One-dimensional kinematics

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2025 W32–[1]

[1]Phys 20.01 Mod 1. All figures are from Urone (2022) 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!

Quick!

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? 🦟

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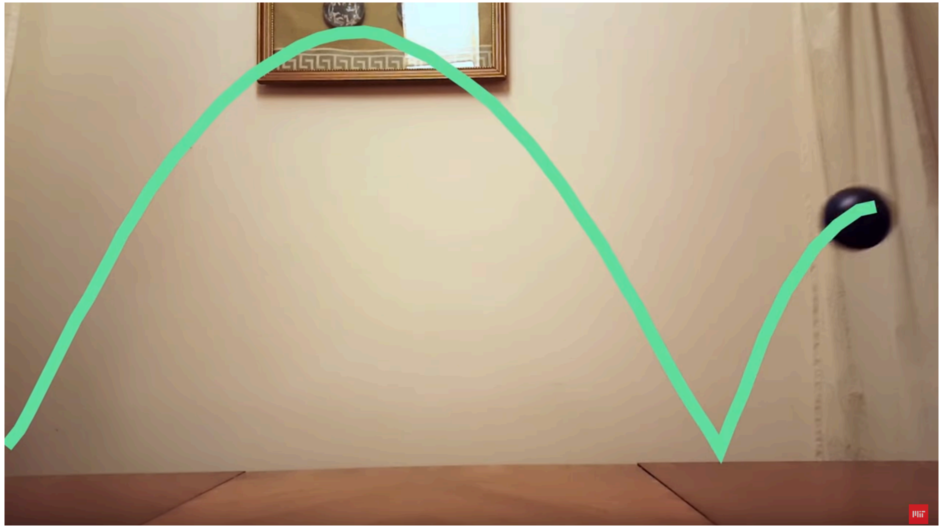
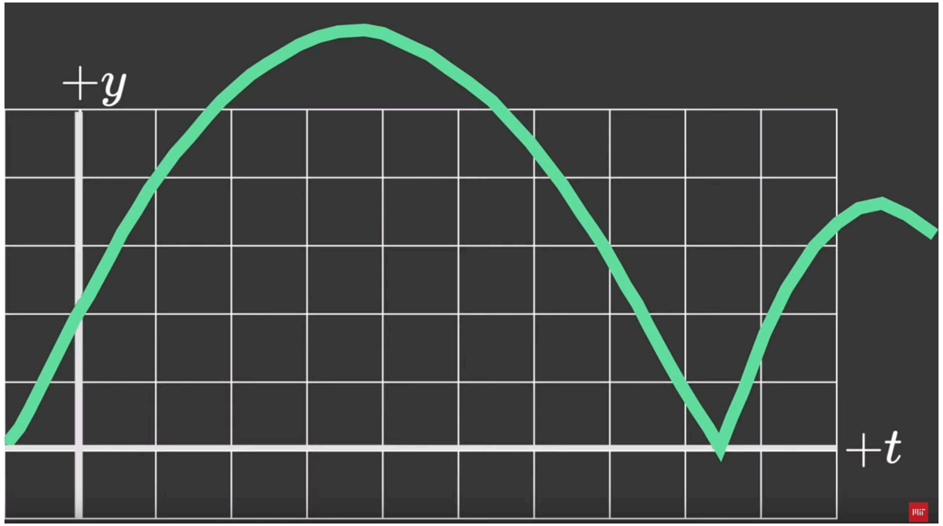
It should fly toward you into the breeze. When just above you, it should fly at 3 m/s in order to hover at rest. Unless its grip on your skin is strong enough after landing, it must continue flying at 3 m/s to keep from being blown off. That’s why a breeze is an effective deterrent to mosquito bites.

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

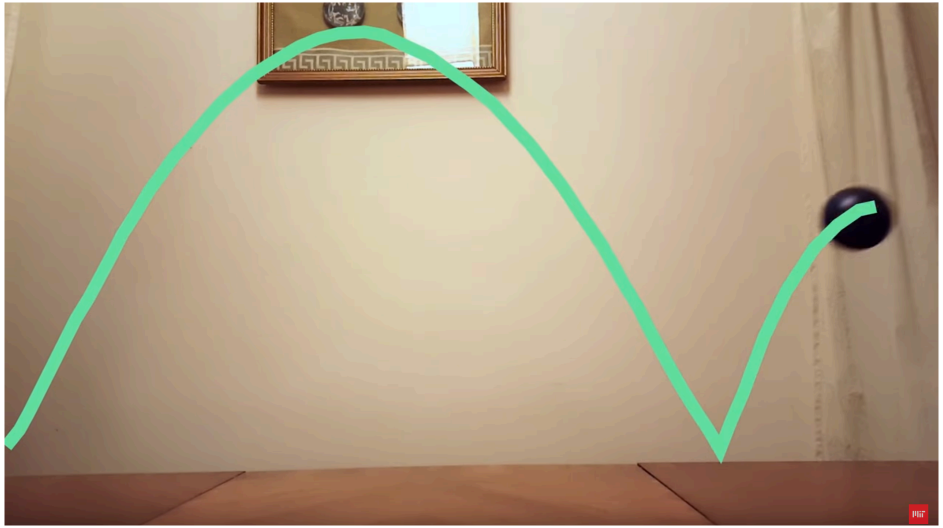


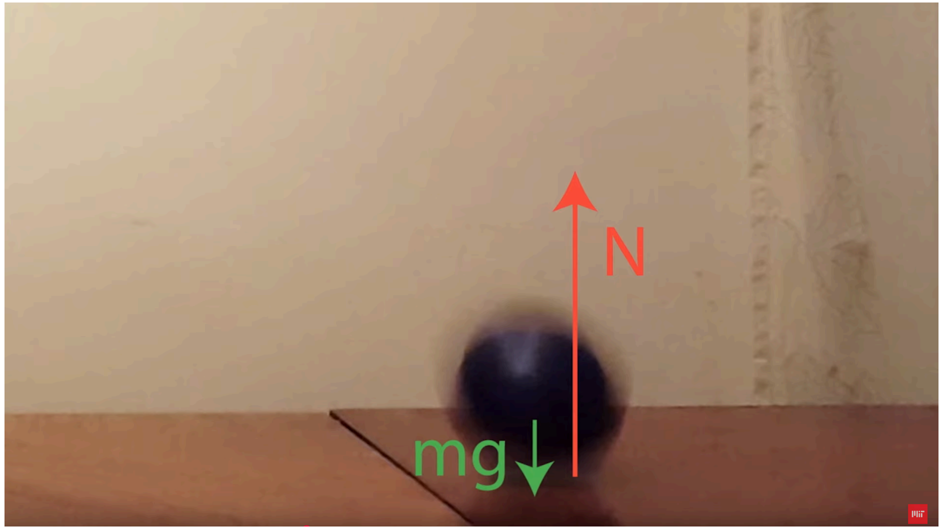


Studying motion

- **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





Studying motion

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

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

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

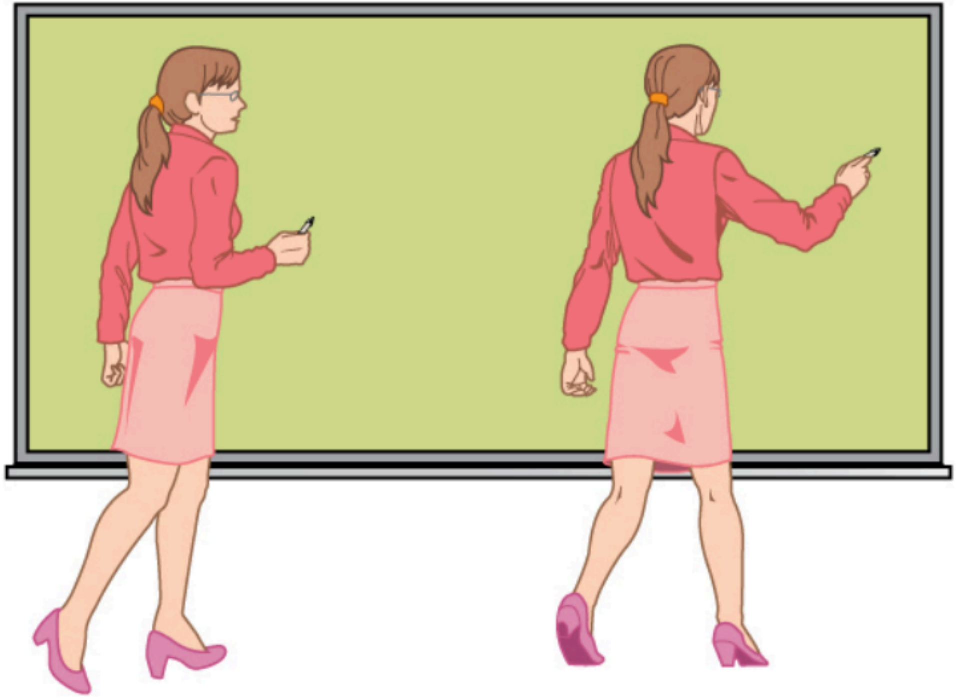
$$\text{why} \leftrightarrow \text{how}$$

Questions? 🤔

Displacement 📍

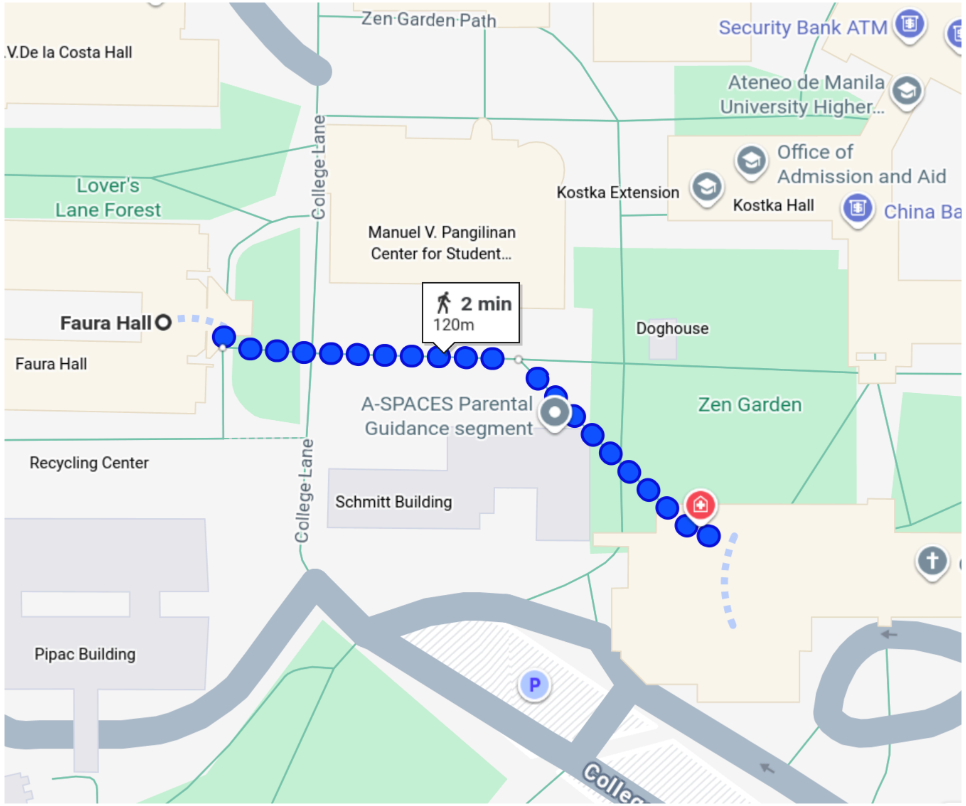
Position

- **Position** is where an object is at any particular time
- More precisely, where is the object relative to another object
  - As in relative to a convenient reference frame



Distance

- **Distance** is the total length of the path traveled between two positions
- It is path dependent
- eg. I'm hungry, I'll go to gonz real quick



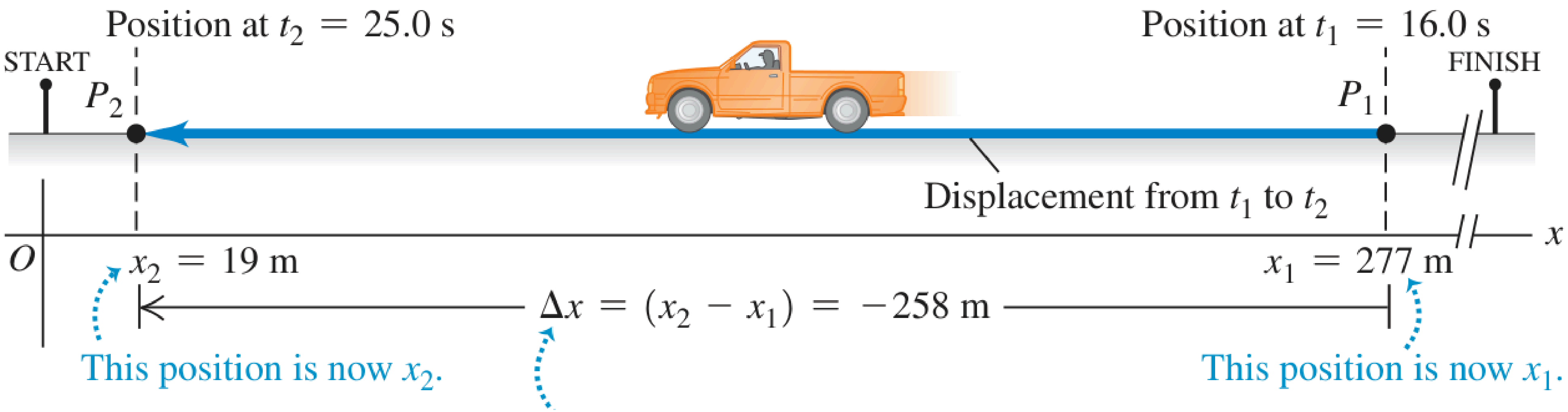
Displacement

- **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)

Displacement



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)
- Initial time t_0 is often taken to be zero, as in $t_0 = 0$, as if measured with a stopwatch. Then the elapsed time is just t instead of t_f

Speed

- Speed is the distance covered per unit of time, as in

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Example. A cyclist who covers 16 meters in a time of 2 seconds, for example, has a speed of 8 meters per second. 🚴

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

Speed

Example. A car traveling at 50 km/h usually goes at that speed for <1 hour. If it did go at that speed for a full hour, it would cover 50 km. If it continued at that speed for half an hour, it would cover half: 25 km. If it continued for only 1 min, it would cover less than 1 km.

Speed

- **Average speed** is simply 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,

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

- If we know average speed and time interval, distance is findable

Velocity

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

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

  - It is a vector and its SI unit is m/s
- **Instantaneous velocity** v is the velocity at a specific instant or the average velocity for an infinitesimal interval

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

  - Btw, an infinitesimal number is a non-zero quantity that is closer to 0 than any non-zero real number is. Practically, infinitesimal means very, very small
- Instantaneous speed is the magnitude of instantaneous velocity
  - But, average speed is not the magnitude of average velocity
  - Both are scalar quantities as they don't have specified directions

Constant velocity

- Constant speed means steady speed. Something with constant speed doesn't speed up or slow down.
- Constant velocity, on the other hand, means both constant speed and constant direction
  - Constant direction is a straight line, that is the object's path doesn't curve
  - So constant velocity means motion in a straight line at a constant speed

Changing velocity

- If either speed or direction changes (or if both change), then velocity changes

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

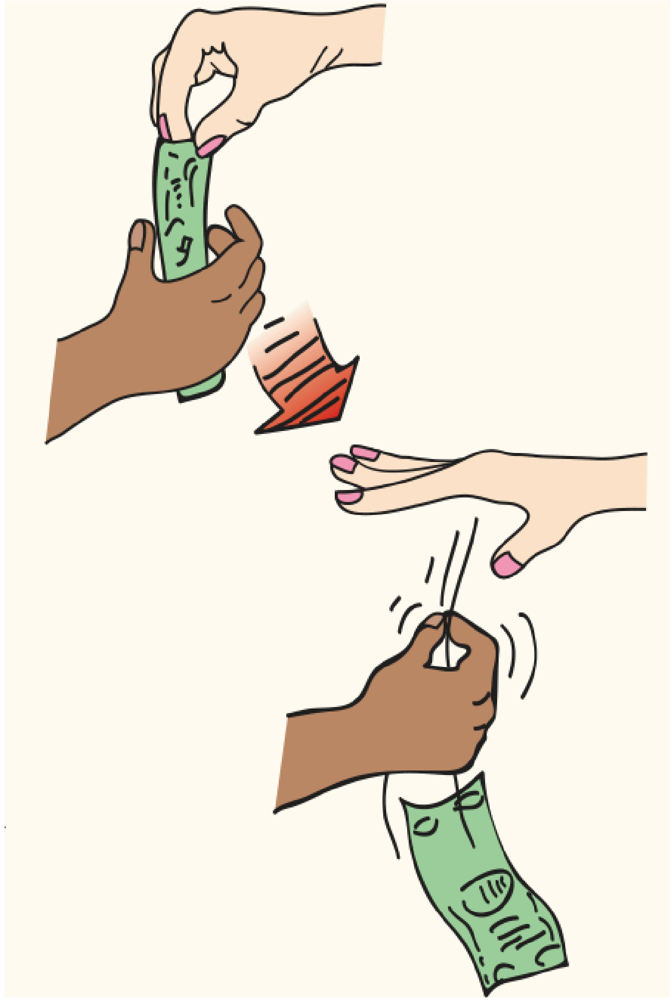
Questions? 🥱

Brain break! 🧠 💤

Changing velocity

Catch me if you can

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



Catch me if you can

They shouldn't be able to. From $d = \frac{1}{2}gt^2$ (which we'll study soon), the bill will fall a distance of 8 cm (half the 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.

Acceleration 🚀

Acceleration

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

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 m/s^2
  - It is a vector so it can be caused by either a change in the magnitude or the direction of the velocity

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

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

- Deceleration is an acceleration with a direction opposite to that of the velocity

Acceleration

Example. A particular car can go from rest to 90 km/h in 10 s. What is its acceleration?

Acceleration

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The acceleration is 9 km/h-s. Strictly speaking, this would be its average acceleration because there may have been some variation in its rate of picking up speed

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?

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?

The accelerations of both the car and the bicycle are the same:

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

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

Although the velocities are quite different, the rates of change of velocity are the same. Hence, the acceleration is equal.

Quick check 🤔

- Can you make this concise: "She moves at a constant speed in a constant direction."
- The speedometer of a car moving to the east reads 100 km/h. The car passes another car that is moving to the west at 100 km/h. Do both cars have the same speed? Do they have the same velocity?
- During a certain period of time, the speedometer of a car reads a constant 60 km/h. Does this indicate a constant speed? A constant velocity?

Quick answers 😌

- "She moves at a constant velocity."
- Both cars have the same speed, but they have opposite velocities because they are moving in opposite directions.
- The constant speedometer reading indicates a constant speed but not a constant velocity, because the car may not be moving along a straight-line path, in which case it is accelerating.

Some notes 📎

Some demo? Google “colorado phet”, or click here 👉 👈

Up next? Some board work, then 2d 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.