Linear Motion

Today

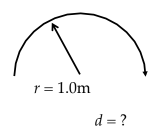
- Intro to Linear Motion:
  - *time*
  - *distance*
  - *speed*
  - *displacement*
  - *velocity*
  - *acceleration*

Linear Motion

Linear motion refers to "motion in a line." The motion of an object can be described using a number of different quantities...

Time & Distance

Time refers to how long an object is in motion for. In here, we'll usually use *seconds*, but we might use *minutes*, *hours*, *years*, *milliseconds*, or any other unit of time.



Distance is simply how far something travels along its path, whether measured in miles, kilometers, meters, centimeters, feet, or any other unit.

Distance

Distances and **lengths** are measure using:

ruler, meter stick, tape measure

The **English system** of length units includes includes:

inches, feet, yards, miles

The **SI system** of length units includes includes:

millimeters, centimeters, meters, kilometers...

It's convenient to know "about how big" a meter is, for the purpose of quick estimates and analyses.

Converting units of length

- 1 kilometer (km) = 1000 meters (m)
- 1 m = 1000 millimeters (mm)
- 1 m = 100 centimeters (cm)
- 12 inches (in. or ") = 1 foot (ft or ')
- 3 ft = 1 yard (yd) $\neq$ 1.00 m
- 5280 ft = 1 mile (mi) = 1609 m
- 2.54 cm = 1 inch

Speed, Velocity, & Acceleration

Speed = how fast you're going

Velocity = how fast you're going in a certain direction

Acceleration = how fast your velocity is changing (in a direction)

Speed

Speed is simply a measure of how quickly an object is moving: how much *distance* it travels in a given *time*.

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

Example

A swimmer travels one complete lap in a pool that is 50.0-meters long. The first leg is covered in 20.0 seconds, the the second leg is covered in 25.0 seconds. What was her average speed for the lap?

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

$$speed = \frac{50 + 50}{20 + 25} = 2.22 m/s$$

Some quantities are *Scalars*

Time, *distance,* and *speed* are examples of *scalar quantities*. They have a *magnitude* (a number with its unit), but *no direction*.

How fast were you going?
"I was going 55 miles per hour, Officer."

What is your mass?
"75 kilograms"

How hot is it?
"It's 130° Fahrenheit."

How much time left in this class?
"45 minutes."

Some quantities are *Vectors*

Vector quantities have a *magnitude* (a number with its unit), *and a direction*.

The vector quantities that we'll be starting with include:

- *displacement*
- *velocity*
- *acceleration*

Displacement

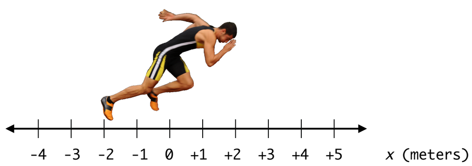
Displacement is a measure of how far you have "displaced," or changed your position. Because displacement is a *vector* quantity, you need to specific a *direction* for your displacement.

What was your displacement coming to this class?
"157 meters, *East*"

How high can you jump?
"1.3 meters, *up*"

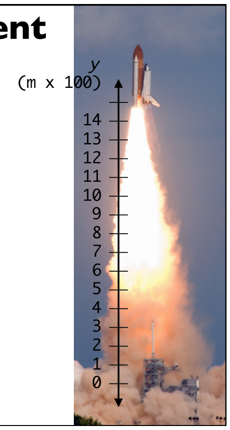
Horizontal displacement

For horizontal motion, we'll often describe the displacement in regards to an imaginary number line, with "to the right" being the positive-*x* direction, and "to the left" being the negative-*x* direction.



Vertical displacement

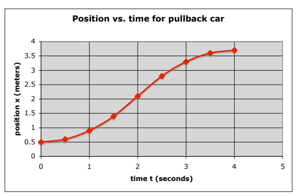
For vertical motion, we'll often describe the displacement in regards to an imaginary number line, with "up" being the positive-*y* direction, and "down" being the negative-*y* direction.



Example

What distance does this car travel?

What is the *displacement* of the car?



$$displacement = \text{change in position along the } x\text{-axis}$$

$$displacement = \Delta x = x_f - x_i$$

Example

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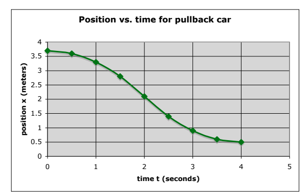


$$displacement = \text{change in position along the } x\text{-axis}$$

$$displacement = \Delta x = x_f - x_i$$

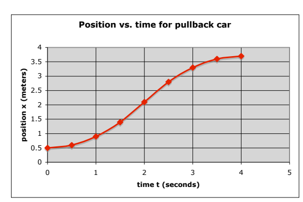
Average Velocity

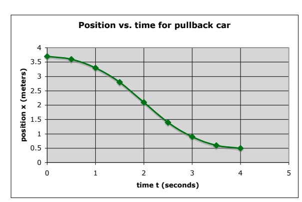
Average velocity is a vector quantity that describes how quickly an object's position is changing.

$$average\ \ velocity\ \ \boldsymbol{v} = \frac{displacement}{time} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

Example

Calculate the average velocity for each of these cars.





Acceleration

Acceleration is a measure of how quickly velocity changes.

TIME	0.00 s	1.00 s	2.00 s	3.00 s	4.00 s
VELOCITY	0 mi/hr	10mi/hr	20mi/hr	30mi/hr	40mi/hr

This data table is for a car that accelerated "from rest."
What is the velocity of the car? What is it called when velocity changes over time? What is the acceleration of this car?

Acceleration

TIME	0.00 s	1.00 s	2.00 s	3.00 s	4.00 s
VELOCITY	0 mi/hr	10mi/hr	20mi/hr	30mi/hr	40mi/hr

Making a chart like this any time we need to calculate acceleration isn't practical, so we usually use a formula:

$$acceleration = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t}$$

Acceleration

We can look at it another way: what if the acceleration of an object is 10 meters/second/second, or 10m/s^2? If it starts "at rest," how fast is it moving at the end of each second? Fill in the chart below.

TIME					
VELOCITY					

Acceleration

Sometimes we're given the acceleration, and want to know the velocity of the moving object after a certain amount of time has passed. In that case, we rearrange the formula:

$$acceleration = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t}$$

$$v_f = v_i + at$$

Example

A car traveling at 25 m/s accelerates at 3.0 m/s^2 for 5.0 seconds. How fast is it traveling at the end of the 5.0 seconds?

$$v_f = v_i + at$$
$$v_f = 25 + (3.0m/s^2)(5.0s)$$
$$v_f = 40m/s$$

Example

A toy traveling at +50 cm/s slows down to +20 cm/s in 10.0 s. What is the toy's acceleration?

$$a = \frac{v_f - v_i}{t}$$
$$a = \frac{20cm/s - 50cm/s}{10s}$$
$$a = -3.0cm/s^2$$

Acceleration Downwards

Galileo collected data concerning falling objects, and observed the following when those objects were dropped near the surface of the earth:

TIME	0.0s	1.0s	2.0s	3.0s	4.0s
VELOCITY	0m/s	-10m/s	-20m/s	-30m/s	-40m/s

Based on Galileo's data, what is the acceleration due to Earth's gravity of a falling object?

Free-Fall

Objects falling near the surface of the earth, with negligible air friction, accelerate toward the earth's surface with an acceleration of -9.80 m/s^2.

$$a_{gravity} = -9.80\text{m/s}^2 = -\mathbf{g}$$

You may find it convenient in class, in homework, or on tests to round this value to -10m/s^2.

Example

A rock is dropped off a high cliff. What is its velocity after 3.0 seconds have passed?

$$\begin{aligned} &0 \rightarrow -10, \\ &-10 \rightarrow -20, \\ &-20 \rightarrow -30m/s \\ &v_f = v_i + at \\ &v_f = 0 + (-10)(3) = -30m/s \end{aligned}$$

What is the velocity of a rock that is thrown downwards at 5 m/s, 2 seconds after it is released?

$$\begin{aligned} &v_f = v_i + at \\ &v_f = -5 + (-10)(2) = -25m/s \end{aligned}$$

"Free-Fall" for upwards motion

What happens if we start by throwing an object up into the air?

TIME	0.0s	1.0s	2.0s	3.0s	4.0s
VELOCITY	+20m/s				

How Fast → How *Far?*

Let's drop an object, and see how *far* it falls as time passes.

TIME	0.0s	1.0s	2.0s	3.0s	4.0s
INSTANTANEOUS VELOCITY	0m/s	-10m/s	-20m/s	-30m/s	-40m/s
AVG VELOCITY during the second	---				
DISTANCE TRAVELED during the second	---				
TOTAL DISPLACEMENT from top	---				

How far during acceleration

Again, making a chart like this any time we need to calculate acceleration isn't practical, so we usually use a formula:

$$displacement = \Delta x = v_i t + \frac{1}{2}at^2$$

Acceleration analysis

So if someone asks you a problem that involves changing velocity, you've got several different ways to analyze it.

1. Think about it conceptually.
2. $a = \frac{v_f - v_i}{t}$
3. $v_f = v_i + at$
4. $d = v_i t + \frac{1}{2}at^2$

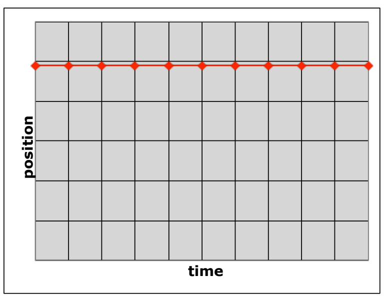
Graphs of Motion

While formulae can be used to calculate motion, it can be useful to *visualize* an object's motion by looking at a graph.

Position-time graphs show how *position* changes over time.
Velocity-time graphs examine a changing *velocity* over time.
Acceleration-time graphs look at *acceleration* over time.

Position-time graphs

What motion is represented by this graph?



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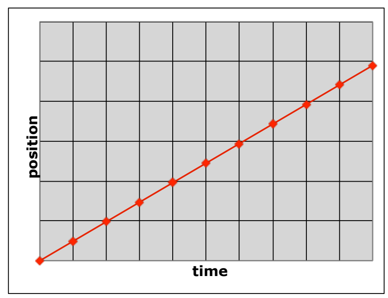

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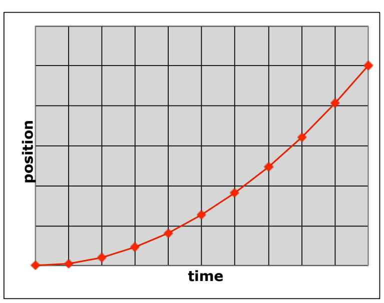

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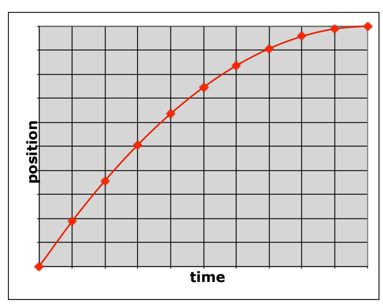
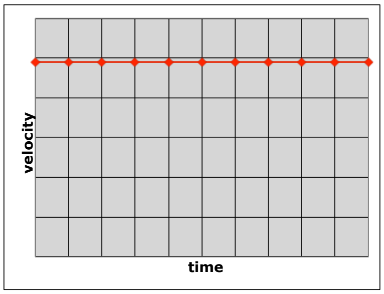


Velocity-time graphs

What motion is represented by this graph?



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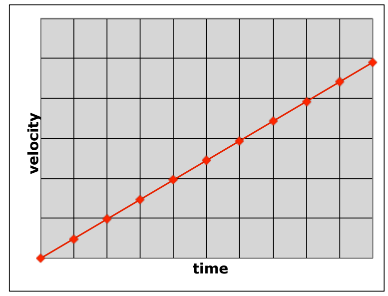

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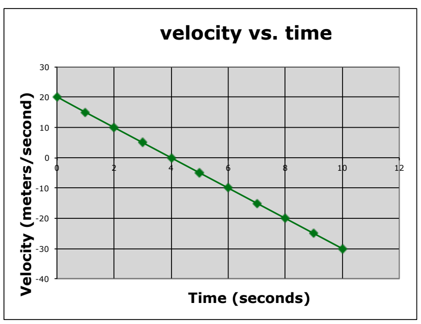
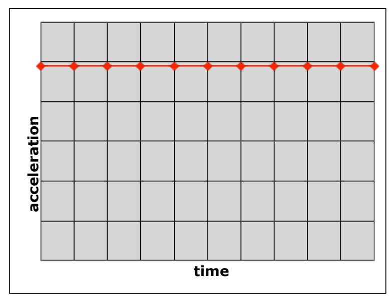


Acceleration-time graphs

What motion is represented by this graph?



Graphic Demos