Chapter 3
Falling Objects and Projectile Motion

Gravity influences motion in a particular way. Drop an object and then two objects from a height above ground:

1. Does the (first) object accelerate, or is the speed constant?
2. Do the two objects behave differently if they have:
   i. different masses?
   ii different shapes

Gravitational Acceleration:

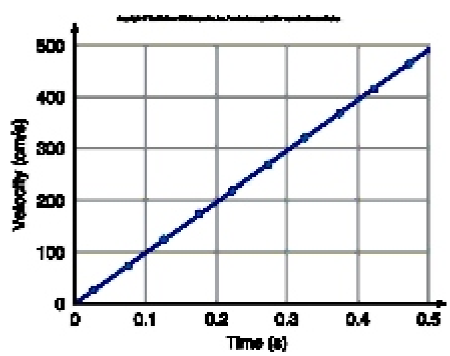
Earth exerts a gravitational force on objects that is attractive (towards Earth's surface).
Near Earth's surface, this force produces a constant acceleration downward.. To measure this acceleration, we need to slow down the action.

Galileo was the first to accurately measure this ***acceleration due to gravity***. By rolling objects down an inclined plane (**Inclined Plane Experiment**), he slowed the motion enough to establish that the ***gravitational acceleration*** is uniform, or constant with time

Stroboscope and the Study of a Fallen Object:

Flashes of a stroboscope illuminate a falling ball at equal time intervals. Distance covered in successive time intervals increases regularly. Since distance covered in equal time intervals is increasing, the velocity must be increasing. (See the picture on page 40 of the book).

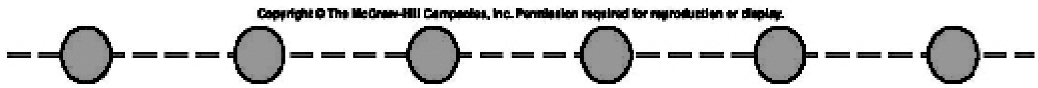
Look at the table of time and position of a falling object on page 40 of your book. The average velocity over the equal length intervals are calculated in the third column. Then the velocity is plotted verses time and it gives the graph below.



Analysis of the Graph: The velocity values steadily increase and the graph is a straight line. So the slope of the line is constant. Thus, the acceleration is constant. We now compute this constant acceleration:

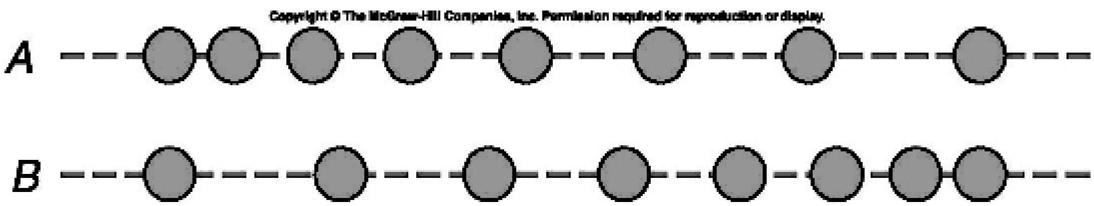
$$a = \frac{464\text{ cm/s} - 72\text{ cm/s}}{8\text{ flashes} \times (0.05\text{ s/flash})} = \frac{392\text{ cm/s}}{0.4\text{ s}} = 980\text{ cm/s}^2 = 9.8\text{ m/s}^2$$

Question: The diagram below shows the positions at 0.10-sec intervals of a ball moving left to right. Does the ball accelerated?



Answer: The ball moves an equal distance during each 0.10-sec interval, so the speed does not change. Thus, the ball is not accelerated.

Question:
The diagram shows the positions at 0.05-sec intervals of two balls moving left to right. Are either or both of these balls accelerated?



Answer: Both balls are accelerated. Ball A covers an increasing distance in each 0.05-sec interval, so it is speeding up. Ball B is covering less and less distance with each interval, so it is slowing down. Both of these are accelerations.

How does a dropped object behave? Drop a brick and a feather from a height above the ground. (See page 41).

Do two objects behave differently if they have: different masses? different shapes?
Clearly the feather falls more slowly than the brick. But what is the REAL reason?

If we drop a feather and a brick in a vacuum, they reach the ground at the same time. Gravitational acceleration does **NOT** depend on the weight of the object.

Example: Drop a ball from a sixth-story window (see page 42).

Question 1: How long does it take for the ball to reach the ground?
Question 2: How fast is it traveling when it gets there?

Answers: Assuming air resistance effects are small, the ball accelerates at 9.8 m/s^2 $\approx$10 m/s2. Each second, its velocity increases by10 m/s

Now See the Picture on Page 43: Starting from rest, its velocity has increased to 10 m/s after the first second; to 20 m/s after 2 s; to 30 m/s after 3 s; etc.

In this case we can use the formulas below that we learned from chapter 2 to compute the velocity and distance that the ball has dropped at various times. The results are shown in figure 3.7 of th book are calculated using the following formulas:

$$v = at \qquad d = \frac{1}{2}at^2$$

Some sample calculations:

Throwing a Ball Downward:

Let the ball be thrown downward instead of being dropped. It will have a starting velocity different from zero. It will reach the ground more rapidly. It will have a larger velocity when it reaches the ground. In this case we use the following formulas:

$$v = v_0 + at \qquad d = v_0 t + \frac{1}{2} a t^2$$

Example:

Throwing a Ball Upward:

What if the ball is thrown upward?
Gravitational acceleration is always directed downward, toward the center of the Earth. Here, the acceleration is in the opposite direction to the original upward velocity. (See picture on page 44).

(See figure 3.10) Let the initial velocity be 20 m/s upward. It immediately starts experiencing a downwardacceleration due to gravity, of approximately 10 m/s. Every second, the velocity decreases by 10 m/s. After 2 s, the ball has reached its highest point. Its velocity changes direction, from upward to downward, passing through a value of 0 m/s Now, the downward acceleration increases the downward velocity.

Question: What is the ball's acceleration at the top of its path at t=2 s?

Answer: Gravity does not "turn off" at the top! The balls velocity is still changing, as it changes from going up to going down. For a moment the velocity is zero throughout the path.

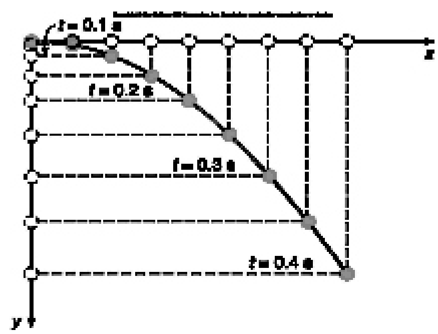
Projectile Motion

Definition: The motion of a thrown object under the influence of the gravity of the Earth is called a **projectile motion**.

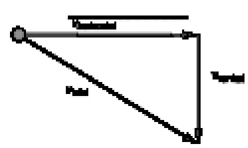
The path that a moving object follows is called its ***trajectory***. Consider an object thrown horizontally . The object accelerates downward under the influence of gravity. Gravitational acceleration is only vertical (always vertical), not horizontal. The object has both the horizontal and vertical velocities. The object's horizontal velocity is unchanged, if we can neglect air resistance. Projectile motion involves the trajectories and velocities of objects that have been launched, shot, or thrown.

What does the trajectory look like?

The acceleration of the horizontal motion is zero(in the absence of air resistance). The object moves with constant horizontal velocity. It travels equal horizontal. distances in equal time intervals. The acceleration in the vertical direction is constant. Its vertical velocity increases downward just like the falling ball. In each successive time interval, it falls a greater distance than in the previous time interval.

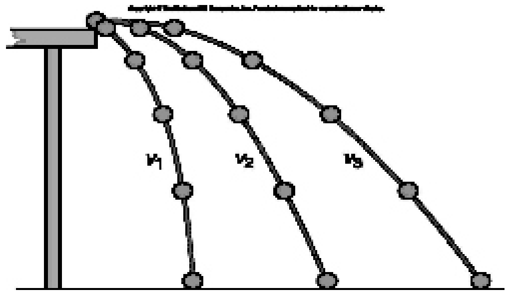


The total velocity at any point is found by adding the vertical component of the velocity, at that point, to the horizontal component of the velocity at that point. The horizontal velocity remains constant, because there is no acceleration in that direction. The downward (vertical) velocity gets larger and larger, due to the acceleration due to gravity.



Trajectories for different initial velocities of a ball rolling off a table:

The largest initial velocity is v_3.The smallest initial velocity is v_1. The ball travels greater horizontal distances when. projected with a larger initial horizontal velocity.



Question:

Which of these three balls in the picture at the bottom of the previous page would hit the floor first if all three left the tabletop at the same time?

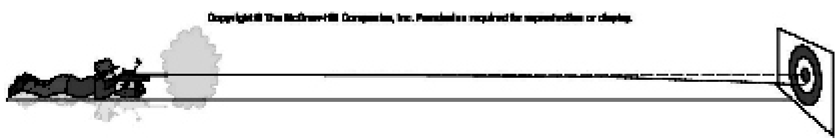
Answer:

Since all three balls undergo the same downward acceleration, and they all start with a vertical velocity of zero, they would all fall the same distance in the same time! **So they would all hit at the same time.**

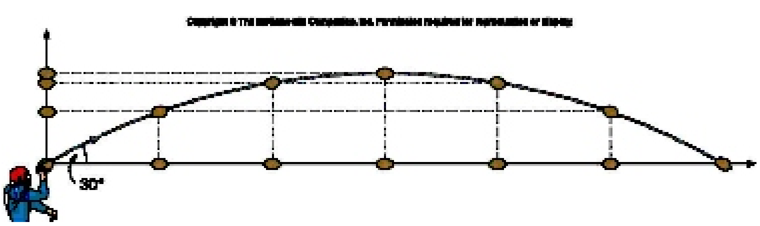
Treating the vertical motion independently of the horizontal motion, and then combining them to find the trajectory, is the secret. A horizontal glide combines with a vertical plunge to produce a graceful curve. The downward gravitational acceleration behaves the same as for any falling object. There is no acceleration in the horizontal direction if air resistance can be ignored. The projectile moves with constant horizontal velocity while it is accelerating downward.

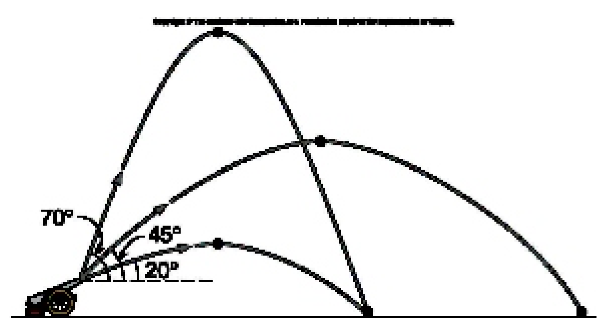
Example:

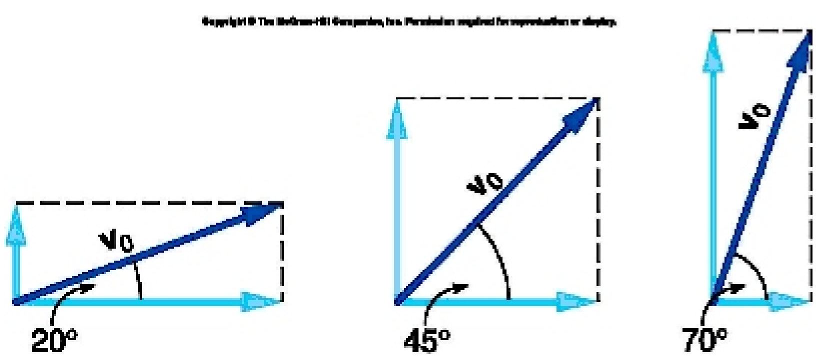
If the rifle is fired directly at the target in a horizontal direction, will the bullet hit the center of the target? Does the bullet fall during its flight?



The trajectory of a projectile depends on the initial velocity. The trajectory depends also on the launch angle. We will consider lunches with angles above the horizontal







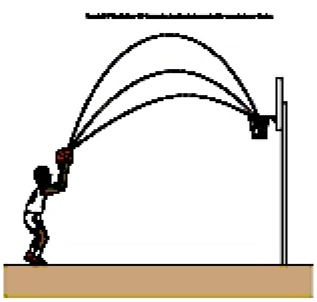
1. For the lowest angle, the horizontal velocity is much greater than the initial vertical velocity. The ball does not go very high, so its time of flight is short.

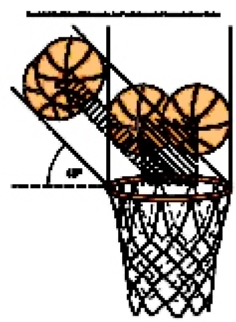
2. The intermediate angle of 45˚divides the initial velocity equally between the vertical and the horizontal. The ball stays in the air longer than at low angles, but also travels with a greater horizontal velocity than at high angles.

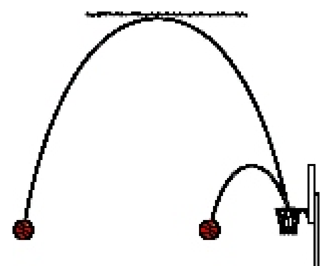
3. For the highest angle, the initial vertical velocity is much greater than the horizontal velocity. The ball goes higher, so its time of flight is longer, but it does not travel very far horizontally.

Question: Which free throw trajectory has the greatest chance of success?

Answer: The ball coming straight down has a wider range of possible paths.







Away from the basket, flatter trajectories allow more accurate control.Spin of the basketball, height of release, and other factors also play a role.

Question: Which of the two trajectories shown will result in a longer time for the ball to reach home plate?

Answer: The higher trajectory takes longer. The time of flight is determined by the initial vertical velocity component which also determines the maximum height reached.