Linear Motion, Speed & Velocity

Unit: Kinematics (Motion)

NGSS Standards: N/A

MA Curriculum Frameworks (2006): 1.1, 1.2

AP Physics 1 Learning Objectives: 3.A.1.1, 3.A.1.3

Knowledge/Understanding Goals:

- understand terms relating to position, speed & velocity
- understand the difference between speed and velocity

Language Objectives:

- Understand and correctly use the terms “position,” “distance,” “displacement,” “speed,” and “velocity.”
- Accurately describe and apply the concepts described in this section using appropriate academic language.

Labs, Activities & Demonstrations:

- Walk in the positive and negative directions (with positive or negative velocity).
- Walk and change direction to show distance *vs.* displacement.

Notes:

coördinate system: a framework for describing an object’s ***position*** (location), based on its distance (in one or more directions) from a specifically-defined point (the ***origin***). (You should remember these terms from math.)

direction: which way an object is oriented or moving within its coördinate system. Note that direction can be positive or negative.

position (x): the location of an object relative to the origin (zero point) of its coördinate system. We will consider position to be a zero-dimensional vector, which means it can be positive or negative with respect to the chosen coördinate system.

distance (d): [scalar] how far an object has moved.

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displacement ($\vec{d}$ or Δx): [vector] how far an object's current position is from its starting position ("initial position"). Displacement can be positive or negative (or zero), depending on the chosen coördinate system.

rate: the change in a quantity over a specific period of time.

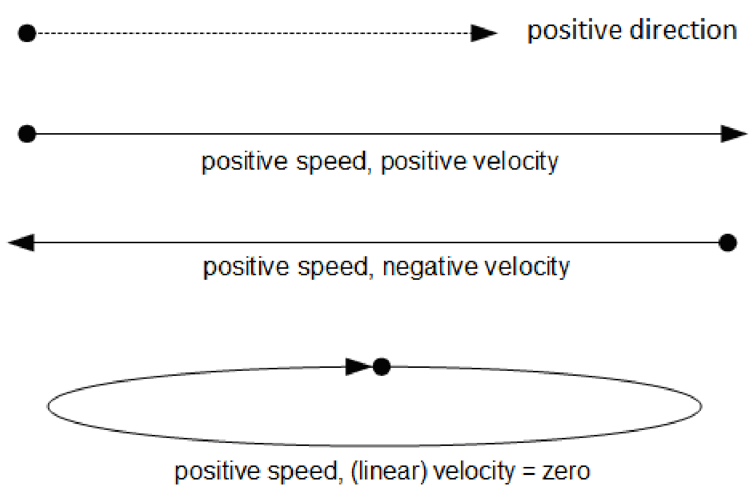
motion: when an object's position is changing over time.

speed: [scalar] the rate at which an object is moving at an instant in time. Speed does not depend on direction, and is always nonnegative.

velocity: ($\vec{v}$) [vector] an object's displacement over a given period of time. Because velocity is a *vector*, it has a *direction* as well as a *magnitude*. Velocity can be positive, negative, or zero.

uniform motion: motion at a constant velocity (*i.e.,* with constant speed and direction)

An object that is moving has a positive speed, but its velocity may be positive, negative, or zero, depending on its position.



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Variables Used to Describe Linear Motion

Variable	**Quantity**	**MKS Unit**
x	position	m
d, Δx	distance	m
$\vec{\boldsymbol{d}}$, $\Delta\boldsymbol{x}$	displacement	m
h	height	m
$\vec{\boldsymbol{v}}$	velocity	$\frac{\text{m}}{\text{s}}$
$\bar{\vec{\boldsymbol{v}}}$	average velocity	$\frac{\text{m}}{\text{s}}$

The average velocity of an object is its displacement divided by the time, or its change in position divided by the (change in) time:

$$\bar{\vec{\boldsymbol{v}}} = \frac{\vec{\boldsymbol{d}}}{t} = \frac{x - x_o}{t} = \frac{\boldsymbol{\Delta x}}{t} = \frac{\boldsymbol{\Delta x}}{\Delta t}$$

(Note that elapsed time is always a difference (Δt), though we usually use t rather than Δt as the variable.)

We can use calculus to turn $\bar{v}$ into v by taking the limit as Δt approaches zero:

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

i.e., velocity is the first derivative of displacement with respect to time.

We can rearrange this formula to show that displacement is average velocity times time:

$$\vec{\boldsymbol{d}} = \bar{\vec{\boldsymbol{v}}}t$$

Position is the object's starting position plus its displacement:

$$x = x_o + \vec{\boldsymbol{d}} = x_o + \bar{\vec{\boldsymbol{v}}}t$$

where x_0* means "position at time = 0". This formula is often expressed as:

$$x - x_o = \vec{\boldsymbol{d}} = \bar{\vec{\boldsymbol{v}}}t$$

* x_o is pronounced "x-zero" or "x-naught".

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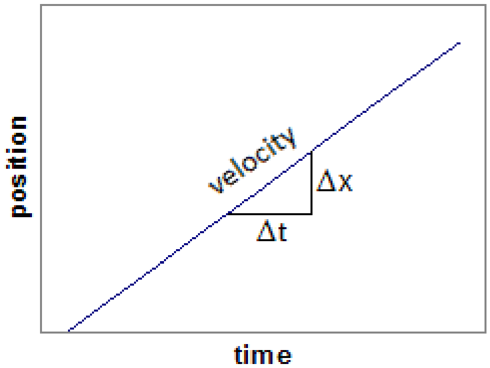
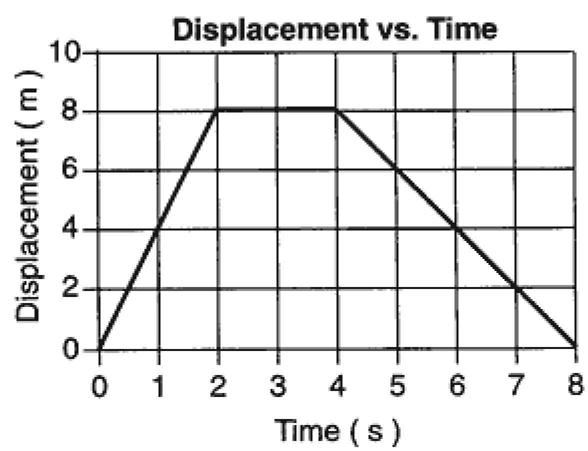
Note that $\frac{\Delta x}{\Delta t}$ is the slope of a graph of position (x) *vs.* time (t). Because $\frac{\Delta x}{\Delta t} = v$, this means that the ***slope*** of a graph of position *vs.* time is equal to the velocity.



In fact, *on any graph, the quantity you get when you divide the quantity on the* x-*axis by the quantity on the* y-*axis is, by definition, the slope. I.e.,* the slope is $\frac{\Delta y}{\Delta x}$, which means the quantity defined by $\frac{y\text{-axis}}{x\text{-axis}}$ will always be the slope.

Recall that velocity is a vector, which means it can be positive, negative, or zero. On the graph below, the velocity is $+4\,\frac{\text{m}}{\text{s}}$ from 0 s to 2 s, zero from 2 s to 4 s, and $-2\,\frac{\text{m}}{\text{s}}$ from 4 s to 8 s.



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Sample problems:

Q: A car travels 1200 m in 60 seconds. What is its average velocity?

A: $\bar{v} = \frac{d}{t}$

$$\bar{v} = \frac{1200\text{ m}}{60\text{ s}} = 20\ \tfrac{\text{m}}{\text{s}}$$

Q: A person walks 320 m at an average velocity of $1.25\ \tfrac{\text{m}}{\text{s}}$. How long did it take?

A: "How long" means what length of <u>*time*</u>.

$$\bar{v} = \frac{d}{t}$$

$$1.25 = \frac{320}{t}$$

$$t = 256\ s$$

It took 256 seconds for the person to walk 320 m.

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