursday, Oct. 5, Chapters 1-6, 90 minutes, 7-8:45 PM
- NOTE: Assigned Rooms are 105 and 113 Psychology

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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)

\[ F_{\text{APPLIED}} - F_{\text{FRICTION}} = m_a \]

\[ \mu_k mg = \mu_k N \]

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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 \( |F_f| \) is proportional to the magnitude of the normal force \( |N| \): \( |F_f| = \mu_k |N| \) ( \( \mu_k \) is the coefficient of kinetic friction).
- The constant \( \mu_k \) is called the “coefficient of kinetic friction”.
- Depending on the other forces speed may increase or decrease

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Case study ...

- Dynamics:
  - x-axis: \( m_a x = F - \mu_k N \)
  - y-axis: \( m_a y = 0 = N - mg \) or \( N = mg \)

\[ F = \mu_k mg = m a \]

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Lecture 7, Example 1

Friction and Motion

- A box of mass \( m_1 = 1 \) kg is being pulled by a horizontal string having tension \( T = 30 \) 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 an ice rink (frictionless). Let \( g = 10 \) m/s²

- What is the acceleration of the second box?
  1. Focus first on the top block
  2. Find frictional force and use action/reaction force pairs
  3. Then discuss the second block

\[ a = 0 \text{ m/s}^2 \]  \( \Rightarrow \) \( m_1 = 1 \text{ kg} \)
\[ a = 2.5 \text{ m/s}^2 \]  \( \Rightarrow \) \( m_2 \) and \( \mu_k = 0.5 \)
\[ a = 10 \text{ m/s}^2 \]  \( \Rightarrow \) \( m_2 \) and \( \mu_k = 0.5 \)

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Lecture 7, Exercise 1

Solution

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

\[ \mu_k m_1 g = \frac{m_1}{m_2} g = \frac{1 \text{ kg}}{2 \text{ kg}} \times 0.5 \times 10 \text{ m/s}^2 \]

\[ = 2.5 \text{ m/s}^2 \text{ to the left} \]

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Lecture 7, Exercise 2

Incline 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 $2m$ 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

Solution

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

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

$$ma = 0 \quad \text{(case when just } m)$$

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

Speed will still be constant!

(C)

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 general there is a second parameter, the coefficient of static friction or $\mu_S$.
- In these cases, the force provided by friction depends on the forces applied to the system (with $f_s \leq \mu_S N$)
- Opposes motion (i.e., acceleration) that would occur if $\mu_S$ were zero

While the block is static: $f_s = F_{net}$ (unlike kinetic friction)

$f_s$ is NOT fixed in magnitude

The maximum possible force that the friction between two objects can provide is $F_{MAX} = \mu_S N$, where $\mu_S$ is the “coefficient of static friction”.

$\mu_S \leq \mu_N$.

As one increases $F$, $f_s$ gets bigger until $f_s = \mu_S N$ and the object “breaks loose” and starts to move.

$\mu_S$ is discovered by increasing $F$ until the block starts to slide:

$$F_{MAX} - \mu_S N = 0$$

$$N = mg$$

$\mu_S = F_{MAX}/mg$

Active Figure
Additional comments on Friction:

- Since \( f = \mu N \), the force of friction does not depend on the area of the surfaces in contact (this is not strictly true, for example narrow tires reduce rolling resistance).
- Logic dictates that \( \mu_s > \mu_k \) for any system.

Coefficients of Friction

<table>
<thead>
<tr>
<th>Material on Material</th>
<th>( \mu_s ) – static friction</th>
<th>( \mu_k ) – kinetic friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel / steel</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>add grease to steel</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>metal / ice</td>
<td>0.022</td>
<td>0.02</td>
</tr>
<tr>
<td>brake lining / iron</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>tire / dry pavement</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>tire / wet pavement</td>
<td>0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Lecture 7, Exercise 3

Friction and Motion

A box of mass \( m_1 = 1 \text{ kg} \), initially at rest, is now pulled by a horizontal string having tension \( T = 30 \text{ N} \). 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 2 boxes are \( \mu_s = 3.5 \) and \( \mu_k = 0.5 \). The second box can slide freely (frictionless) on an ice rink surface.

The acceleration of box 1 is

(A) Greater than

(B) Equal to

(C) Smaller than

the acceleration of box 2?

Newton’s Laws and Circular Motion

(Chapter 6)

Centripetal Acceleration

\[ a_c = \frac{v^2}{R} \]

What is Centripetal Force?

\[ F_C = m a_c = m \frac{v^2}{R} \]

Animation

Applications

- Mass based separations:
  - Centrifuges
  - Mass Spectroscopy

How many g’s?

- \( a = \frac{v^2}{r} \) and \( f = 10^4 \text{ rpm} \) is typical with \( r = 0.1 \text{ m} \) and \( v = 2 \pi f r \)
- \( v = (2 \pi \times 10^4 / 60) \times 0.1 \text{ m/s} = 100 \text{ m/s} \)
- \( a_c = 1 \times 10^4 / 0.1 \text{ m/s}^2 = 10 000 \text{ g’s} \)

Lecture 7, Example 4

Circular Motion Forces with Friction

(recall \( m a_c = m \frac{v^2}{R} \) \( F_i \leq \mu N \))

- How fast can the race car go? (How fast can it round a corner with this radius of curvature?)
  - \( m_{car} = 1600 \text{ kg} \)
  - \( \mu_s = 0.5 \text{ for tire/road} \)
  - \( R = 80 \text{ m} \)
  - \( g = 10 \text{ m/s}^2 \)

(A) 10 m/s

(B) 20 m/s

(C) 75 m/s

(D) 750 m/s
Banked Corners

In the previous scenario, we drew the following free body diagram for a race car going around a curve on a flat track.

For very small banking angles, one can approximate that \( F_f \) is parallel to \( m_a \). This is equivalent to the small angle approximation \( \sin \theta = \tan \theta \).

Banked Corners

Free Body Diagram for a banked curve. Use rotated x-y coordinates. Resolve into components parallel and perpendicular to bank.

Non uniform Circular Motion

Earlier we saw that for an object moving in a circle with non uniform speed then \( a = a_r + a_t \) (radial and tangential).

What are \( F_r \) and \( F_t \) ?\( m_a \) and \( m_a t \).

Lecture 7, Example 5
Gravity, Normal Forces etc.

Consider a women on a swing:

When is the tension on the rope largest? And is it:
(A) greater than (B) the same as (C) less than the force due to gravity acting on the woman.

Loop-the-loop 1

A match box car is going to do a loop-the-loop of radius \( r \). What must be its minimum speed, \( v \), at the top so that it can manage the loop successfully?

To navigate the top of the circle its tangential velocity, \( v \), must be such that its centripetal acceleration at least equals the force due to gravity. At this point \( N \), the normal force, goes to zero.

\[
F_c = -ma = -mg = -\frac{mv^2}{r}
\]

\[
v = (gr)^{1/2}
\]
The match box car is going to do a loop the loop. If the speed at the bottom is \( v_B \), what is the normal force, \( N \), at that point?

Hint: The car is constrained to the track.

You are a passenger in a car and not wearing your seatbelt. Without increasing or decreasing speed, the car makes a sharp left turn, and you find yourself colliding with the right-hand door. Which is a correct description of the situation?

(A) Before and after the collision there is a rightward force pushing you into the door.
(B) Starting at the time of the collision, the door exerts a leftward force on you.
(C) Both of the above.
(D) Neither of the above.

Air Resistance and Drag

- So far we’ve “neglected air resistance” in physics
- Can be difficult to deal with
- Affects projectile motion
- Friction force opposes velocity through medium
- Imposes horizontal force, additional vertical forces
- Terminal velocity for falling objects
- Dominant energy drain on cars, bicyclists, planes
- This issue has been with us a very long time....

Recapping

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