Physics 207, Lecture 7, Sept. 25

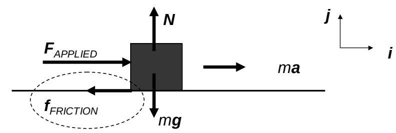
Agenda:
- Chapter 5 (Forces and Newton's Laws)
  - ❖ Static Friction
  - ❖ Problem exercise
- Chapter 6 (Circular Motion and Other Applications)
  - ❖ Friction (a external force that opposes motion)
  - ❖ Uniform and non-uniform circular motion
  - ❖ Accelerated Frames
  - ❖ Resistive Forces

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

See text: 5.8

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)!



See text: 6-1

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 $|f_K|$ is proportional to the magnitude of the normal force $|N|$.
  - ❖ $|f_K| = \mu_K |N|$ ($= \mu_K |mg|$ in the previous example)
  - ❖ The "heavier" something is, the greater the frictional force
- The constant μ_K is called the "coefficient of kinetic friction".
- Depending on the other forces speed may increase or decrease

See text: 6-1

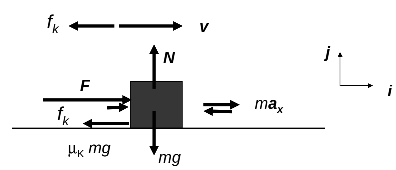
Case study ...

- Dynamics:

x-axis *i* : $ma_x = F - \mu_K N$

y-axis *j* : $ma_y = 0 = N - mg$ or $N = mg$

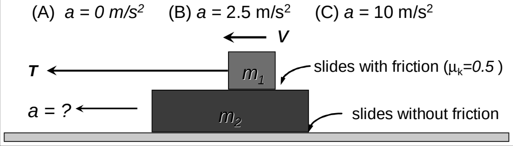
so $F - \mu_K mg = m\,a_x$



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) $a = 0$ m/s² (B) $a = 2.5$ m/s² (C) $a = 10$ m/s²

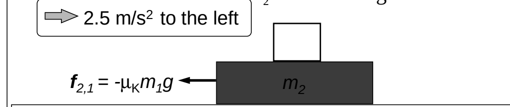


Lecture 7, *Exercise 1*
Solution

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

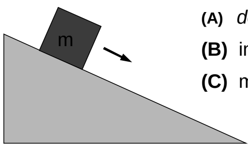
$$\Rightarrow -\mu_K m_1 g = m_2 a \Rightarrow a = \frac{-m_1}{m_2}\mu_K g = \frac{-1\,\text{kg}}{2\,\text{kg}} \text{ x } 0.5 \text{ x} 10 \text{ m/s}^2$$

⇒ 2.5 m/s² to the left



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 μ) 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

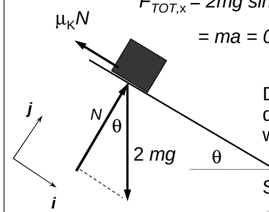
(C) move with constant speed

Lecture 7, *Exercise 2*
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 !

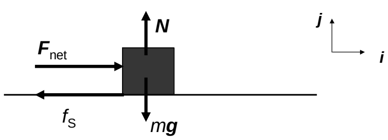
Speed will still be constant !

(C)

See text: Ch 5.8

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 μ_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 μ_S were zero



See text: Ch 5.8

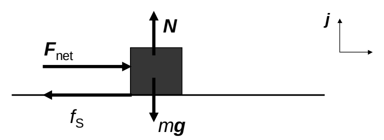
Static Friction...

- Opposes motion except here $a = 0$ is the constaint

  i : $F_{net} - f_S = 0$

  j : $N = mg$

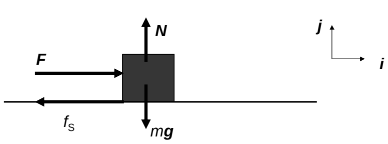
- While the block is static: $f_S = F_{net}$ *(unlike kinetic friction)*
- f_s is NOT fixed in magnitude



See text: Ch 5.8

Static Friction...

- The maximum possible force that the friction between two objects can provide is $f_{MAX} = \mu_S N$, where μ_s is the "coefficient of static friction".
  - ❖So $f_S \leq \mu_S N$.
  - ❖As one increases F, f_S gets bigger until $f_S = \mu_S N$ and the object "breaks loose" and starts to move.



See text: Ch 5.8

Static Friction...

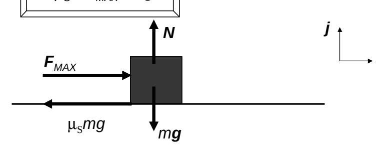
- μ_S is discovered by increasing ***F*** until the block starts to slide:

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

  j : $N = mg$

$\mu_S = F_{MAX} / mg$

Active Figure



See text: 6-1

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

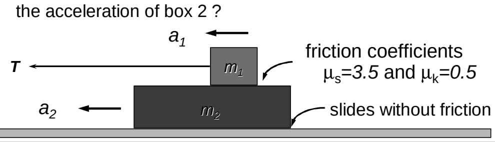
Coefficients of Friction

Material on Material	μ_s = static friction	μ_k = kinetic friction
steel / steel	0.6	0.4
add grease to steel	0.1	0.05
metal / ice	0.022	0.02
brake lining / iron	0.4	0.3
tire / dry pavement	0.9	0.8
tire / wet pavement	0.8	0.7

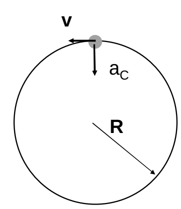
Lecture 7, *Exercise 3*
Friction and Motion

- A box of mass $m_1 = 1$ kg, initially at rest, is now pulled by a horizontal string having tension $T = 30$ 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 $\mu_s = 3.5$ 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)



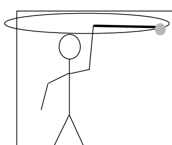
Centripedal Acceleration
$a_C = v^2/R$

What is Centripedal Force ?

$F_C = ma_C = mv^2/R$

Animation

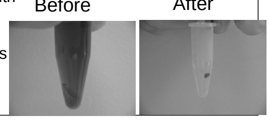
Applications



- Mass based separations:
  - Centrifuges
  - Mass Spectroscopy

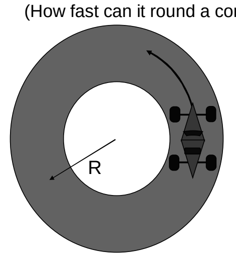
How many *g*'s?
$a_c = v^2 / r$ and $f = 10^4$ rpm is typical with
$r = 0.1$ m
and $v = \omega r = 2\pi f r$
$v = (2\pi \times 10^4 / 60) \times 0.1$ m/s =100 m/s
$a_c = 1 \times 10^4 / 0.1$ m/s^2 = 10 000 g's

Before After



Lecture 7, *Example 4*
Circular Motion Forces with Friction
(recall $ma_C = m v^2 / R$ $F_f \le \mu_s N$)

- How fast can the race car go ?
  (How fast can it round a corner with this radius of curvature?)

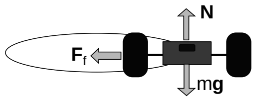


m_{car}= 1600 kg
μ_S = 0.5 for tire/road
R = 80 m
g = 10 m/s^2

(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.



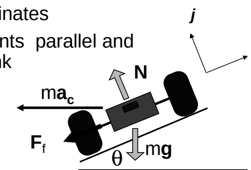
What differs on a banked curve ?

Banked Corners

Free Body Diagram for a banked curve.

Use rotated x-y coordinates

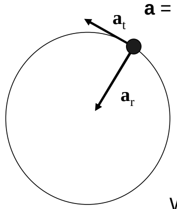
Resolve into components parallel and perpendicular to bank



For very small banking angles, one can approximate that $\mathbf{F}_f$ is parallel to m**a**. This is equivalent to the small angle approximation sin θ = tan θ.

Non uniform Circular Motion

Earlier we saw that for an object moving in a circle with non uniform speed then $\mathbf{a} = \mathbf{a}_r + \mathbf{a}_t$ (radial and tangential)



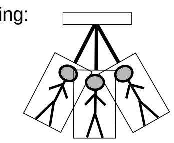
$$a_r = \frac{v^2}{r}$$

$$a_\theta = \frac{d|\vec{v}|}{dt}$$

What are F_r and F_t ?
ma_r and ma_t

Lecture 7, Example 5
Gravity, Normal Forces etc.

Consider a women on a swing:



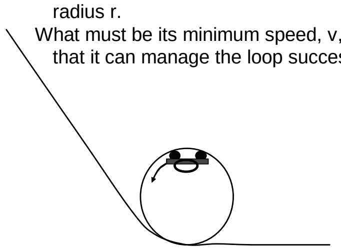
Active Figure

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 ?

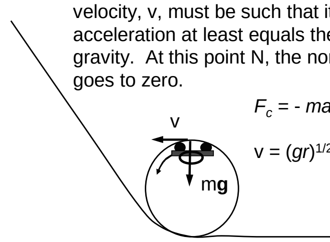


Loop-the-loop 1

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.

$F_c = - ma = - mg = - mv^2/r$

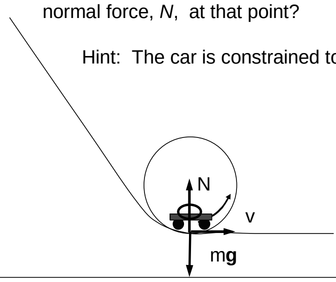
$v = (gr)^{1/2}$



Loop-the-loop 3

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.



Lecture 7, *Example 7*
Accelerated Reference Frames

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

Agenda:

- Chapter 5 (Forces and Newton's Laws)
  - ❖ Static Friction
  - ❖ Problem exercise
- Chapter 6 (Circular Motion and Other Applications)
  - ❖ Friction (a external force that opposes motion)
  - ❖ Uniform and non-uniform circular motion
  - ❖ Accelerated Frames
  - ❖ Resistive Forces

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