Solutions to Free Fall Problems

1. An object is tossed into the air. As it rises, what happens to the acceleration of the object?

   The acceleration is due to gravity and, therefore, constant. It does not change.

2. A 10 [kg] object is dropped from rest.
   a. How far will it drop in 2 [s]?

   $$v_i = 0$$
   $$t = 2\,[\text{s}]$$
   $$a = g = 9.81\,[\text{m/s}^2]$$
   $$d = ?$$

   $$d = v_i t + \tfrac{1}{2}at^2$$
   $$d = \tfrac{1}{2}(9.81)(2)^2$$
   $$d = 19.62\,[\text{m}]$$

   b. How long will it take a 5 [kg] object to drop the same distance?

   It will take the less massive object the same amount of time (2 [s]) to fall the same distance because the acceleration due to gravity is a constant and doesn't depend upon mass.

3. An object is dropped from rest from the top of a 100 [m] building. How long will it take for the object to hit the ground?

   Let's define down as the positive direction and up as the negative direction. From this point on, we must remember that any vector pointing down is positive and any vector pointing up is negative.

   $$d = 100\,[\text{m}]$$
   $$v_i = 0$$
   $$a = g = 9.81\,[\text{m/s}^2]$$
   $$t = ?$$

   $$d = v_i t + \tfrac{1}{2}at^2$$
   $$d = \tfrac{1}{2}at^2$$
   $$t = \sqrt{\frac{2d}{a}}$$
   $$t = \sqrt{\frac{2(100)}{9.81}} = 4.52\,[\text{s}]$$

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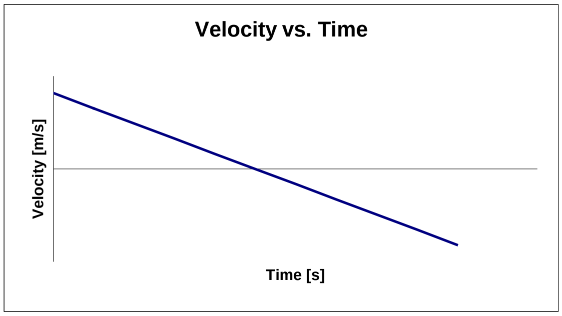
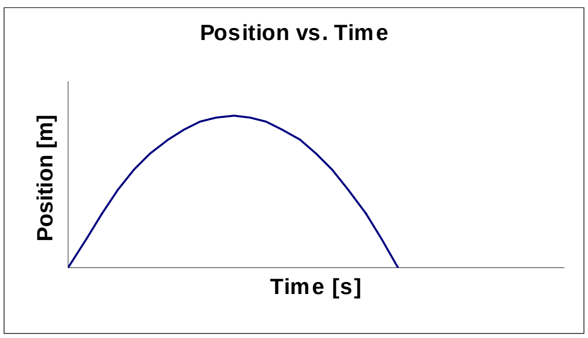
4. An object is tossed into the air and allowed to drop to the ground.
    a. Sketch a graph of position vs. time for the motion of the object.



    b. Sketch a graph of velocity vs. time for the motion of the object.



5. A cliff diver from the top of a 100 [m] cliff. He begins his dive by jumping up with a velocity of 5 [m/s].
    a. How long does it take for him to hit the water below?
    b. What is his velocity right before he hits the water?

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Let's start by defining up as the positive direction and down as the negative direction. From this point on we must remember to consider any vector that points up as positive and any vector that points down as negative.

It is easier to solve part b of this problem prior to solving part a.

$d = -100\,[\text{m}]$

$v_i = +5\,[\text{m/s}]$

$a = g = -9.8\,[\text{m/s}^2]$

$t = ?$

$$v_f^2 = v_i^2 + 2ad$$

$$v_f = \sqrt{(5)^2 + 2(-9.8)(-100)}$$

$$v_f = -44.6\,[\text{m/s}]$$

$$v_f = v_i + at$$
$$t = \frac{v_f - v_i}{a}$$
$$t = \frac{-44.6 - 5}{-9.8} = 5.06\,[\text{s}]$$

6. Alan Iverson slam dunks a basketball and a physics student observes that Iverson’s feet are 1 [m] above the floor at his peak height. At what upward velocity must Iverson leave the floor to achieve this?

   Let’s define up as the positive direction and down as the negative direction. From this point on we must consider any vectors pointing up as positive and any vectors pointing down as negative.i

   $$d = 1\,[\text{m}]$$
   $$a = g = -9.8\,[\text{m/s}^2]$$
   $$v_f = 0$$
   $$v_i = ?$$

   $$v_f^2 = v_i^2 + 2ad$$
   $$v_i = \sqrt{v_f^2 - 2ad}$$
   $$v_i = \sqrt{0 - 2(-9.8)(1)}$$
   $$v_i = 4.4\,[\text{m/s}]$$

7. A bullet is shot vertically into the air with a velocity of +450 [m/s]. Neglecting air resistance,
   a. How long is the bullet in the air?

      In this problem, the frame of reference has already been set for us. The author has defined up as positive. From this point on we must consider all vectors pointing upward as positive and all those pointing downward as negative.

      To start, we can solve for the time it takes the bullet to reach its maximum height. The total time it is in the air is twice that.

      $$v_i = 450\,[\text{m/s}]$$
      $$v_f = 0$$
      $$a = g = -9.8\,[\text{m/s}^2]$$
      $$t_{up} = ?$$

      $$v_f = v_i + at_{up}$$
      $$t_{up} = \frac{v_f - v_i}{a}$$
      $$t_{up} = \frac{0 - 450}{-9.8} = 45.9\,[\text{s}]$$
      $$t_{total} = 2t_{up} = 91.8\,[\text{s}]$$

   b. How high does the bullet go?

$$d = ?$$
$$v_f^2 = v_i^2 + 2ad$$
$$d = \frac{v_f^2 - v_i^2}{2a}$$
$$d = \frac{0 - (450)^2}{2(-9.8)}$$
$$d = 10332\,[\text{m}]$$

8. A sandbag is dropped from a hot air balloon that is 300 [m] above the ground and rising at a rate of 13 [m/s].
   a. How long does it take for the sandbag to hit the ground?
   b. How fast is the sand bag going when it hits the ground?

   Let's define up as the positive direction and down as the negative direction. From this point on we must consider all vectors that point up as positive and all vectors that point down as negative.

   Note that the sandbag is initially traveling with the balloon and, therefore, shares its initial velocity.

   Like with number 5, it is easier to solve part b prior to solving part a.

$$v_i = 13\,[\text{m/s}]$$
$$d = -300\,[\text{m}]$$
$$a = g = -9.8\,[\text{m/s}^2]$$
$$t = ?$$

$$v_f^2 = v_i^2 + 2ad$$
$$v_f = \sqrt{(13)^2 + 2(-9.8)(-300)}$$
$$v_f = -77.8\,[\text{m/s}]$$

$$v_f = v_i + at$$
$$t = \frac{v_f - v_i}{a}$$
$$t = \frac{-77.8 - 13}{-9.8} = 9.27\,[\text{s}]$$

   c. At what height is the balloon when the sand bag hits the ground? (Remember that the balloon is rising at a constant rate while the sand bag is in the air.)

While the sandbag is falling, the balloon is still rising at a rate of 13 [m/s]. The height of the balloon is then the initial 300 [m] plus the displacement of the balloon in the time the sandbag was falling.

$$d = d_i + \bar{v}t$$
$$d = 300 + (13)(9.27) = 420.5\,[\mathrm{m}]$$