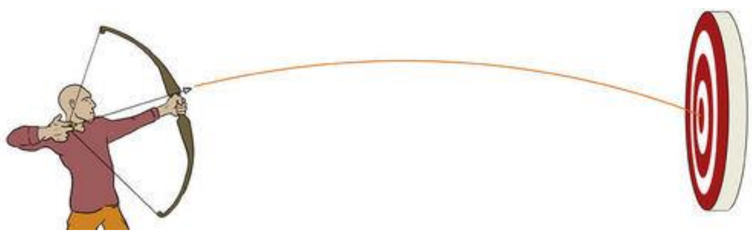
Name: ____ Date: _______

PHYSICS
UNIT 3: APPLIED FORCES & GRAVITY

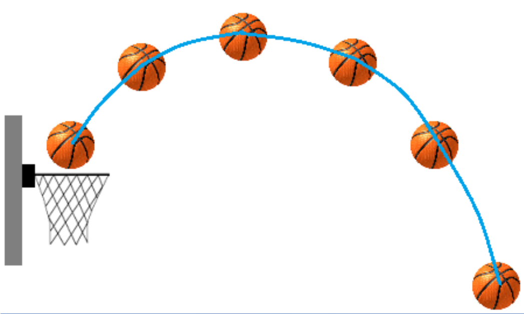
PROJECTILE MOTION

A **projectile** is any object that is launched and flies through air where the only external force acting upon the airborne object is the downward pull of the Earth's gravity. Bullets, arrows, some rockets, cannonballs, and kicked footballs are examples of projectiles. When a projectile is launched, the project is ALWAYS being accelerated downward by Earth's gravity at all points during its flight. In other words, gravity always accelerates in the downward direction regardless of if the object is moving up, moving horizontally, or moving down.

Illustrative Example 1



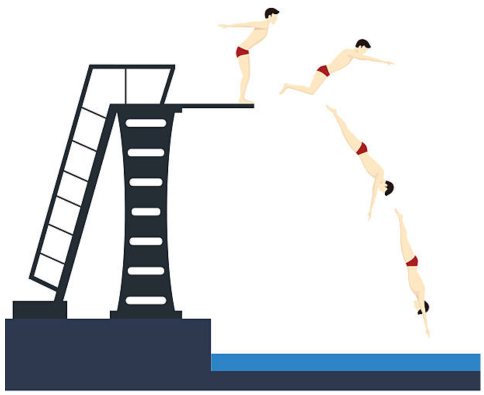
An arrow launched by a bow is an example of a projectile. The force of the bow's tensor gives the arrow its motion. After the arrow leaves the bow, gravity force is the only force acting upon it until it comes to rest.



A basketball thrown by the player is a projectile. The push force of the player's hands and arms gives the ball its motion. After the ball leaves the hands, gravity force is the only force acting upon it until it comes to rest.

The stuntman doing an acrobatic jump from ramp to ramp is a human projectile on a bicycle. The stuntman on the bicycle launches itself off the right ramp. He moves through the air, only acted on by gravity force, and lands on the left ramp.

The woman on the trampoline is projectile while she is in the air. The elastic force of the trampoline's fabric pushes her upward into the air. While she is in the air, she is only acted on by gravity force.



The boy dives from the diving board. He is a projectile as he moves through the air from the diving board to the water.   While he is moving through the air, he is only acted upon by gravity force.

Variables

Launch velocity (or initial velocity)	How fast the projectile was launched into the air. How fast the projectile was initially going after the launch force put it into the air. Launch velocity is in units of m/s.
Launch angle	The angle at which the projectile was launched relative to the horizontal. Horizontal projectile: Launch angle = 0° Vertical projectile: Launch angle = 90° Parabolic projectile: Launch angle = 1° to 89°
Trajectory	The flight path of the projectile. The shape of the flight path as the projectile moves through the air.

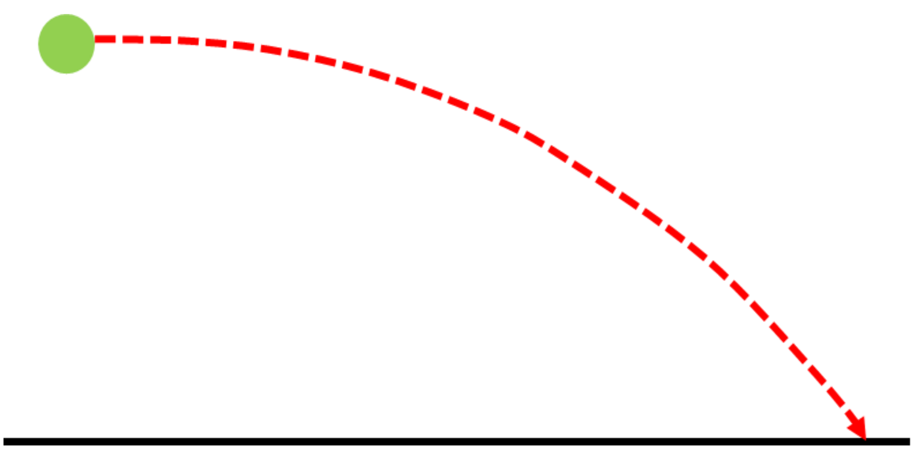
Range	The horizontal displacement of the projectile from the instant it is launched to impact. "How far" the projectile flies laterally away from its point of launch. Range is in units of meters (m).
Height	The vertical displacement of the projectile. "How high" above the ground the projectile flew from its point of launch. Height is in units of meters (m).
Time of flight	The amount of time the projectile remained airborne. The total time the projectile was in the air from launch to impact. Time of flight is in units of seconds (s)

Horizontal projectile motion

A **horizontal projectile** is an object that flies after being launched horizontally. The launch angle is 0º, parallel to the Earth's horizontal surface. Common horizontal projectiles include arrows shot from a bow, bullets fired from a rifle or handgun, and rocks launched from sling shots.

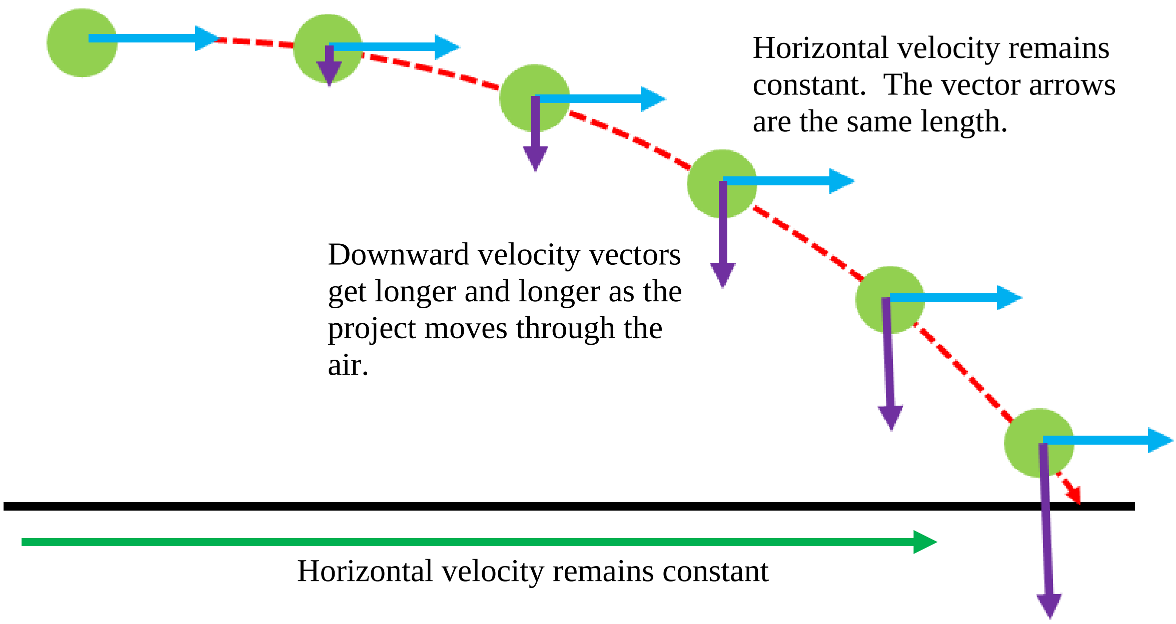
- Launch angle = 0°
- Trajectory is a downward curved path

Horizontal projectiles are launched with an initial velocity that is only in the horizontal direction, at 0°. This causes the projectile to move away from the place where it was launched, so it will have range. Once the projectile is airborne, gravity begins to affect the projectile's motion, and it immediately falls towards the Earth's surface. The simultaneous moving away and falling gives the horizontal projectile its characteric downward curving trajectory (curved red dashed arrow). If gravity did not affect the motion of the horizontal projectile, it would fly in a straight line forever moving at its launch velocity.



The horizonal projectile's trajectory is a downward curving path. The projectile is falling as it moves horizontally away from its launch position. As it moves away, it drops at the same time.

A horizontally launched projectile has two independent motions happening at the same time. The projectile is moving away horizontally from its point of launch. At the same time, it is moving downward under the influence of gravity. As stated before, the projectile falls as it moves away.

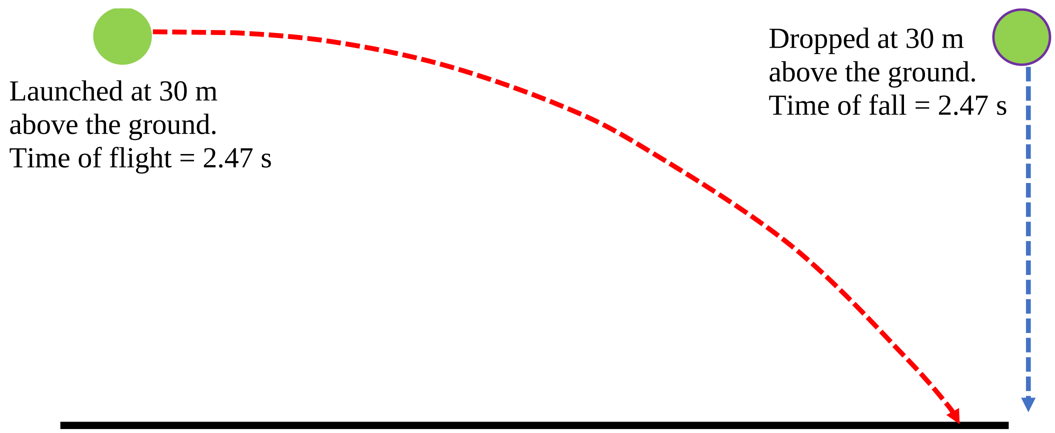


The **vector diagram** for a horizontal projectile shows the horizontal velocity vectors (light blue) and the downward velocity vectors because of gravity (purple) superimposed over the trajectory (curving red dashed line). The horizontal velocity arrows (light blue) are equal length, indicating equal magnitudes. The horizontal velocity remains constant throughout its time in the air. The project moves away from its launch position at a constant velocity equal to launch velocity. If the projectile was launched at 50 m/s, it will continue to move away from its launch position at 50 m/s until it hits the ground. The downward pointing velocity vector arrows (purple) get longer with increasing distance away from launch. The downward velocity gets faster and faster with time. Gravity causes acceleration in the down direction. The longer the projectile is in the air, the faster it will move in the down direction. The horizontal motion does not affect the downward motion of the projectile, and vice versa.

The time of flight for the horizontal projectile only depends on the height above the ground from which the horizontal projectile was launched, and NOT the initial launch velocity in the horizontal direction. Remember, gravity accelerates the projectile downward as it moves through the air. The time to impact the ground after launch equals the amount of time if the projectile were dropped from the same height as it was launched. It is falling the same distance.

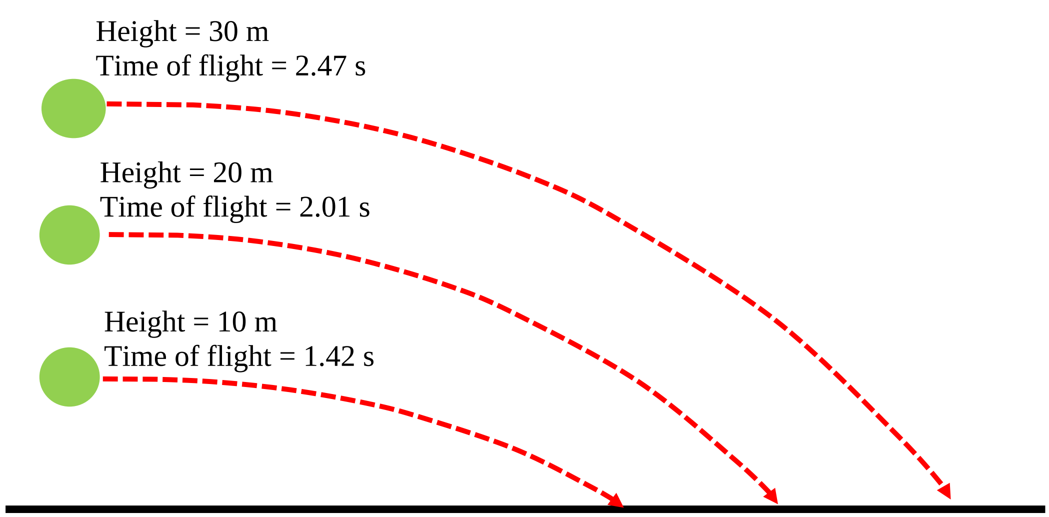
Illustrative Example 1

A projectile was launched horizontally from a height of 30 m above the ground. It will impact the ground 2.47 s after launch. The projectile falls 30 m to the ground as it flies away through the air (red trajectory). Likewise, a ball dropped from 30 m above the ground will impact the ground in 2.47 s. Their motions through the air are very different, but because they fall the same distance to the ground, they are airborne for equal amounts of time.



Illustrative Example 2

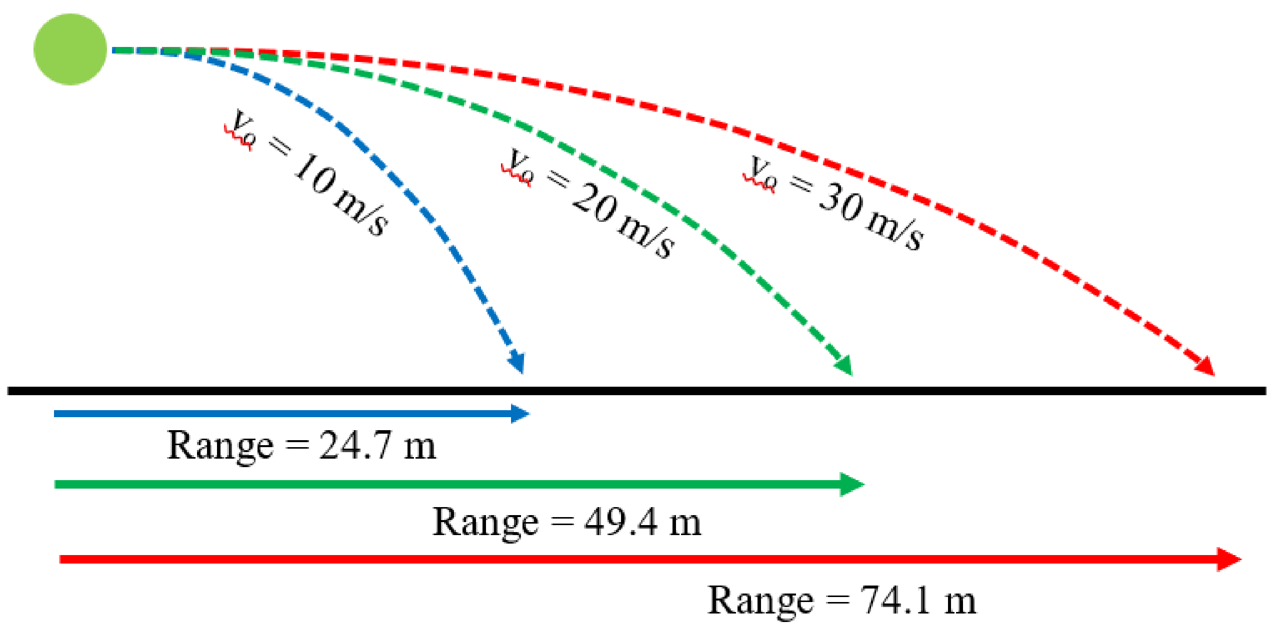
Three identical balls were launched horizontally with the same initial launch velocity, but from different heights above the ground. The time of flight of the projectiles depends on the heigh from which they were launched. The higher above the ground, the greater the time in the air. Their ranges were also different. They longer the time moving through the air, the farther the projectile was able to travel horizontally from launch.



The range of the horizontal projectile depends on height of launch and the initial launch velocity. As seen in Illustrative Example 2, range will be farther the higher the projectile is launched because the longer the amount of time the projectile is airborne, the longer the amount of time it must move horizontally. Range also depends on the initial launch speed. The faster the projectile is launched, the farther it will move away from its launch site.

Illustrative Example 3

The horizontal projectile is launched from the same height above the ground, but at different initial launch velocities. All three will impact the ground in the same amount of time after launch because they essentially fall from the same height as they move away. Their ranges will increase with increasing launch speed. When launched faster, the projectile will move farther.



Vertical projectile motion

Vertical means "up and down". A **vertical projectile** is a projectile that is launched straight up into the air, reaches its highest position, stops for an instant as it changes direction, and freefalls straight down without any horizontal movement.

- Launch angle = 90° (straight up)
- Trajectory is only in the vertical direction (up and down).
- Range is zero. There is no horizontal displacement.

The vector diagram to the right shows the relative instantaneous velocities of the vertical projectile between launch and impact.

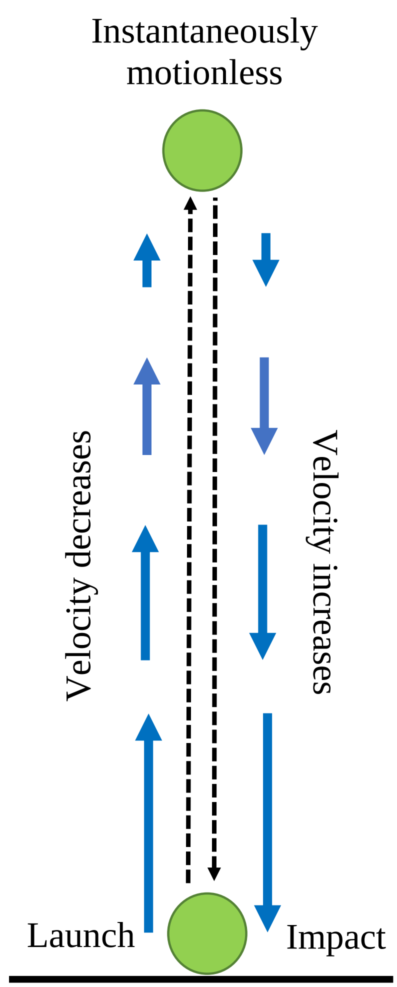
At launch, the vertical projectile is moving with its greatest upward velocity.

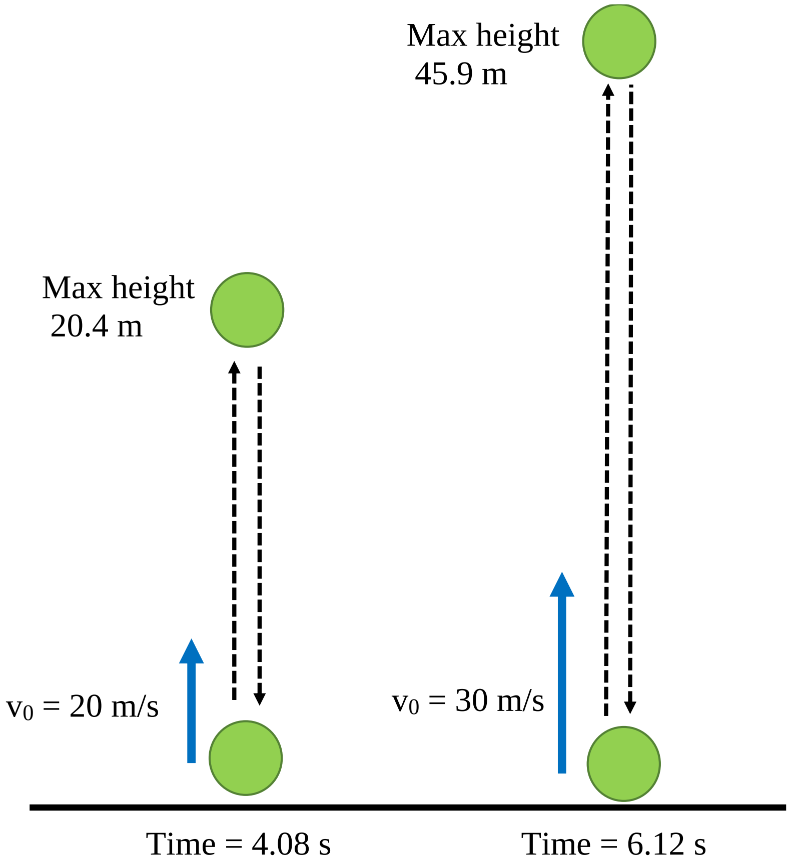
The upward velocity becomes progressively slower and slower the farther the projectile travels upwards (the arrows become shorter) because gravity is accelerating the projectile downward by 9.81 m/s^2 (opposite direction of motion).

At its maximum height above the ground the vertical projectile is instantaneously motionless—a velocity of 0 m/s—and changes direction from upward to downward. After changing direction, the projectile freefalls to the ground.

The vector arrows become progressively longer in the down direction because the freefalling projectile is being accelerated downward at 9.81 m/s^2— freefall velocity gets faster and faster in the downward direction.

The projectile moves the fastest in the down direction at impact. If the launch position and the impact position are at the same exact elevation, the magnitude of the upward velocity at launch is equal to the magnitude of the downward velocity at impact.





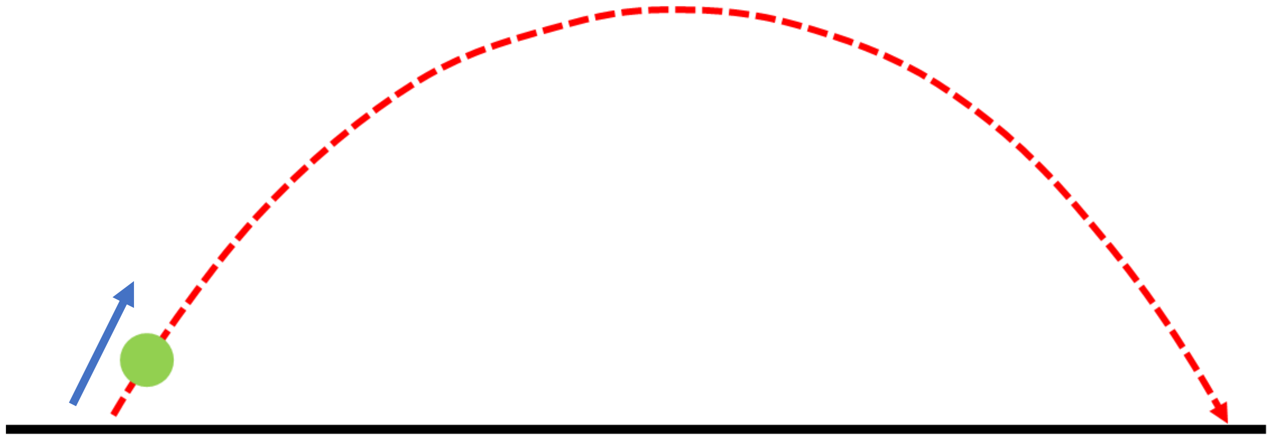
The time of flight and the maximum height above the ground depends on the initial upward launch velocity. The faster the projectile is launched upward, the farther it will fly upward into the air (greater maximum height), the longer it will remain airborne before impacting the ground.

When the initial launch speed is faster, the projectile will go higher into the air. Consequently, the projectile will remain airborne for a longer time of flight. In the example, a projectile launched at 20 m/s will have a lower maximum height and a shorter time of flight than a projectile launched at a 30 m/s.

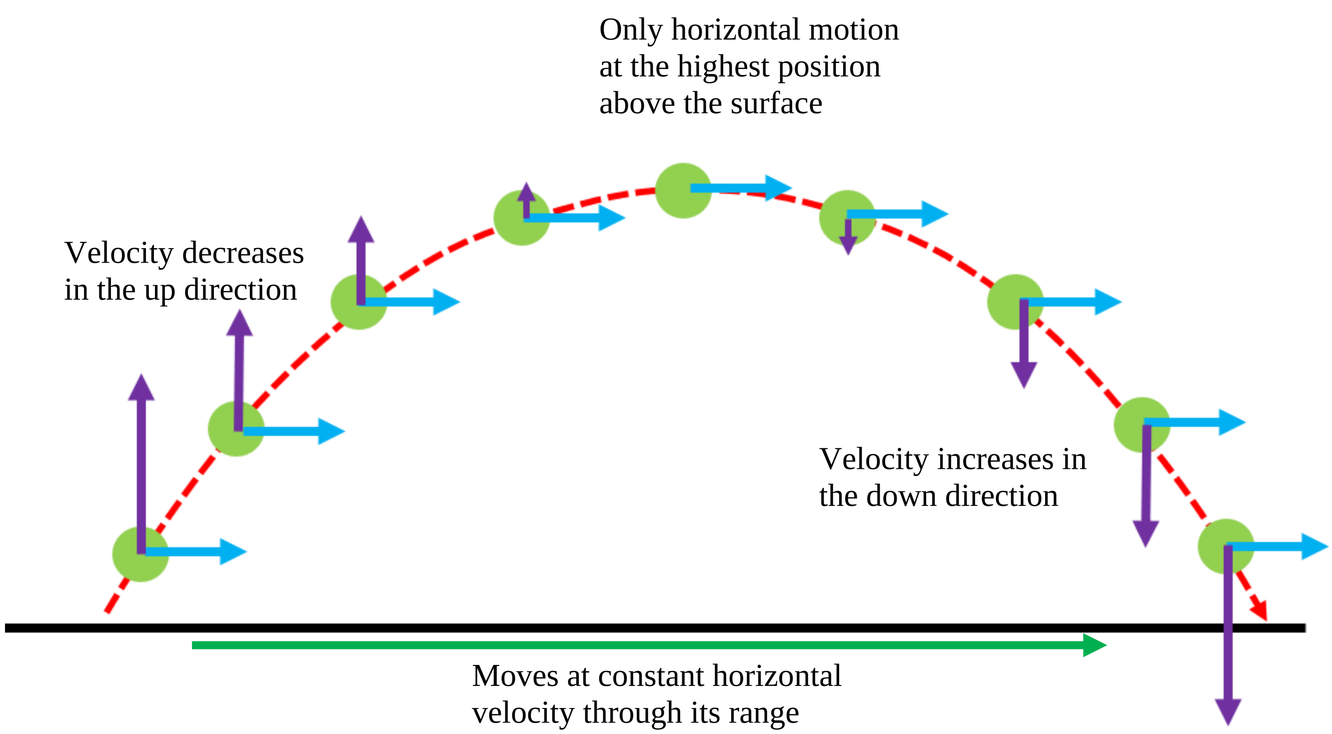
Parabolic projectile motion

A **parabolic projectile** is an object that is launched at an upward angle or diagonal direction ($0^o < \theta < 90^o$) and travels through the air with a parabolic (upside down U-shape) trajectory. Parabolic projectile motion is the most common, and is the most frequently observed at sporting events: passing a football, hitting a golf ball, throwing a javelin, etc.…

- Launch angle: 1°-89°
- Trajectory is an upside-down U path

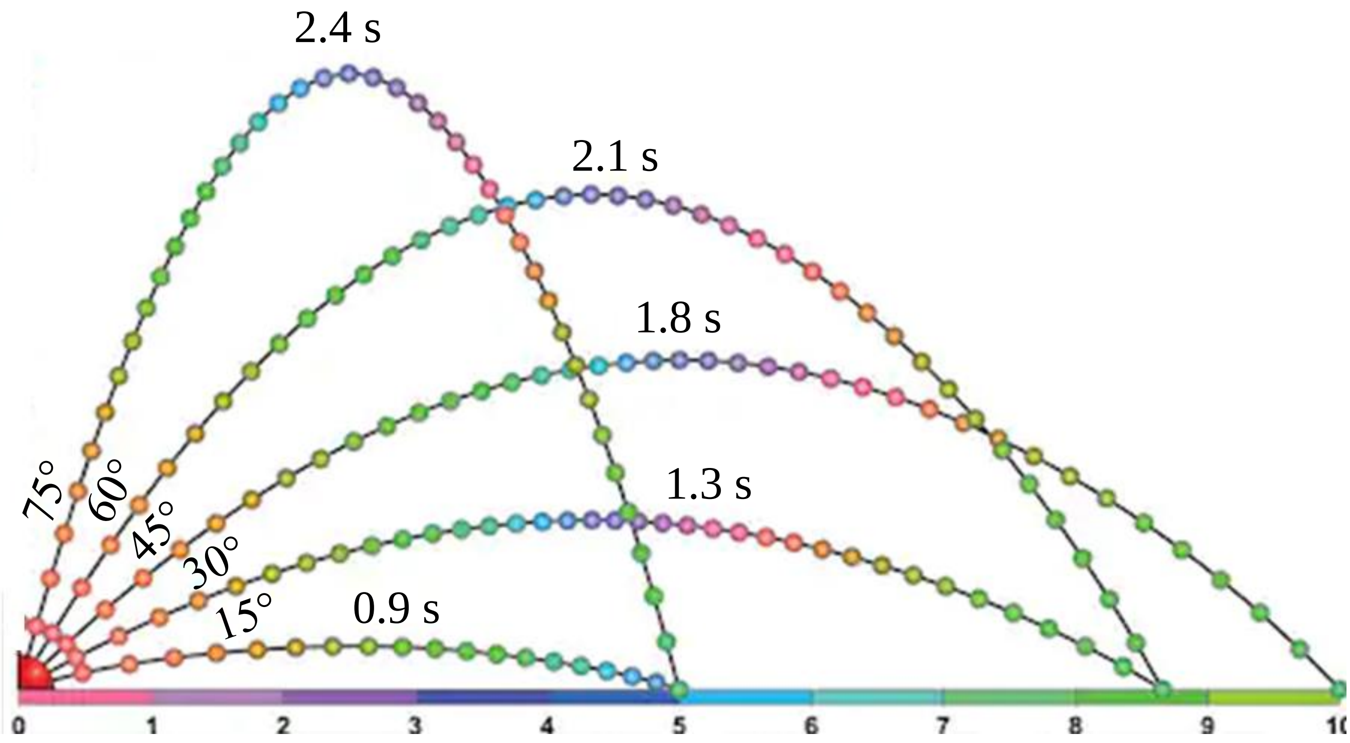


Parabolic projectiles are launched at an upward angle of 1º to 89º relative to the ground. The launch at the upward angle causes the projectile simultaneously to move upward and away from its launch position. Once the projectile is airborne, gravity begins to affect the projectile's motion by accelerating the projectile in the down direction at 9.81 m/s^2 at all positions during its flight. The projectile experiences a direction change from upward to downward after reaching its highest position above the ground, giving the projectile's flight path the upside-down U shape (curved dashed arrow). If gravity did not affect the motion of the horizontal projectile, it would fly in a straight line forever moving at its launch velocity (straight solid arrow).

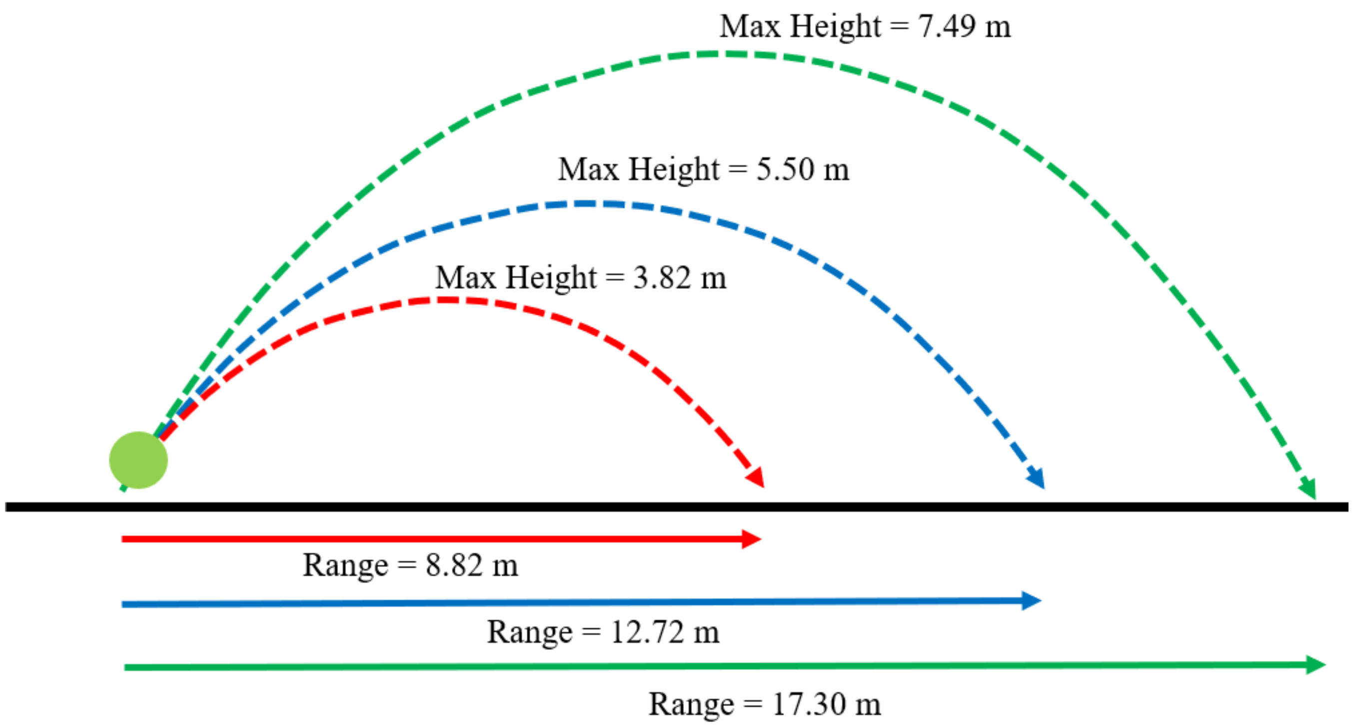


The **vector diagram** for a parabolic projectile (see previous page) shows the horizontal velocity vectors (light blue) and the vertical velocity vectors (purple) superimposed over the trajectory (curving red dashed line). All the horizontal blue arrows are equal length. The horizontal velocity remains constant throughout its time in the air. The project moves away from its launch position through its range at a constant rate. The vertical velocity vectors (purple arrows) change length in the up direction and change length in the down direction. The length of the up arrows gets shorter from launch to the highest position above the ground, then the arrows get longer in the down direction to impact. The projectile slows in the up direction, then gets faster in the down direction. At the highest position above the ground, the projectile only moves with horizontal motion and zero vertical motion.

Launch angle is important. The greater the launch angle, the higher into the air the projectile will go, the longer the projectile will remain airborne. In the diagram below, five identical projectiles were launched at the same initial magnitude of velocity, but at different launch angles (15°, 30°, 45°, 60°, and 75°). The trend is that the higher the launch angle then the higher the projectile will reach at its maximum height. Likewise, the higher above the ground the projectile goes, the time of flight will be longer.



Launch velocity is important. The greater the initial launch velocity, the higher the projectile will go into the air, and the greater the range of the projectile's horizontal movement. In the example below, three identical projectiles were launched at the same launch angle but at different initial launch velocities.



The diagram above shows three identical projectiles that were launched from the same position at the same initial launch angle. The initial launch velocities were different. Red, blue, and green trajectories are for projectiles launched at 10 m/s, 12 m/s and 14 m/s at 60°. The greater the initial launch velocity, the higher the projectiles went into the air, and the farther they moved horizontally through their ranges. Additionally, the higher the projectile moves into the air, the longer its time of flight. Of the three projectiles, the projectile launched at 14 m/s will have the longest time of flight because it went highest into the air.