

Freely Falling Objects

Physics 1425 Lecture 3

Today's Topics

- In the previous lecture, we analyzed one-dimensional motion, defining displacement, velocity, and acceleration and finding formulas for motion at constant acceleration.
- Today we'll apply those formulas to objects falling, but first we'll review how we know that falling motion *is* at constant acceleration.

Galileo's Idea

- Before Galileo, it was believed that falling objects quickly reached a natural speed, proportional to weight, then fell at that speed.
- Galileo argued that in fact falling objects continue to *pick up speed* (unless air resistance dominates) and that this acceleration is the same for all objects.
- **But how to convince people?** Watching a falling object, it's all over so quickly.

Dropping a Brick

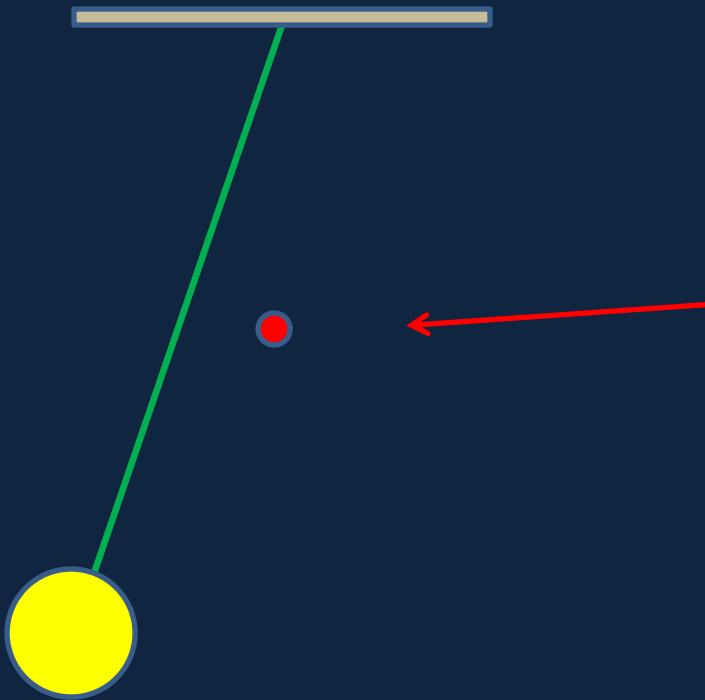
- Galileo claimed people already knew this without realizing it:
- Imagine driving a nail into a board by dropping a weight on it from various heights. Everyone already knows that the further it falls, the more impact—which must mean it's moving faster.
- But how much faster? Not so easy to tell!
Is there some way to slow down the motion?

Slowing down the motion...

- A feather falls slowly—but Galileo argued that *that* motion (fairly steady speed) was dominated by air resistance, so was **unlike** ordinary falling of a weighty object.
- He found another way to slow things down ... here's his experiment—in two parts, the pendulum and the ramp.

A Two-Timing Pendulum

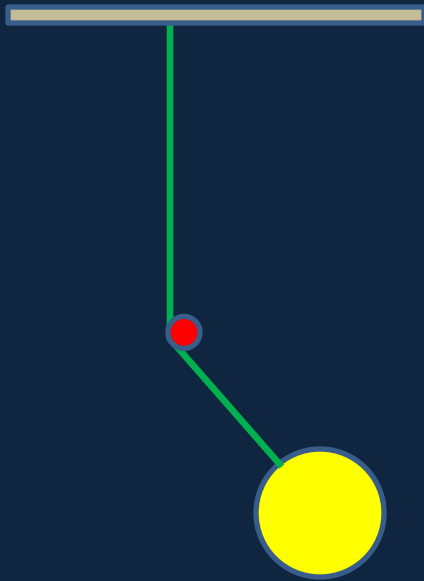
- Pendulum with peg



- First he took a pendulum swinging freely back and forth, then he introduced a **fixed peg** directly below the point the pendulum hangs from.

A Two-Timing Pendulum

- Pendulum with peg



- The pendulum will now move around a tighter arc on the right-hand side.

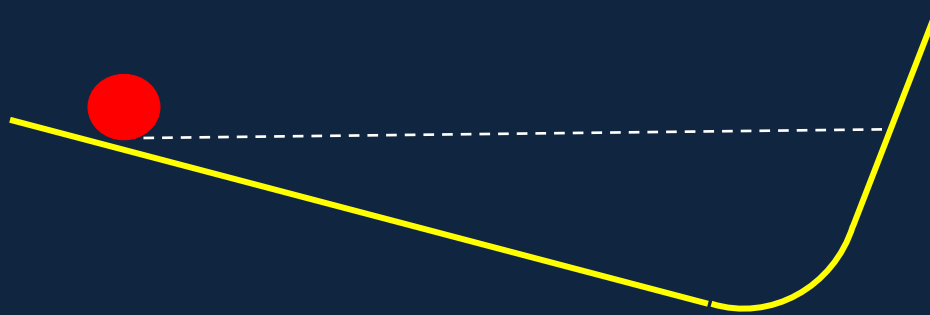
Clicker Question: Which is correct?

- A. The pendulum is moving **faster** at the lowest point when it is **coming in from the left** (from the wider arc).
- B. The pendulum is moving **faster** at the bottom when it is **coming in from the right** (from the tighter arc).
- C. The pendulum speed at the bottom is the **same either way**.

(All neglecting the small effects of air resistance.)

Galileo's Ramp Idea

- Galileo argued that his two-sided pendulum was like two ramps,



one steep and one shallow, and a ball rolling to the bottom would have the same speed from either side.

And why not take one side **vertically** steep? Then the ball would just be falling!

Rolling Down the Ramp is Slow Mo Falling

- If rolling down the ramp the ball picks up the same speed that it would by just *falling* the same *vertical* distance, timing the slow roll can check Galileo's claim that speed is picked up *uniformly* in falling!
- In particular, Galileo **compared the times** for the **full distance** roll and that for **one-quarter of the full distance**. We'll do this.

Galileo's Ramp Experiment Result

- Galileo found that in **twice the time**, the ball rolled **four times the distance**.
- This agrees with the constant acceleration formula for motion starting from rest at the origin:

$$x = \frac{1}{2}at^2$$

- He also checked many other distances and found good agreement.

Clicker Question

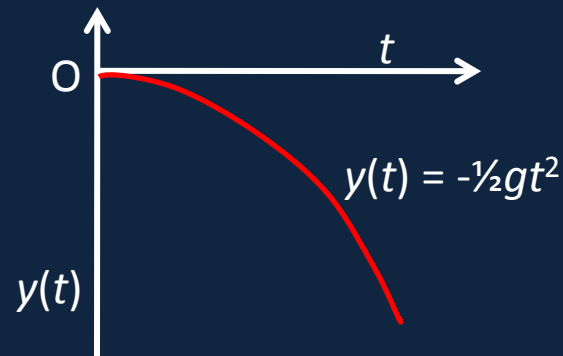
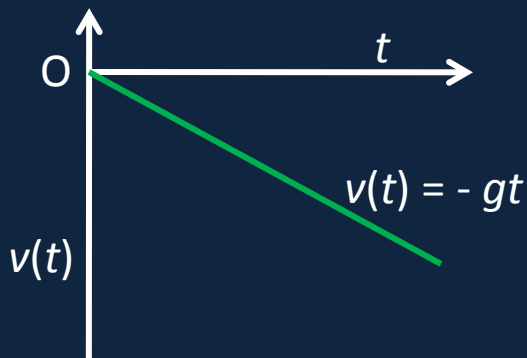
- Suppose in rolling down the ramp from rest at the top the ball is moving at 4 m/s at the bottom. What is its speed **half way down** the ramp?

- A. 2 m/s
- B. less than 2 m/s
- C. more than 2 m/s.

(Neglect friction.)

Acceleration Due to Gravity g

- Having established that in the absence of air resistance all objects fall (near the Earth's surface) with the same acceleration g , g can be measured by timing a fall and using $y = \frac{1}{2}gt^2$. Demo: chain of spaced weights.
- **Taking upwards as positive**, velocity and position as functions of time will look like this:

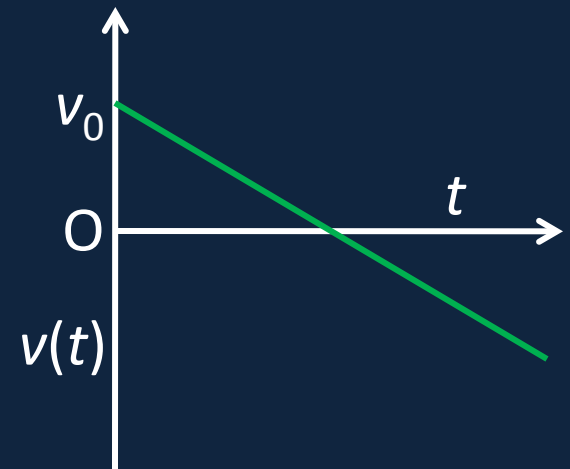


Ball Thrown Vertically Upwards

- Having chosen **upwards as positive**, the acceleration $a = -g = -9.8 \text{ m/s}^2$.
- While the ball is moving upwards it is **losing speed** at this rate.

- The velocity/time graph:

$$v(t) = v_0 - gt.$$



- The **slope** of the line is the **acceleration** $a = -g$.

Clicker Question

A ball is thrown vertically upwards. What is the direction of its acceleration *at the highest point* it reaches?

- A. Downwards
- B. Upwards
- C. At that point, the acceleration is zero.