Physics 101 Lecture 4: Kinematics
Projectile and Circular Motion

Announcements

- James Scholars should get their HCLAs done. All source articles need to be approved by me. All papers/talks need to include a quantitative component. (See course web site for details)
- Clicker scores are up-to-date. Make sure you are getting grades for lecture clicker scores and if not, register your clicker (appropriately) in grade book.
- I attempted to upload the flipit grades to gradebook (the prelecture, checkpoint, and homework grades and something went wrong. We will fix it sometime this week. Please don't email me saying that your grades are wrong in these categories.

Review: 1-dimensional Kinematics Example

- A car is traveling 30 m/s and applies its brakes (constant negative acceleration) to stop after traveling 150 m.
- How fast is the car going after it has traveled ½ the distance (75 meters) ?

A) $v < 15$ m/s B) $v = 15$ m/s C) $v > 15$ m/s

Let's think about a plan for solving this problem

Plan:

1. First use kinematics to find acceleration from first bullet's information
2. Use kinematics again to find speed at $x = 75$ m

Review: 1-dimensional Kinematics Example

- Solution will be discussed in this slide in lecture

Ready for motion in 2D

Important Concepts for Motion in 2 Dimensions

- X and Y directions are **independent**!
- Position, velocity and acceleration are vectors (they have directions and magnitudes)
- Vectors and vector equations are worked out component-by-component

Kinematics in Two Dimensions: Equations and Facts

Must be able to identify variables in these equations!

• $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2$	• $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$
• $v_x = v_{0x} + a_x t$	• $v_y = v_{0y} + a_y t$
• ${v_x}^2 = {v_{0x}}^2 + 2a_x \Delta x$	• ${v_y}^2 = {v_{0y}}^2 + 2a_y \Delta y$

Remember: x and y directions are *independent*.

Independent means:

Calculate the x-direction by itself and
the y-direction by itself, then use math to combine if needed

Demo: Ball shot vertically from moving train

This demo illustrates the independence of x and y motion.

Projectile Motion: Clicker Q— Throwing a Ball at an Angle

A ball is thrown with a speed of 40 m/s at a 30^{o} angle to the horizontal.

What is the speed of the ball when it returns to exactly the same height from which it was thrown?

[Neglect air resistance]

A. More than 40 m/s
B. Less than 40 m/s
C. Exactly 40 m/s

Projectile Motion: A Special Case

$a_x = 0$	$a_y = -g$
➢ $x = x_0 + v_{0x}\,t$	➢ $y = y_0 + v_{0y}\,t - ½\,gt^2$
➢ $v_x = v_{0x}$	➢ $v_y = v_{0y} - g\,t$
	➢ $v_y^{\,2} = v_{0y}^{\,2} - 2g\Delta y$

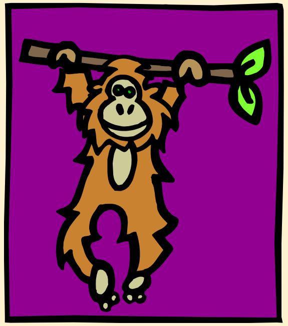
- *Procedure*:
  - Choose standard coordinate system (that's how + and – are determined)
  - Solve kinematics equations in each direction separately.
  - As time evolves, motion in each direction proceeds independently

Monkey Clicker Q

You are a vet trying to shoot a tranquilizer dart into a monkey hanging from a branch in a distant tree.

You know that the monkey is very nervous, and will let go of the branch and start to fall as soon as your gun goes off.

In order to hit the monkey with the dart, where should you point the shooting?



1 Right at the monkey

2 Below the monkey

3 Above the monkey

Demo: Shooting the Monkey...

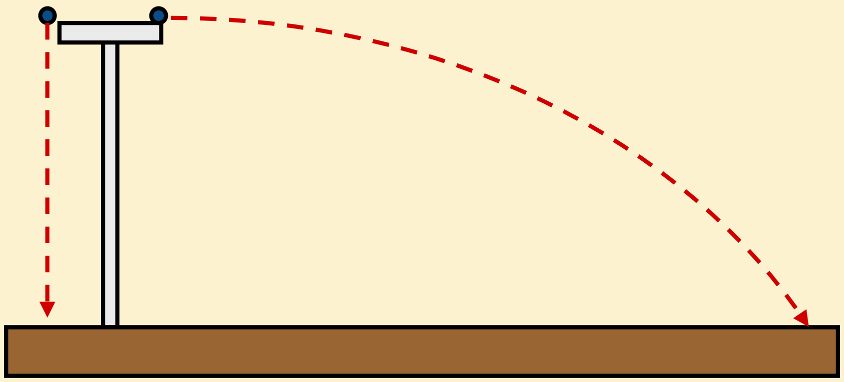
Demo: Projectile Motion Clicker Q and Checkpoint 3

One marble is pushed thus given an initial horizontal velocity, the other simply dropped. Which marble hits the ground first? (Look familiar?)

A) dropped

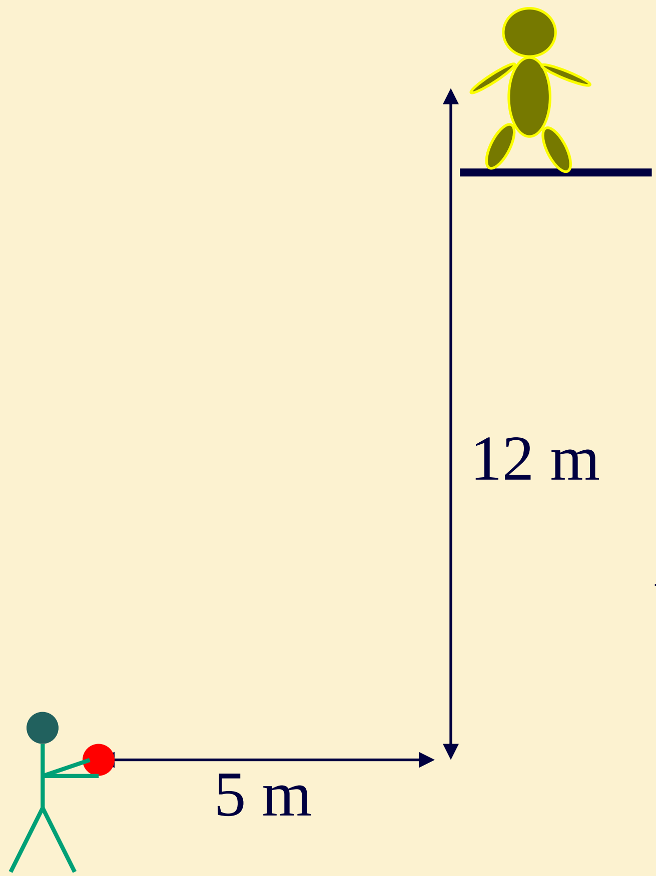
B) pushed

C) They both hit the ground at the same time



Ex: Throw ball to your friend at a window

You throw a ball to your friend at a window of a building 12 meters above and 5 meters to the right of you. Determine the speed and angle you should throw it such that the ball "just reaches" your friend moving at 0 speed in y-direction.



y-direction (v_{0y})

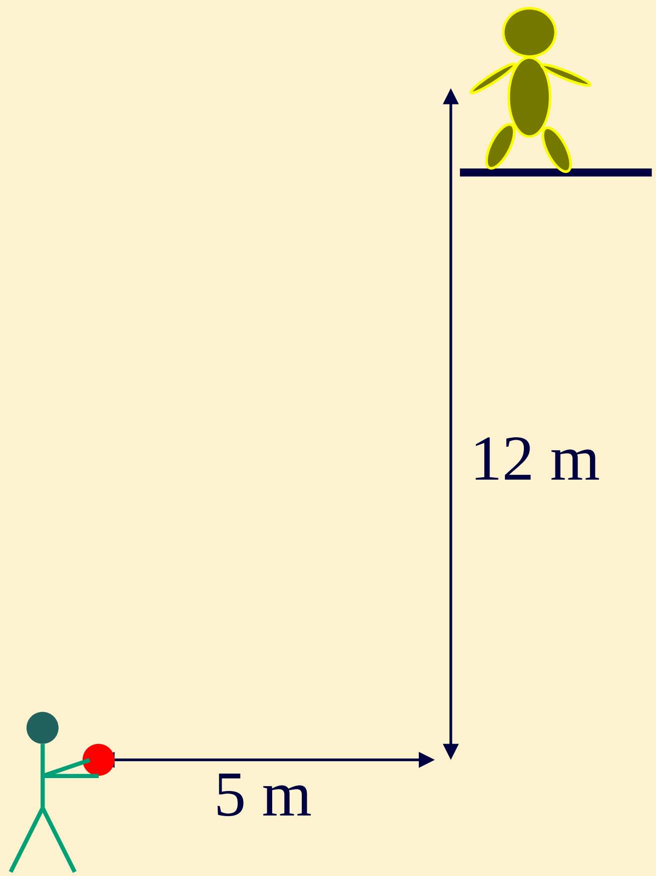
$v_{fy}{}^2 = v_{0y}{}^2 + 2(-g)\Delta y$, with $v_{fy}=0$

$v_{0y} = \sqrt{2 \times 9.8 \times 12} = 15.3\ m/s$

The reason why $v_{fy}=0$ is that the vertical velocity when ball gets to your friend is 0 m/s.

Ex: Throw ball to your friend at a window

You throw a ball to your friend at a window of a building 12 meters above and 5 meters to the right of you. Determine the speed and angle you should throw it such that the ball "just reaches" your friend moving at 0 speed in y-direction.



x-direction (v_{0x}):

First find the time it takes ball to get to your friend (this is a *y-direction question*):

$v_{fy} = v_{0y} - gt$, with $v_{fy} = 0$

$t = v_{0y}/g = (15.3 \text{ m/s})/g = 1.56$ s.

Then use the time to find the required horizontal velocity (*x-direction question*):

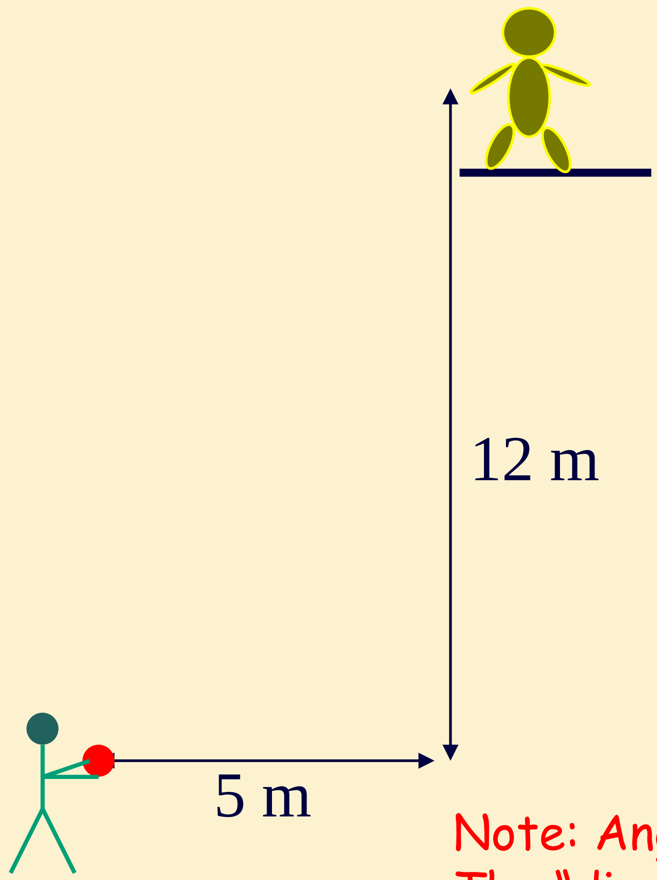
$x = xo + v_{ox}t + ½a_xt^2$ (x_o=0, x=5m, a_x=0)

$v_{ox} = 5\,m \,/\, 1.56$ s

$= 3.2$ m/s

Ex: Throw ball to your friend at a window

You throw a ball to your friend at a window of a building 12 meters above and 5 meters to the right of you. Determine the speed and angle you should throw it such that the ball "just reaches" your friend moving at 0 speed in y-direction.



Speed and Angle:

First use the x- and y-direction velocities you calculated to find the angle for the *initial velocity vector*:

$$\alpha = \tan^{-1}\frac{v_{0y}}{v_{0x}} = \tan^{-1}\frac{15.3\ m/s}{3.2\ m/s} = 78.2°$$

Then use these values to find the magnitude (speed) of the initial velocity vector (Pythagorean Thm):

$$|v| = \sqrt{v_{0_x}^2 + v_{0_y}^2} = \sqrt{3.2^2 + 15.3^2} = 15.6\ m/s$$

Note: Angle is not the same as throwing directly to your friend. The "direct" angle is 63.4°.

Projectile Motion: Summary

- Velocity, position, and acceleration are vectors
  - ➔They have *both* magnitude and direction
  - ➔Magnitude of a vector called “A”: $|A| = \sqrt{A_x^2 + A_y^2}$
  - ➔Vector direction (described by angle): $\theta = \tan^{-1}\frac{A_y}{A_x}$
- x- and y-directions are *independent*
- Kinematic Equations for 2-D: *Must be able to identify variables in these equations!*

• $x = x_0 + v_{0x}\,t + \frac{1}{2}\,a_x t^2$	• $y = y_0 + v_{0y}\,t + \frac{1}{2}\,a_y t^2$
• $v_x = v_{0_x} + a_x t$	• $v_y = v_{0_y} + a_y t$
• ${v_x}^2 = {v_{0x}}^2 + 2a_x\Delta x$	• ${v_y}^2 = {v_{0y}}^2 + 2a_y\Delta y$

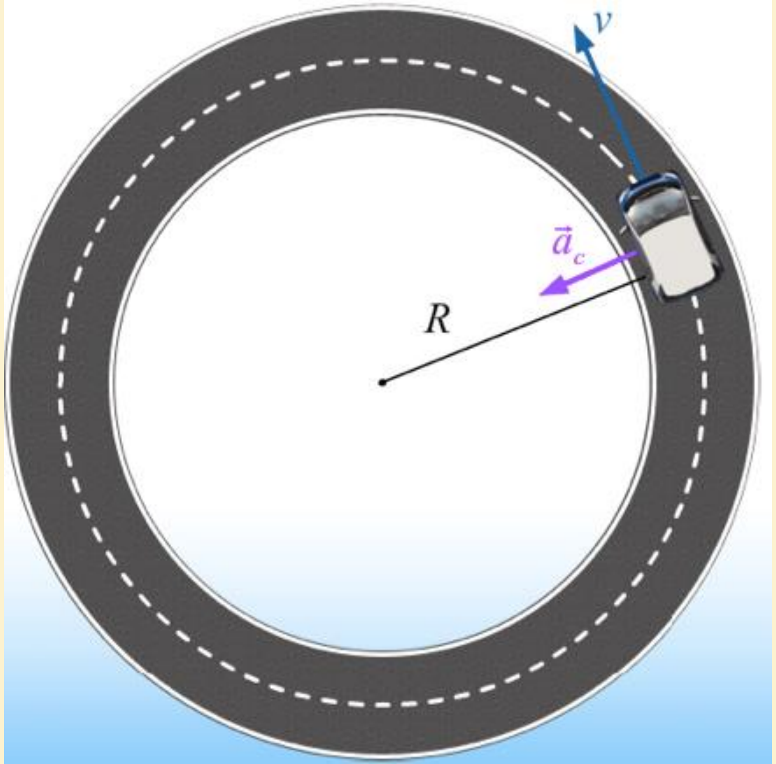
- *Projectile Motion*: a special case where $a_x = 0$ and $a_y = -g$

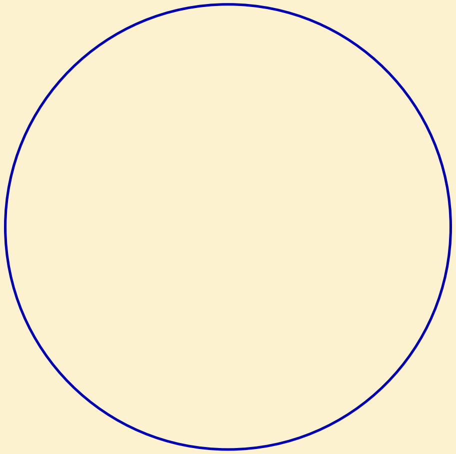
Motion in a Circle with Constant Speed: Uniform circular motion

(Here "uniform" means "constant speed")

- If an object moves ***with constant speed v*** in a perfect circle of radius r then:
  - ➔ Its velocity vector is constantly changing direction (though its speed is constant). As a result, it must be ***accelerating***.
  - ➔ The magnitude of the object's acceleration is $a = v^2/r$ and is directed *towards the* ***center of the circle***. *(Centripetal Acceleration)*
- Unless the acceleration is v^2/r, the motion will not be circular with constant speed.
- Note: A car *could* also have a "tangential acceleration" a_t in addition to it centripetal acceleration (if it speeds up or slows down). That would NOT be uniform circular motion.

Demos: Consider the wine glass on a plate, water in bucket…

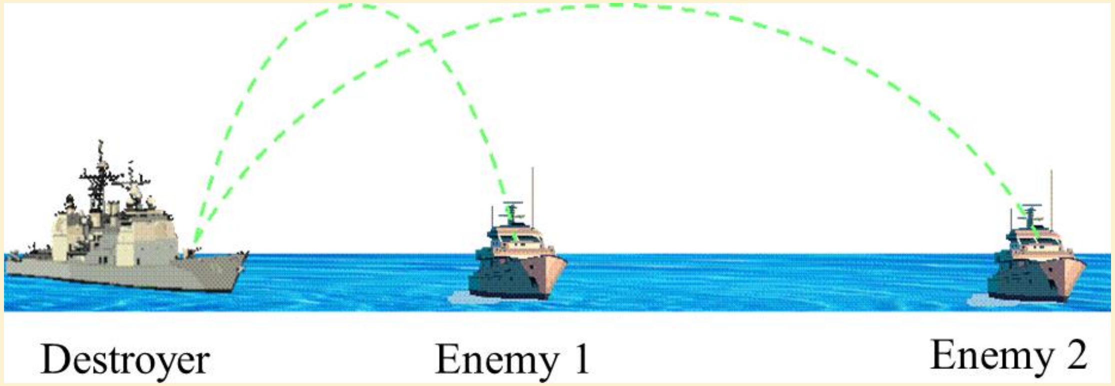




Checkpoint 2

A destroyer simultaneously fires two shells with different initial speeds at two different enemy ships. The shells follow the parabolic trajectories shown. Which ship gets hit first?

a) Enemy 1   b) Enemy 2   c) Both ships are hit at the same time



Summary of Concepts

- Projectile Motion
  - Kinematic Equations for 2-D: *Must be able to identify variables in these equations!*

• $x = x_0 + v_{0x}\,t + \frac{1}{2}\,a_x t^2$	• $y = y_0 + v_{0y}\,t + \frac{1}{2}\,a_y t^2$
• $v_x = v_{0_x} + a_x t$	• $v_y = v_{0_y} + a_y t$
• $v_x{}^2 = v_{0x}{}^2 + 2a_x \Delta x$	• $v_y{}^2 = v_{0y}{}^2 + 2a_y\,\Delta y$

  - *Projectile Motion*: special case where $a_x = 0$ and $a_y = g$

- Uniform Circular Motion
  - Speed is constant
  - Direction is changing
  - Acceleration toward center $a_c = v^2 / r$, and $a_t = 0$