Physics 207, Lecture 8, Oct. 2

Agenda:

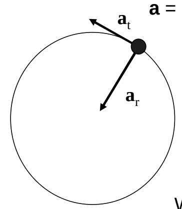
- Chapter 6 (Circular Motion and Other Applications)
  - ❖ Uniform and non-uniform circular motion
  - ❖ Accelerated Frames
  - ❖ Resistive Forces
- Problem Solving and Review for MidTerm I

Assignment:

- WebAssign Problem Set 3 due Oct. 3, Tuesday 11:59 PM
- MidTerm Thurs., Oct. 5, Chapters 1-6, 90 minutes, 7:15-8:45 PM
- NOTE: Assigned Rooms are 105 and 113 Psychology

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)



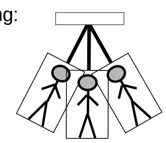
$$a_r = \frac{v^2}{r}$$

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

What are F_r and F_t ?
ma_r and ma_t

Example
Gravity, Normal Forces etc.

Consider a person on a swing:



Active Figure

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

Lecture 8, *Exercise 1*
Gravity, Normal Forces etc.

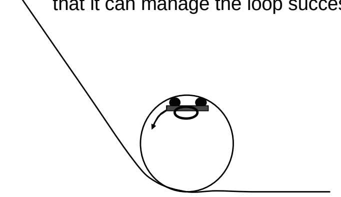
$F_c = m\,0^2 / r = 0 = T - mg \cos\theta$
$F_T = m\,a_T = mg \sin\theta$

$F_c = m\,a_c = m\,v^2 / r = T - mg$
$T = mg + m\,v^2 / r$

At the bottom of the swings and is it (A) greater than the force due to gravity acting on the person

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 ?

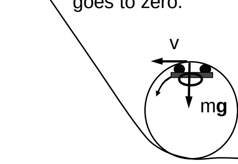


Loop-the-loop 1

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.

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

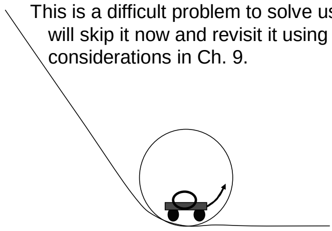
$v = (gr)^{1/2}$



Loop-the-loop 2

Once again the the box car is going to execute a loop-the-loop. What must be its minimum speed at the bottom so that it can make the loop successfully?

This is a difficult problem to solve using just forces. We will skip it now and revisit it using energy considerations in Ch. 9.



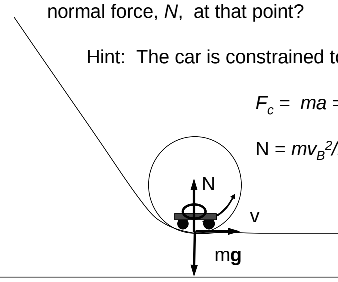
Loop-the-loop 3

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.

$F_c = ma = mv_B^2/r = N - mg$

$N = mv_B^2/r + mg$

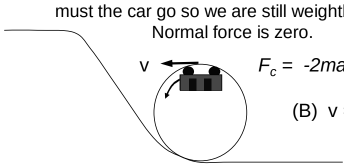


Lecture 8, *Exercise 2*
Non uniform Circular Motion

We construct a roller coaster designed so that when one rider alone becomes weightless at the top and has a speed v_1.

Now two additional passenger get in so that the total weight of the car (at rest) and people doubles. How fast must the car go so we are still weightless at the top ?

Normal force is zero.



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

(B) $v = (gr)^{1/2} = v_1$

(A) 1/2 v_1 (B) v_1 (C) 2 v_1 (D) 4 v_1

See text: 6-3

Accelerated Reference Frames: The Accelerometer

- Your first job is with Ford. You are working on a project to design an accelerometer. The inner workings of this gadget consist of a weight of mass m that is hung inside a box that is attached to the ceiling of a car. You design the device with a very light string so that you can mathematically ignore it. The idea is that the angle the string makes with the vertical, θ, is determined by the car's acceleration. Your preliminary task is to think about calibration of the accelerometer when the car travels on a flat road.

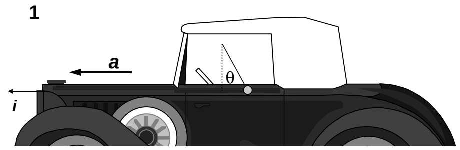
What is the car's acceleration a when the hanging mass makes an angle θ with the vertical?

See example 6-9: Train Car

See text: 6-3

Accelerated Reference Frames: The Accelerometer

1

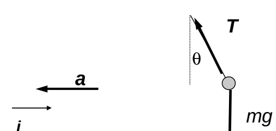


We need to solve for the angle the plum bob makes with respect to vertical.

We will solve by using Newton's Second Law and checking x and y components.

See text: 6-3

Accelerated Reference Frames: The Accelerometer



x-dir $F_x = -ma = -T \sin\theta$

y-dir $F_y = 0 = T\cos\theta - mg$

$T = mg / \cos\theta$

$a = T \sin\theta / m = g \tan\theta$

Lecture 8, *Exercise 3*
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.

Lecture 7, *Exercise 3*
Accelerated Reference Frames

Newton's first law says that you will continue to travel with a constant velocity as long as there are no forces acting on you. This is also known as inertia.

As you try to continue to travel straight, you collide with the car door which is starting to accelerate leftward. This contact force forces your body to accelerate and turn with the car.

(B) Starting at the time of the collision, the door exerts a leftward force on you.

Active Figure

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 a very long time….

Aristotle's Laws of Motion

- Aristotle was the first to think *quantitatively* about the speeds involved in these movements. He made two quantitative assertions about how things fall (natural motion):

1. Heavier things fall faster, the speed being proportional to the weight.
2. The final speed during the fall of a given object depends *inversely* on the density of the medium it is falling through, so, for example, the same body will fall twice as fast through a medium of half the density.

Asserted that the natural state of an object was at rest.

These observations were based on casual observations but never rigorously tested.

- In most biological systems (at the microscopic level) drag, viscous forces and Browning motion dominate. Newtonian mechanics, as described so far, will have little impact. Inertia is often irrelevant.

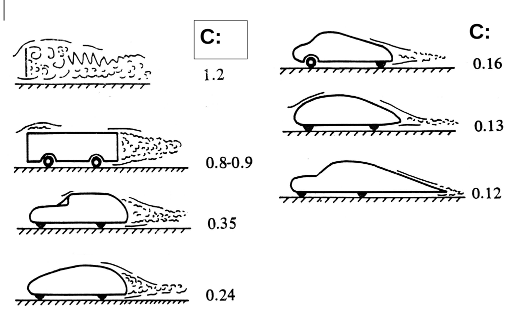
Drag Force Quantified

- With a cross sectional area, *A* (in m^2), coefficient of drag of 1.0 (most objects), sea-level density of air, and velocity, *v* (m/s), the drag force is:

  $D = (1/2)\, C\, \rho A\, v^2$ in Newtons

  When D equals mg then at terminal velocity
- Example: Bicycling at 10 m/s (22 m.p.h.), with projected area of 0.5 m^2 exerts ~30 Newtons
  - ❖ Requires (*F v*) of *power* $\rightarrow$ 300 Watts to maintain speed
  - ❖ Minimizing drag is often important

Air Drag in Auto Design:
$D = (1/2)\, C\, \rho\, A\, v^2$



"Free" Fall

- Terminal velocity reached when $F_{drag} = F_{grav}$ (= mg)
- For 75 kg person subtending 0.5 m^2,

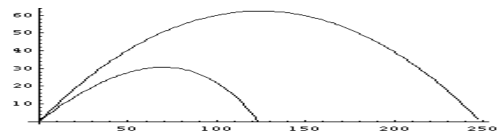
  $v_{terminal} \approx$ 50 m/s, or 110 m.p.h.

  which is reached in about 5 seconds, over 125 m of fall
  - Actually takes slightly longer, because acceleration is reduced from the nominal 9.8 m/s^2 as you begin to encounter drag
- Free fall only lasts a small number of seconds, even for skydivers

And just a few days ago: French Surgeons Claim Zero-Gravity Surgery a Success

Trajectories with Air Resistance

- Baseball launched at 45° with v = 50 m/s:
  - ❖ Without air resistance, reaches about 63 m high, 254 m range
  - ❖ With air resistance, about 31 m high, 122 m range



Vacuum trajectory *vs.* air trajectory for 45° launch angle.

Recapping

Agenda:

- 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:

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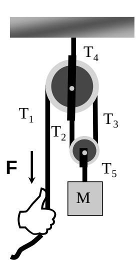
Problem solving…

Example with pulley

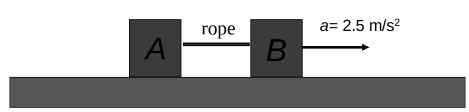
- A mass M is held in place by a force **F**. Find the tension in each segment of the rope and the magnitude of **F**.
  - ❖ Assume the pulleys are massless and frictionless.
  - ❖ Assume the rope is massless.
- The action of a massless frictionless pulley is to change the direction of a tension.
- Here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

  Answer: |F| = *Mg/2 (exercise for home)*



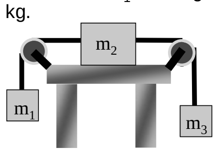
Lecture 8, *Exercise 4*

- You are going to pull two blocks (m_A=4 kg and m_B=6 kg) at constant acceleration (a= 2.5 m/s^2) on a horizontal frictionless floor, as shown below. The rope connecting the two blocks can stand tension of only 9.0 N. Would the rope break ?
- (A) YES (B) CAN'T TELL (C) NO



Example
Problem 5.40 from Serway

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 ?