Chapter 3

1

Motion in one dimension

1

Lecture 03

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Freely Falling Objects

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Freely Falling Objects

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- A freely falling object is any object moving vertically under the influence of gravity alone.
- We will neglect air resistance
- It is a motion in one dimension
- It is a motion with constant acceleration
- It does not depend upon the initial velocity of the object. Including:
  - Dropped (released from rest)
  - Thrown vertically (straight) down
  - Thrown vertically (straight) up

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Acceleration of Freely Falling Object

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- The acceleration of an object in free fall is directed downward, regardless of the initial motion.
- The magnitude of free fall acceleration is

$$g = 9.8\ m/s^2$$

- Let upward be positive
- Use the kinematic equations and:
  - replace the acceleration (a) with (-g).
  - replace the displacement (Δx) with (Δy)

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Equations – Freely Falling

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$$g = 9.8\ m/s^2$$

Equations	Missing
$v_f = v_i - gt$	Δy : displacement (m)
$v_f^2 = v_i^2 - 2g\Delta y$	t : time (s)
$\Delta y = v_i t - \frac{1}{2}gt^2$	v_f : final velocity (m/s)
$\Delta y = v_f t + \frac{1}{2}gt^2$	v_i : initial velocity (m/s)

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Equations – Freely Falling

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NOTE : when applying kinematic equations:

- Consider the launching point as our reference point ($y_i = 0$). Therefore; the final position will be:
  - positive when the object above (y_i),
  - and negative when it is below (y_i).
- The velocity is:
  - positive while the object is moving upward,
  - negative while it is moving downward
  - and Zero at its maximum height.

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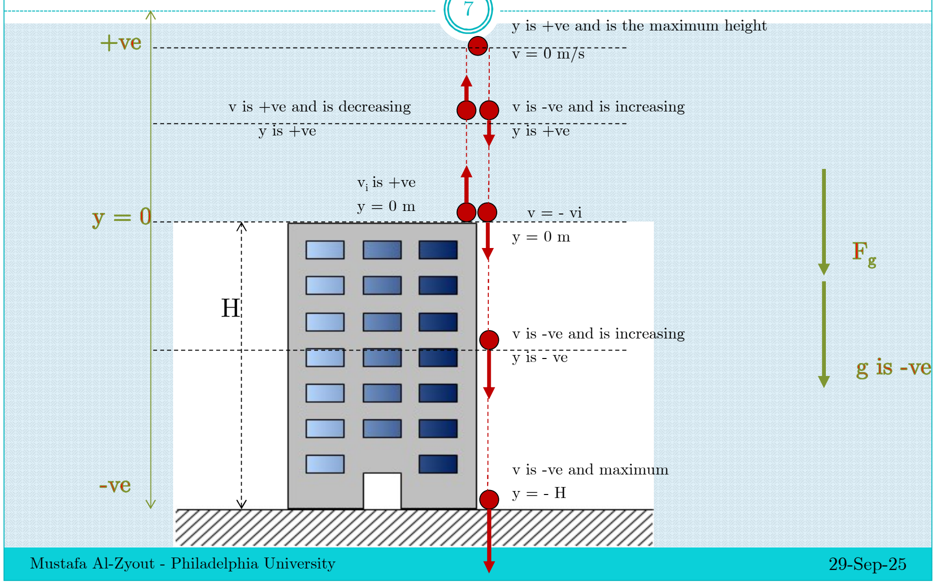
Freely Falling, signs of : y , v and g



Mustafa Al-Zyout - Philadelphia University 29-Sep-25

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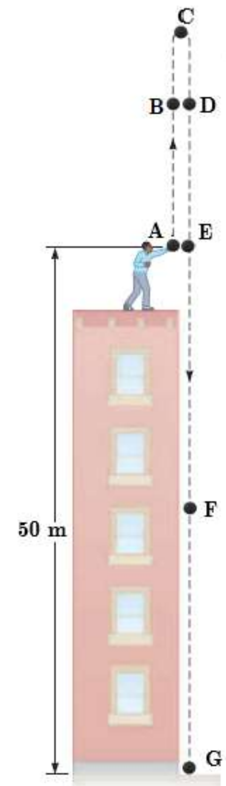
Free Falling - 1

Friday, 29 January, 2021 21:33

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

A stone thrown from the top of a building is given an initial velocity of $20\ m/s$ straight upward. The stone is launched $50\ m$ above the ground, and the stone just misses the edge of the roof on its way down as shown.



- Determine the time at which the stone reaches its maximum height.
- Find the maximum height of the stone.
- Determine the velocity of the stone when it returns to the height from which it was thrown.
- Find the position of the stone at $t = 5\ s$.
- Find the velocity of the stone at $t = 5\ s$.
- How long does the stone take to reach the ground?
- How long does the stone take to reach a point $15\ m$ above its release point?

(A) Solution

We use the equation that does not involve position:

$$v_{yf} = v_{yi} - gt \Rightarrow t = \frac{v_{yf} - v_{yi}}{-g}$$

$$\Rightarrow t = t_B = \frac{0 - 20.0m/s}{-9.80m/s^2} = 2.04s$$

(B) Solution

We use the equation that does not involve time:

$$v_{yB}^2 = v_{yA}^2 - 2g(y_B - y_A)$$

$$0^2 = (20)^2 - 2(9.8)(y_B - 0) \Rightarrow y_B = 20.4m$$

(C) Solution

We use the equation that does not involve time:

$$v_{yc}^2 = v_{yA}^2 - 2g(y_c - y_A)$$

$$v_{yc}^2 = (20)^2 - 2(9.8)(0 - 0) = 400m^2/s^2$$

$$v_{yc} = -20.0m/s$$

(D) Solution

We use the equation that does not involve final velocity:

$$y_D = y_A + v_{yA}t - \frac{1}{2}gt^2$$

$$= 0 + (20.0m/s)(5.00_s)^2 - \frac{1}{2}(9.80m/s^2)(5.00s)^2 = -22.5m$$

(E) Solution

We use the equation that does not involve position:

$$v_{yD} = v_{yA} - gt = (20.0m/s) - (9.80m/s^2)(5.00s) = -29.0m/s$$

(F) Solution

We know $v_i = +20\ m/s$, $a\ = -g$, and displacement $y_i = 0$, $y_f\ = -50\ m$, and we want t, so:

$$y_f - y_i = v_i t - \frac{1}{2}gt^2\ \Rightarrow\ 50 = (20)t - \left(\frac{1}{2}\right)(9.8)t^2$$

$$\Rightarrow\ 4.9t^2 - 20t - 50 = 0\ \Rightarrow\ t = 5.83s\ and\ t = -1.75s.$$

The negative answer represents the time the stone will take if it was initially thrown downward.

(G) Solution

We know v_i, $a\ = -g$, and displacement $y_i = 0$, $y_f\ = 15\ m$, and we want t, so:

$$y_f - y_i = v_0 t - \frac{1}{2}gt^2\ \Rightarrow\ 15.0m = (20m/s)t - \left(\frac{1}{2}\right)(9.8m/s^2)t^2$$

$$\Rightarrow\ 4.9t^2 - 20t + 15.0 = 0\ \Rightarrow\ t = 0.99s \text{ and } t = 3.09s.$$

There are two such times! This is not really surprising because the ball passes twice through y $=\ 15\ m$, once on the way up and once on the way down.

Free Falling - 2

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A boy throws a ball upwards, giving it an initial speed $v_i = 15\ m/s$. How long does the ball take to return to the boy's hand?

Solution:

Observe that both the initial and final velocities are equal in magnitude, but in opposite directions. We use the equation that does not involve position:

$$v_f = v_i - gt$$

$$-15 = 15 - 9.8t$$

$$t = \frac{-30}{-9.8} = 3.06s$$

Free Falling - 3

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R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

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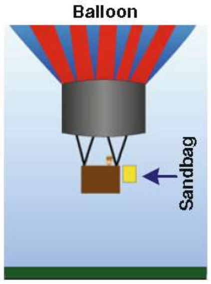

A sandbag dropped from a balloon reaches the ground in 5 s. Find the height of the balloon if:

(a) it was at rest in the air,

(b) it was ascending with a speed of 10 m/s when the sandbag was dropped,

(c) it was descending with a speed of 10 m/s when the sandbag was dropped.

(a) Solution

We know $v_i = 0\ m/s$, $a = -g$, and $t = 5\ s$, and we want y_f, so:

$$y_f - y_i = v_i t - \frac{1}{2} g t^2$$

$$\Rightarrow\ y_f - 0 = 0 \times 5 - \frac{1}{2} \times 9.8 \times 5^2 = -122.5\ m$$

$$\Rightarrow H = 122.5\ m$$

(b) Solution

We know $v_i = 10\ m/s$, $a = -g$, and $t = 5\ s$, and we want y_f, so:

$$y_f - y_i = v_i t - \frac{1}{2} g t^2$$

$$\Rightarrow\ y_f - 0 = 10 \times 5 - \frac{1}{2} \times 9.8 \times 5^2 = -72.5\ m$$

$$\Rightarrow H = 72.5\ m$$

(c) Solution

We know $v_i = -10\ m/s$, $a = -g$, and $t = 5\ s$, and we want y_f, so:

$$y_f - y_i = v_i t - \frac{1}{2} g t^2$$

$$\Rightarrow\ y_f - 0 = -10 \times 5 - \frac{1}{2} \times 9.8 \times 5^2 = -172.5\ m$$

$$\Rightarrow H = 172.5\ m$$