Name: ______________________________________ Date: ________________________

Student Exploration: Golf Range

Vocabulary: acceleration, air resistance, gravity, hang time, launch angle, projectile motion, trajectory, vector, velocity

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. You are in a contest with your friends to see who can drive a golf ball the farthest. Should you hit a "line drive" (low to the ground) or a shot with a very high angle? Explain.

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2. Golf drives travel much farther than Major League home runs. Why might this be?

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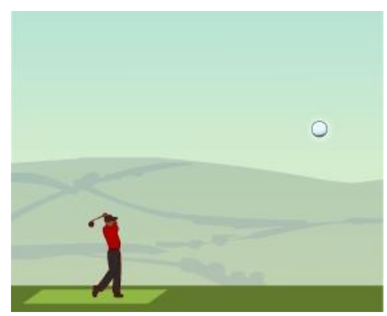
Gizmo Warm-up

Have you ever hit a hole-in-one? You will have a chance to do that in the *Golf Range* Gizmo™, where you will see how a variety of factors affect the path of a golf ball. The movement of objects such as a ball through space is called **projectile motion**.



1. Press **Play** (▶). Did the ball go too far, the right distance, or not far enough? ________________________________

2. Click **Reset** (↺). Move the $v_{initial}$ and θ *sliders* to adjust the **velocity** and **launch angle** until you get a hole-in-one. (With the Gizmo sound on (🔊) you will hear "Hole in one!")

   What were the velocity and launch angle values? ________________________________

3. Can you get holes-in-one using other combinations of $v_{initial}$ and θ? If so, give an example.

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Activity A: **Maximum distance**	Get the Gizmo ready: • Click **Reset** and check that **Atmosphere: Air** is selected. • Set $v_{initial}$ to 75 m/s and θ to 45.0 degrees.	

Question: What launch angle will produce the longest drive?

1. Form hypothesis: What launch angle do you think will yield the longest drive? ____________

2. Experiment: Turn on the **Show grid** checkbox. With the velocity set to 75 m/s, experiment with a variety of launch angles until you find the one that yields the longest driving distance.

   A. What launch angle produced the longest drive? ________________________________

   B. How far did the ball travel? ____

3. Observe: Click **Reset** and turn on **Show paths**. Click **Clear paths**. Take a swing with the optimum launch angle. The curved path the ball takes through the air is its **trajectory**.

   Look closely at the trajectory. Does it appear symmetrical? _____________________________

   The curve is slightly steeper on the right than on the left as a result of **air resistance**.

4. Experiment: Click **Reset**, then select **Atmosphere: None**. As before, use trial and error until you find the launch angle that produces the longest drive.

   A. What launch angle produced the longest drive? ________________________________

   B. How far did the ball travel? ____

   C. Why do you think the ball traveled farther in this situation? _______________________

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5. Extend your thinking: The Moon has much less gravity than Earth and has an extremely thin atmosphere. How would these factors affect the trajectory of a golf ball on the Moon?

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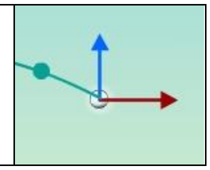
Activity B: **Physics of projectile motion**	Get the Gizmo ready: • Click **Clear paths** and select **Atmosphere: None**. • Turn off **Show grid** and **Show paths**. • You will need a scientific calculator for this activity.	

Introduction: Velocity is an example of a **vector** quantity because it describes the speed and direction of an object. The velocity of an object through space can be shown by two components: a horizontal component ($\mathbf{v_x}$) and a vertical component ($\mathbf{v_y}$).

Question: How does the velocity of an object change as it flies through space?

1. Observe: Click **Reset**. Turn on **Show velocity vectors**, set $\boldsymbol{v_{initial}}$ to 50 m/s, and set $\boldsymbol{\theta}$ to 45.0 degrees. Click **Play**, and focus on the blue and red arrows that represent the vertical and horizontal components of the golf ball's velocity.

   A. As the ball flies through the air, what do you notice about the blue (vertical) arrow?

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   B. As the ball flies through the air, what do you notice about the red (horizontal) arrow?

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   C. Try other velocities and launch angles. Do these results hold up? _______________

2. Calculate: You can use trigonometry to find the initial horizontal and vertical components of the golf ball's velocity. Take out your calculator now. Click **Reset**, and turn off **Show velocity vectors**. Set $\boldsymbol{v_{initial}}$ to 50.0 m/s and $\boldsymbol{\theta}$ to 60.0 degrees.

   A. To calculate $\mathbf{v_x}$, multiply $v_{initial}$ by the *cosine* of the angle: $\mathbf{v_x} = v_{initial} \bullet \cos(\theta)$: ________

   B. To calculate $\mathbf{v_y}$, multiply $v_{initial}$ by the *sine* of the angle: $\mathbf{v_y} = v_{initial} \bullet \sin(\theta)$: __________

   C. Turn on **Show velocity vectors**. Were you correct? __________________________

3. Analyze: An object flying through the air is said to be in free fall. As you observed, the horizontal component of velocity ($\mathbf{v_x}$) does not change as the object moves, but the vertical component ($\mathbf{v_y}$) decreases over time. (Note: Air resistance is not included in this model.)

   A. What force causes $\mathbf{v_y}$ to change as the golf ball travels? ______________________

   B. Why doesn't $\mathbf{v_x}$ change as the object travels? (Hint: Are there any horizontal forces acting on the ball?) ____

(Activity B continued on next page)

Activity B (continued from previous page)

4. Set up Gizmo: **Acceleration** is a change in velocity. As the ball moves through its trajectory, it undergoes a downward acceleration due to the force of **gravity**. To calculate the acceleration of a falling object, divide the velocity change by the time interval.

$$a = (v_{current} - v_{initial}) / t$$

   Set $\boldsymbol{v_{initial}}$ to 75.0 m/s and $\boldsymbol{\theta}$ to 60.0 degrees. Record the initial vertical velocity of the golf ball in the first row of the table below. Include all units.

Time (s)	**v_y (m/s)**
0.00 s	

5. Gather data: Click **Play**, and then click **Pause** (⏸) at some point before the ball reaches its peak height. Record the time and $\mathbf{v_y}$ in the table.

6. Calculate: Compute the velocity difference by subtracting the initial velocity from the current velocity (your answer should be a negative number). Then divide this number by the time to find the acceleration. (Units of acceleration are meters per second per second, or m/s^2.)

   Velocity difference: ___________ Time: _____________ Acceleration: ________________

7. Compare: Turn on **Advanced features** and observe the value of *g*, a measure of gravitational acceleration. Gravitational acceleration is the negative of *g*: $a = -g$.

   Is the value of *g* equal to the negative of the acceleration you measured? _______________

8. Experiment: Click **Reset**. Try launching the ball with different values of *g*. How does the value of *g* affect the flight of the ball?

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9. Extend your thinking: One of the problems aeronautical engineers face is building rockets that generate enough thrust to escape Earth's gravitational field. How would this problem be affected if the rocket was launched from the Moon? From a massive planet such as Jupiter?

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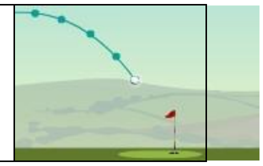
Activity C: **Hang time**	Get the Gizmo ready: • Set $\boldsymbol{v_{initial}}$ to 75 m/s, $\boldsymbol{\theta}$ to 50.0 degrees, and $\boldsymbol{g}$ to 9.8 m/s^2. (Be sure **Advanced features** is on.) • Check that **Atmosphere: None** is selected.	

Question: How can you calculate the distance a golf ball travels?

1. Think about it: Suppose you know a golf ball's horizontal velocity ($\mathbf{v_x}$) and the time it had traveled through the air (t). How could you calculate how far the ball traveled?

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2. Observe: What is the initial value of $\mathbf{v_y}$? ____

3. Calculate: The vertical velocity of a projectile is found with the equation: $\mathbf{v_y} = \mathbf{v_{y(initial)}} - gt$.

   A. What will be the value of $\mathbf{v_y}$ when the ball is at the top of its trajectory? ___________

   B. Using the equation above, solve for t when $\mathbf{v_y}$ = 0.0 m/s, $\mathbf{v_{y(initial)}}$ = 57.45 m/s, and g = 9.81 m/s^2. ____

   C. Now use the same method to determine how long it will take the ball to fall from its maximum height to the ground: ____

   D. Based on your answers to B and C, how long will the ball spend in the air? ________

   This is the **hang time** of the ball.

4. Check: Now press **Play** and observe the total time the ball spends in the air.

   Were your calculations correct? ________

5. Evaluate: Click **Reset**. If the ball has a horizontal velocity ($\mathbf{v_x}$) and a hang time (t), you can find the horizontal distance the ball travels using $d = \mathbf{v_x} \cdot t$ (distance = velocity × time).

   A. What is the horizontal velocity of the golf ball? ______________________________

   B. What is the hang time of the ball? ____

   C. How far will the ball travel before it hits the ground? _______________________

   D. Turn on **Show grid** and click **Play**. About how far did the ball travel? ____________

(Activity C continued on next page)

Activity C (continued from previous page)

6. Calculate: Click **Reset**. Set ***v**initial* to 50 m/s and ***θ*** to 40 degrees. Use what you have learned to calculate $\mathbf{v_x}$, $\mathbf{v_y}$, the hang time of the ball, and the horizontal distance the ball will travel.

   $\mathbf{v_x}$ ____________ $\mathbf{v_y}$ ____________ Hang time ____________ Distance ____________

7. Test: Check your answers using the Gizmo. Were your calculations correct? ____________

8. Apply: Complete the following table, first calculating the answers and then verifying them with the Gizmo. Include all units.

$v_{initial}$	θ	v_x (m/s)	$v_{y(initial)}$ (m/s)	Hang time (s)	Distance (m)
60 m/s	30°				
30 m/s	45°				
80 m/s	60°				
50 m/s	75°				

9. Challenge yourself: A classic problem in projectile motion is how far a projectile will travel if launched from a cliff. To solve this problem, you need to use the free-fall equation: $h = gt^2/2$.

   Click **Reset**. Check that the selected atmosphere is **None**. With the **Advanced features** checkbox turned on, set the height of the person ($\boldsymbol{h_{person}}$) to 200.0 m. Set $\boldsymbol{v_{initial}}$ to 50.0 m/s, $\boldsymbol{\theta}$ to 0.0 degrees, and $\boldsymbol{g}$ to 9.8 m/s^2.

   A. Solve the free-fall equation ($h = gt^2/2$) for t. ________________________________

   B. Calculate the time it will take the ball to fall to the ground from a height of 200 meters and acceleration (g) of 9.81 m/s^2. ____

   C. Based on the time and the horizontal velocity, how far will the ball travel horizontally?

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   D. Press **Play**. What were the actual hang time and distance? ____________________

10. Advanced challenge: Click **Reset**. Change ***θ*** to 30°. Calculate the hang time and distance traveled. (Hint: Use $\mathbf{v_y} = \mathbf{v_{y(initial)}} - gt$ for the time to apex, $h = h_{initial} + gt^2/2$ for the height of the apex, and $h = gt^2/2$ for the time from apex to ground.)

    Predicted hang time: __________ Predicted distance traveled: __________

    Check your answers: Actual hang time: __________ Actual distance: __________