Preview

< Back Next > Preview Main

What do you think?

- How are measurements such as mass and volume different from measurements such as velocity and acceleration?
- How can you add two velocities that are in different directions?

< Back Next > Preview Main

Introduction to Vectors

- Scalar - a quantity that has magnitude but no direction
  - Examples: volume, mass, temperature, speed
- Vector - a quantity that has both magnitude and direction
  - Examples: acceleration, velocity, displacement, force

< Back Next > Preview Main

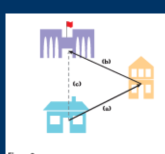
Vector Properties

- Vectors are generally drawn as arrows.
  - Length represents the magnitude
  - Arrow shows the direction
- Resultant - the sum of two or more vectors

< Back Next > Preview Main

Two-Dimensional Motion and Vectors Section 1

Finding the Resultant Graphically



- Method
  - Draw each vector in the proper direction.
  - Establish a scale (i.e. 1 cm = 2 m) and draw the vector the appropriate length.
  - Draw the resultant from the tip of the first vector to the tail of the last vector.
  - Measure the resultant.
- The resultant for the addition of **a** + **b** is shown to the left as **c.**

< Back Next > Preview Main

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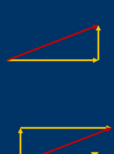
Two-Dimensional Motion and Vectors Section 1

Vector Addition



- Vectors can be moved parallel to themselves without changing the resultant.
  - the red arrow represents the resultant of the two vectors

< Back Next > Preview Main

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Vector Addition

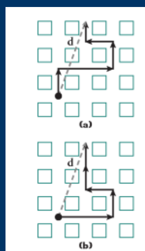


Figure 4

- Vectors can be added in any order.
  - The resultant (**d**) is the same in each case
- Subtraction is simply the addition of the opposite vector.

Properties of Vectors

Click below to watch the Visual Concept.

Visual Concept

Sample Resultant Calculation

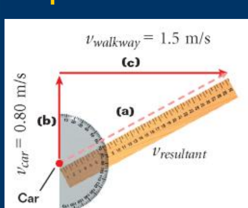


Figure 3

- A toy car moves with a velocity of .80 m/s across a moving walkway that travels at 1.5 m/s. Find the resultant speed of the car.

Now what do you think?

- How are measurements such as mass and volume different from measurements such as velocity and acceleration?
- How can you add two velocities that are in different directions?

What do you think?

- What is one disadvantage of adding vectors by the graphical method?
- Is there an easier way to add vectors?

Vector Operations

- Use a traditional *x-y* coordinate system as shown below on the right.
- The Pythagorean theorem and tangent function can be used to add vectors.
  - More accurate and less time-consuming than the graphical method

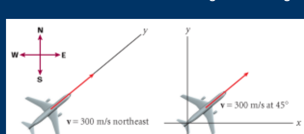


Figure 6

Pythagorean Theorem and Tangent Function

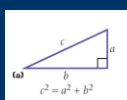
PYTHAGOREAN THEOREM FOR RIGHT TRIANGLES

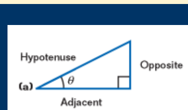
$$c^2 = a^2 + b^2$$

$$(\text{length of hypotenuse})^2 = (\text{length of one leg})^2 + (\text{length of other leg})^2$$

DEFINITION OF THE TANGENT FUNCTION FOR RIGHT TRIANGLES

$$\tan \theta = \frac{opp}{adj} \qquad \text{tangent of angle} = \frac{\text{opposite leg}}{\text{adjacent leg}}$$



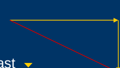


Vector Addition - Sample Problems

- 12 km east + 9 km east = ?
  - Resultant: 21 km east

- 12 km east + 9 km west = ?
  - Resultant: 3 km east

- 12 km east + 9 km south = ?
  - Resultant: 15 km at 37° south of east



- 12 km east + 8 km north = ?
  - Resultant: 14 km at 34° north of east

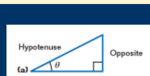
Resolving Vectors Into Components

DEFINITION OF THE SINE FUNCTION FOR RIGHT TRIANGLES

$$\sin \theta = \frac{opp}{hyp} \qquad \text{sine of an angle} = \frac{\text{opposite leg}}{\text{hypotenuse}}$$

DEFINITION OF THE COSINE FUNCTION FOR RIGHT TRIANGLES

$$\cos \theta = \frac{adj}{hyp} \qquad \text{cosine of an angle} = \frac{\text{adjacent leg}}{\text{hypotenuse}}$$



Resolving Vectors into Components

- Opposite of vector addition
- Vectors are resolved into *x* and *y* components
- For the vector shown at right, find the vector components v_x (velocity in the *x* direction) and v_y (velocity in the *y* direction). Assume that that the angle is 20.0˚.

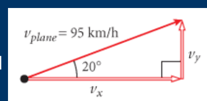
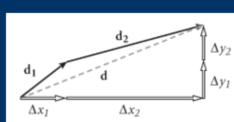


Figure 11

- Answers:
  - v_x = 89 km/h
  - v_y = 32 km/h

Adding Non-Perpendicular Vectors



- Four steps
  - Resolve each vector into x and y components
  - Add the *x* components ($x_{total} = \Delta x_1 + \Delta x_2$)
  - Add the *y* components ($y_{total} = \Delta y_1 + \Delta y_2$)
  - Combine the *x* and *y* totals as perpendicular vectors

Adding Vectors Algebraically

Click below to watch the Visual Concept.

Visual Concept

Classroom Practice

- A camper walks 4.5 km at 45° north of east and then walks 4.5 km due south. Find the camper's total displacement.
- Answer
  - 3.4 km at 22° S of E

Now what do you think?

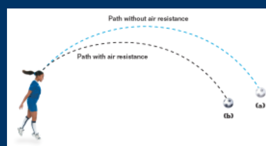
- Compare the two methods of adding vectors.
- What is one advantage of adding vectors with trigonometry?
- Are there some situations in which the graphical method is advantageous?

What do you think?

- Suppose two coins fall off of a table simultaneously. One coin falls straight downward. The other coin slides off the table horizontally and lands several meters from the base of the table.
  - Which coin will strike the floor first?
  - Explain your reasoning.
- Would your answer change if the second coin was moving so fast that it landed 50 m from the base of the table? Why or why not?

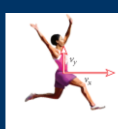
Projectile Motion

- Projectiles: objects that are launched into the air
  - tennis balls, arrows, baseballs, wrestlers
- Gravity affects the motion
- Path is parabolic if air resistance is ignored
- Path is shortened under the effects of air resistance



< Back Next > Preview Main

Components of Projectile Motion



- As the runner launches herself ($\mathbf{v}_i$), she is moving in the *x* and y directions.

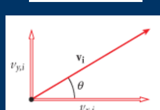


Figure 17

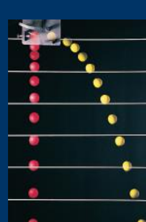
$$v_{x,i} = v_i \cos\theta$$
$$v_{y,i} = v_i \sin\theta$$

< Back Next > Preview Main

Analysis of Projectile Motion

- Horizontal motion
  - No horizontal acceleration
  - Horizontal velocity ($\mathbf{v}_x$) is constant.
- How would the horizontal distance traveled change during successive time intervals of 0.1 s each?
- Horizontal motion of a projectile launched at an angle:

$$v_x = v_{x,i} = v_i \cos\theta = \text{constant}$$
$$\Delta x = (v_i \cos\theta)\Delta t$$



< Back Next > Preview Main

Analysis of Projectile Motion

- Vertical motion is simple free fall.
  - Acceleration (a_g) is a constant -9.81 m/s^2.
  - Vertical velocity changes.
- How would the vertical distance traveled change during successive time intervals of 0.1 seconds each?
- Vertical motion of a projectile launched at an angle:

$$v_{y,f} = v_i \sin\theta + a_y \Delta t$$
$$v_{y,f}^2 = v_i^2 (\sin\theta)^2 + 2a_y \Delta y$$
$$\Delta y = (v_i \sin\theta)\Delta t + \frac{1}{2}a_y(\Delta t)^2$$

Projectile Motion

Click below to watch the Visual Concept.

Visual Concept

Projectile Motion - Special Case

Initial velocity is horizontal only ($v_{i,y} = 0$).

HORIZONTAL MOTION OF A PROJECTILE

$$v_x = v_{x,i} = \text{constant}$$
$$\Delta x = v_x \Delta t$$

VERTICAL MOTION OF A PROJECTILE THAT FALLS FROM REST

$$v_{y,f} = a_y \Delta t$$
$$v_{y,f}^2 = 2a_y \Delta y$$
$$\Delta y = \frac{1}{2}a_y(\Delta t)^2$$

Projectile Motion Summary

- Projectile motion is free fall with an initial horizontal speed.
- Vertical and horizontal motion are independent of each other.
  - Horizontally the velocity is constant.
  - Vertically the acceleration is constant (-9.81 m/s^2).
- Components are used to solve for vertical and horizontal quantities.
- Time is the same for both vertical and horizontal motion.
- Velocity at the peak is purely horizontal ($v_y = 0$).

< Back Next > Preview Main

Classroom Practice Problem (Horizontal Launch)

- People in movies often jump from buildings into pools. If a person jumps horizontally by running straight off a rooftop from a height of 30.0 m to a pool that is 5.0 m from the building, with what initial speed must the person jump?
- Answer: 2.0 m/s

< Back Next > Preview Main

Classroom Practice Problem (Projectile Launched at an Angle)

- A golfer practices driving balls off a cliff and into the water below. The edge of the cliff is 15 m above the water. If the golf ball is launched at 51 m/s at an angle of 15°, how far does the ball travel horizontally before hitting the water?
- Answer: 1.7×10^2 m (170 m)

< Back Next > Preview Main

Now what do you think?

- Suppose two coins fall off of a table simultaneously. One coin falls straight downward. The other coin slides off the table horizontally and lands several meters from the base of the table.
  - Which coin will strike the floor first?
  - Explain your reasoning.
- Would your answer change if the second coin was moving so fast that it landed 50 m from the base of the table? Why or why not?

What do you think?

- One person says a car is traveling at 10 km/h while another states it is traveling at 90 km/h. Both of them are correct. How can this occur?
- Consider the frame of reference.
  - Suppose you are traveling at a constant 80 km/h when a car passes you. This car is traveling at a constant 90 km/h. How fast is it going, relative to your frame of reference? How fast is it moving, relative to Earth as a frame of reference?

Relative Motion

- Velocity differs in different frames of reference.
- Observe as your instructor walks across the front of the room at a steady speed and drops a tennis ball during the walk.
  - Describe the motion of the ball from the teacher's frame of reference.
  - Describe the motion of the ball from a student's frame of reference.
  - Which is the correct description of the motion?

Relative Motion

Click below to watch the Visual Concept.

Visual Concept

< Back Next > Preview Main

Frames of Reference

- A falling object is shown from two different frames of reference:
  - the pilot (top row)
  - an observer on the ground (bottom row)

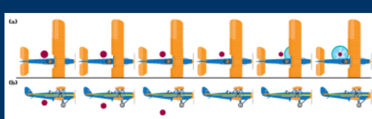


Figure 19
When viewed from the plane **(a)**, the stunt dummy (represented by the maroon dot) falls straight down. When viewed from a stationary position on the ground **(b)**, the stunt dummy follows a parabolic projectile path.

< Back Next > Preview Main

Relative Velocity

- $\mathbf{v}_{ac} = \mathbf{v}_{ab} + \mathbf{v}_{bc}$
  - $\mathbf{v}_{ac}$ means the velocity of object "a" with respect to frame of reference "c"
  - Note: $\mathbf{v}_{ac} = -\mathbf{v}_{ca}$
- When solving relative velocity problems, follow this technique for writing subscripts.

< Back Next > Preview Main

Sample Problem

- A boat is traveling downstream. The speed of the boat with respect to Earth ($\mathbf{v}_{be}$) is 20 km/h. The speed of the river with respect to Earth ($\mathbf{v}_{re}$) is 5 km/h. What is the speed of the boat with respect to the river?
- Solution:

  $\mathbf{v}_{br} = \mathbf{v}_{be} + \mathbf{v}_{er} = \mathbf{v}_{be} + (-\mathbf{v}_{re})$ = 20 km/h + (-5 km/h)

  $\mathbf{v}_{br}$ = 15 km/h

< Back Next > Preview Main

Classroom Practice Problem

- A plane flies northeast at an airspeed of 563 km/h. (Airspeed is the speed of the aircraft relative to the air.) A 48.0 km/h wind is blowing to the southeast. What is the plane's velocity relative to the ground?
- Answer: 565.0 km/h at 40.1° north of east
- How would this pilot need to adjust the direction in order to to maintain a heading of northeast?

< Back Next > Preview Main

Now what do you think?

- Suppose you are traveling at a constant 80 km/h when a car passes you. This car is traveling at a constant 90 km/h.
  - How fast is it going, relative to your frame of reference?
  - How fast is it moving, relative to Earth as a frame of reference?
- Does velocity always depend on the frame of reference?
- Does acceleration depend on the frame of reference?

< Back Next > Preview Main