

# Physics 111 - Class 4A

## 2D and 3D Motion I

September 26, 2022

# Class Outline

- Logistics / Announcements
- Test 1 Reflection
- Introduction to Chapter 4
- Clicker Questions
- Activity: Worked Problem

# Logistics/Announcements

- Remember: No Labs this week!
  - Friday is a holiday: Truth & Reconciliation Day (LL04 will be about this)
- HW4 due this week on Thursday at 6 PM
- Learning Log 4 due on Saturday at 6 PM
- HW and LL deadlines have a 48 hour grace period
- No Tests this week! 🎉

# Test 1 Reflection

# Test 1 Reflection

- Preface
- ▼ Mechanics
  - ▶ 1 Units and Measurement
  - ▶ 2 Vectors
  - ▼ 3 Motion Along a Straight Line
    - Introduction**
    - 3.1 Position, Displacement, and Average Velocity
    - 3.2 Instantaneous Velocity and Speed
    - 3.3 Average and Instantaneous Acceleration
    - 3.4 Motion with Constant Acceleration
    - 3.5 Free Fall
    - 3.6 Finding Velocity and Displacement from Acceleration
- ▼ Chapter Review
  - Key Terms
  - Key Equations
  - Summary
  - Conceptual Questions
  - Problems
  - Additional Problems
  - Challenge Problems

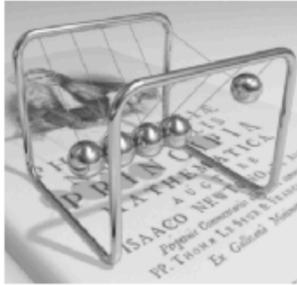


**Figure 3.1** A JR Central L0 series five-car maglev (magnetic levitation) train undergoing a test run on the Yamanashi Test Track. The maglev train's motion can be described using kinematics, the subject of this chapter. (credit: modification of work by "Maryland GovPics"/Flickr)

## Chapter Outline

- [3.1 Position, Displacement, and Average Velocity](#)
- [3.2 Instantaneous Velocity and Speed](#)
- [3.3 Average and Instantaneous Acceleration](#)
- [3.4 Motion with Constant Acceleration](#)
- [3.5 Free Fall](#)
- [3.6 Finding Velocity and Displacement from Acceleration](#)

Our universe is full of objects in motion. From the stars, planets, and galaxies; to the motion of people and animals; down to the microscopic scale of atoms and molecules—everything in our universe is in motion. We can describe motion using the two disciplines of kinematics and dynamics. We study dynamics, which is concerned with the causes of motion, in [Newton's Laws of Motion](#); but, there is much to be learned about motion without referring to what causes it, and this is the study of kinematics. Kinematics involves describing motion through properties such



## Physics 111

Search this book...

Unsyllabus

### ABOUT THIS COURSE

Course Syllabus (Official)

Course Schedule

Accommodations

How to do well in this course

### GETTING STARTED

Before the Term starts

After the first class

In the first week

Week 1 - Introductions!

### PART 1 - KINEMATICS

Week 2 - Chapter 2

Week 3 - Chapter 3

**Week 4 - Chapter 4**

Readings

**Videos**

Homework

Week 2 Classes

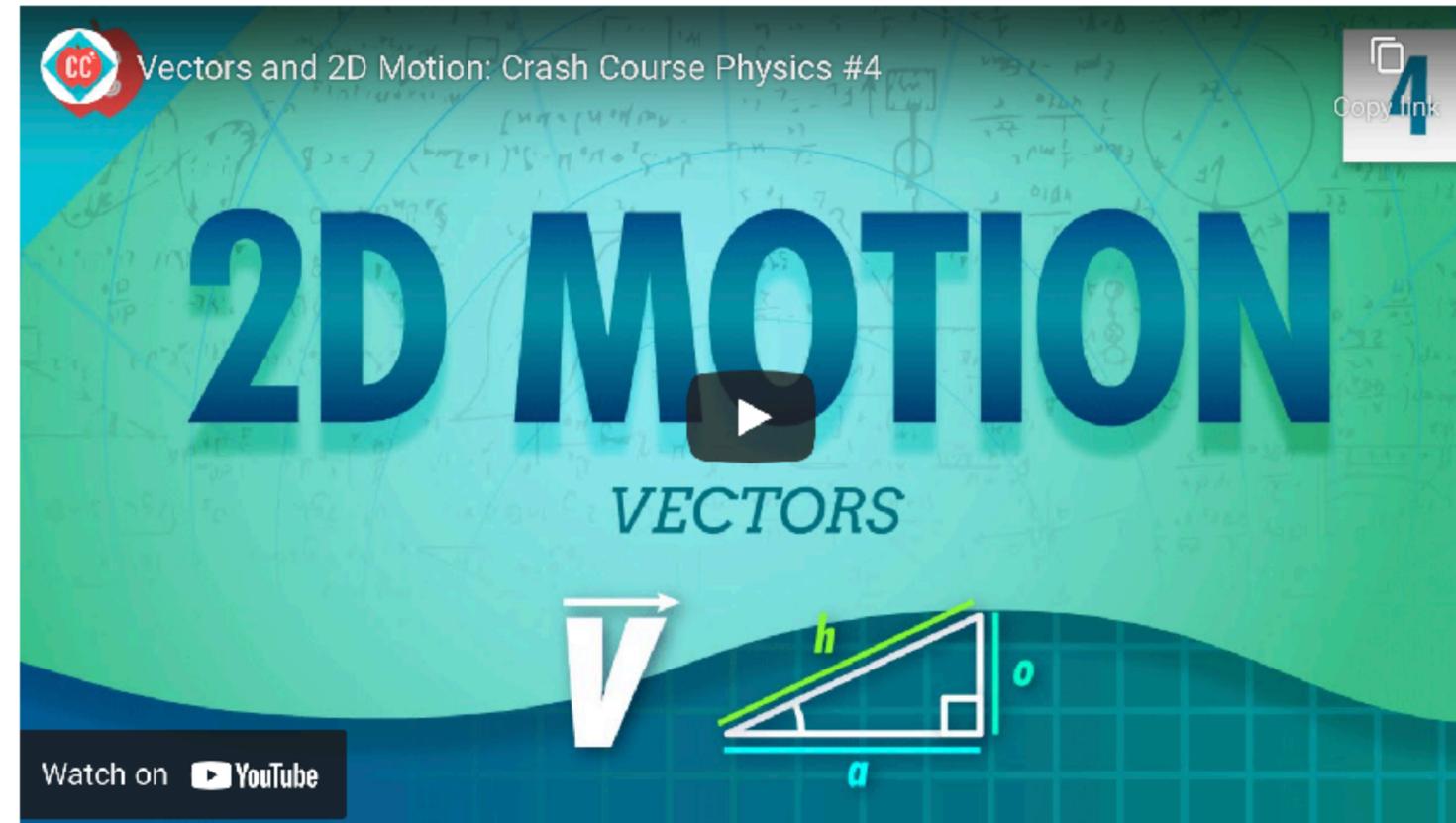
Bonus Test 01

## Videos

Below are the assigned videos for this week. The videos are collapsible so once you're done with one, you can move to the next one. In the sidebar on the right, you can use the checklists to keep track of what's done.

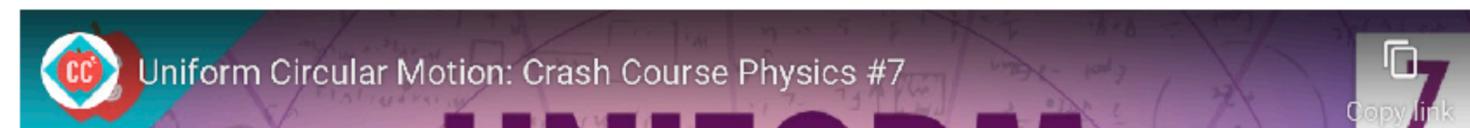
## Content Summary from Crash Course Physics

### 2D Motion



The video on uniform circular motion mentions forces - this we will cover in Chapter 5.

### Uniform Circular Motion



Contents

- Content Summary from Crash Course Physics
- Videos
- Optional Videos
- Additional examples (Optional)

### Checklist of items

- CrashCourse Physics I - 2D Motion
- CrashCourse Physics I - Uniform Circular Motion
- Video 1 - Introduction to Projectile Motion
- Video 4 - Nerd-A-Pult - An Introductory Projectile Motion Problem
- Video 7 - Understanding the Range Equation of Projectile Motion
- Video 12 - A Projectile Motion Problem using Unit Vectors
- Video 16 - Introduction to Relative Motion using a Quadcopter Drone

# Conventions for Motion in 1D, 2D, 3D

$$x = x(t) \quad y = y(t) \quad z = z(t)$$

$$\vec{\mathbf{r}} = x(t)\hat{\mathbf{i}} + y(t)\hat{\mathbf{j}} + z(t)\hat{\mathbf{k}}$$

$$\vec{\mathbf{v}} = \frac{d}{dt} \vec{\mathbf{r}} = v_x(t)\hat{\mathbf{i}} + v_y(t)\hat{\mathbf{j}} + v_z(t)\hat{\mathbf{k}}$$

$$\vec{\mathbf{a}} = \frac{d^2}{dt^2} \vec{\mathbf{r}} = a_x(t)\hat{\mathbf{i}} + a_y(t)\hat{\mathbf{j}} + a_z(t)\hat{\mathbf{k}}$$

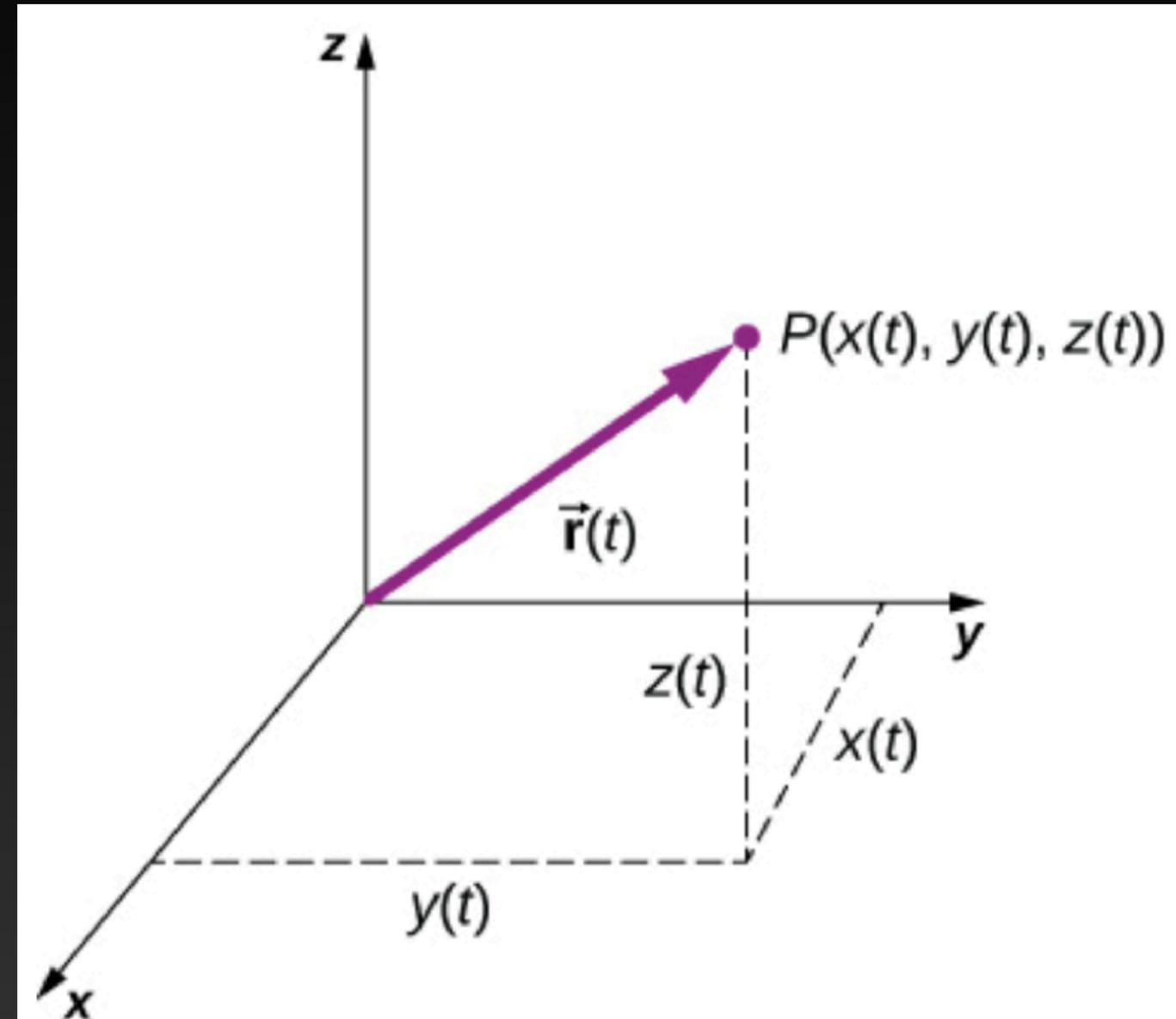
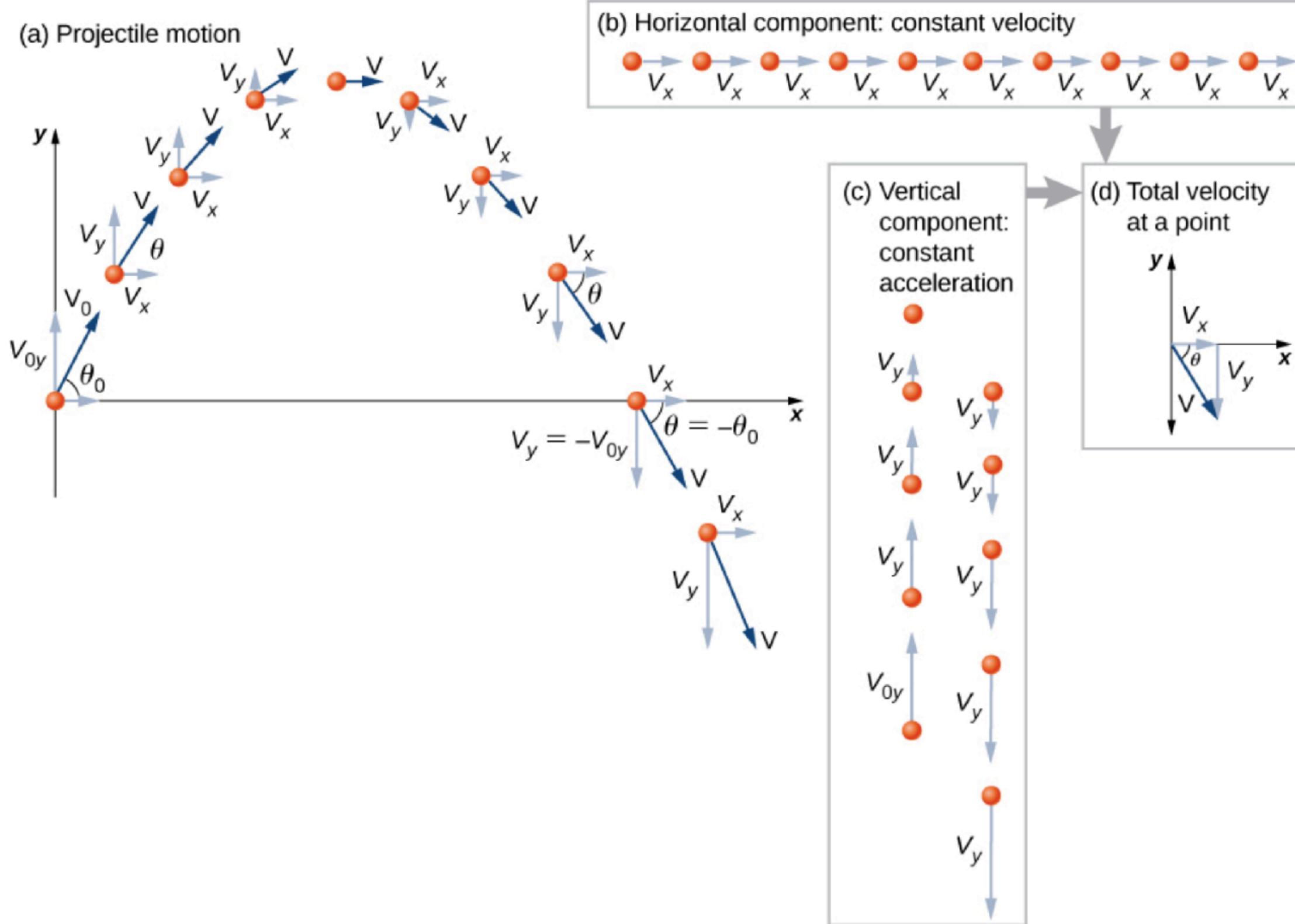


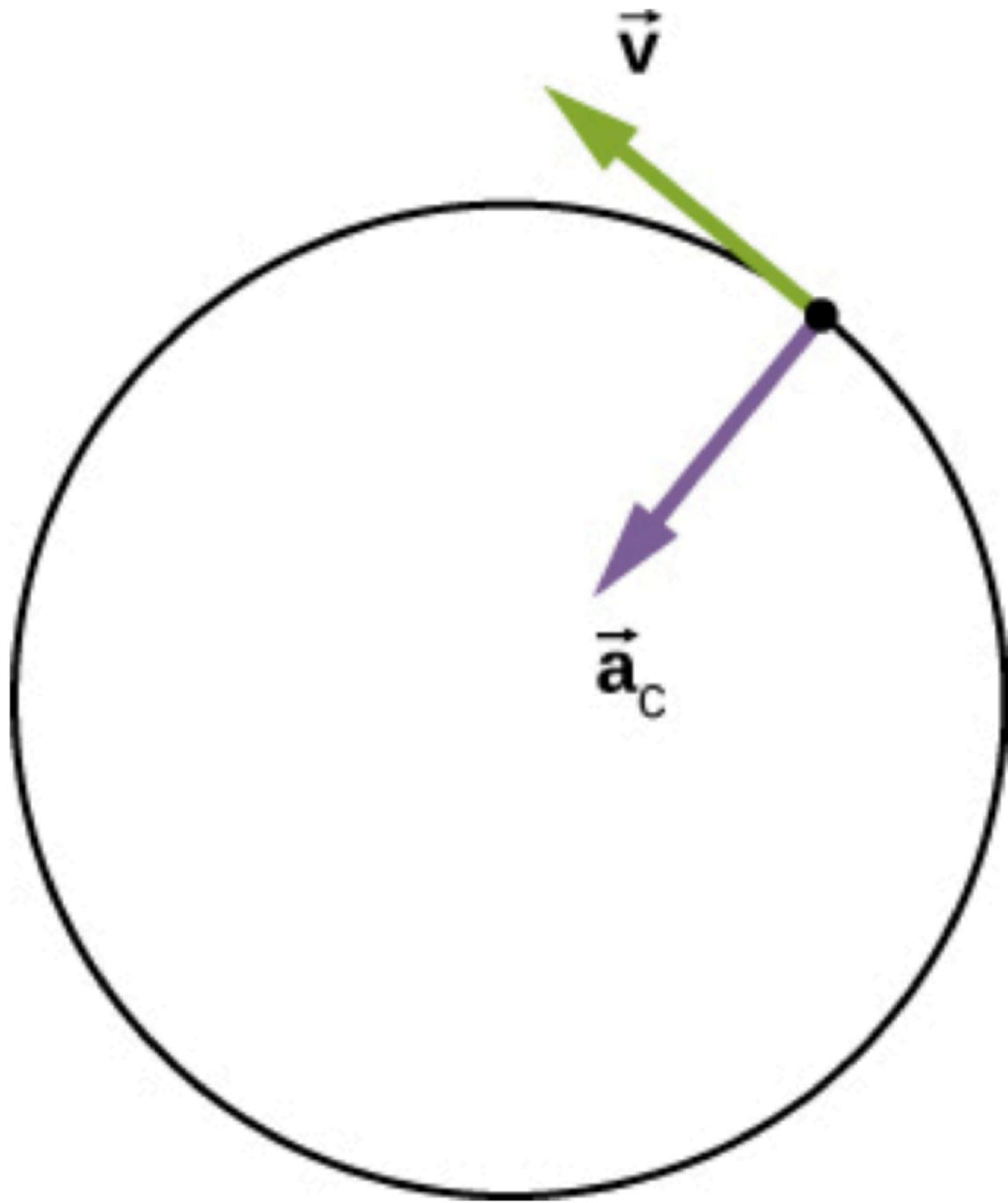
Figure 4.2 A three-dimensional coordinate system with a particle at position  $P(x(t), y(t), z(t))$ .

# Projectile Motion



**Figure 4.12** (a) We analyze two-dimensional projectile motion by breaking it into two independent one-dimensional motions along the vertical and horizontal axes. (b) The horizontal motion is simple, because  $a_x = 0$  and  $v_x$  is a constant. (c) The velocity in the vertical direction begins to decrease as the object rises. At its highest point, the vertical velocity is zero. As the object falls toward Earth again, the vertical velocity increases again in magnitude but points in the opposite direction to the initial vertical velocity. (d) The  $x$  and  $y$  motions are recombined to give the total velocity at any given point on the trajectory.

# Uniform Circular Motion



**Figure 4.19** The centripetal acceleration vector points toward the center of the circular path of motion and is an acceleration in the radial direction. The velocity vector is also shown and is tangent to the circle.

# Key Equations

Position vector	$\vec{\mathbf{r}}(t) = x(t)\hat{\mathbf{i}} + y(t)\hat{\mathbf{j}} + z(t)\hat{\mathbf{k}}$
Displacement vector	$\Delta\vec{\mathbf{r}} = \vec{\mathbf{r}}(t_2) - \vec{\mathbf{r}}(t_1)$
Velocity vector	$\vec{\mathbf{v}}(t) = \lim_{\Delta t \rightarrow 0} \frac{\vec{\mathbf{r}}(t+\Delta t) - \vec{\mathbf{r}}(t)}{\Delta t} = \frac{d\vec{\mathbf{r}}}{dt}$
Velocity in terms of components	$\vec{\mathbf{v}}(t) = v_x(t)\hat{\mathbf{i}} + v_y(t)\hat{\mathbf{j}} + v_z(t)\hat{\mathbf{k}}$
Velocity components	$v_x(t) = \frac{dx(t)}{dt} \quad v_y(t) = \frac{dy(t)}{dt} \quad v_z(t) = \frac{dz(t)}{dt}$
Average velocity	$\vec{\mathbf{v}}_{\text{avg}} = \frac{\vec{\mathbf{r}}(t_2) - \vec{\mathbf{r}}(t_1)}{t_2 - t_1}$
Instantaneous acceleration	$\vec{\mathbf{a}}(t) = \lim_{\Delta t \rightarrow 0} \frac{\vec{\mathbf{v}}(t+\Delta t) - \vec{\mathbf{v}}(t)}{\Delta t} = \frac{d\vec{\mathbf{v}}(t)}{dt}$
Instantaneous acceleration, component form	$\vec{\mathbf{a}}(t) = \frac{dv_x(t)}{dt}\hat{\mathbf{i}} + \frac{dv_y(t)}{dt}\hat{\mathbf{j}} + \frac{dv_z(t)}{dt}\hat{\mathbf{k}}$
Instantaneous acceleration as second derivatives of position	$\vec{\mathbf{a}}(t) = \frac{d^2x(t)}{dt^2}\hat{\mathbf{i}} + \frac{d^2y(t)}{dt^2}\hat{\mathbf{j}} + \frac{d^2z(t)}{dt^2}\hat{\mathbf{k}}$

# Key Equations

Time of flight	$T_{\text{tof}} = \frac{2(v_0 \sin \theta_0)}{g}$
Trajectory	$y = (\tan \theta_0)x - \left[ \frac{g}{2(v_0 \cos \theta_0)^2} \right] x^2$
Range	$R = \frac{v_0^2 \sin 2\theta_0}{g}$
Centripetal acceleration	$a_C = \frac{v^2}{r}$
Position vector, uniform circular motion	$\vec{\mathbf{r}}(t) = A \cos \omega t \hat{\mathbf{i}} + A \sin \omega t \hat{\mathbf{j}}$
Velocity vector, uniform circular motion	$\vec{\mathbf{v}}(t) = \frac{d\vec{\mathbf{r}}(t)}{dt} = -A\omega \sin \omega t \hat{\mathbf{i}} + A\omega \cos \omega t \hat{\mathbf{j}}$
Acceleration vector, uniform circular motion	$\vec{\mathbf{a}}(t) = \frac{d\vec{\mathbf{v}}(t)}{dt} = -A\omega^2 \cos \omega t \hat{\mathbf{i}} - A\omega^2 \sin \omega t \hat{\mathbf{j}}$
Tangential acceleration	$a_T = \frac{d \vec{\mathbf{v}} }{dt}$
Total acceleration	$\vec{\mathbf{a}} = \vec{\mathbf{a}}_C + \vec{\mathbf{a}}_T$

# Key Equations

Position vector in frame  $S$  is the position vector in frame  $S'$  plus the vector from the origin of  $S$  to the origin of  $S'$

$$\vec{r}_{PS} = \vec{r}_{PS'} + \vec{r}_{S'S}$$

Relative velocity equation connecting two reference frames

$$\vec{v}_{PS} = \vec{v}_{PS'} + \vec{v}_{S'S}$$

Relative velocity equation connecting more than two reference frames

$$\vec{v}_{PC} = \vec{v}_{PA} + \vec{v}_{AB} + \vec{v}_{BC}$$

Relative acceleration equation

$$\vec{a}_{PS} = \vec{a}_{PS'} + \vec{a}_{S'S}$$

# Clicker Questions

# CQ.4.1

Consider vectors  $\vec{A}$ ,  $\vec{B}$ , and their resultant  $\vec{R} = \vec{A} + \vec{B}$ . How can you express its magnitude in terms of  $A_x$ ,  $A_y$ ,  $B_x$ , and  $B_y$ ?

a)  $|\vec{R}| = (A_x + B_x) + (A_y + B_y)$

b)  $|\vec{R}| = (A_x + B_x) - (A_y + B_y)$

c)  $|\vec{R}| = (A_x + B_x)^2 + (A_y + B_y)^2$

d)  $|\vec{R}| = \sqrt{(A_x + B_x)^2 + (A_y + B_y)^2}$

**A**

**B**

**C**

**D**

**E**

# CQ.4.2

Consider vectors  $\vec{A}$ ,  $\vec{B}$ , and their resultant  $\vec{R}$ . How can you express its direction as a counterclockwise angle from positive x in terms of  $A_x$ ,  $A_y$ ,  $B_x$ , and  $B_y$ ?

a)  $\theta = \sin^{-1} \left( \frac{A_y + B_y}{A_x + B_x} \right)$

b)  $\theta = \cos^{-1} \left( \frac{A_y + B_y}{A_x + B_x} \right)$

c)  $\theta = \tan^{-1} \left( \frac{A_x + B_x}{A_y + B_y} \right)$

d)  $\theta = \tan^{-1} \left( \frac{A_y + B_y}{A_x + B_x} \right)$

**A**

**B**

**C**

**D**

**E**

# CQ.4.3

When will the x-component of a vector with angle  $\theta$  be greater than its y-component?

a)  $0^\circ < \theta < 45^\circ$

b)  $\theta = 45^\circ$

c)  $45^\circ < \theta < 60^\circ$

d)  $60^\circ < \theta < 90^\circ$

**A**

**B**

**C**

**D**

**E**

# CQ.4.4

A projectile is launched horizontally on level ground, with a launch speed  $v_0$  that cannot be changed. How will the range (the horizontal distance traveled by the projectile before striking the ground) change if the launch angle  $\theta$  is increased?

- a) The distance will decrease as the angle increases until the angle reaches  $45^\circ$ , after which it will increase.
- b) The distance will increase as the angle increases until the angle reaches  $45^\circ$ , after which it will decrease.
- c) The distance will continually increase with the increase in the angle of projection of the projectile.
- d) The distance will continually decrease with the increase in the angle of projection of the projectile.

**A**

**B**

**C**

**D**

**E**

# CQ.4.5

You hit a ball horizontally from the top of a cliff that is 80 m tall. The ball has an initial velocity of 10.0 m/s. What is the horizontal range of the ball?

- a) 80 m
- b) 800 m
- c) 40 m
- d) 63 m
- e) 72 m

**A**

**B**

**C**

**D**

**E**

# CQ.4.6

A football player punts the ball at a  $45.0^\circ$  angle. Without an effect from the wind, the ball would travel 60.0 m horizontally.

**What is the initial speed of the ball?**

- a) Not enough information
- b) 0.00 m/s
- c) 28.8 m/s
- d) 24.2 m/s

**A**

**B**

**C**

**D**

**E**

# CQ.4.7

A football player punts the ball at a  $45.0^\circ$  angle. Without an effect from the wind, the ball would travel 60.0 m horizontally.

**When the ball is near its maximum height it experiences a brief gust of wind that reduces its horizontal velocity by 1.50 m/s. What distance does the ball travel horizontally?**

- a) 69.6 m
- b) 57.4 m
- c) 60.0 m
- d) 57.8 m

**A**

**B**

**C**

**D**

**E**

# Activity: Worked Problem

## A Skier

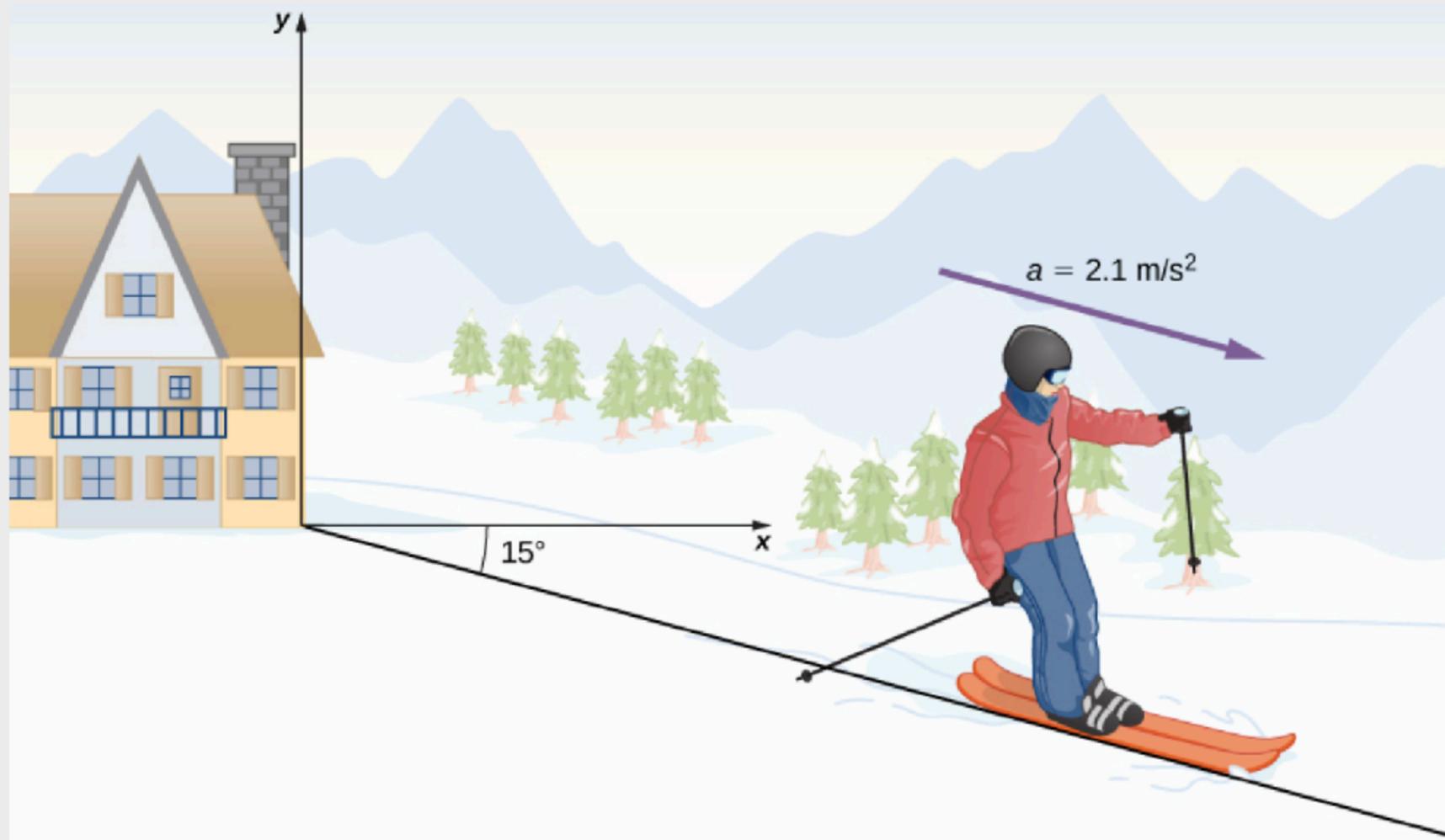
Figure 4.10 shows a skier moving with an acceleration of  $2.1 \text{ m/s}^2$  down a slope of  $15^\circ$  at  $t = 0$ . With the origin of the coordinate system at the front of the lodge, her initial position and velocity are

$$\vec{r}(0) = (75.0\hat{i} - 50.0\hat{j}) \text{ m}$$

and

$$\vec{v}(0) = (4.1\hat{i} - 1.1\hat{j}) \text{ m/s.}$$

(a) What are the  $x$ - and  $y$ -components of the skier's position and velocity as functions of time? (b) What are her position and velocity at  $t = 10.0 \text{ s}$ ?

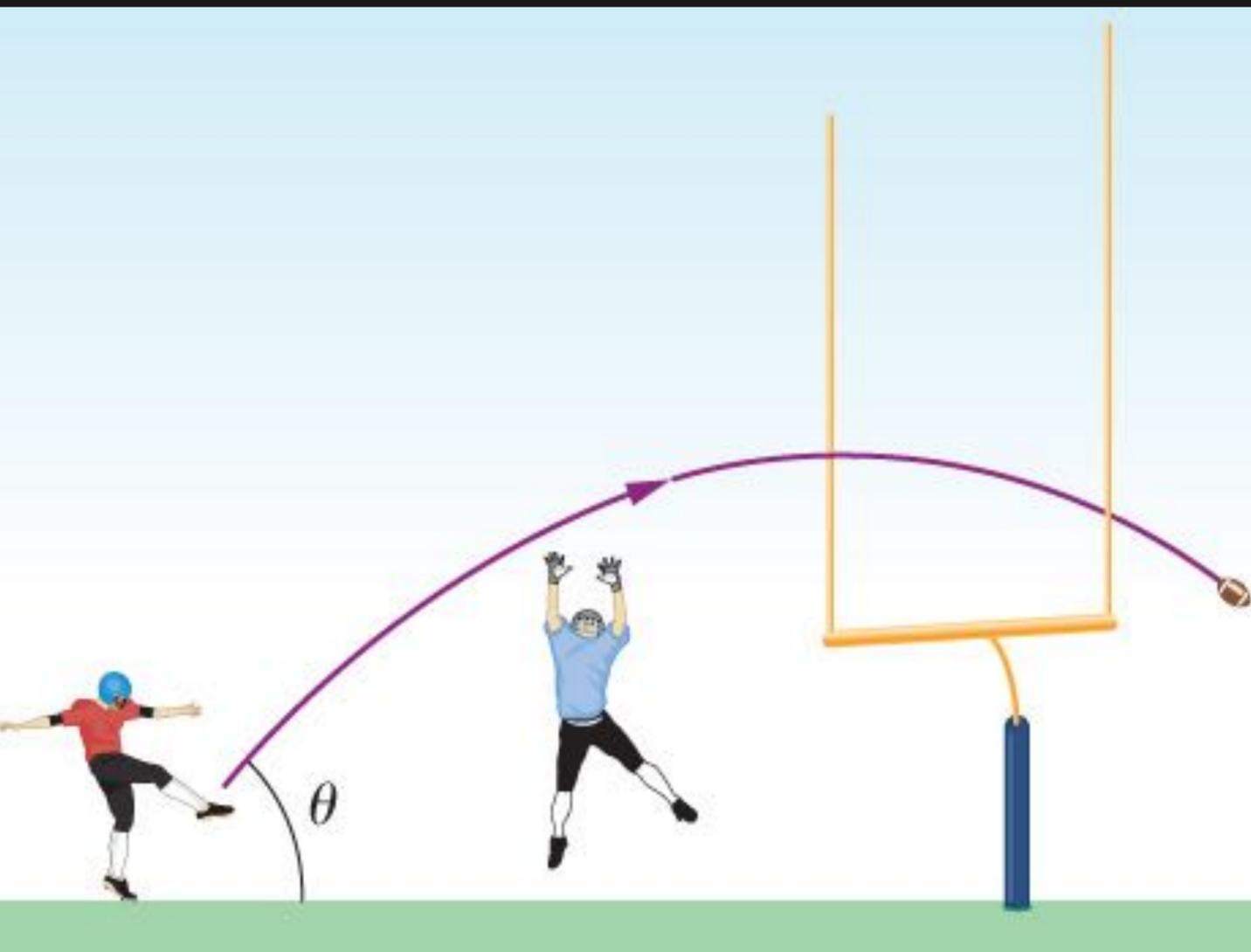


When a field goal kicker kicks a football as hard as he can at  $45^\circ$  to the horizontal, the ball just clears the 3-m-high crossbar of the goalposts 45.7 m away.

(a) What is the maximum speed the kicker can impart to the football?

(b) In addition to clearing the crossbar, the football must be high enough in the air early during its flight to clear the reach of the onrushing defensive lineman. If the lineman is 4.6 m away and has a vertical reach of 2.5 m, can he block the 45.7-m field goal attempt?

(c) What if the lineman is 1.0 m away? Is the ball blocked?



**See you next class!**

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