Physics 2048, General Physics A
Prof. Stephen Hill, Course Leader

An Introduction to Mechanics, Waves and Thermodynamics

Calculus and Trigonometry will be used (MAC 2311 a pre-requisite)

NATIONAL MAGLAB

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Newton's laws:

From the Gatorade ad:

A. "What makes bodies in motion remain in motion?"
B. "What makes what goes up, stay up?"
C. "What makes what goes down, get back up?"

One of these statements may be attributed to Newton

The answer is A

Newton's first law (Law of inertia): A body at rest remains at rest, and a body in motion will remain in motion at a constant velocity unless acted upon by an external force.

Standing the test of time

- The classical laws of physics, including mechanics and thermodynamics, have been rigorously studied through centuries of experiment.
- This is the so-called *"scientific method."*
- During this course, we will explore many (though by no means all**) of the classical laws of physics using controlled experimental demonstrations.
- We will compare the results with simple mathematically based theoretical principles.
- We will then use these theoretical principles to solve a wide range of problems.

**PHY2049 will introduce you to more of these laws.

What do physicists do?

At the end of the 19th century, A. A. Michelson (very famous physicist) stated that *"all of the grand underlying physical principles had been firmly established."*

Then came two revolutions:

- Relativity

  concepts of space and time change at large relative velocities

- Quantum mechanics

  concept of matter changes on small length scales

- Classical laws of mechanics break down in these limits, and much remains to be discovered

These are the things physicists study today through experiment and theory, just as physicists have done through the ages.

Physics, the 21st century, & you

A technological revolution

- 20th century microelectronics & the computer revolution

- Now we have "nanoscience" (and molecular sciences)
  - Devices/molecules which are made up from just a few atoms
  - 1 nanometer = 1 meter / 1,000,000,000
  - 1 millionth of the diameter of a grain of rice

- Nanoscience is revolutionizing electronic and mechanical engineering, biology, chemistry and medicine

- Physics is playing a larger and larger role in all of these fields

However, before you can tackle these modern subjects, you have to have a fundamental grasp of the underlying classical laws of physics

Ch.1: International System of Units

Système International (SI) d'Unités in French
a.k.a. metric or SI units

- Scientists measure quantities through comparisons with standards.
- Every measured quantity has an associated unit.
- The important thing is to define sensible and practical "units" and "standards" that scientists everywhere can agree upon. (e.g. Rocket Scientists)

Ch.1: International System of Units

Système International (SI) d'Unités in French
a.k.a. metric or SI units

- Even though there exist an essentially infinite number of different physical quantities, we need no more than **seven** base units/quantities from which all others can be derived.

In 1971, the 14th General Conference on Weights and Measures picked these seven base quantities for the SI, or metric system.

- In Mechanics, we really only need three of these base units (see table)
- In Thermodynamics, we need two more Temperature in kelvin (K) Quantity in moles (mol)

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

Prefixes for SI Units

Factor	Prefix[a]	Symbol
10^{24}	yotta-	Y
10^{21}	zetta-	Z
10^{18}	exa-	E
10^{15}	peta-	P
10^{12}	tera-	T
10^{9}	**giga-**	**G**
10^{6}	**mega-**	**M**
10^{3}	**kilo-**	**k**
10^{2}	hecto-	h
10^{1}	deka-	da
10^{-1}	deci-	d
10^{-2}	**centi-**	**c**
10^{-3}	**milli-**	**m**
10^{-6}	**micro-**	**μ**
10^{-9}	**nano-**	**n**
10^{-12}	**pico-**	**p**
10^{-15}	femto-	f
10^{-18}	atto-	a
10^{-21}	zepto-	z
10^{-24}	yocto-	y

Scientific notation:

3 560 000 000 m = 3.56×10^{9} m

0.000 000 492 s = 4.92×10^{-7} s

On LONCAPA = 4.92E-7 s

On your calculator:

4.92×10^{-7} = 4.92 E-7 or 4.92 $^{-07}$

Prefixes (also works in LONCAPA):

5×10^{9} watts = 5 gigawatts = 1 GW

2×10^{-9} s = 2 nanoseconds = 2 ns

Orders of magnitude

Measurement	Length in Meters
Distance to the first galaxies formed	2×10^{26}
Distance to the Andromeda galaxy	2×10^{22}
Distance to the nearest star (Proxima Centauri)	4×10^{16}
Distance to Pluto	6×10^{12}
Radius of Earth	6×10^{6}
Height of Mt. Everest	9×10^{3}
Thickness of this page	1×10^{-4}
Length of a typical virus	1×10^{-8}
Radius of a hydrogen atom	5×10^{-11}
Radius of a proton	1×10^{-15}

Changing units

Chain-link **conversion - an example:**

$$1 \text{ minute} = 60 \text{ seconds}$$

therefore $\dfrac{1 \text{ min}}{60 \text{ sec}} = 1$ or $\dfrac{60 \text{ sec}}{1 \text{ min}} = 1$

Note: this does not imply 60 = 1, or 1/60 = 1!

$$2 \text{ min} = (2 \text{ min}) \times (1) = (2 \cancel{\text{min}}) \times \left(\frac{60 \text{ s}}{1 \cancel{\text{min}}} \right) = 120 \text{ s}$$

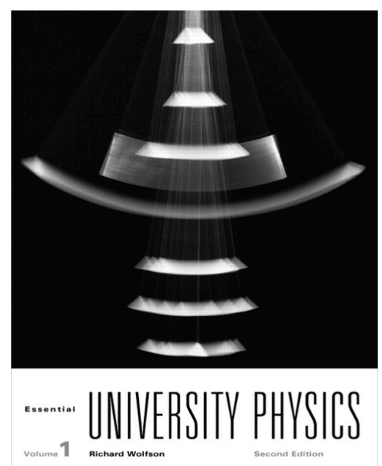
Conversion Factors

Equivalent Measures of Length	
1 meter (m)	39.37 inches (in.)
1 centimeter (cm)	0.39 in.
1 millimeter (mm)	0.039 in.
1 yard (yd)	91.44 centimeters (cm)
1 foot (ft)	30.48 cm
1 inch (in.)	2.54 cm
Household Measures (Approximate)	
1 drop	1/20 mL
1 teaspoon	5 mL
1 tablespoon	15 mL
1 cup	250 mL
Weight and Apothecaries' Equivalents	
1 milligram (mg)	1/65 grain (1/60)
1 gram (g)	15.43 grains (15)

Etc., etc., etc.......

Resources at your fingertips...

LON-CAPA
The LearningOnline Network with CAPA



Wikipedia
The Free Encyclopedia

Quiz #1

Which of the following have been used as the standard for the unit of length corresponding to 1 meter?

a) One ten millionth of the distance from the North pole to the equator.

b) The distance between two fine lines engraved near the ends of a platinum-iridium bar.

c) 1 650 763.73 wavelengths of a particular orange-red light emitted by atoms of krypton-86 (^{86}Kr).

d) The length of the path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second.

Length

1792: French established a new system of weights and measures

$$1 \text{ m} = \frac{\text{distance from N. pole to equator}}{\text{ten-million}}$$

- Then, in the 1870s:

  1 m = distance between fine lines on Pt-Ir bar

  Accurate copies sent around the world

- Then, in 1960:

  1 m = 1 650 763.73 × wavelength ^{86}Kr (orange)

- 1983 until now (strict definition):

  1 m = distance light travels in 1/(299 792 458) sec

Time

Measurement	Time Interval in Seconds
Lifetime of the proton (predicted)	1×10^{39}
Age of the universe	5×10^{17}
Age of the pyramid of Cheops	1×10^{11}
Human life expectancy	2×10^{9}
Length of a day	9×10^{4}
Time between human heartbeats	8×10^{-1}
Lifetime of the muon	2×10^{-6}
Shortest lab light pulse	6×10^{-15}
Lifetime of the most unstable particle	1×10^{-23}
The Planck time[a]	1×10^{-43}

[a] This is the earliest time after the big bang at which the laws of physics as we know them can be applied.

Some standards used through the ages:

- Length of the day
- Period of vibration of a quartz crystal
- Now we use atomic clocks

1 second equivalent to 9 192 631 770 oscillations of the light emitted by a cesium-133 atom (^{133}Cs) at a specified wavelength (adopted 1967)

United States Naval Observatory

Mass

Object	Mass in Kilograms
Known universe	1×10^{53}
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Small mountain	1×10^{12}
Ocean liner	7×10^{7}
Elephant	5×10^{3}
Grape	3×10^{-3}
Speck of dust	7×10^{-10}
Penicillin molecule	5×10^{-17}
Uranium atom	4×10^{-25}
Proton	2×10^{-27}
Electron	9×10^{-31}

- Kilogram standard is a Pt-Ir cylinder in Paris
- Accurate copies have been sent around the world; the US version is housed in a vault at NIST

A second mass standard:

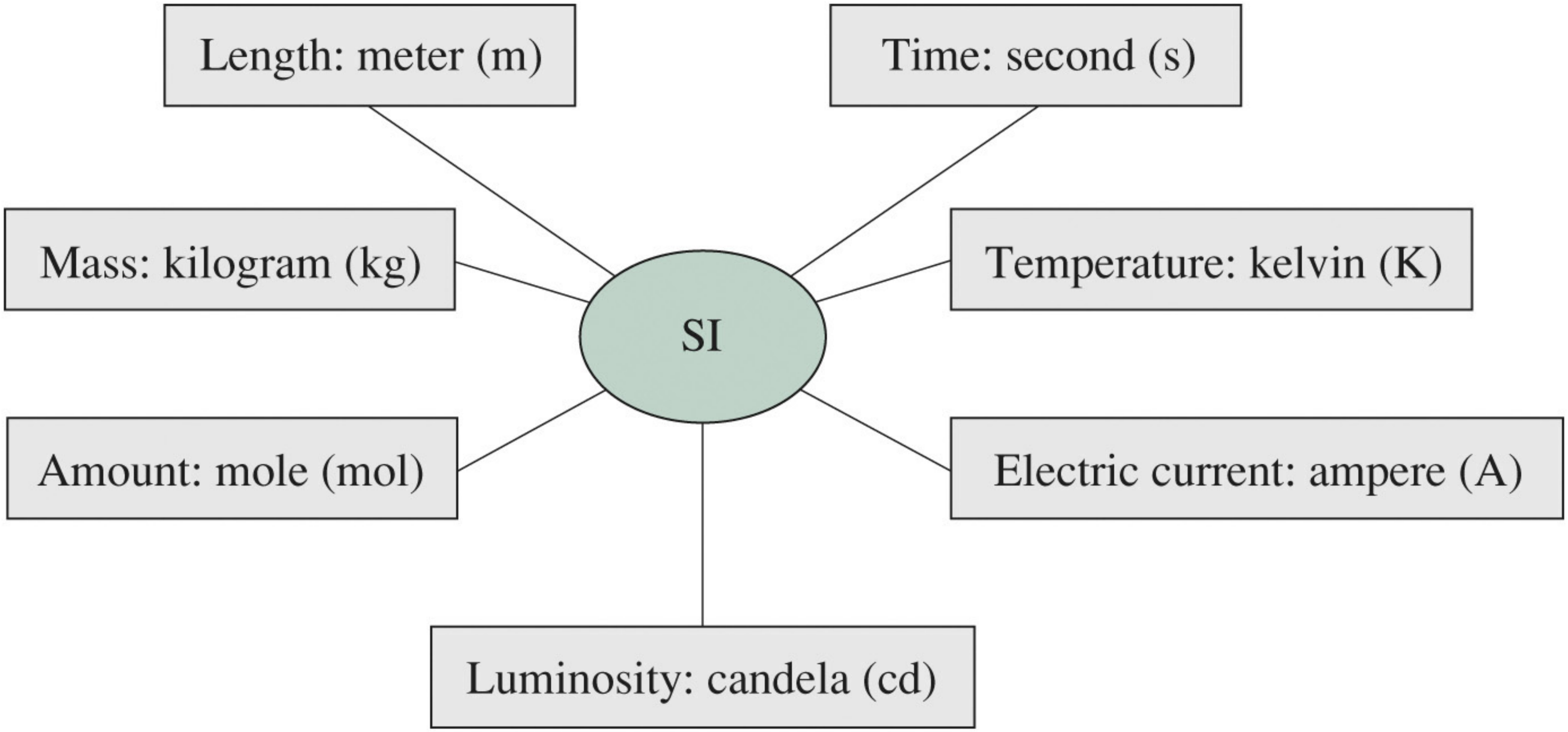
- The ^{12}C atom has been assigned a mass of 12 atomic mass units (u)

$$1 \text{ u} = 1.6605402 \times 10^{-27} \text{ Kg}$$

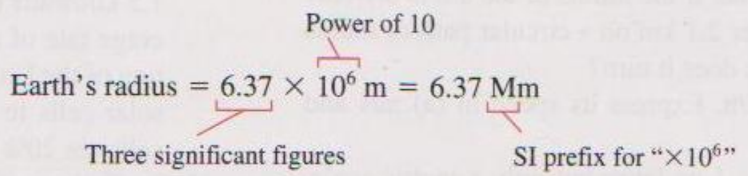
- The masses of all other atoms are determined relative to ^{12}C

Note: we measure "mass" in kilograms. Weight is something completely different, which we measure in Newtons (= kg.m/s^2)

Chapter 1 Summary

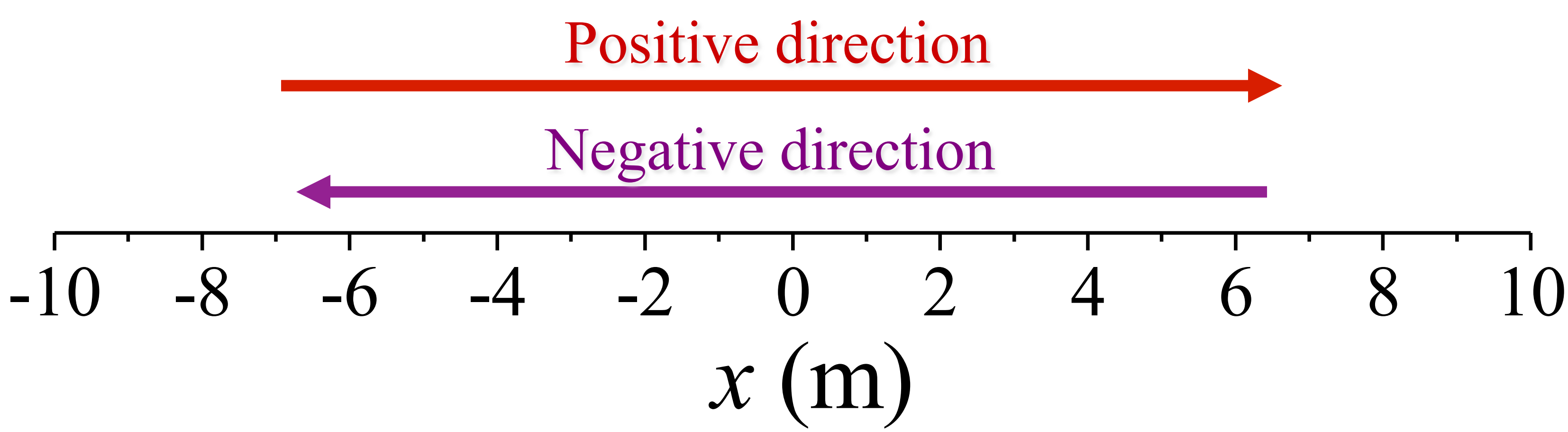


Numbers are often written with prefixes or in scientific notation to express powers of 10. Accuracy is shown by the number of significant figures:

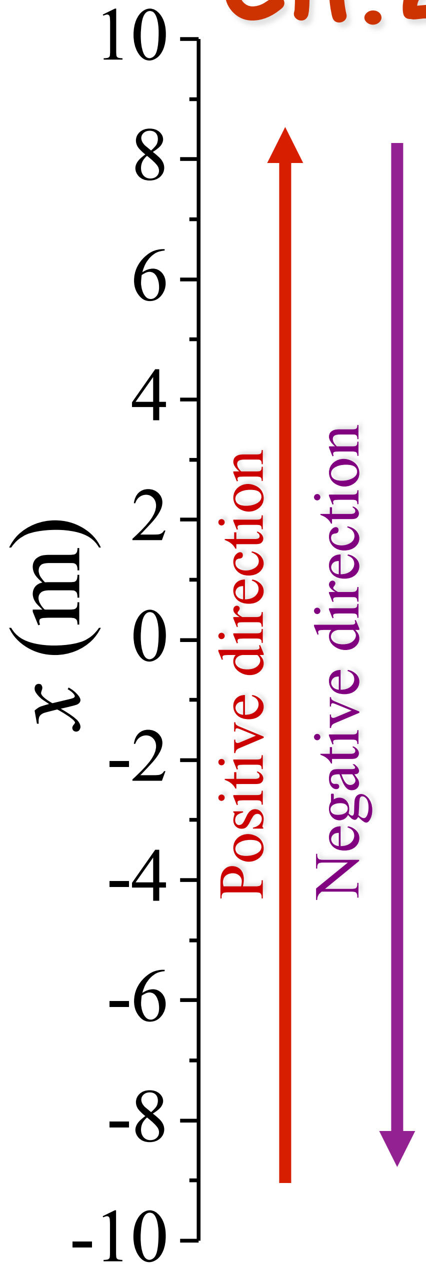


Ch.2: Motion in one-dimension

- We will define the position of an object using the variable x, which measures the position of the object relative to some reference point (origin) along a straight line (x-axis).

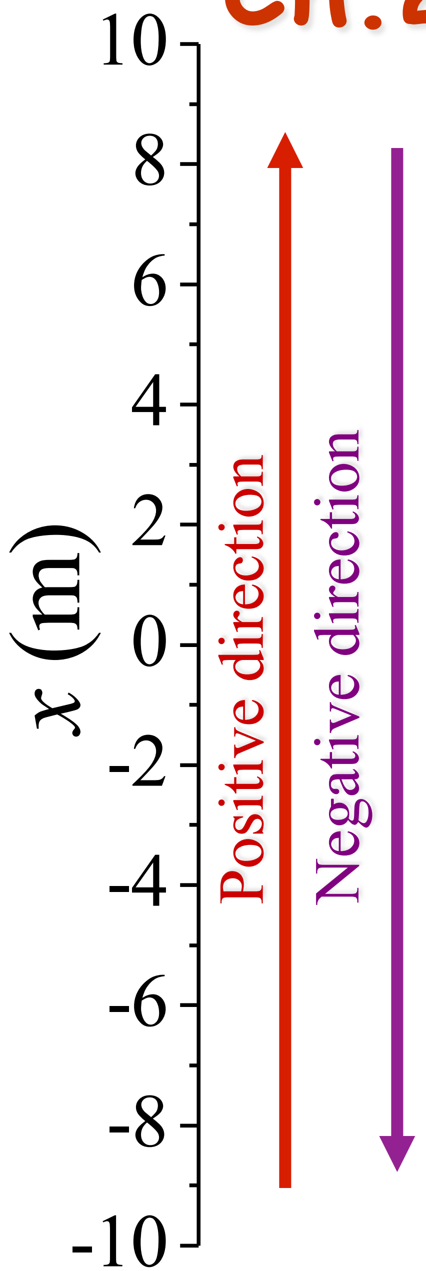


Ch.2: Motion in one-dimension



- We will define the position of an object using the variable x, which measures the position of the object relative to some reference point (origin) along a straight line (x-axis).

Ch.2: Motion in one-dimension



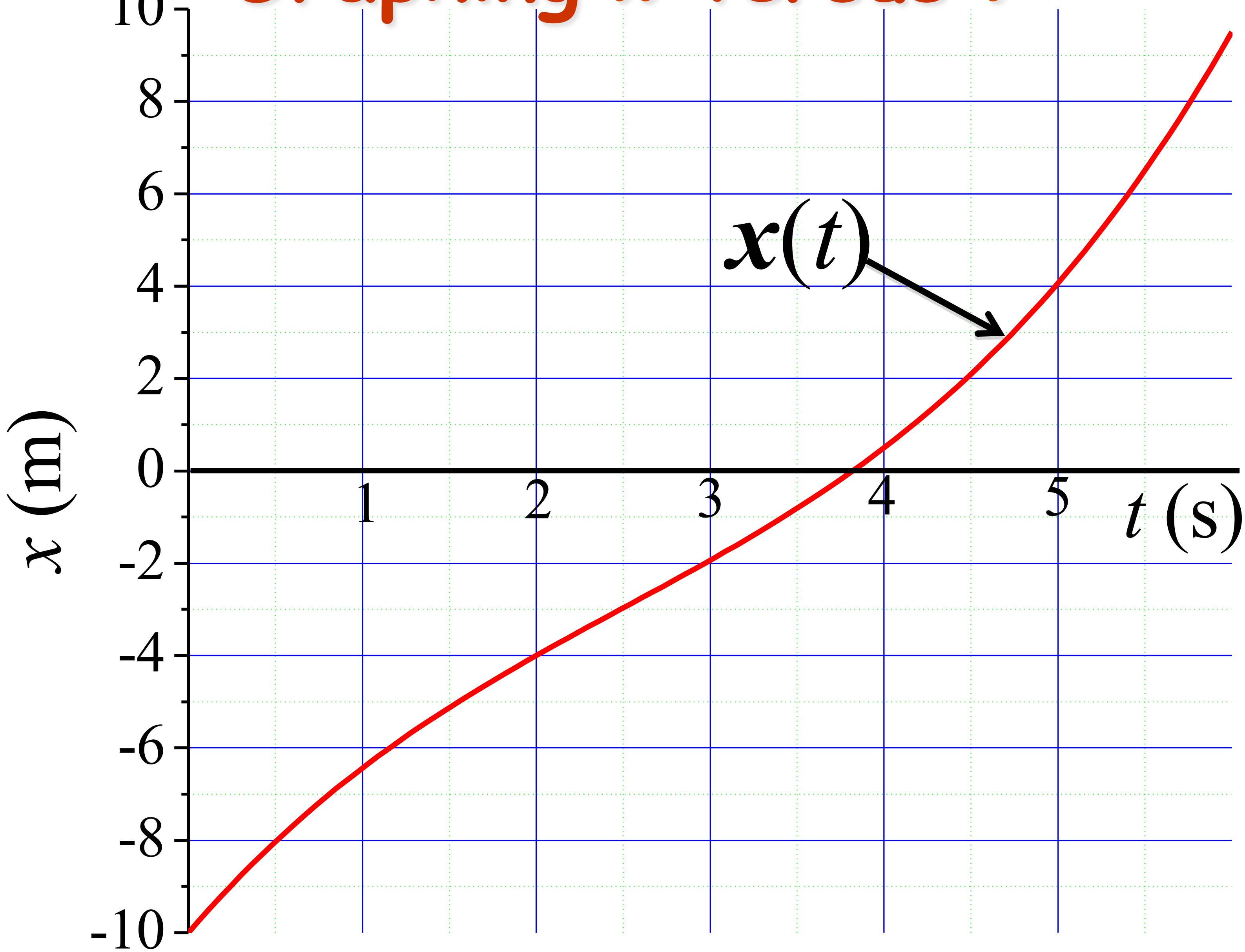
- We will define the position of an object using the variable x, which measures the position of the object relative to some reference point (origin) along a straight line (x-axis).

- In general, x will depend on time t.

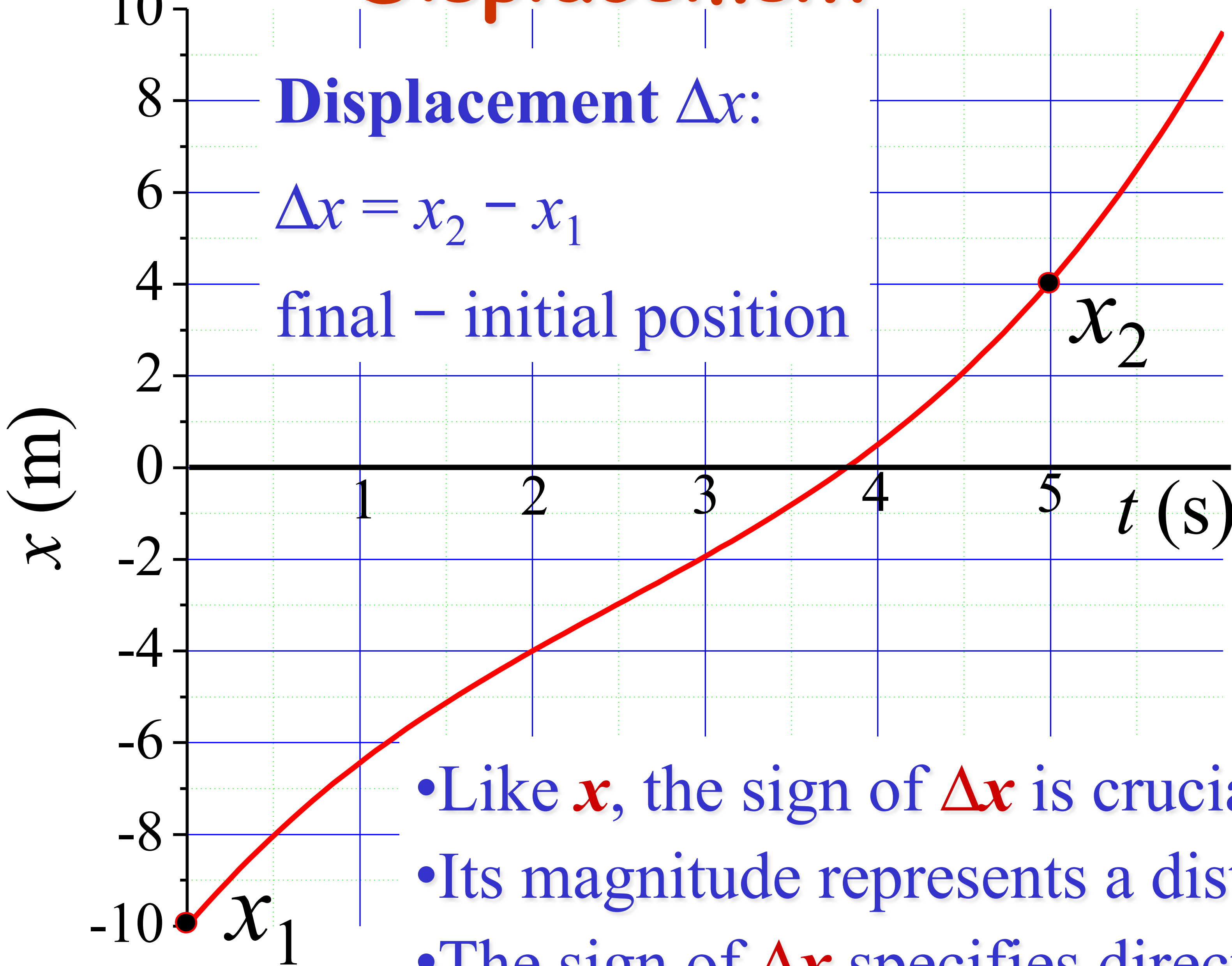
- We shall measure x in meters, and t in seconds, *i.e.* SI units.

- Although we will only consider only one-dimensional motion here, we should not forget that x is a component of a vector. Thus, motion in the $+x$ and $-x$ directions correspond to motions in opposite directions.

Graphing x versus t



Displacement



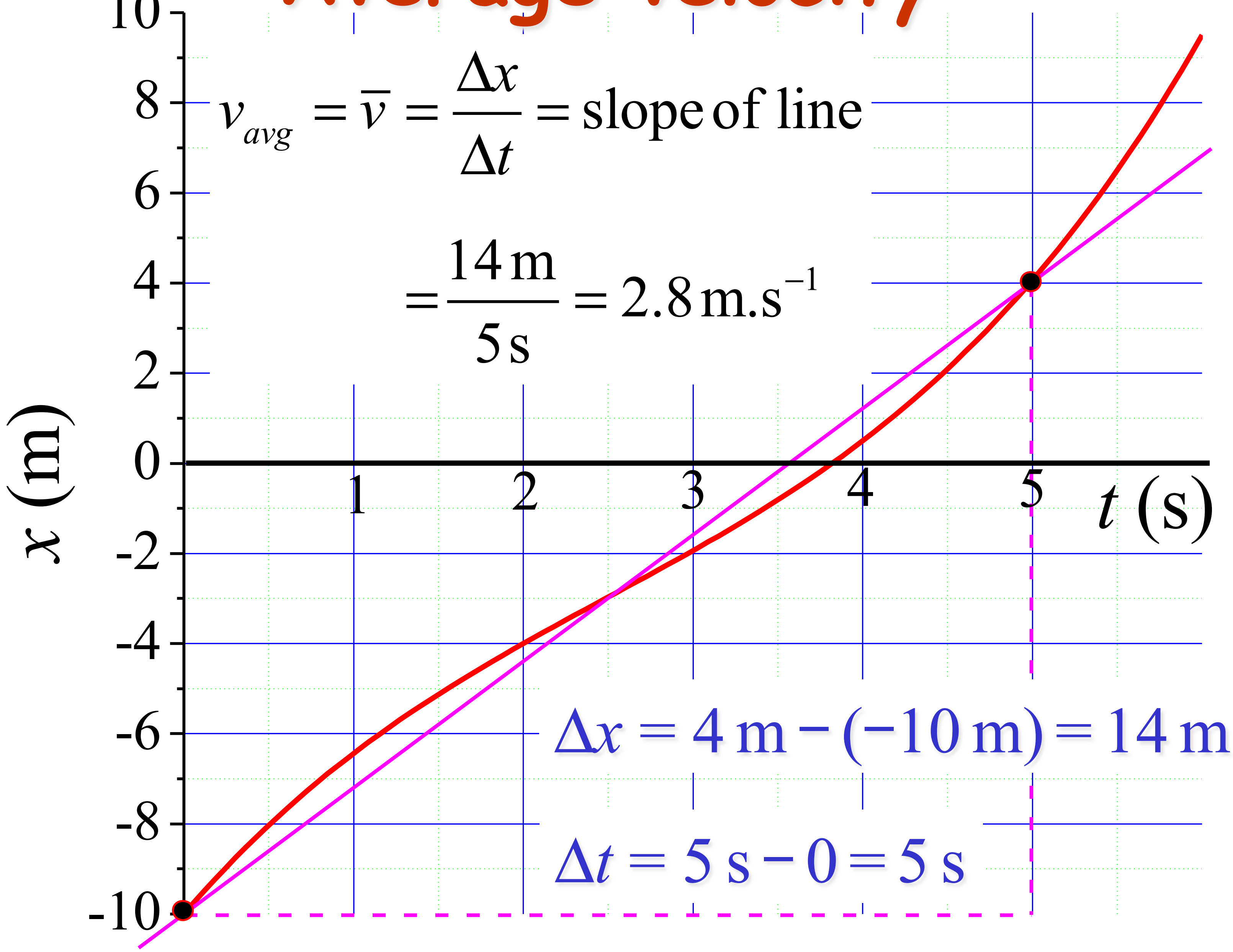
Displacement Δx:

$\Delta x = x_2 - x_1$

final − initial position

- Like ***x***, the sign of **Δx** is crucial
- Its magnitude represents a distance
- The sign of **Δx** specifies direction

Average velocity



Average velocity and speed

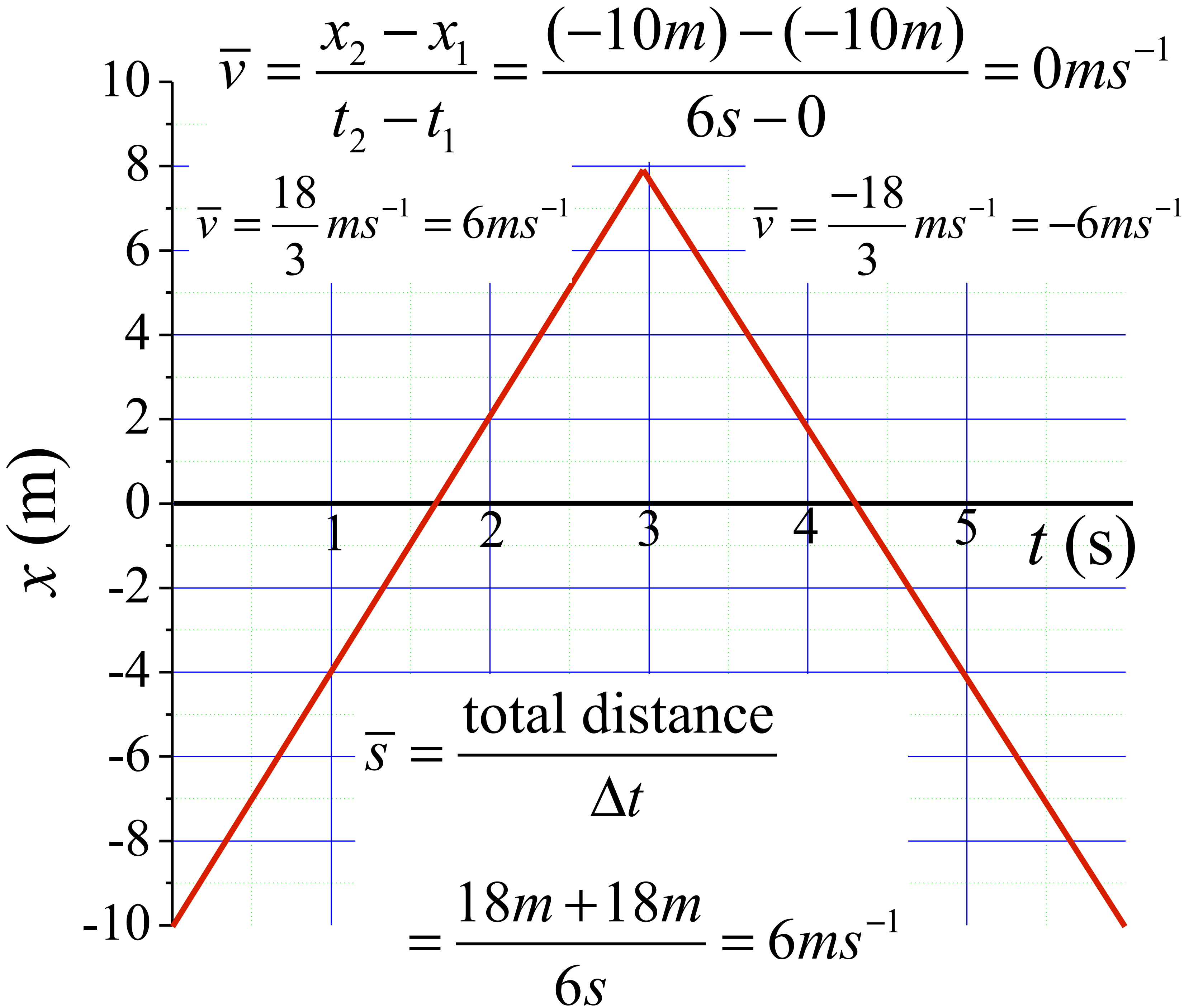
$$v_{avg} = \bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

- Like displacement, the sign of v_{avg} indicates direction

Average speed s_{avg}:

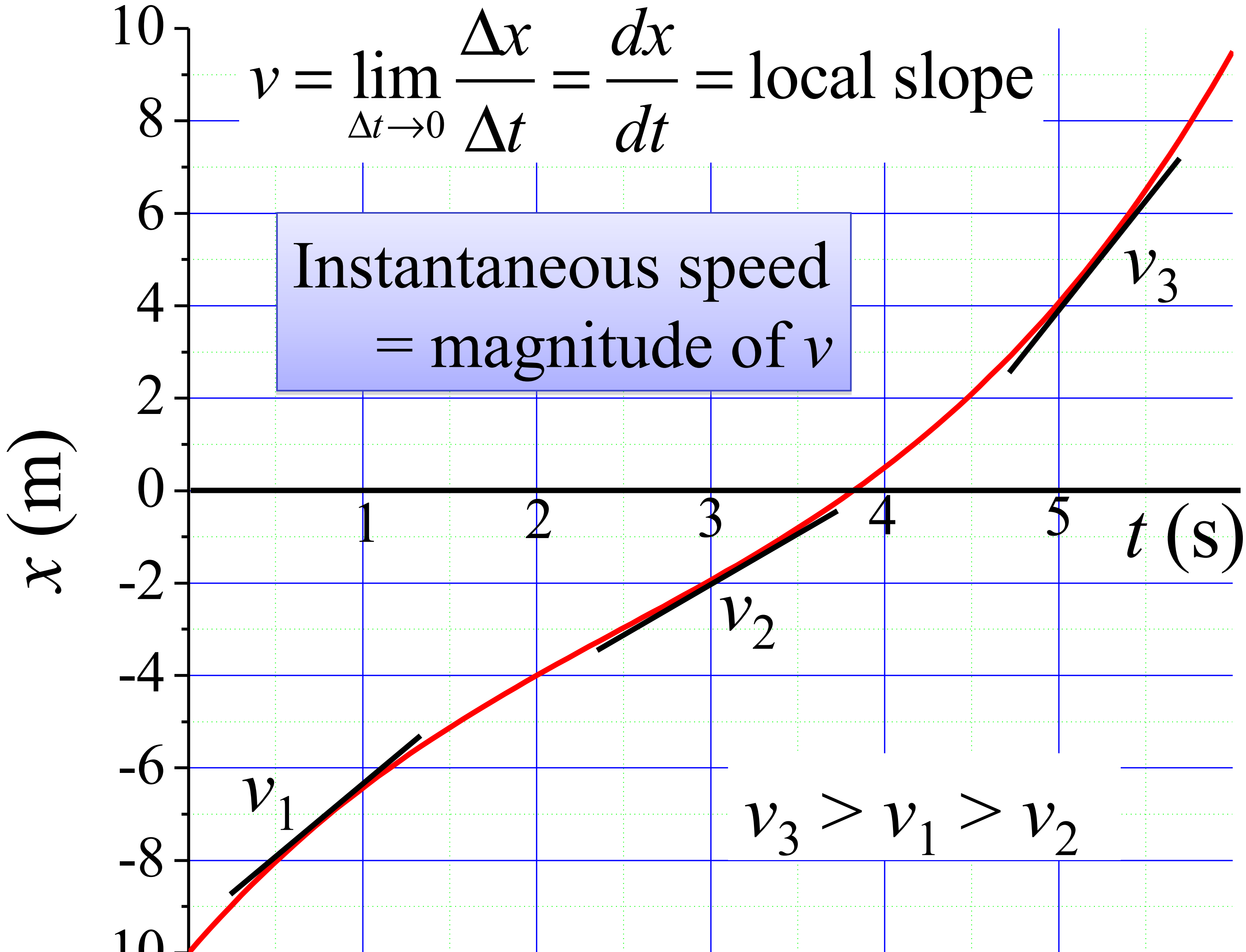
$$s_{avg} = \bar{s} = \frac{\text{total distance}}{\Delta t}$$

- s_{avg} does not specify a direction; it is a scalar as opposed to a vector &, thus, lacks an algebraic sign
- How do v_{avg} and s_{avg} differ?



$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{(-10m) - (-10m)}{6s - 0} = 0ms^{-1}$
$\bar{v} = \frac{18}{3} ms^{-1} = 6ms^{-1}$
$\bar{v} = \frac{-18}{3} ms^{-1} = -6ms^{-1}$
$\bar{s} = \frac{\text{total distance}}{\Delta t}$
$= \frac{18m + 18m}{6s} = 6ms^{-1}$
x (m)
t (s)
10
8
6
4
2
0
-2
-4
-6
-8
-10
1
2
3
4
5

Instantaneous velocity and speed



Acceleration

•An object is accelerating if its velocity is changing

Average acceleration a_{avg}:

$$a_{avg} = \bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

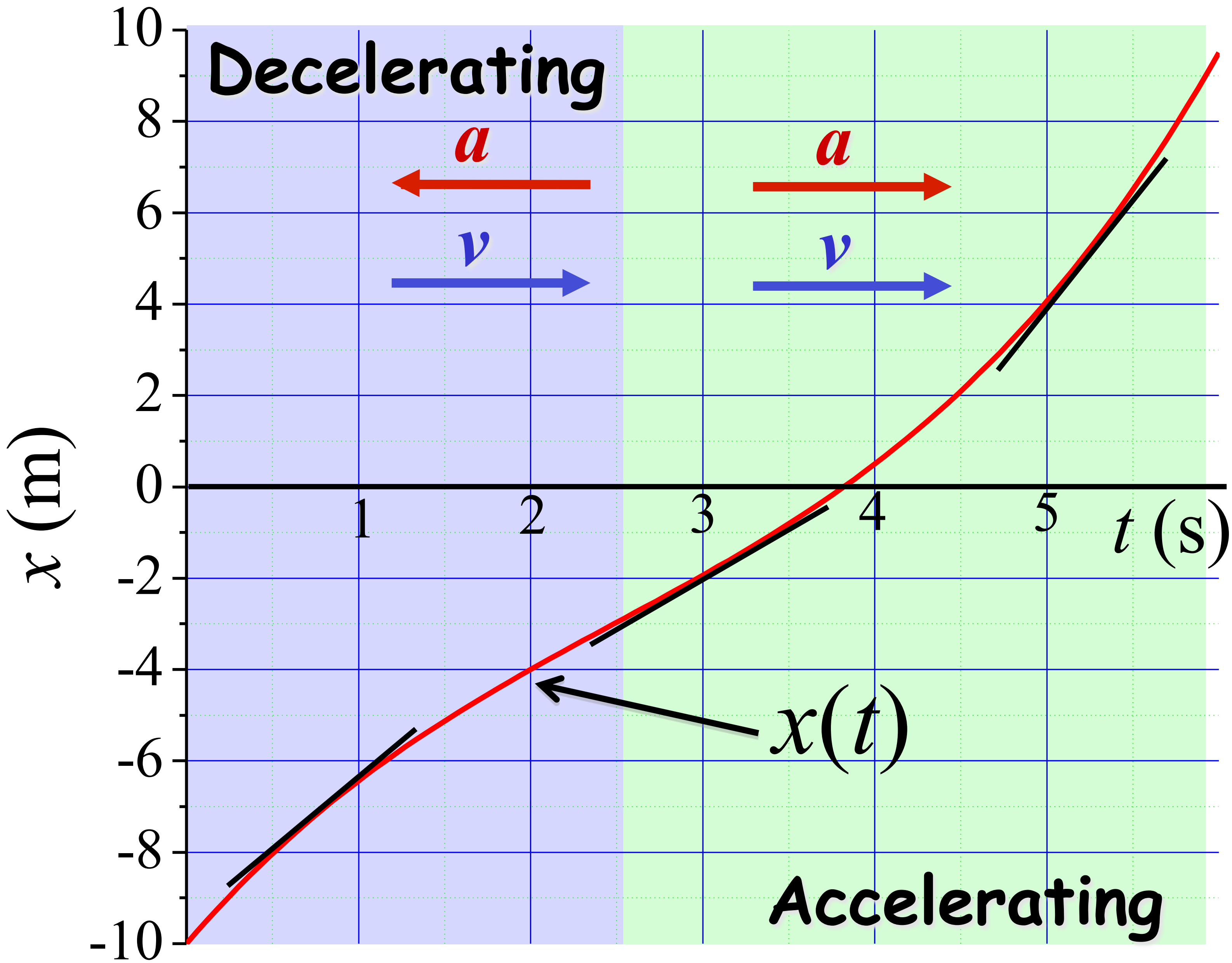
Instantaneous acceleration a:

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2 x}{dt^2}$$

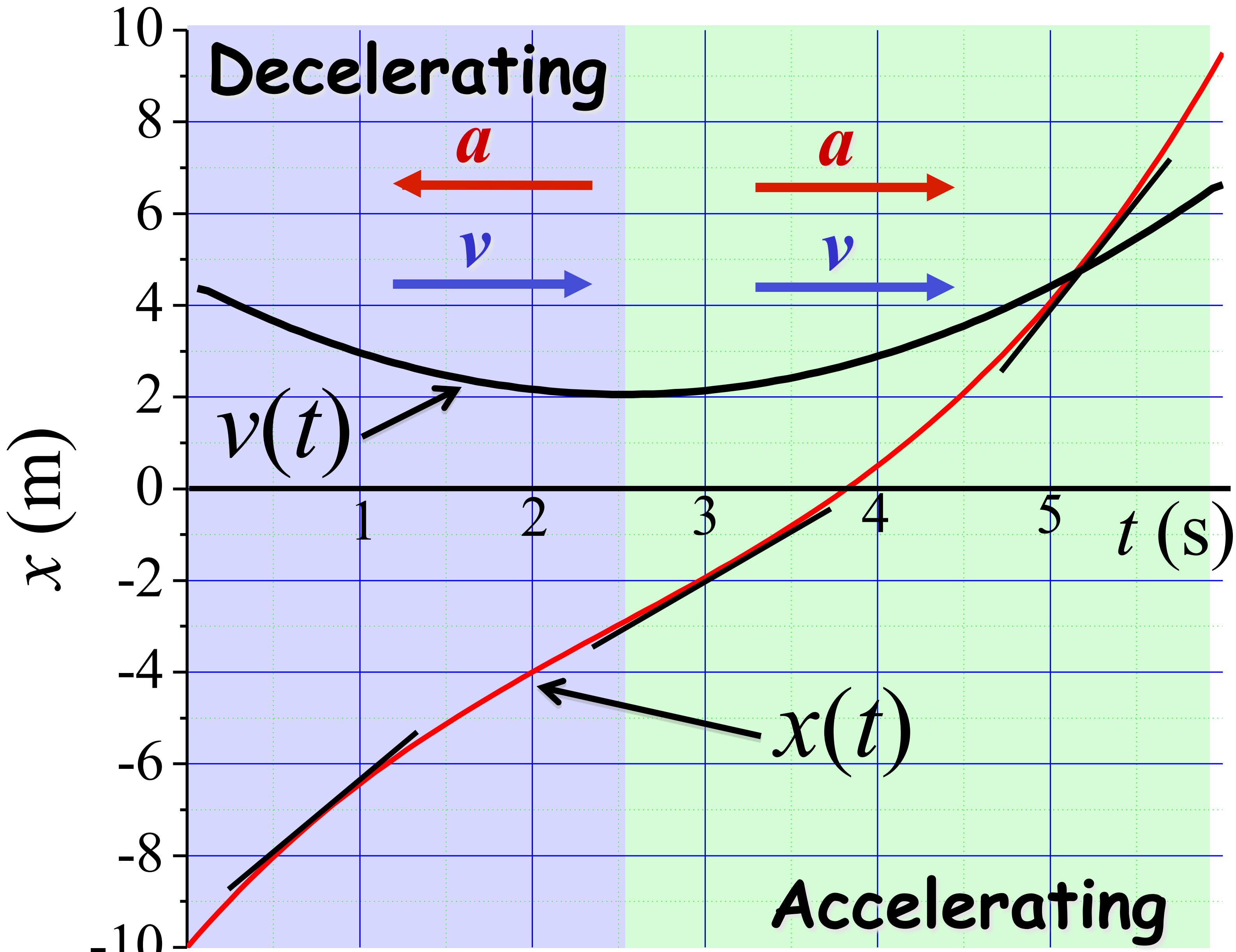
•This is the second derivative of the x vs. t graph

•Like x and v, acceleration is a vector

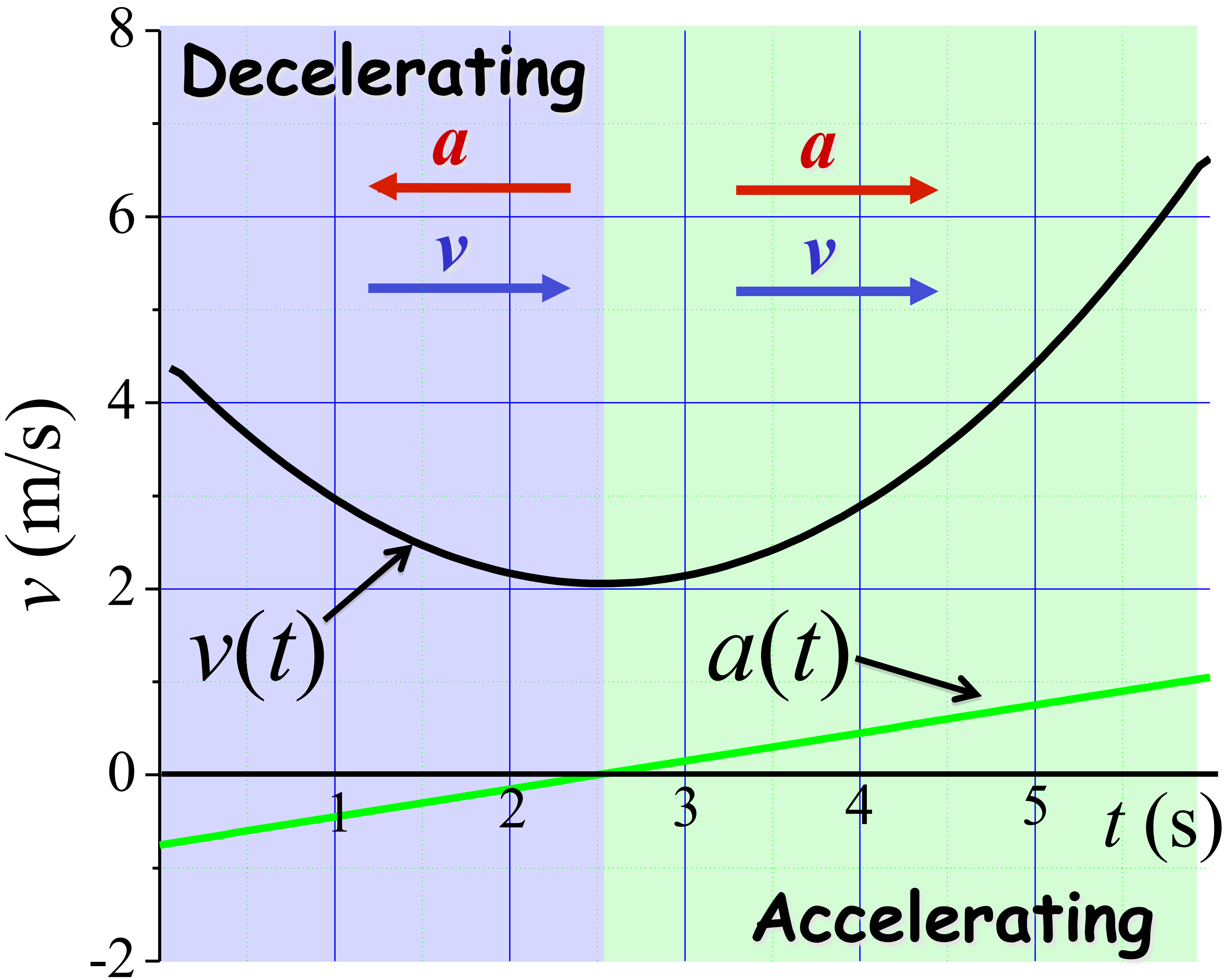
•Note: direction of a need not be the same as v



Decelerating
a
v
a
v
x(t)
Accelerating
x (m)
t (s)
10
8
6
4
2
0
-2
-4
-6
-8
-10
1
2
3
4
5


10
8
6
4
2
0
-2
-4
-6
-8
-10
x (m)
1
2
3
4
5
t (s)
Decelerating
Accelerating
a
v
a
v
v(t)
x(t)

$v_3 > v_1 > v_2$



Decelerating
Accelerating
a
v
a
v
v(t)
a(t)
v (m/s)
t (s)
8
6
4
2
0
-2
1
2
3
4
5

Summarizing

Displacement: $\Delta x = x_2 - x_1$

Average velocity: $$v_{avg} = \bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

Average speed: $$s_{avg} = \bar{s} = \frac{\text{total distance}}{\Delta t}$$

Instantaneous velocity:

$$v = \frac{dx}{dt} = \text{local slope of } x \text{ versus } t \text{ graph}$$

Instantaneous speed: magnitude of v

Summarizing

Average acceleration: $$a_{avg} = \bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

Instantaneous acceleration:

$$a = \frac{dv}{dt} = \text{local slope of } v \text{ versus } t \text{ graph}$$

In addition:

$$a = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2x}{dt^2} = \text{curvature of } x \text{ versus } t \text{ graph}$$

SI units for a are m/s^2 or $m.s^{-2}$ (ft/min^2 also works)