From last time...

- Theories are tested by observations.
- Different theories can predict equivalent behavior within experimental accuracy.
- Simplicity or symmetry of a theory may be hints of its ‘truth’.
- In some cases, a new theory forced by observations can require acceptance of radical, non-intuitive ideas.

More Aristotle

- Heavier objects should fall vertically faster than lighter ones.
  - Why?
    - Theoretically:
      - Heavier ones contain more of the ‘earth’ element.
    - Experimentally:
      - Light objects often observed to fall slowly
      - Harder to lift heavier objects
  - How much faster?
    - Aristotle says proportional to their weight.
    - Unclear why, but is simplest relation.

Aristotle’s views on motion

- Aristotle’s observations
  
  **VERTICAL MOTION**
  - The element earth moves down toward its natural resting place.
  - Water’s natural place is just above earth.
  - Air rises to its natural place in the atmosphere
  - Fire leaps upwards to its natural place above the atmosphere.

  **HORIZONTAL MOTION**
  - Qualitatively different.
  - Bodies seem to need push or pull to maintain horizontal motion (contrary to their ‘natural’ motion).

We can do the experiment

- Release two objects of different masses.

Which falls faster?

A. Heavier mass hits first
B. Lighter mass hits first
C. Both masses hit at the same time

Galileo

- Objects move downward because gravity disturbs their motion.
- Claimed that heavy and light objects drop in the same way.
- Seems counterintuitive.
- Clearly doesn’t work in some cases e.g. Feather vs penny.
  - Flat paper vs crumpled paper
Why doesn’t it seem exactly right?

- Confused by air resistance. Air exerts a force on the falling body.
- Would be clearer if we could do it in vacuum.

Apollo 15 on the moon

Just how does the object fall?

Galileo showed that the falling motion is independent of mass, but...

- How long does it take to fall?
- How fast is it going?
- Does the speed change during the fall?

Or... What makes something move?

Galileo’s ideas about motion

Principle of Inertia
Object moving on level surface moves in unchanging direction at constant speed unless disturbed.

Principle of superposition
An object subject to two separate influences (disturbances) responds to each without modifying its response to the other.

Inertia

- No continued pushing/pulling required to maintain horizontal motion.
  - Object retains constant speed (possibly zero) unless pushed or pulled.
- Direct contradiction to previous views.

Inertia: describes degree to which an object will maintain its state of motion, whether moving or at rest.

Large inertia -> difficult to change state of motion of object

Superposition

- Hit the ball with two hammers
- Both these disturbances act on the ball, causing it to change its motion.
- Net effect on the ball is the superposition, or adding up, of the two disturbances (hammer hits)
Another example of superposition

- Hitting ball with hammer disturbs it from rest, changing its motion.
- After the hammer hit, there is no more disturbance. Motion no longer changes.
- The ball moves at constant speed.
- We measure speed in meters per second (m / s)
  - 2 m/s -> For every second, the ball moves two meters
  - E.g. after 2 seconds, the ball has traveled 4 meters.

Average speed

\[
\text{Average speed} = \frac{\text{distance traveled}}{\text{traveling time}}
\]

As an equation:

Distance traveled = \( d \)
Traveling time = \( t \)
Average speed = \( \tau \)

\[
\tau = \frac{d}{t}
\]

The instantaneous speed is the speed over a short time interval. If the speed is constant, the average and instantaneous speed are the same.

Instantaneous speed

Instantaneous speed is the average velocity over an infinitesimal (very short) time interval.
This is what your speedometer reads.
Instantaneous speed gives you a better understanding of the motion.

Hit ball off end of table.
Ball falls downward because gravity now disturbs it.
We know that the gravity ‘disturbance’ causes a motion straight downward.
The hammer hit caused a motion to the right.
These two motions are ‘superposed’ - the ball moves to the right at 2 m/s, and also moves downward.

Back to falling objects

I drop two balls, one from twice the height of the other. The time it takes the higher ball to fall is how much longer than the lower ball?

A. Twice
B. Three time
C. Four times
D. None of the above

Galileo measured this

- But falling motion too fast for accurate measurement.
- Galileo was able to measure a different aspect, that let him determine the time.
- In this way he made extremely accurate measurements.
Used principle of superposition and principle of inertia

Ball leaves ramp with constant horizontal speed.

After leaving ramp, it continues horizontal motion at some constant speed $s$ (no horizontal disturbances).

But gravitational disturbance causes change in vertical motion (the ball falls downward).

For every second of fall, it moves to the right ($s$ meters/second)$\times$(1 second) = $s$ meters.

Determine falling time by measuring horizontal distance!

How much longer does it take?

I drop two balls, one from twice the height of the other. The time it takes the higher ball to fall is how much longer than the lower ball?

A. Two times longer
B. Three times longer
C. Four times longer
D. None of the above

An equation

From this, Galileo determined that the falling time varied proportional to the square root of the falling distance.

Falling time $\propto \sqrt{\text{Falling distance}}$

Falling time = $t$
Falling distance = $d$

$d \propto t^2$

$d = at^2$

Falling speed

As an object falls, its speed is

A. Constant
B. Increasing proportional to time
C. Increasing proportional to time squared

Details of a falling object

• Just how does the object fall?
• Apparently independent of mass, but how fast?

• Starts at rest (zero speed), ends moving fast
  • Hence speed is not constant.
• Final speed increases with height.
• Falling time increases with height.

Constant acceleration

• In fact, the speed of a falling object increases uniformly with time.
• We say that the acceleration is constant.
• Acceleration:

$$a = \frac{\Delta v}{\Delta t}$$

Units are then (meters per second)/second
= (m/s)/s abbreviated $m/s^2$