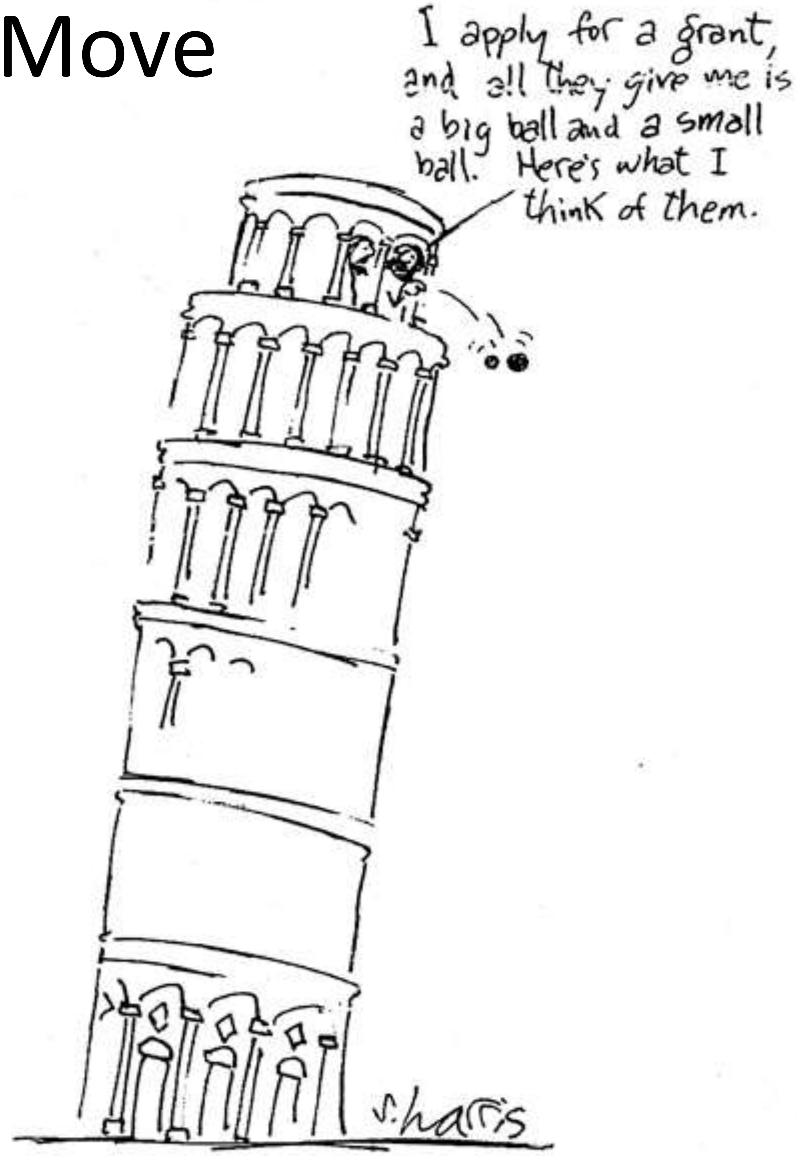
Lecture 2
How Things Move



Aristotle (384 to 335 B.C.E.)

He was an influential:

- Moralist
- Political scientist
- Literary critic
- Physicist
- Biologist
- Naturalist
- Logician
- Teacher
- Philosopher

Unfortunately, his physics was wrong…

Aristotle's Ideas about Motion

- Vertical and horizontal motion obey different rules
- Vertical motion
  - Objects fall towards the earth's surface
  - Heavier objects fall faster
- Horizontal motion
  - Moving objects come to rest
  - Objects at rest remain at rest

Hypothesis for vertical motion

$$\text{Speed of fall} \propto \frac{\text{Force}}{\text{Resistance}}$$

is proportional to

This would imply that:

- Heavy objects should fall faster
- Objects should fall more slowly through denser (more resistive) media
- Falling objects should not accelerate

- What if we were to drop a light (e.g. feather) and heavier (e.g. penny or rock) object simultaneously?

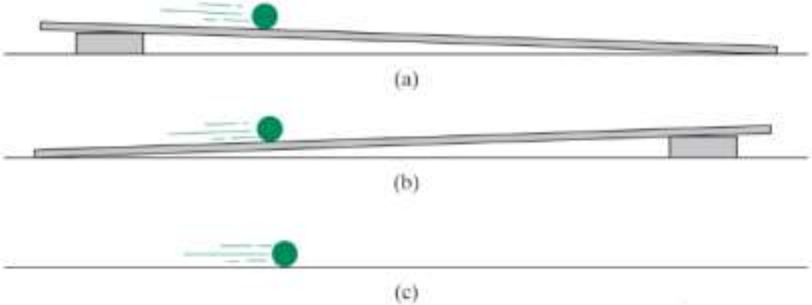
Animation

Problem: Falling motion is too fast!

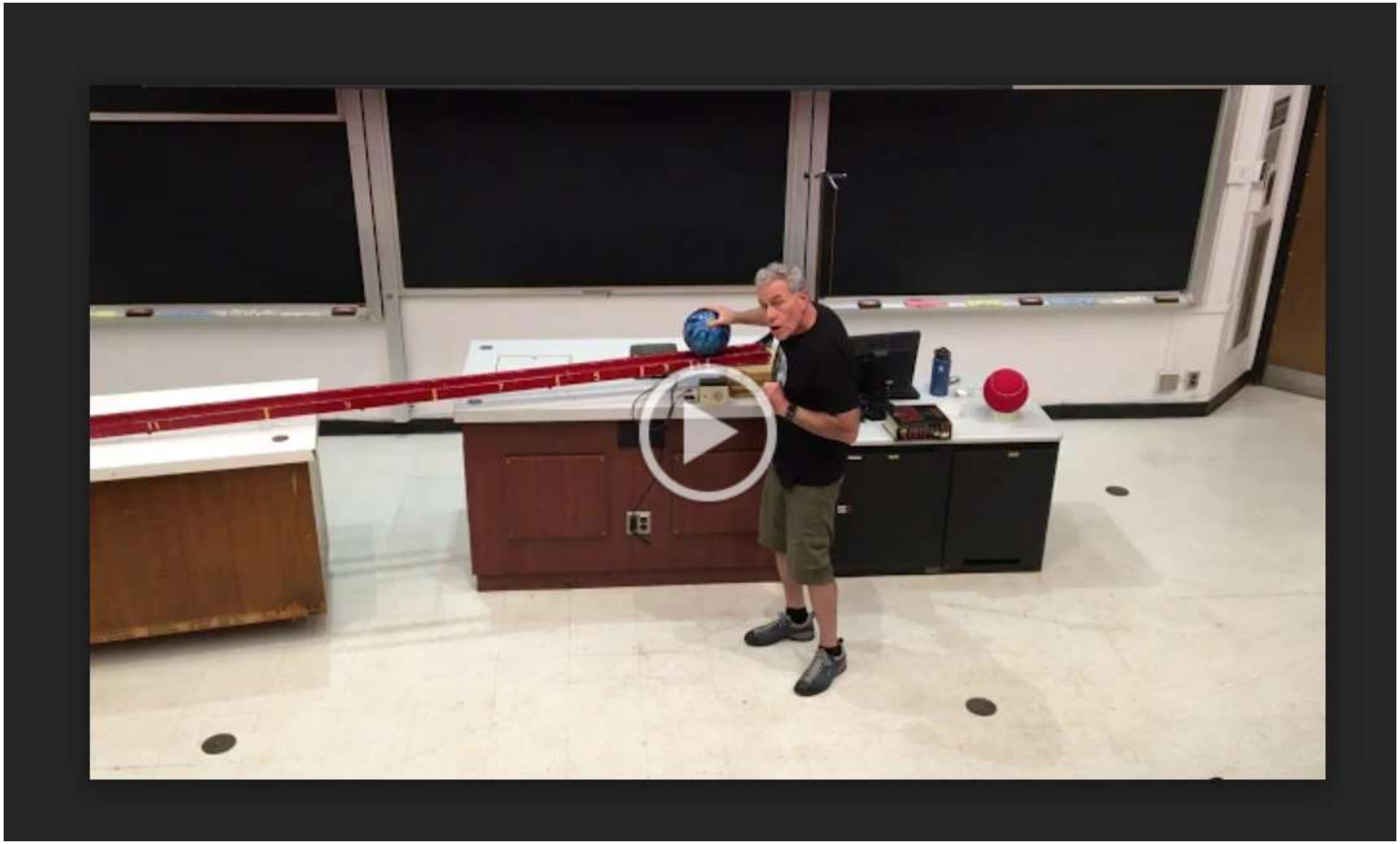
How to slow down the motion?

- Modern approach:
  - Slow-motion video

- Galileo approach:
  - Balls and ramps



[Rolling Ball Demo]



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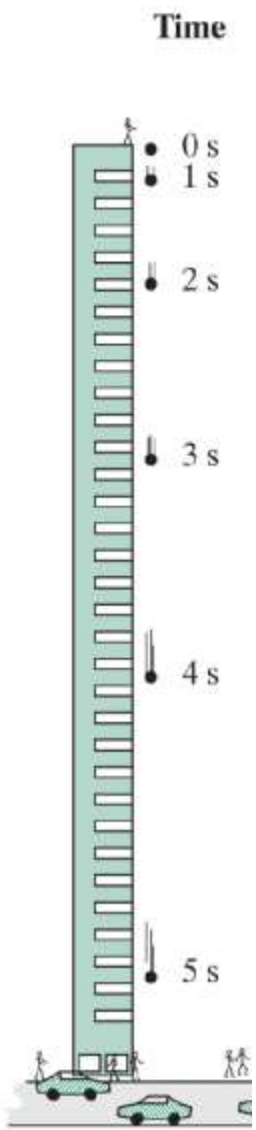
Galileo's Laws for Falling

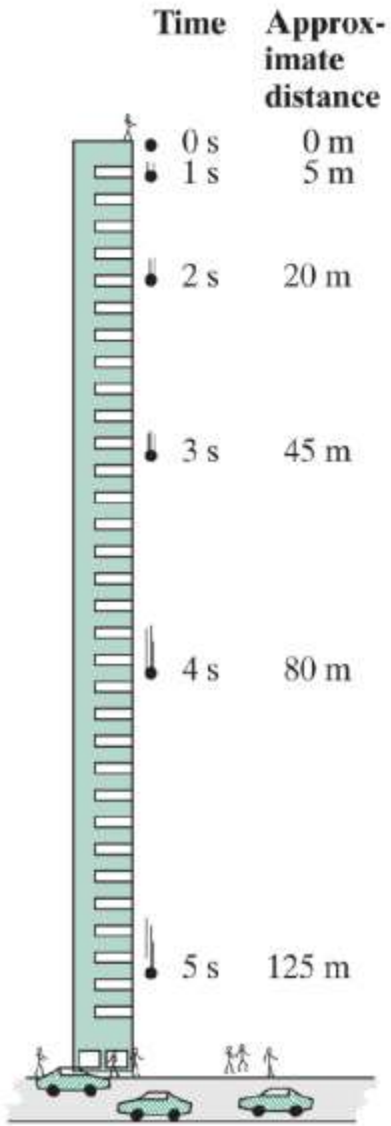
If air resistance is negligible:

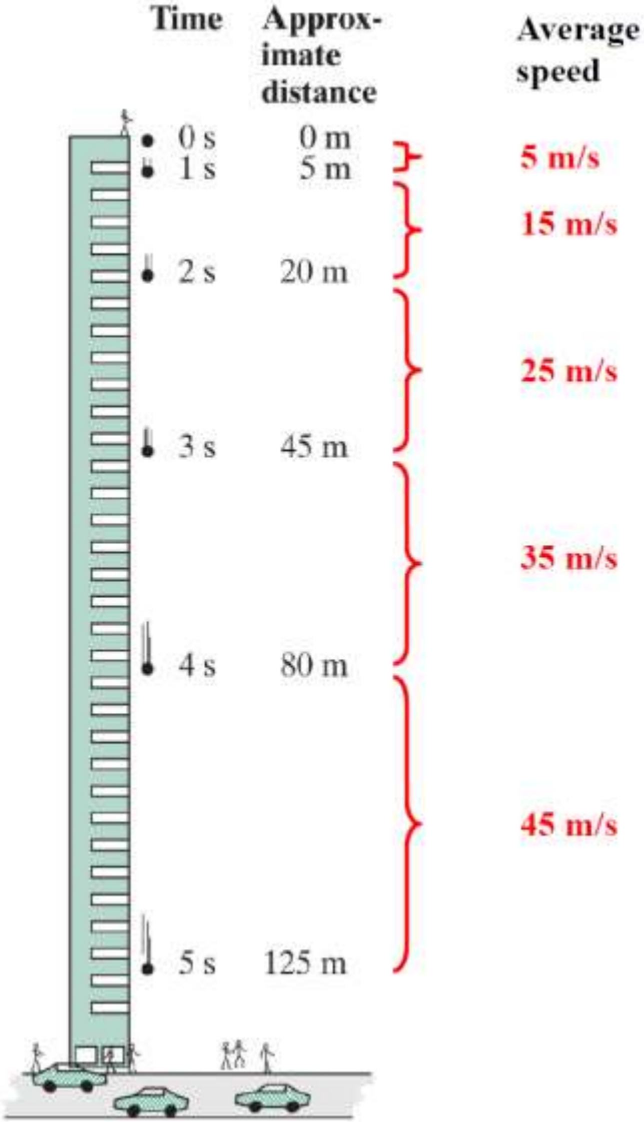
- Any two objects dropped together will fall together (regardless of material, shape, weight, etc.) !
- Falling objects gain an equal increment of speed in each equal increment of time

Measuring distance

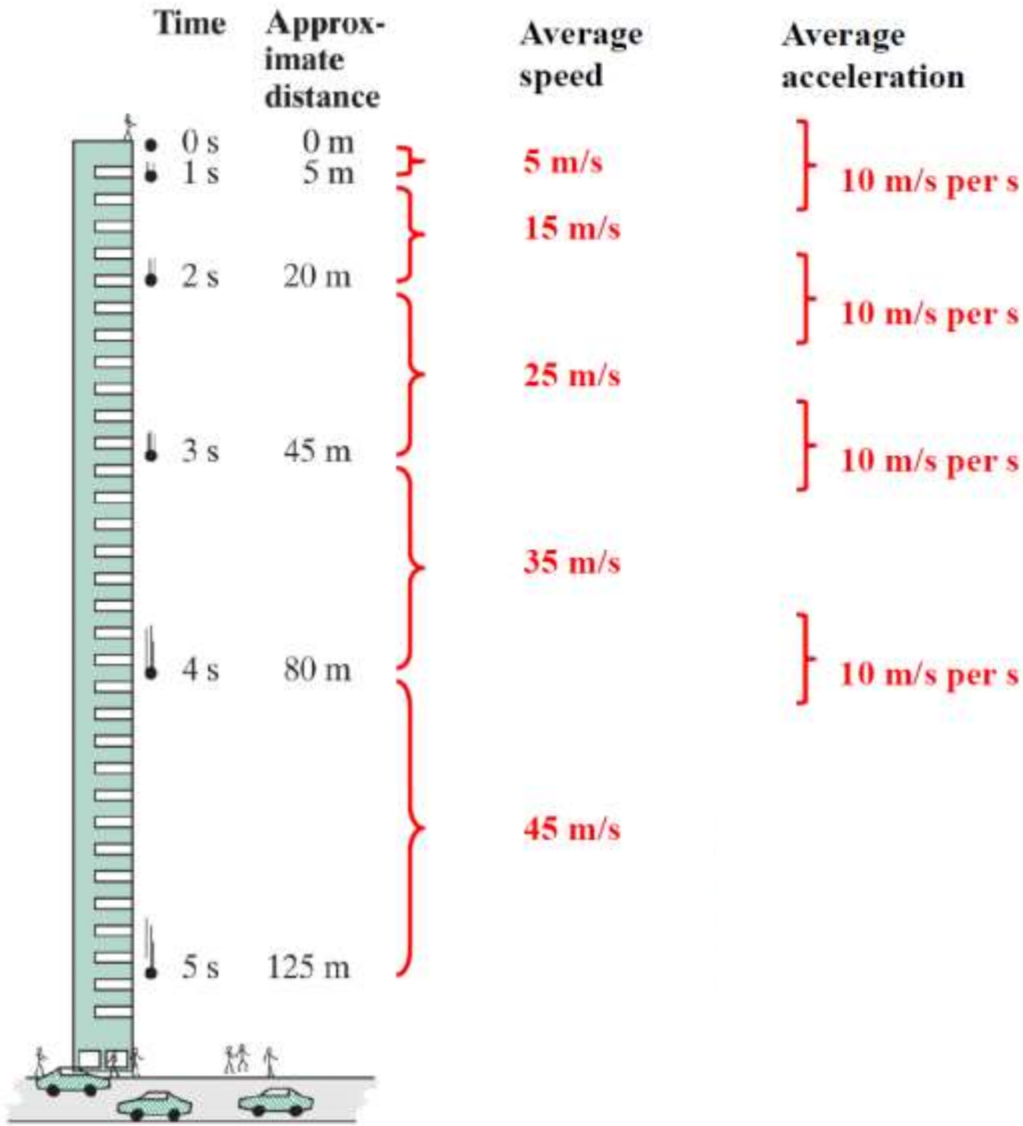
- Make marks at equal time increments
- Measure between them

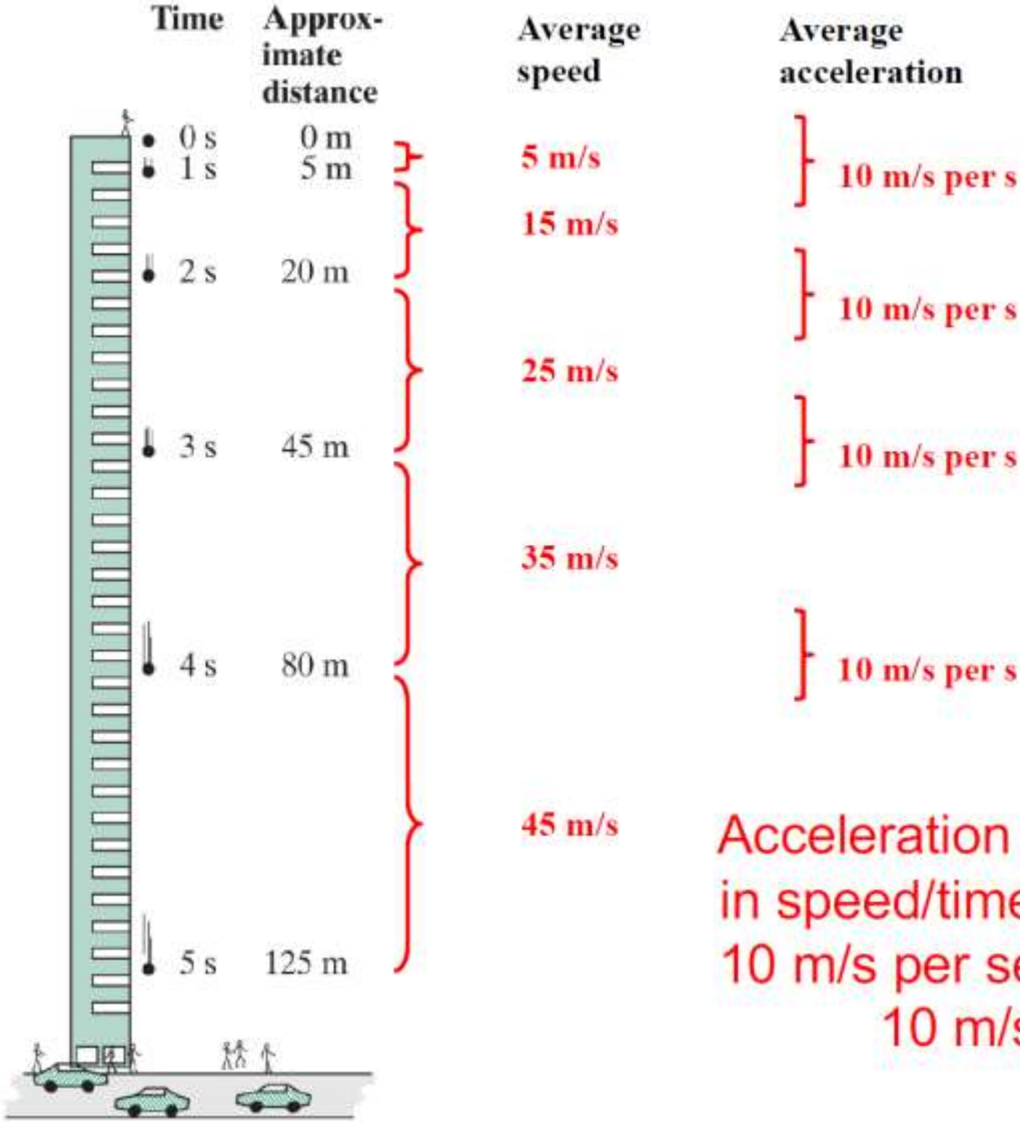

Time
0 s
1 s
2 s
3 s
4 s
5 s


Time
Approximate distance
0 s
0 m
1 s
5 m
2 s
20 m
3 s
45 m
4 s
80 m
5 s
125 m



Time
Approximate distance
Average speed
0 s
0 m
1 s
5 m
2 s
20 m
3 s
45 m
4 s
80 m
5 s
125 m
5 m/s
15 m/s
25 m/s
35 m/s
45 m/s


Time
Approx-imate distance
Average speed
Average acceleration
0 s
0 m
1 s
5 m
2 s
20 m
3 s
45 m
4 s
80 m
5 s
125 m
5 m/s
15 m/s
25 m/s
35 m/s
45 m/s
10 m/s per s
10 m/s per s
10 m/s per s
10 m/s per s



Acceleration (change in speed/time): about 10 m/s per second or 10 m/s^2

Galileo/Newton: Horizontal and vertical motion

- **The same laws of physics govern horizontal and vertical motion**
- **The Law of Inertia applies to both**

  → we'll come back to this.
- **Horizontal and vertical motion happen independently at the same time**

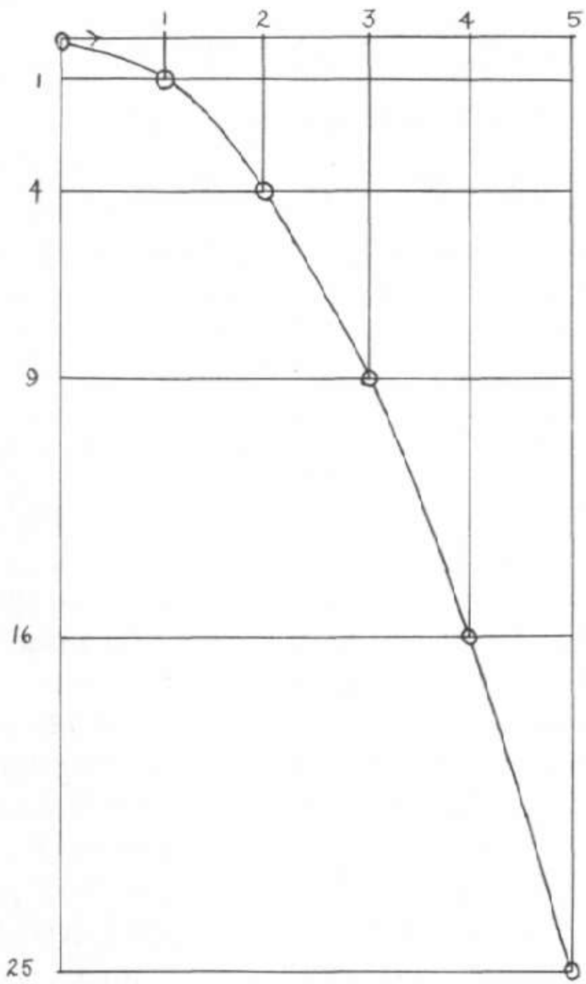
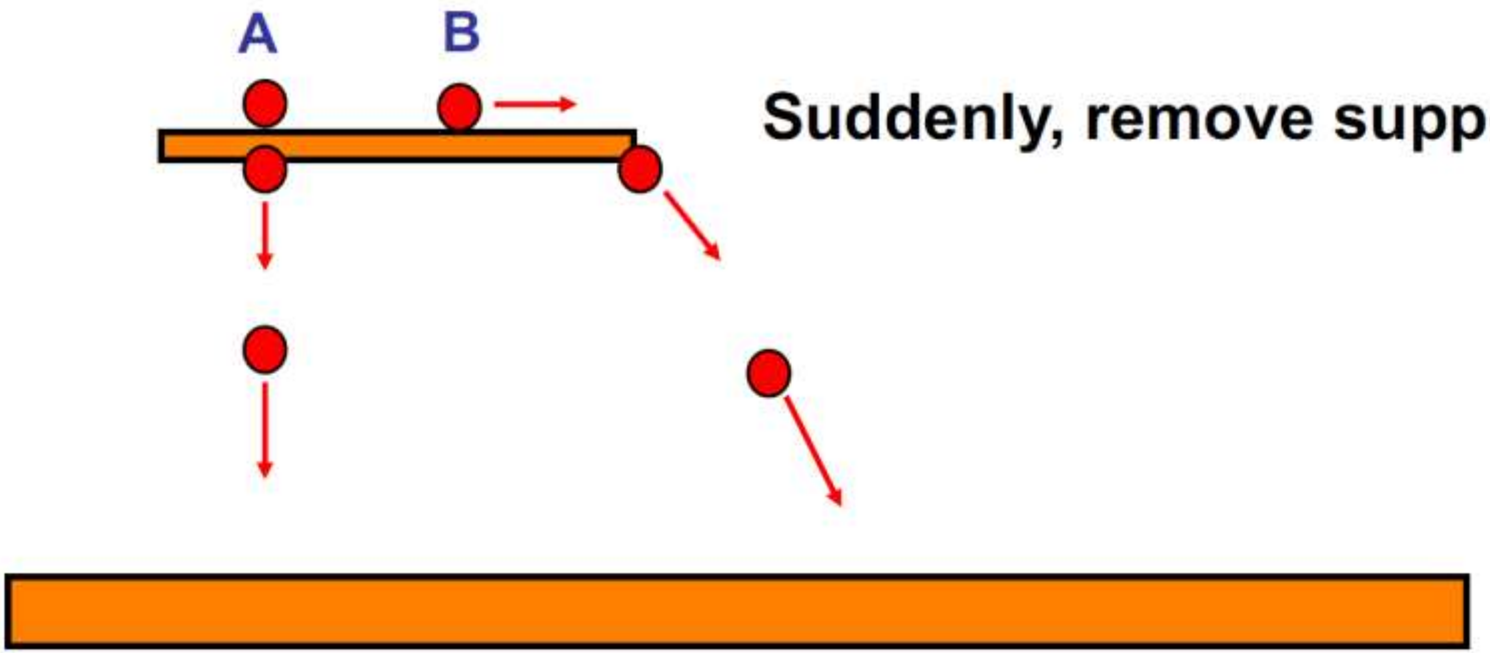


FIG. II–6.

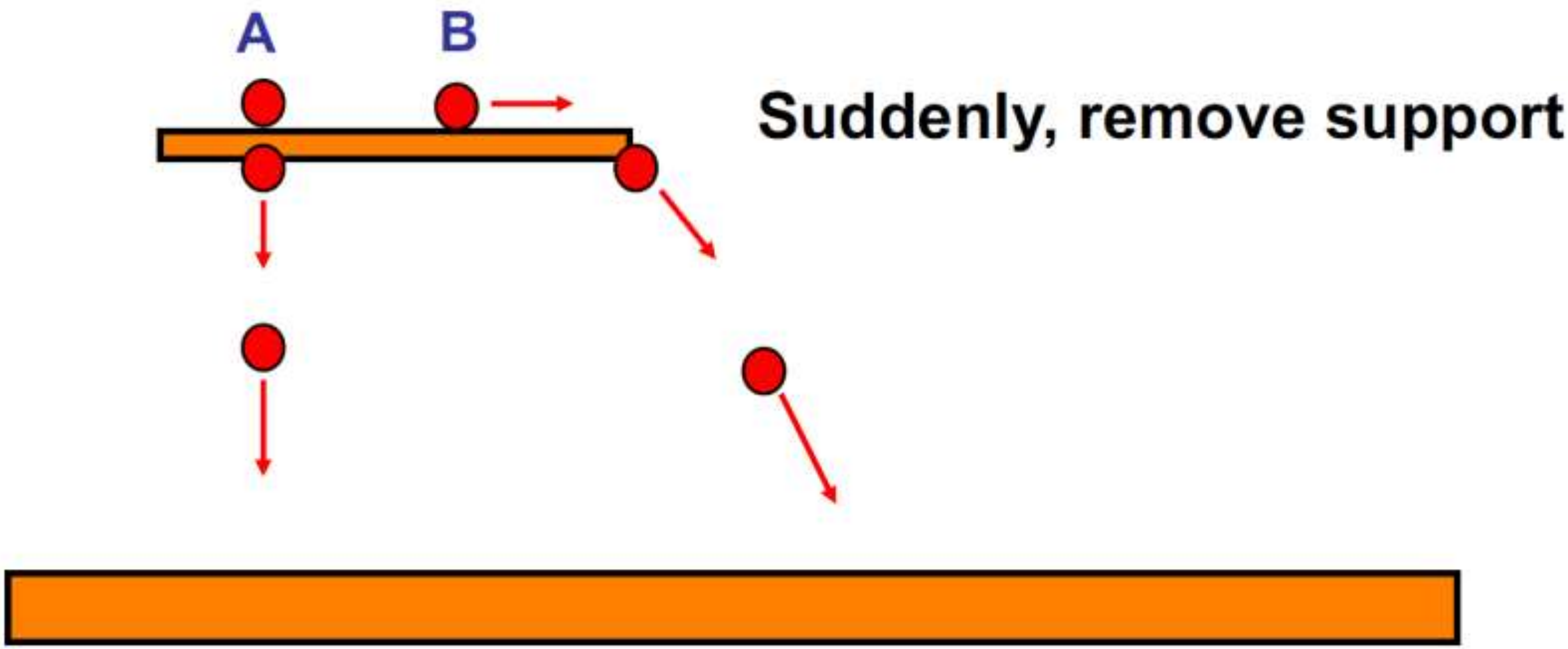
The addition of a uniform motion in a horizontal direction and accelerated motion in a vertical direction. The resulting curve is known as a parabola.



Which ball hits first?

A. Object A
B. Object B
C. Both at the same time

Demonstration



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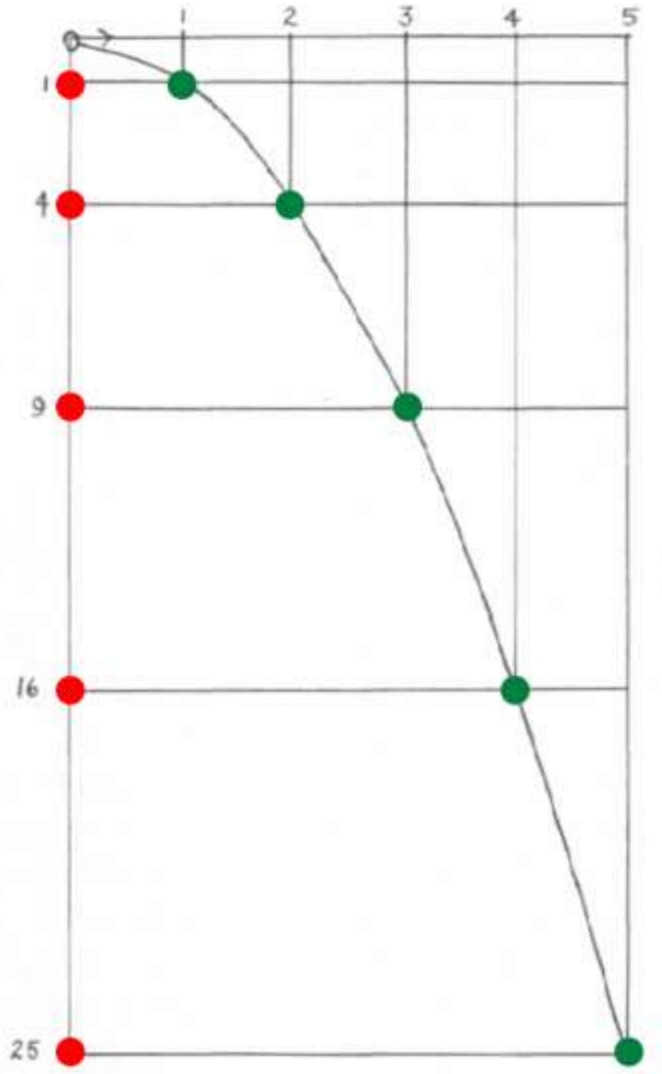

0
1
2
3
4
5
1
4
9
16
25

Speed

The rate of motion of a body

$$\text{Speed} = \frac{\text{Distance traveled}}{\text{Elapsed time}}$$

Which of the following situations represents a car whose speed is *increasing*?

A. A car takes longer and longer to cover equal distances
B. A car covers equal distances in equal times
C. In equal times, a car covers shorter and shorter distances
D. A car covers equal distances in shorter and shorter times
E. None of the above

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E. None of the above

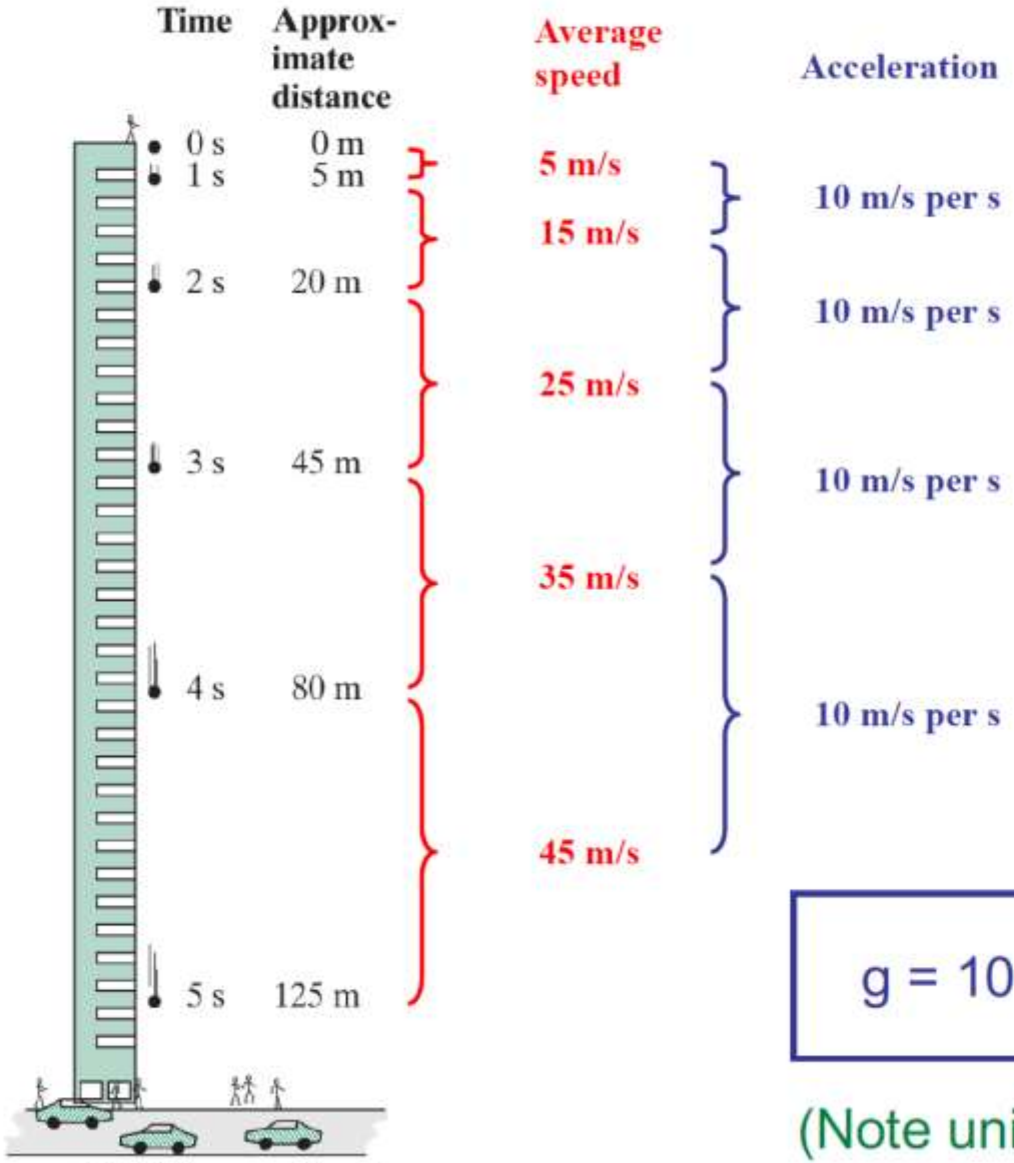
Acceleration

The rate change of velocity

For linear motion, velocity is the same as speed, so

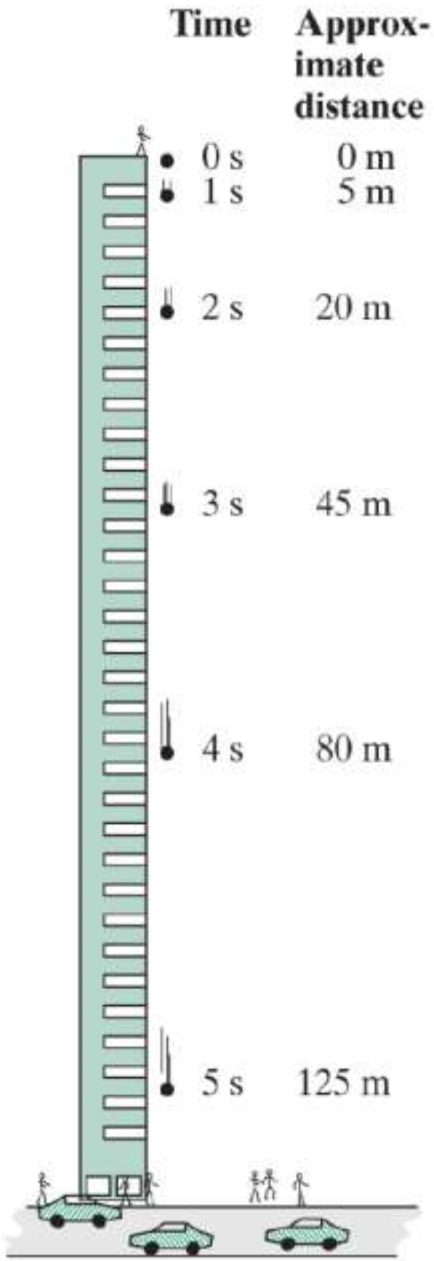
$$\text{Acceleration} = \frac{\text{Change of speed}}{\text{Elapsed time}}$$

Let's revisit this.



$g = 10\ m/s^2$

(Note units…)



Distance fallen

Time since drop

$$y = (g/2)\, t^2$$

$$g = 10 \text{ m/s}^2$$

An ancient Mayan noticed that a rubber ball would fall 3 tree-lengths in 5 heartbeats. What distance would it fall in 10 heartbeats?

A. 6 tree-lengths
B. 10 tree-lengths
C. 12 tree-lengths
D. 18 tree-lengths

Distance fallen $\propto$ square of elapsed time

A: 12 tree-lengths

On the planet Xena, a Xenosian (Xenite?) picks up a stone and drops it into a deep hole. If it falls 2 m in 1 second, how far will it fall in 3 seconds? (Neglect air resistance.)

A) 6 m

B) 9 m

C) 12 m

D) 15 m

E) 18 m

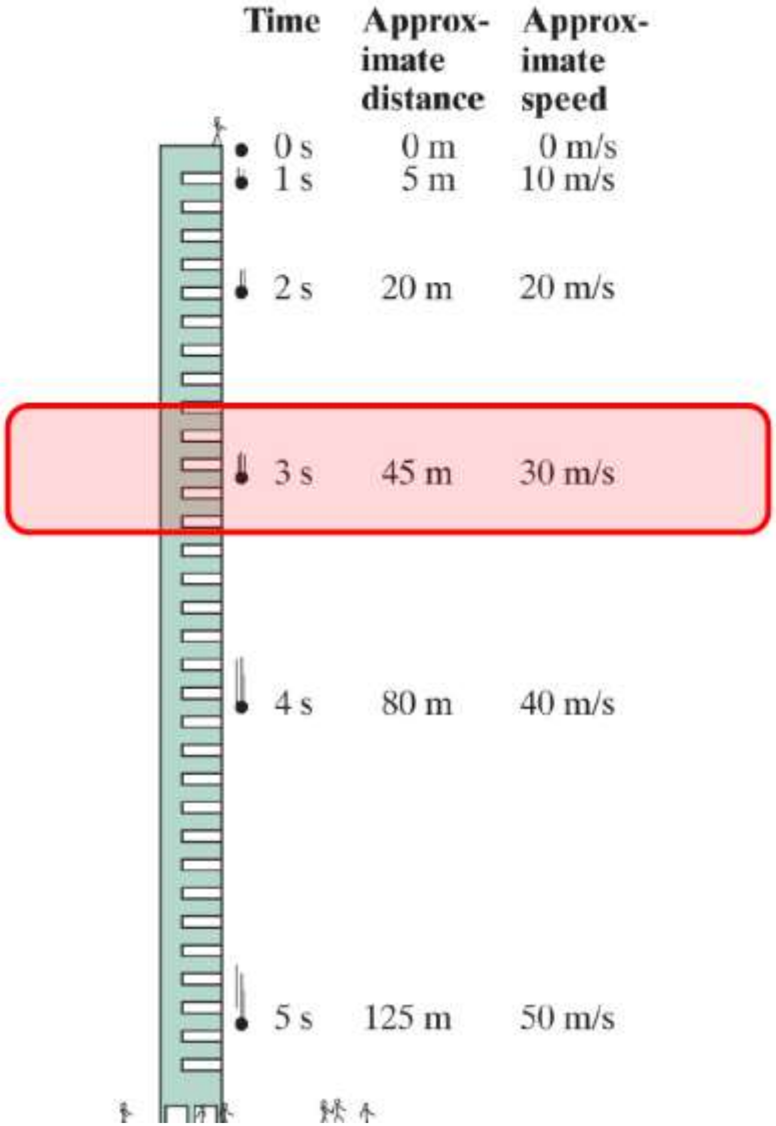
Distance fallen $\propto$ square of elapsed time

Speed

The rate of motion of a body.

Velocity

The combination of *speed and direction.*



What is the ball's <u>speed</u>?

30 m/s

What is the ball's <u>velocity</u>?

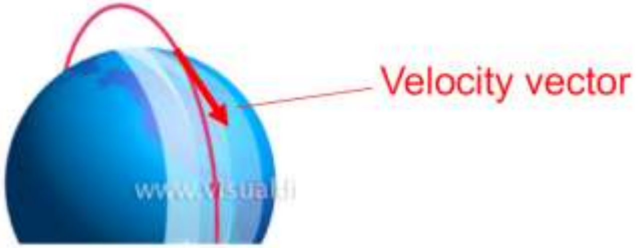
30 m/s <u>downward</u>

A satellite is in a circular orbit around the earth, moving at a constant speed. Does it have a **constant** (unchanging) velocity?

Vector

A quantity that has *magnitude* and *direction.*

Example: *Velocity* has *speed* and *direction.*



Speed

Not a vector!

The rate of motion of a body.

Velocity

A vector

The combination of *speed* and *direction*.

Acceleration

A vector

Any change of velocity, including:

- An increase in speed
- A decrease in speed
- A change in direction

Acceleration

- Can an object have a constant speed and still be accelerated?

Acceleration

- Can an object have a constant speed and still be accelerated?
  - Yes!

Acceleration

- Can an object have a constant speed and still be accelerated?
  - Yes!
- Can an object be going in a straight line and still be accelerated?

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- A car is decelerating to a stop at a traffic light. Is it undergoing a kind of acceleration?

Acceleration

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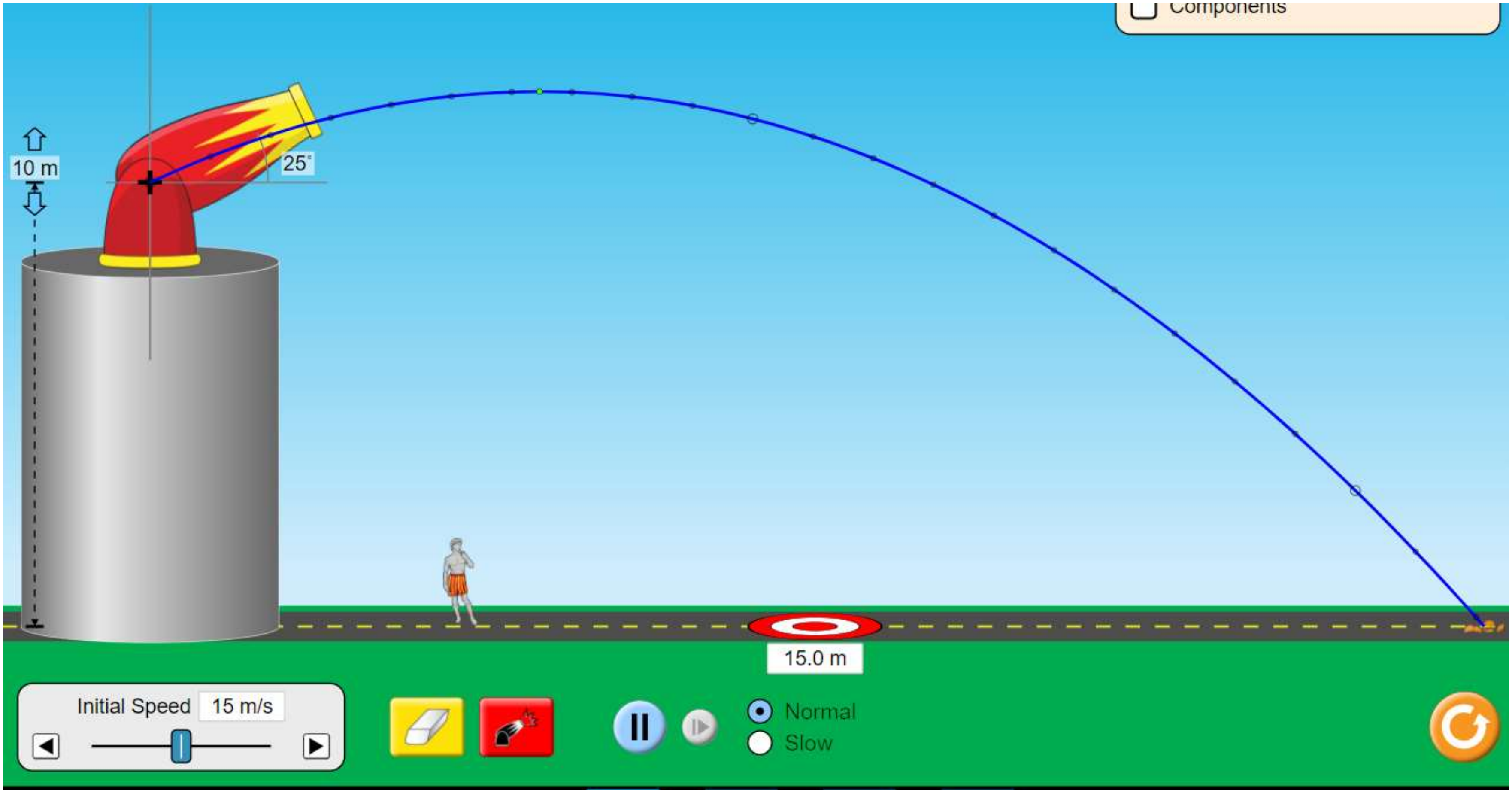
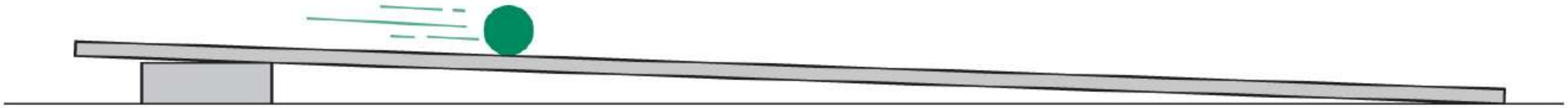
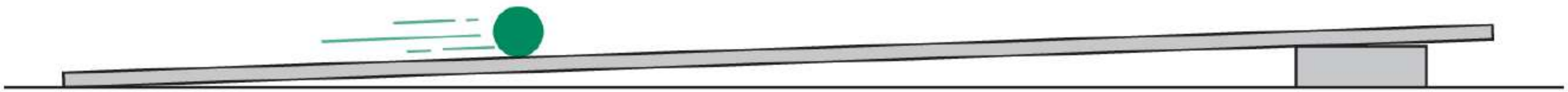
  - Yes!
- Can an object be going in a straight line and still be accelerated?
  - Yes!
- A car is decelerating to a stop at a traffic light. Is it undergoing a kind of acceleration?
  - Yes!!

Projectile Motion Simulation





(a)



(b)

(c)

In which cases is there acceleration?

In which direction is the acceleration?

Inertia

The tendency of all bodies to keep moving in a straight line at a constant speed unless acted on by external forces.

Law of inertia

For a body that is subjected to no external influences (also called external forces):

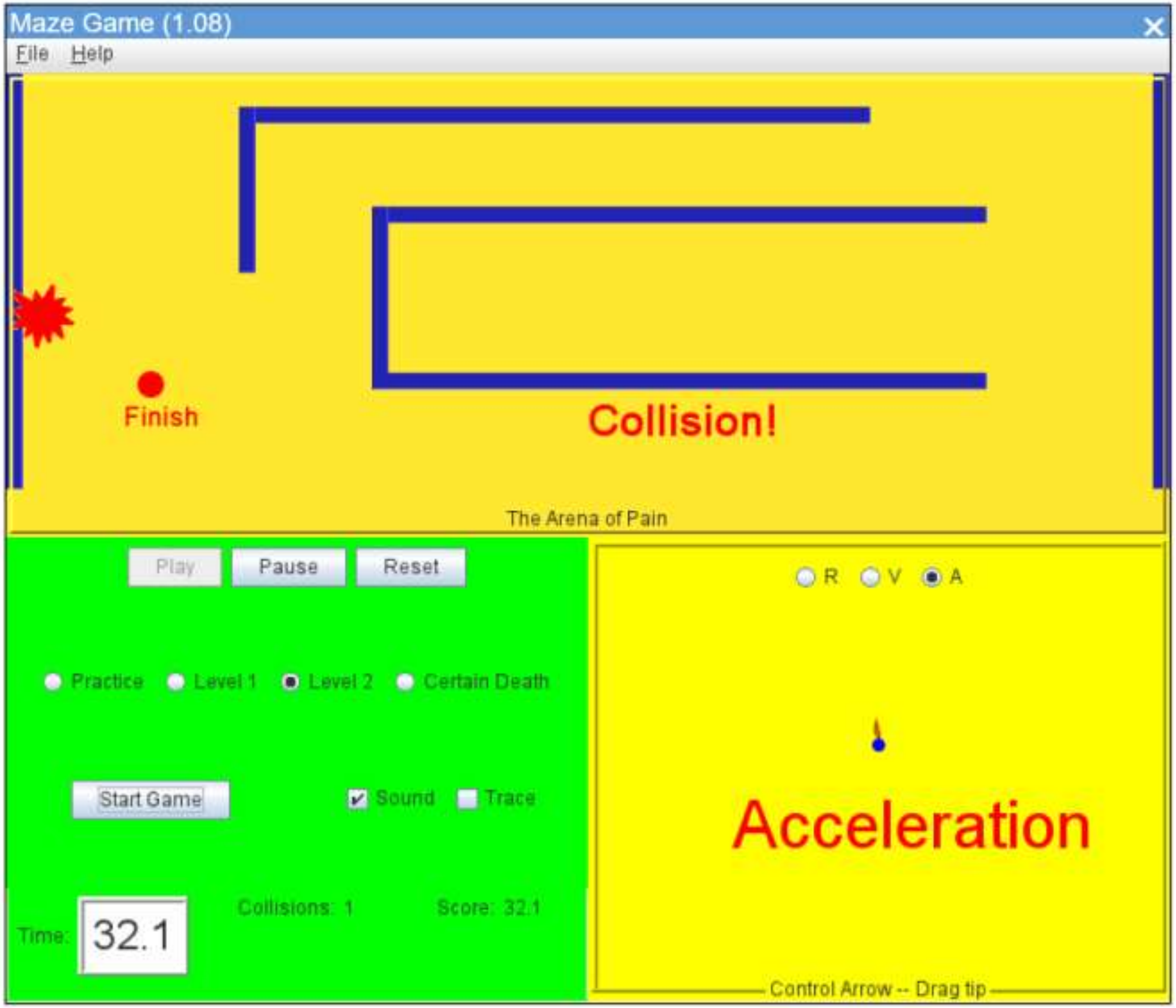
- **If initially at rest, it will stay at rest!**
- **If initially moving, it will keep moving along a straight line at an unchanging speed!**

What keeps the ball rolling?

Restatement:

A body that is subject to **no external forces** will maintain a constant velocity

Maze Game



Maze Game (1.08)
File
Help
Finish
Collision!
The Arena of Pain
Play
Pause
Reset
R
V
A
Practice
Level 1
Level 2
Certain Death
Start Game
Sound
Trace
Acceleration
Time:
32.1
Collisions: 1
Score: 32.1
Control Arrow -- Drag tip