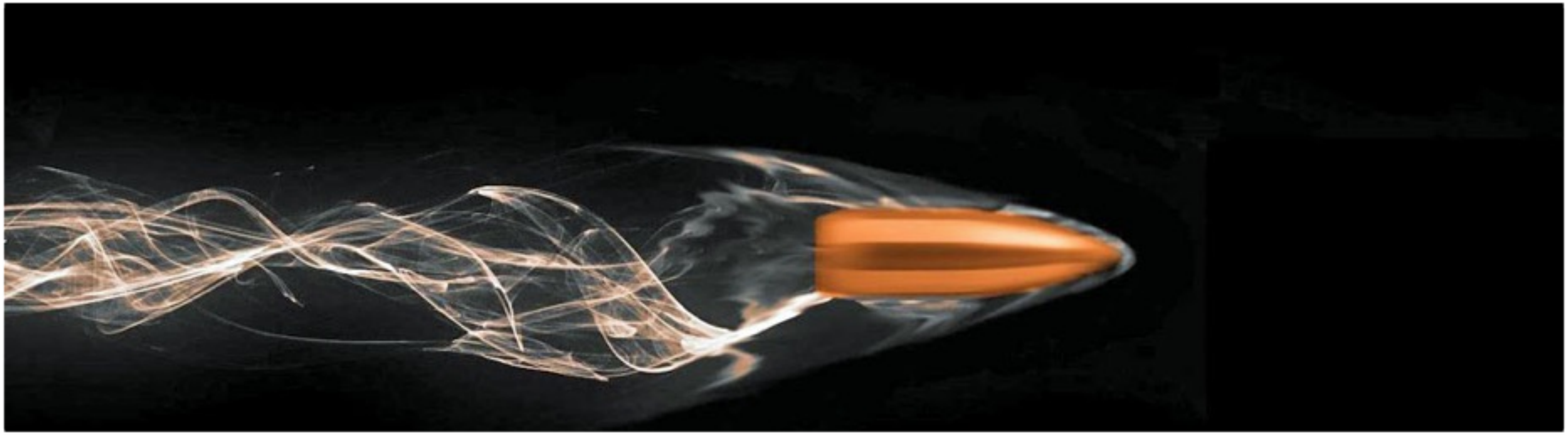


General Physics

Linear Motion

"Life is in infinite motion; at the same time it is motionless."
— Debasish Mridha

High Throw

- How high can a human throw something?

Mechanics

- The study of motion
- *Kinematics*
  - Description of *how* things move
- *Dynamics*
  - Description of *why* things move

Reference Frames

- What does it mean to be motionless?
- Sitting there in your seat, you're not moving, right?
- BUT! the Earth is rotating about its axis at **1,500 km/h**
- and orbiting around the Sun at **107,000 km/h**
- which itself orbiting around the supermassive blackhole at the center of the galaxy at **792,000 km/h**
- in an ever-expanding Universe (another **2.1 million km/h**!)

It's All Relative

- A train zips past a train station at 80 km/h
- While standing on the train, you throw a baseball at 20 km/h
- From the reference frame of you and the train, the ball leaves you at 20 km/h
- But from the reference frame of your friend at the train station, the ball is moving at 80 km/h + 20 km/h = 100 km/h!
- Both are equally valid observations of the baseball, it all just depends on the reference frame you pick

It’s All Relative

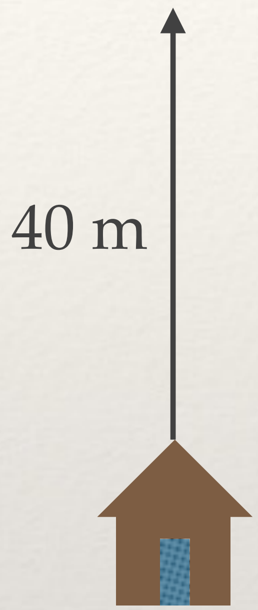
- Likewise, there’s no point in me telling you “Disneyland is 40 km away” unless I specify 40 km away *from where*
- Also, 40 km *in what direction*?

Lab Frame

- Often in science, we implicitly choose the reference frame to be what we call the *lab frame*
- For our purposes, that will mean relative to this room we are sitting in right now
- Good to get comfortable with changing between reference frames

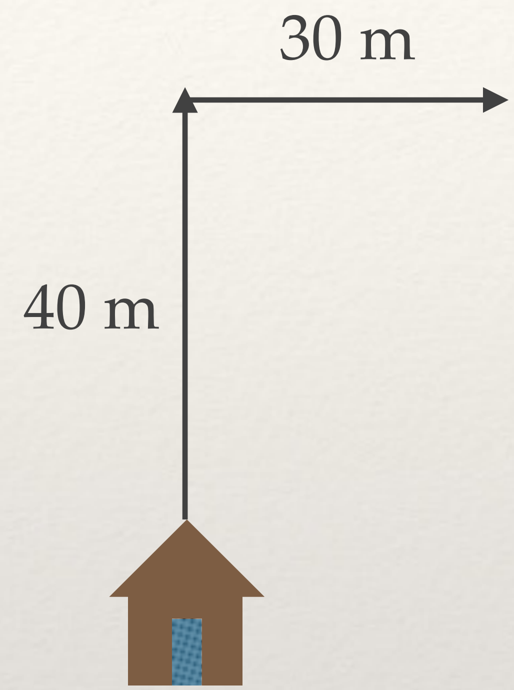
Distance vs. Displacement

- Little Sally leaves her home, walks **40 m north**



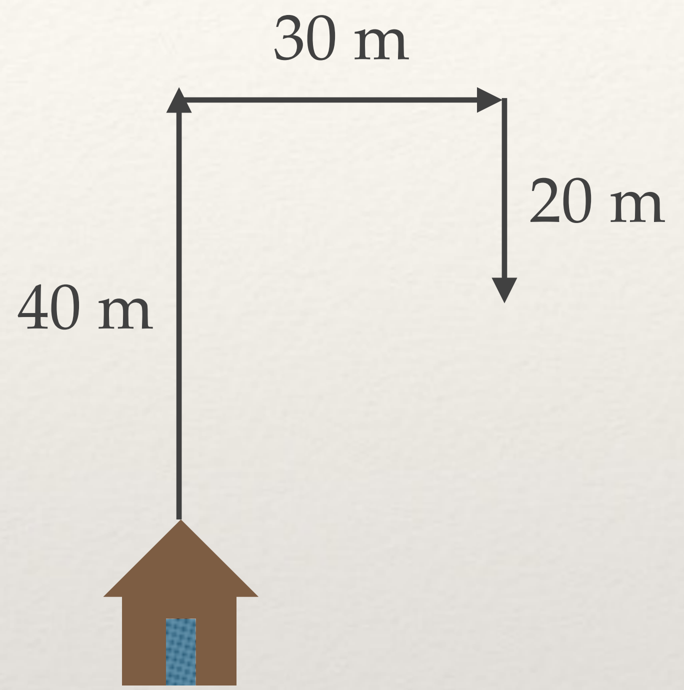
Distance vs. Displacement

- Little Sally leaves her home, walks 40 m north, **30 m east**



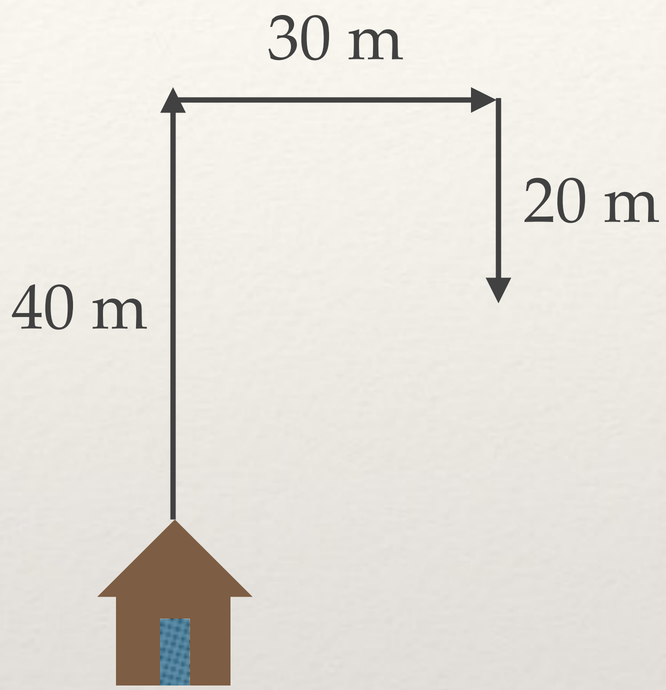
Distance vs. Displacement

- Little Sally leaves her home, walks 40 m north, 30 m east, and **20 m south**



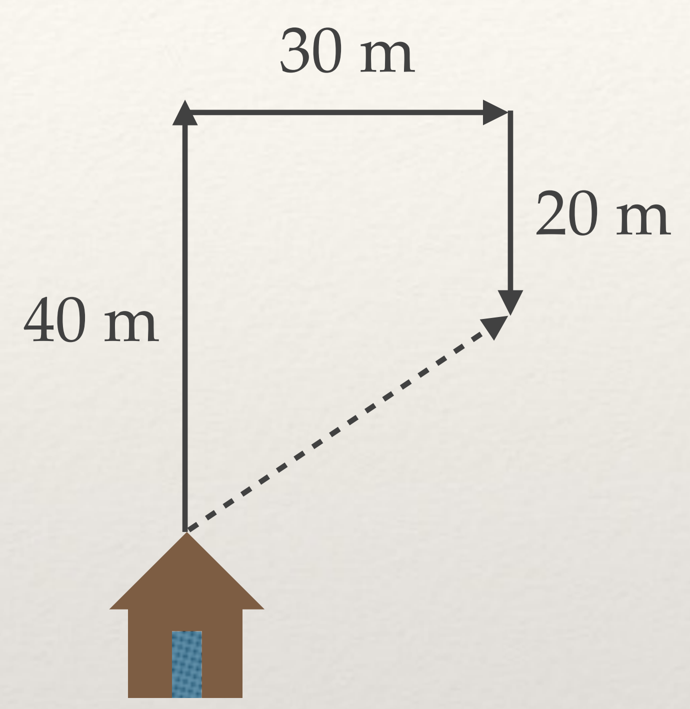
Distance vs. Displacement

- Little Sally leaves her home, walks 40 m north, 30 m east, and 20 m south
- How far did Little Sally travel?
- 40 m + 30 m + 20 m = 90 m
- This is the *distance* she traveled



Distance vs. Displacement

- Little Sally leaves her home, walks 40 m north, 30 m east, and 20 m south
- How far is Sally from home?
- $\sqrt{(20^2 + 30^2)} = 36$ m
- In what direction?
- $\tan^{-1}(20/30) = 34^{o}$ North of East
- **36 m @ 34º N of E**
- This is Sally's *displacement*



Scalars vs. Vectors

- **Scalars** only includes magnitude
  - E.g. distance is a scalar quantity
- **Vectors** include both magnitude and direction
  - E.g. displacement is a vector quantity

Speed vs. Velocity

- Both refer to how fast an object is moving
- *Average speed*
  - distance traveled divided by the time it takes to travel this distance
  - $\text{average speed} = \dfrac{\text{distance traveled}}{\text{time elapsed}}$

Speed vs. Velocity

- **Velocity** signifies both the *magnitude* of how fast an object is moving and the *direction* in which it is moving
- *Average velocity*
  - total displacement divided by time
  - average velocity = $\frac{\text{displacement}}{\text{time elapsed}}$

Speed vs. Velocity

- Let's say it took Little Sally 70 s to complete her journey

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Speed vs. Velocity

- Let's say it took Little Sally 70 s to complete her journey
- average speed $= \frac{\text{distance}}{\text{time}} = \frac{90 \text{ m}}{70 \text{ s}} = 1.3 \text{ m/s}$

Speed vs. Velocity

- Let's say it took Little Sally 70 s to complete her journey
- average speed = $\frac{\text{distance}}{\text{time}} = \frac{90\text{ m}}{70\text{ s}} = 1.3\text{ m/s}$
- average velocity = $\frac{\text{displacement}}{\text{time}}$

Speed vs. Velocity

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Speed vs. Velocity

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- average velocity = $\frac{\text{displacement}}{\text{time}} = \frac{36 \text{ m}}{70 \text{ s}} = 0.51 \text{ m/s}$

First Equation of the Year!

- $v = \dfrac{\Delta x}{\Delta t}$

Example Number 1

- Sonic, the world's fastest hedgehog™, is escaping from the city
- During a 3.00 s time interval, Sonic moves from being 30.0 m away from the city to 1,060 m away
- What is Sonic's average velocity?
- *Ans. 343 m/s*

Example Number 2

- Miles “Tails” Prower flies towards the city to try to find Sonic
- During a 5.00 s interval, Tails moves from being 2,540 m away from the city to being 2,330 m away
- What is Tails’ average velocity?
- *Ans. -42.0 m/s*

Ejemplo Numero 3

- Geralt of Rivia rides atop his stallion at 48 km/h for 2.5 h
- How far has he travelled in that time?
- *Ans. 120 km*

Instantaneous Velocity

- You are in a car heading downtown, as you can see from the speedometer your speed is 40 mi/h.
- Downtown is 10 miles away at this speed, how long will it take you?
- IS THIS TRUE???

Average Velocity

- It would take us a lot longer than 15 minutes to drive downtown because of the traffic where we have to slow, stop, start, accelerate, slow, stop, etc., etc,.

Acceleration

- Going in a straight line at the same speed is called **Constant Velocity**.
- But if we change our speed (brake at a light) or our direction (turn a corner) then we have a **Changing Velocity**
- Changing our speed or direction is **Acceleration**

Acceleration

- *Acceleration* is how quickly velocity changes
- $a = \frac{\Delta v}{\Delta t}$
- When we accelerate in a car from rest to 75 km/h in 5 s
- a = (75 km/h - 0 km/h)/(5 s)

  = 15 km/h/s

Acceleration

- To convert to SI units, change km/h over to m/s
- 75 km/h = 21 m/s
- $a = (21\ m/s - 0\ m/s)/(5\ s)$

  $= 4.2\ m/s^2$

Example 4

- Brian O'Connor is driving at 54 m/s before deciding he is driving *way* too fast and a little too furiously
- He slows the car to a reasonable 35 m/s in 5.0 s
- What is O'Connor's average acceleration?
- *Ans. -3.8 m/s*^{2}

Acceleration

- Acceleration also applies to changes in direction.
- We feel the effects when in a car we are pushed to the side when we turn a sharp corner

Sanity Check

- If the instantaneous velocity of an object is zero, does it mean that the instantaneous acceleration is zero?
- If the instantaneous acceleration is zero, does it mean that the instantaneous velocity is zero?
  - Answer: *not necessarily*
- Can you think of examples?

Motion at Constant Acceleration

- If acceleration is constant (which in many practical situations it is), then average and instantaneous acceleration are the same
- Can use this fact to derive some pretty convenient relationships between acceleration, velocity, and position with respect to time

Motion at Constant Acceleration

- $a = \dfrac{\Delta v}{\Delta t} = \dfrac{v_f - v_i}{\Delta t}$

  $\longrightarrow \; v_f = v_i + a\Delta t$

- $v = \dfrac{\Delta x}{\Delta t} = \dfrac{x_f - x_i}{\Delta t}$

  $\longrightarrow \; x_f = x_i + v\Delta t$

Motion at Constant Acceleration

- With a little simple calculus, can find acceleration's contribution to a change in position
- $x_f = x_i + v_i \Delta t + \frac{1}{2} a \Delta t^2$
- $v_f^2 = v_i^2 + 2a\Delta x$
- (For the full derivation check out http://physics.info/kinematics-calculus/)

Kinematic Equations

- $v_f = v_i + a\Delta t$
- $x_f = x_i + v_i\Delta t + \frac{1}{2} a\Delta t^2$
- $v_f^2 = v_i^2 + 2a\Delta x$
- **Important note:** these equations are only valid under *constant* acceleration

Example 5

- You are designing an airport for small planes. One kind of airplane that might use this airfield must reach a speed before takeoff of at least 27.8 m/s (100 km/h) and can accelerate at 2.00 m/s^2. If the runway is 150 m long, can this plane speed to take off?
- *Ans. No*
- What minimum length must the runway have?
- *Ans. 193 m*

Example 6

- How long does it take a car to cross a 30.0-m-wide intersection after the light turns green if it accelerates from rest at a constant 2.00 m/s^2?
- *Ans. 5.48 s*

Example 7

- Minimum stopping distance is important in traffic design. The average human reaction time is 0.22 s, meaning there is a 0.22 s delay between when one decides to break and when he or she actually begins breaking. A typical car can decelerate at 6.0 m/s^2 in good conditions. Knowing this, calculate the total stopping distance in meters for a vehicle is traveling at 100. km/h.
- *Ans. 71 m*

Example 8

- A baseball pitcher throws a fastball with a speed of 44 m/s. If the pitcher accelerates the ball through a displacement of about 3.5 m before releasing it, estimate the average acceleration of the ball during the throwing motion.
- *Ans. 280* m/s^2

Example 9

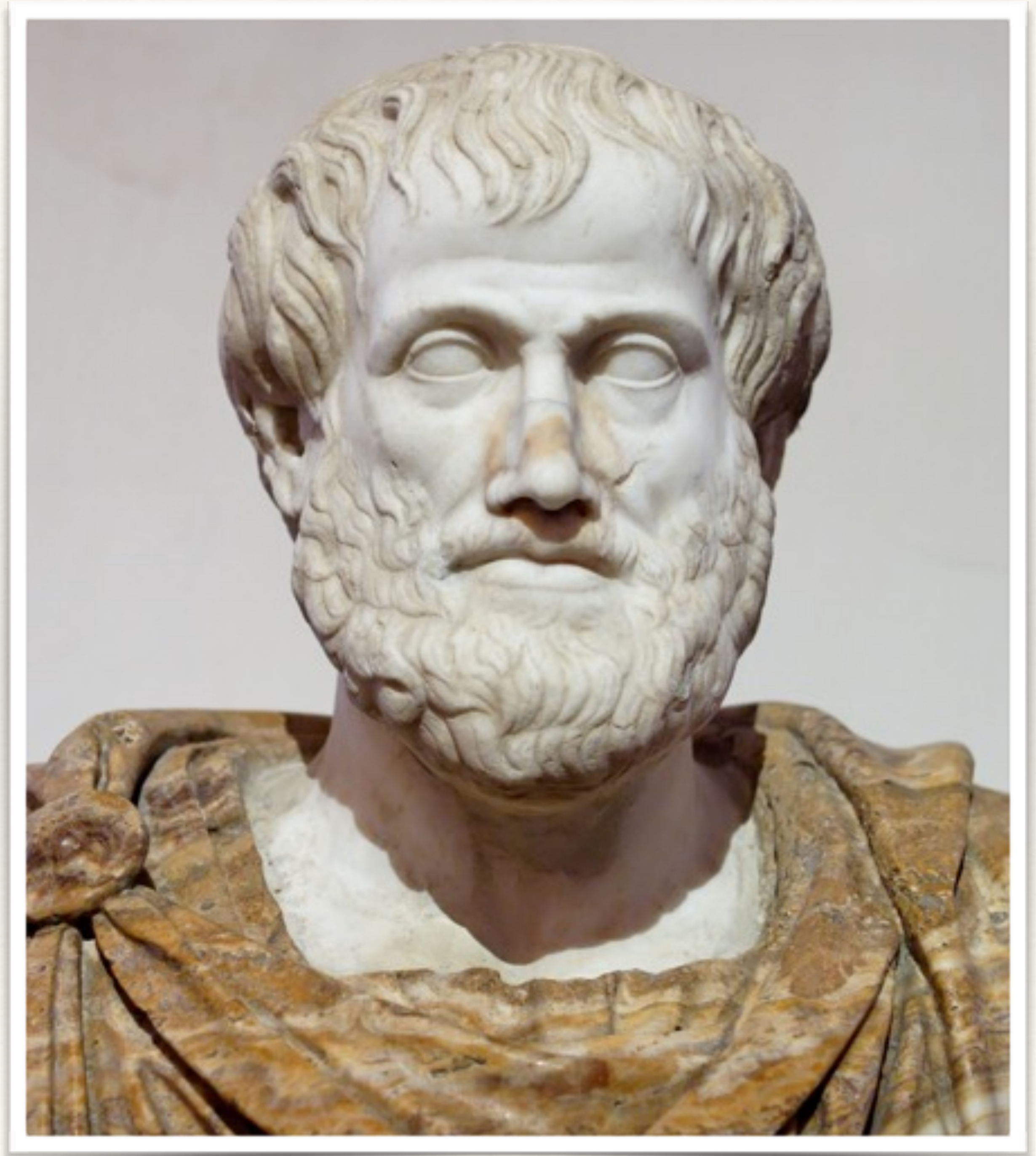
- You want to design an air-bag system that can protect the driver in a head-on collision at a speed of 100 km/h. If the car crumples upon impact over a distance of about 1 m, how much time does the air bag have to inflate in order to effectively protect the driver?
- *Ans. less than 0.07 s*

Freefall

- All object accelerate towards the Earth under the force of gravity
  - *Accelerate* — so they will pick up speed as they descend

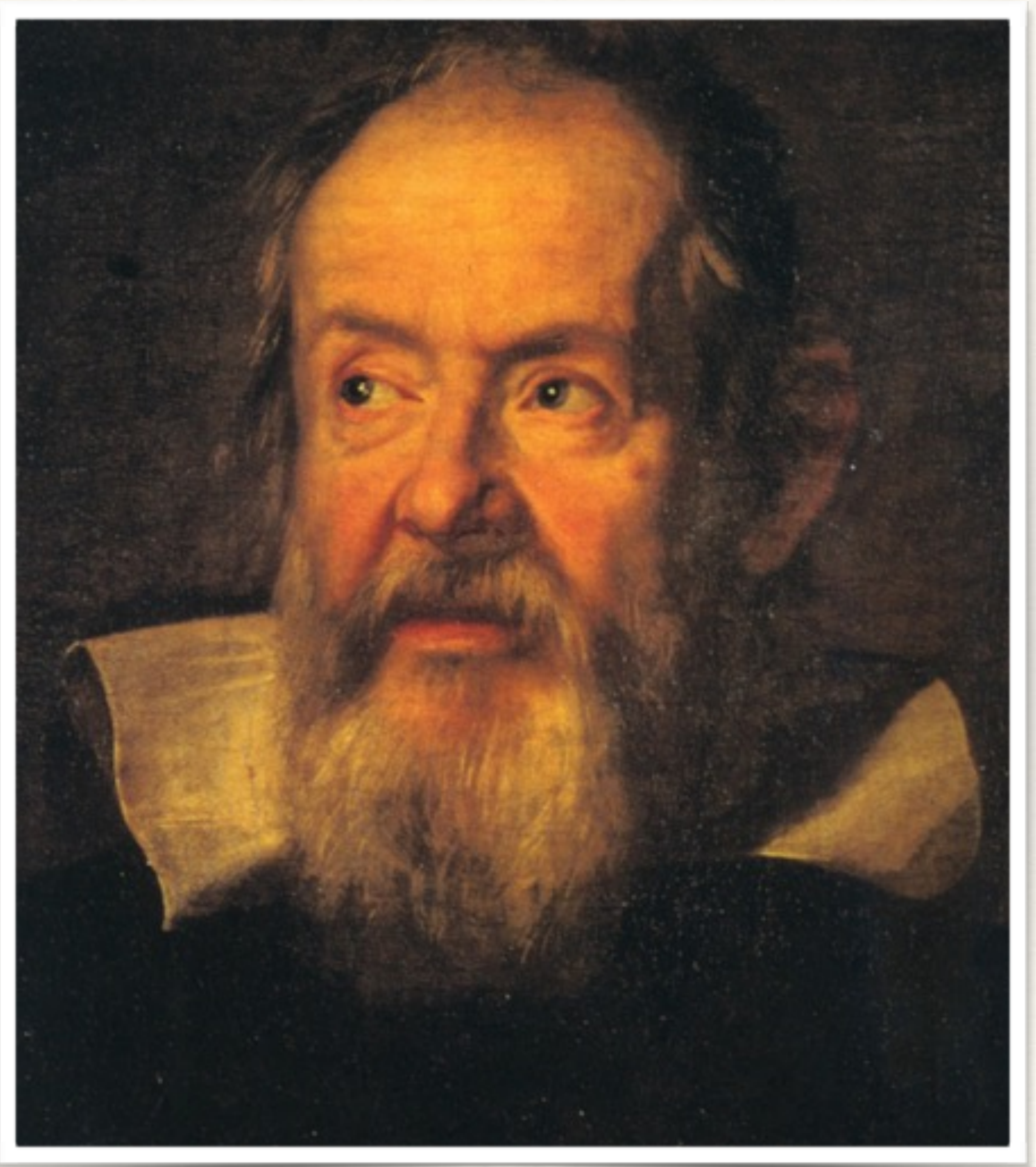
Freefall

- Up through the 16th Century, most people's intuition about freefall centered around the teachings of Aristotle
  - "bodies of different weight […] move in one and the same medium with different speeds which stand to one another in the same ratio as the weights; so that, for example, a body which is ten times as heavy as another will move ten times as rapidly as the other."



Freefall

- Galileo Galilei was the first scientific mind to challenge this commonly help belief
- Dropped masses off the edge of the Leaning Tower of Pisa



Freefall

- Acceleration due to gravity acts on all objects the same regardless of their mass
  - Any observed differences are on account of air resistance

https://www.youtube.com/watch?v=E43-CfukEgs

Freefall

- How fast, exactly, does gravity accelerate objects here on Earth?
- Actual value:
  - $g = 9.81\ m/s^2$
- Only the acceleration due to gravity here on Earth
- Varies slightly depending on latitude and elevation

Example 10

- Saruman is conducting physics experiments from atop the Tower of Orthanc.
- If he drops a ball from the peak of his 150-m-tall fortress, how far will the ball have fallen after 1.00 s, 2.00 s, and 3.00 s? (Neglect air resistance)
- *Ans. 4.90 m*
- *19.6 m*
- *44.1 m*

Example 11

- Wishing to take things a step further, the White Wizard instead *throws* the ball downward with an initial velocity of 3.00 m/s.
- What would be the ball's position and speed after 1.00 s and 2.00 s?
- *Ans @ 1.00 s: 7.90 m, 12.8 m/s*
- *@ 2.00 s: 25.6 m, 22.6 m/s*

Example 12

- Feeling ambitious, Saruman now throws the ball *upward* at 3.00 m/s.
- How high does the ball go?
  - *Ans. 0.458 m*
- How long is the ball in the air before it comes back to his hand?
  - *0.612 s*
- What is the ball's velocity when it comes back to his hand?
  - *-3.00 m/s*

High Throw

- How high can a human throw something?

High Throw

- How to throw the ball upward?

High Throw

- A person with a reasonably good arm can throw a baseball at about 32 m/s (72 mph)
- Let's assume that, thanks to air resistance, you'll only get the ball about 50% as high as you would in a vacuum
- How high can you throw the ball?
  - *Answer*: 26 m
- The average giraffe is about 5 m tall. What's the height of your throw in units of giraffes?
  - *Answer*: just over 5 giraffes

High Throw

- The world record for fastest baseball pitch belongs to Aroldis Chapman, clocking in at 47 m/s (105 mph)
- How high (in giraffes) could he hypothetically launch a baseball?
  - *Answer*: just over 11 giraffes

High Throw

- What could you change to throw even *higher*?