One-dimensional kinematics

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2025 W32[1]

[1]Phys 20.01 Mod 1. All figures are from Urone (2022), Hewitt (2024), Young and Freedman (2019) unless noted.

Agenda

All about motion 🌀

Displacement 📍

Velocity 🏃

Acceleration 🚀

Some notes 📎

Quiz time 🕐

All about motion 🌀

Motion is everywhere

- Objects are in motion everywhere we look
- eg. tennis balls at cov courts, GPS satellites in orbit
- eg. blood in your body even though you're just sitting down
- eg. inanimate objects, which are supposed to be literally not in motion, have continuous motion in the vibrations of their atoms and molecules

Motion is relative

- Again, take yourself sitting on a chair 🪑
  - Your speed is zero relative to Earth but 30 km/s (that's 107000 km/h!) relative to the sun
  - And even faster relative the center of our galaxy
- Have you tried looking out at a train window and viewing another train car zooming at the same speed in the opposite direction? 🚆
  - You'll see it zooming twice at fast
  - That's relative motion for ya!

Motion is relative

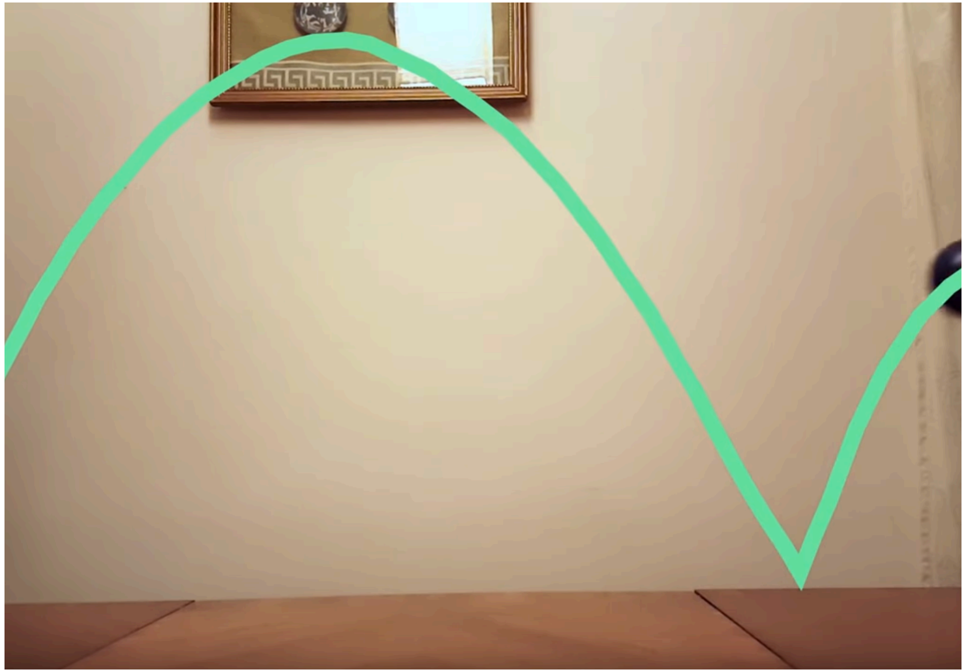
Example. A hungry mosquito sees you resting in a hammock in a 3-m/s breeze. How fast and in what direction should the mosquito fly in order to hover above you for lunch? 🦟

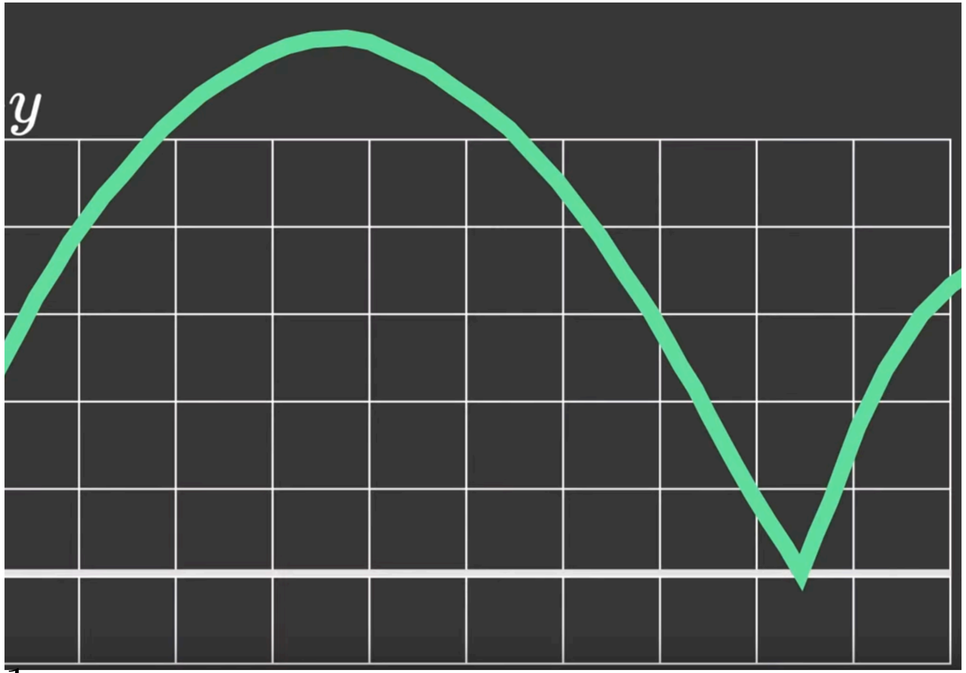
It should fly toward you into the breeze. When just above you, it should fly at 3 m/s in order to hover at rest. Unless its grip on your skin is strong enough after landing, it must continue flying at 3 m/s to keep from being blown off. That's why a breeze is an effective deterrent to mosquito bites.

Studying motion

- Two distinctions related to cause and effect when analyzing the motion of objects
- **How** does a particular object move?
  - Purely descriptive, geometrical question
  - We ask: what does the geometry of the motion look like?
  - The study of the geometry of motion of a trajectory is referred to as **kinematics**
  - It is the study of motion without considering the causes

Studying motion





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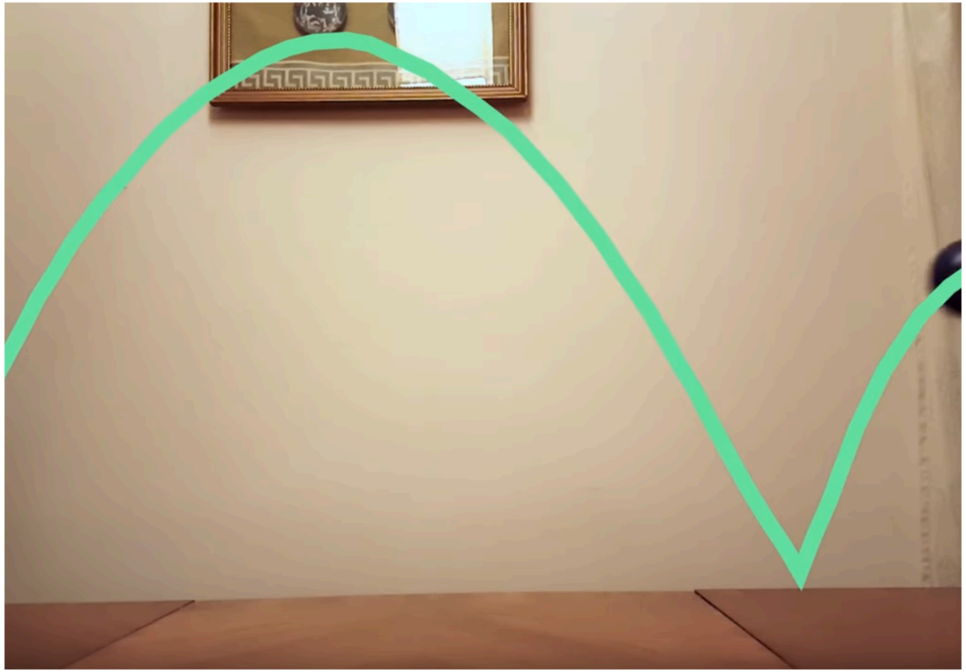
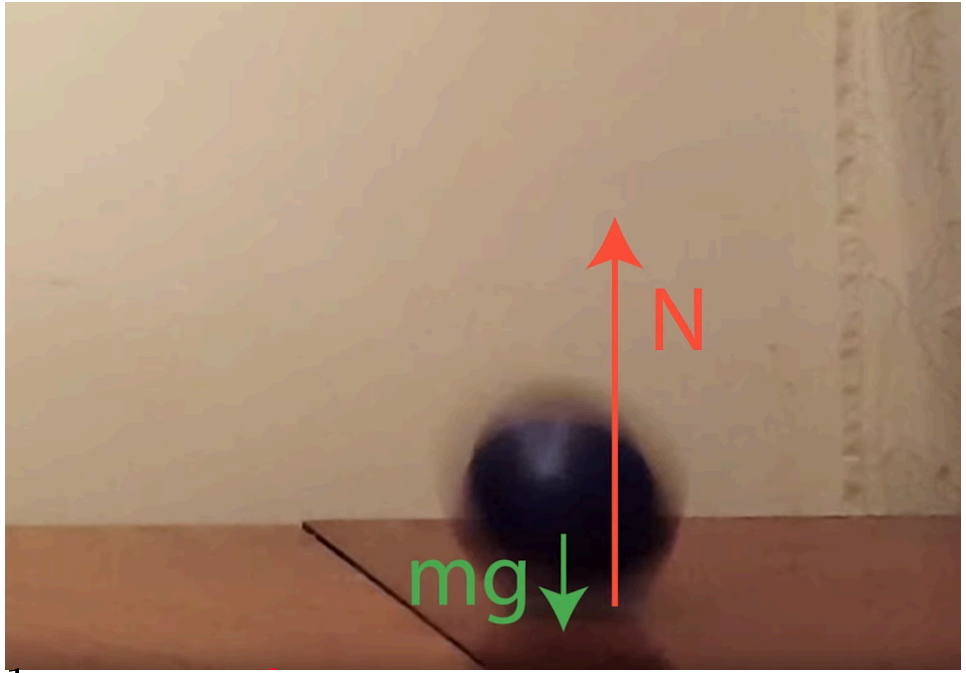
[1] ocw.mit.edu

Studying motion

- **Why** does the object move the way it does?
  - Concerns what the causes are of the motion and of the changes in that motion
  - We ask: why does the kinematics description of the trajectory look the way it does?
  - The study of the cause behind the changes of motion is called **dynamics**
  - It is the study of motion with the causes and whys

Studying motion





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Studying motion

- Newton's second law (later on this) connects these questions

$$\vec{F} = m\vec{a}$$

$$\text{forces} \leftrightarrow \text{geometry}$$

$$\text{why} \leftrightarrow \text{how}$$

Questions? 🤔

Checkpoint. If you look out an airplane window and view another plane flying at the same speed in the opposite direction, what exactly do you see? ✈️

An airplane, true. More precisely, an airplane flying twice as fast.

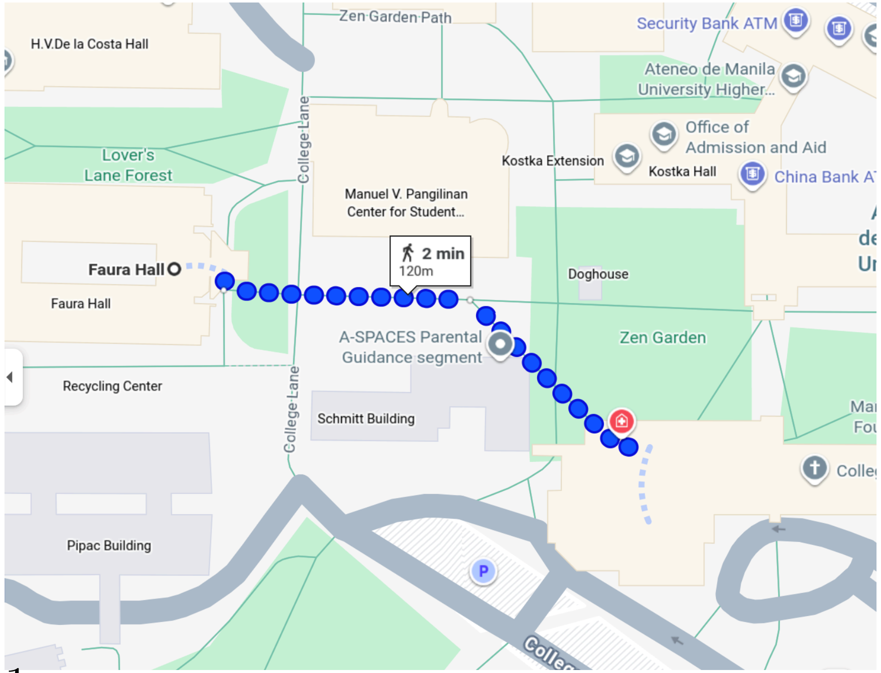
Displacement 📍

Position

- **Position** is where an object is at any particular time
- Precisely, where is the object relative to another object
  - As in relative to a convenient reference frame
- Reference frame is a perspective from which you're making observations

Distance

- **Distance traveled** is the total length of path traveled between two positions
- It is path dependent, and is a scalar quantity $\Rightarrow$ only magnitude and no direction
- eg. I'm hungry, I'll go to gonz real quick



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[1] maps.google.com

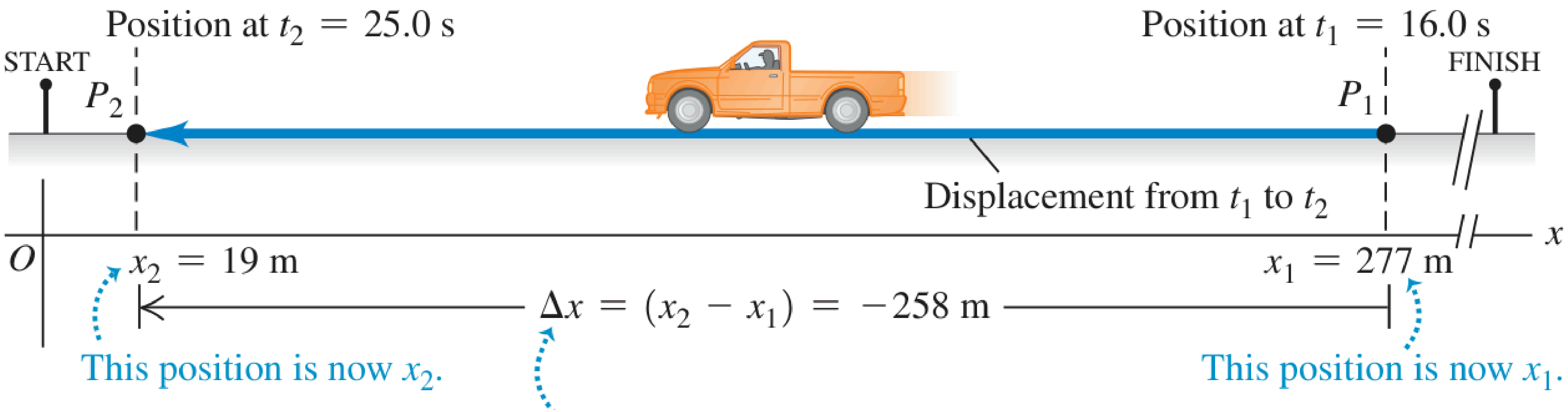
Displacement

- **Displacement** Δx is the change in position of an object

$$\Delta x = x_f - x_0$$

  where x_0 is the initial position and x_f is the final position
- Its SI unit is meter (m)
- It is a vector quantity $\Rightarrow$ has magnitude and direction
- Object moves relative to a reference frame $\Rightarrow$ object's position changes $\Rightarrow$ object has been "displaced" $\Rightarrow$ displacement

Displacement



- Usually, rightward and upward directions are positive directions
- So negative displacement means leftward displacement, as in the car moved 258 m to the left

Velocity 🏃

Time

- Time is measured in terms of change. Elapsed time for event is

$$\Delta t = t_f - t_0$$

  where t_f is the final time and t_0 is the initial time
- Its SI unit is second (s)
- By convention, initial time t_0 is often taken to be zero ($t_0 = 0$) as if measured with a stopwatch. Elapsed time is just then $\Delta t = t_f \equiv t$

Speed

- **Speed**, specifically average speed, is the total distance covered per interval of time

  Example. If we travel a distance of 80 kilometers in a time of 1 hour, we say our average speed is 80 kilometers per hour. Likewise, if we travel 320 kilometers in 4 hours,

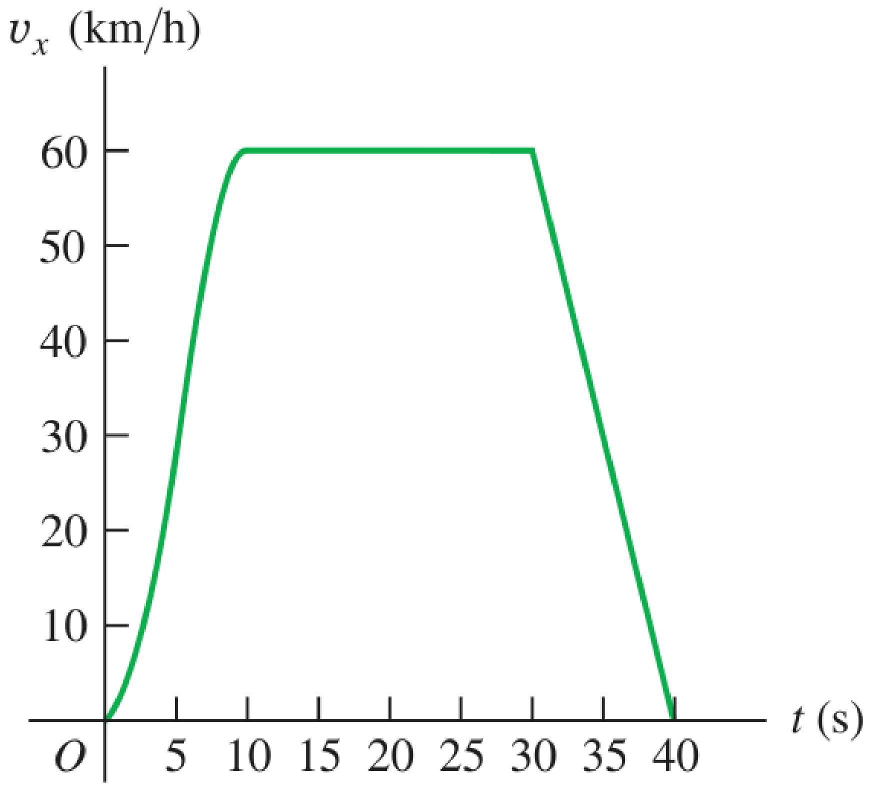
$$\text{speed} = \frac{\text{distance traveled}}{\text{time interval}} = \frac{320 \text{ km}}{4 \text{ h}} = 80 \text{ km/h}$$

- Things in motion often have variations in speed. But the speed at any instant of time is called the **instantaneous speed**

Speed

Example. A car traveling at average speed of 60 km/h usually goes at that speed at many instants of time (where inst speed is 60 km/h).

But if it passes by a pedestrian crossing, its inst speed would be different at specific instants of time (eg. 10 km/h at $t = 38$ s)



Velocity

- **Velocity**, specifically average velocity $\overline{v}$, is defined as displacement divided by travel time. In symbols,

$$\overline{v} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_0}{t_f - t_0}.$$

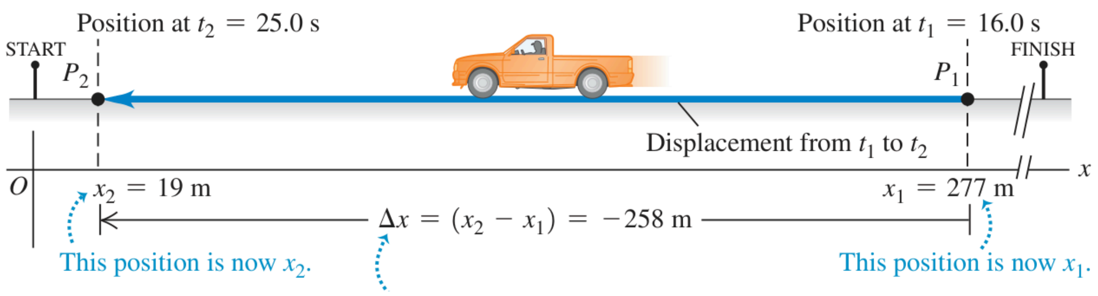
  - It is a vector (since displacement is), and its SI unit is m/s
  - It only considers initial and final positions, providing no info about the motion in between

- **Instantaneous velocity** v is the velocity at a specific instant or the average velocity for an infinitesimal interval

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{\mathrm{d}x}{\mathrm{d}t}$$

  - By considering smaller segments of the motion over shorter time intervals, we obtain more info
- Notes on speed
  - Instantaneous speed is magnitude of instantaneous velocity
  - Average speed is not the magnitude of average velocity since velocity makes use of displacement, not distance traveled

Velocity



Example. Points P_1 and P_2 indicate the positions of the truck at two times t_1 and t_2, respectively. When the truck moves in the $-x$-direction, Δx is negative and so is the average velocity $\overline{v}$:

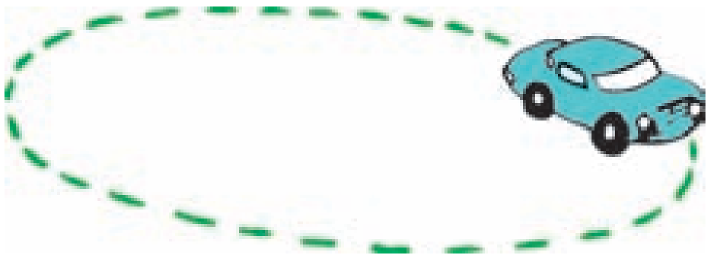
$$\overline{v} = \frac{\Delta x}{\Delta t} = \frac{(19 - 277)\ \text{m}}{(25 - 16)\ \text{s}} = \frac{-258\ \text{m}}{9\ \text{s}} = -29\ \text{m/s}$$

Constant vs changing velocity

- Constant speed means steady speed (no speed up or slow down)
- Meanwhile, being a vector quantity, constant velocity means both constant speed and constant direction
  - Constant direction is a straight path (no curving)
  - So constant velocity means motion in a straight line at a constant speed
  - If either speed or direction changes, or if both change, then velocity changes

Constant vs changing velocity

Example. A car on a curved track may have a constant speed, but because its direction is changing, its does not have constant velocity. In fact, it is changing velocity (accelerating)



Checkpoint. If you're cited for speeding, which does the officer write on the ticket: your instantaneous or average speed? 🚨

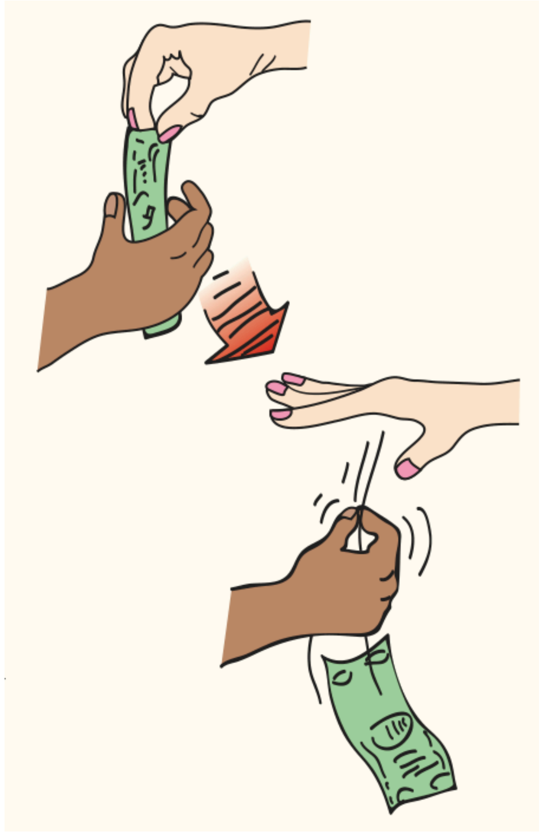
Instantaneous speed, because, legally, speeding means exceeding a speed limit at any given moment (instant of time)

Questions? 🥱

Brain break! 🧠 💤

Catch me if you can

Try with a friend. Hold a peso bill so that the midpoint hangs between your friend's fingers and challenge them to catch it by snapping their fingers shut when you release it. Would they be able to catch it? 🤑



Catch me if you can

Well, they shouldn't be able to catch it! From $d = \frac{1}{2}gt^2$ (which we will study soon), the bill will fall a distance of 8 cm (half length of the bill) in a time of 1/8 s, but the time required for the necessary impulses to travel from his eye to his brain to his fingers is at least 1/7 s.

- Does the bill move with constant velocity?
  - No, because it falls faster and faster as time goes on, courtesy of 👏 acceleration g 👏 due 👏 to 👏 gravity 👏

Acceleration 🚀

Acceleration

- We can change the velocity of something by changing its speed, its direction, or both
  - Here the key idea is change

Example. We only sense motion when we lurch (or experience sudden, unsteady movement), thanks primarily to vestibular system in the inner ear 👂

Acceleration

- How quickly and in what direction velocity changes is **acceleration**. In symbols, average acceleration $\overline{a}$ is

$$\overline{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}.$$

  - Its SI unit is $\mathrm{m/s^2}$
  - It is a vector, so it can be caused by either a change in magnitude or direction of the velocity, or both

- **Instantaneous acceleration** a is the acceleration at a specific instant in time

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

- Deceleration is an acceleration with a direction opposite to that of the velocity, causing an object to slow down

Acceleration

Example. What is the acceleration of a race car that whizzes past you at a constant velocity of 400 km/h?

Zero, because its velocity doesn't change.

Acceleration

Example. In 2.5 s, a car increases its speed from 60 km/h to 65 km/h, while a bicycle goes from rest to 5 km/h. Which undergoes the greater acceleration? What is the acceleration of each?

$$a_{\text{car}} = \frac{\Delta v}{\Delta t} = \frac{(65 - 60)\ \text{km/h}}{2.5\ \text{s}} = \frac{5\ \text{km/h}}{2.5\ \text{s}} = 2\ \text{km/h-s}$$

$$a_{\text{bike}} = \frac{\Delta v}{\Delta t} = \frac{(5 - 0)\ \text{km/h}}{2.5\ \text{s}} = \frac{5\ \text{km/h}}{2.5\ \text{s}} = 2\ \text{km/h-s}$$

v's are different but rates of change of v's are same $\Rightarrow$ a's are equal

Questions? 🙄

Checkpoint. What are the three controls that accelerate a car? 🚗

The gas pedal (accelerator), the brakes, and the steering wheel. This is because to accelerate means to change velocity (magnitude and direction)

Some notes 📎

Want some fun demos? Google "colorado phet" or click here 👉

Up next? Some board work, then continue 1d kinematics

Quiz time 🕐

Displacement vs distance

Pick one and tell me why: An object goes from one point in space to another. After it arrives at its destination, its displacement…

- can be either greater than or equal to
- must be greater than
- must be equal to
- can be either smaller than or equal to
- must be smaller than
- can be either smaller or larger than or equal to

…the distance it traveled.