

MODULE 6

GRAVITY AND VERTICAL MOTION BASICS

INTRODUCTION

Motion can look very simple, yet it hides one of the most powerful ideas in Physics: near the Earth's surface, every object released in the air experiences the same downward pull. Whether you drop a mango from a tree, toss a stone upward, or jump off a step, the motion is controlled by a constant downward acceleration called the **acceleration due to gravity**. This is why a falling object speeds up as it descends and why an upward-moving object slows down until it briefly stops at the highest point before returning downward. Understanding this vertical motion is essential because it forms the entire foundation of **projectile motion**, where vertical and horizontal motions combine to produce curved paths.

Vertical motion under gravity is the motion of an object along a straight vertical line in which the only acceleration acting is due to gravity (air resistance is ignored).

This is going to be very helpful to you!

In dealing with motion under gravity it is important to understand the following facts:

- ✓ The acceleration due to gravity (g) is always directed downward. Its value is 9.8m/s^2 which means that: each second, the vertical velocity changes by 9.8m/s .
- ✓ If an upward-thrown body is moving upward, the velocity will be positive while the acceleration due to gravity will be negative ($a = -g$).
- ✓ If the same body is moving downward, the velocity will be negative while the acceleration due to gravity will be positive ($a = +g$).

- ✓ When an object is thrown upward, gravity acts downward (gravity opposes the motion), so the object loses speed as it rises until it becomes momentarily at rest at highest point just before start returning downward. Thus, velocity=0m/s at the highest point.
- ✓ If a body returns to the same level it was thrown from, the motion is symmetric and hence:
 - Time going up = time coming down.
 - Speed at the same height going up = speed at the same height coming down.

The ingredients are ready; now let us see how they come together in worked examples.

BINDER Example 13

A stone is dropped from rest from the top of a building. Neglect air resistance.

- (a) What is its initial velocity?
- (b) What is its acceleration?

Solution

Tactical idea: “dropped from rest” $\Rightarrow u=0\text{m/s}$

- (a) Initial velocity: $u=0\text{m/s}$ (“dropped from rest” means initial velocity is 0m/s).
- (b) Acceleration: $a = +g = +9.8\text{m/s}^2$.

Making Sense of the Answer: *The stone starts with no speed, but gravity immediately makes it speed up downward.*

Think Like a Physicist: *In free fall, every second adds more speed because gravity acts continuously.*

REAL Example 14

Kipute drops a small coin from the laboratory balcony. **Kipanga** notices the coin moves slowly at first, then faster and faster until it hits the ground. Explain why.

Solution

The coin speeds up because gravity provides a constant downward acceleration, g . As time increases, the downward velocity increases, so the coin falls faster and faster.

Making Sense of the Answer: *The coin is not being pushed by hands, but gravity is pulling it every moment.*

Think Like a Physicist: *Falling objects accelerate because their velocity changes each second.*

BINDER Example 15

A stone is dropped from rest and falls for 3s. Take $g = 10\text{m/s}^2$. Find its final velocity.

Solution

Using $v = u + at$

Where: $u = 0\text{m/s}$, $t = 3\text{s}$, $a = 9.8\text{m/s}^2$

Substituting $v = (0\text{m/s}) + \left(\frac{10\text{m}}{\text{s}^2}\right)(3\text{s}) = v = 30\text{m/s}$

The final velocity is 30m/s.

Making Sense of the Answer: *Each second the stone gains 10m/s, so after 3s it gains 30m/s.*

Think Like a Physicist: *If you start from rest, velocity after time t is simply gt .*

BINDER Example 16

A stone is dropped from rest from a height of 45m. Take $g = 10\text{m/s}^2$. Find the time taken to reach the ground.

Solution

Using $s = ut + \frac{1}{2}at^2$

Where: $u = 0\text{m/s}$, $s = 45\text{m}$, $a = 10\text{m/s}^2$

Substituting $45\text{m} = (0\text{m/s})t + \frac{1}{2}\left(\frac{10\text{m}}{\text{s}^2}\right)t^2$

From which; $t = 3\text{s}$

The time taken is 3s.

Making Sense of the Answer: *The stone does not fall at a constant speed. It starts from rest and gains speed by 10m/s every second, so in the first second it covers a small distance, but in later seconds it covers much more. That is why it reaches the ground in 3s.*

Think Like a Physicist: *In vertical fall from rest, displacement depends on t^2 , so the fall accelerates quickly.*

HOT Example 17

A ball is thrown vertically upward from the ground with initial velocity 19.6m/s. Take $g = 9.8\text{m/s}^2$. Find the time taken to reach the highest point.

Solution

At the highest point, $v = 0\text{m/s}$

Using $v = u + at$

Where: $u = 19.6\text{m/s}$, $v = 0\text{m/s}$, $a = -9.8\text{m/s}^2$

$$\text{Substituting } 0\text{m/s} = 19.6\text{m/s} + (-9.8\text{m/s}^2)t$$

$$\text{From which; } t = 2\text{s}$$

The time to the highest point is 2s.

Making Sense of the Answer: Gravity removes 9.8m/s from the upward speed every second, so it takes 2 seconds to reduce 19.6m/s ($2 \times 9.8\text{m/s}$) to zero.

Think Like a Physicist: Time to the top is equal to $\frac{u}{g}$.

HOT Example 18

A ball is thrown vertically upward from the ground with initial velocity 24.5m/s. Take $g = 9.8\text{m/s}^2$. Find the maximum height reached.

Solution

Again, at the highest point, $v = 0\text{m/s}$.

$$\text{Using } v^2 = u^2 + 2as$$

Where $u = 24.5\text{m/s}$, $v = 0\text{m/s}$, $a = -9.8\text{m/s}^2$ and $s = H$ (maximum height)

$$\text{Substituting } (0\text{m/s})^2 = (24.5\text{m/s})^2 + 2(-9.8\text{m/s}^2)H$$

$$\text{From which; } H = 30.625\text{m}$$

The maximum height is 30.625m.

Making Sense of the Answer: The stone rises until gravity removes all its upward speed at 30.625m above the ground.

Think Like a Physicist: Maximum height depends on the square of the initial velocity; that is $H = \frac{u^2}{2g}$.

HOT Example 19

A ball is thrown vertically upward from the ground with initial velocity 19.6m/s . Take $g = 9.8\text{m/s}^2$. Find the total time of flight before it returns to the ground.

Solution

Time to reach the highest point was found using $v = 0\text{m/s}$.

And by using $v = u + at$

Where: $u = 19.6\text{m/s}$, $a = -9.8\text{m/s}^2$

Then, by substituting $0\text{m/s} = 19.6\text{m/s} + (-9.8\text{m/s}^2)t$; $t = 2\text{s}$

The time to the highest point is 2s .

Since the motion is symmetric, the total time of flight, $T = 2t = 2 \times 2\text{s} = 4\text{s}$.

The time of flight is 4s .

Making Sense of the Answer: *It takes 2 seconds to rise and 2 seconds to fall back to the ground, making a total of 4s.*

Think Like a Physicist: *The total time of flight is equal to $\frac{2u}{g}$.*

HOT Example 20

A ball is thrown vertically upward from the ground with initial velocity 20m/s . Take $g = 9.8\text{m/s}^2$. Find the time when the ball is at a height of 5m on its way downward.

Solution

A given height is reached twice: once going up and once coming down. The larger time corresponds to the downward path.

Using $s = ut + \frac{1}{2}at^2$

Where: $u = 20\text{m/s}$, $a = -9.8\text{m/s}^2$, $s = 5\text{m}$

Substituting $5\text{m} = (20\text{m/s})t + \frac{1}{2}\left(-\frac{9.8\text{m}}{\text{s}^2}\right)t^2$

Rearrange to the quadratic equation:

$$4.9t^2 - 20t + 5 = 0$$

From which; $t = 0.27\text{s}$ or 3.81s

Since the ball is on its way downward, the suitable time is the larger one which is 3.81s .

The time at 5m on the way down is 3.81s .

Making Sense of the Answer: *The ball passes 5m quickly when rising, then returns to 5m much later while falling.*

Think Like a Physicist: *One displacement can correspond to two different times in vertical motion.*

That brings our subtopic-by-subtopic worked examples to a satisfying close. The plates are cleared! Now let us enjoy the full buffet, where all the ideas of this topic come together in miscellaneous worked examples.