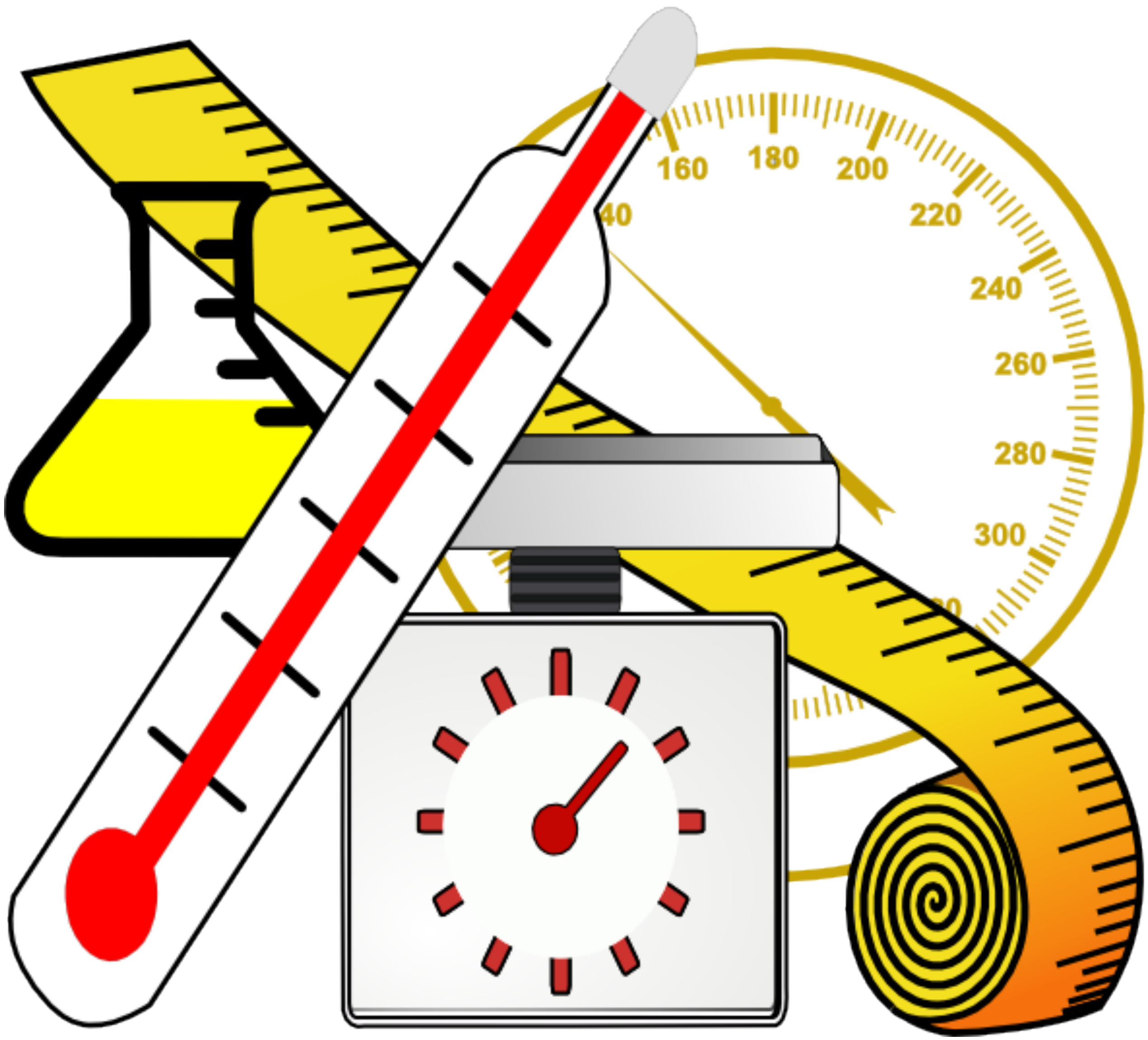
Lesson 1

Physics 168

Luis Anchordoqui



Measurement

Throughout this course we'll make observations

and ask basic questions

How big is an object?

How much mass does it have?

How far did it travel?

To answer these questions

we'll make measurements with various instruments

(e.g., meter stick, balance, stopwatch, etc.)

The measurements of physical quantities are expressed in terms of units which are standardized values

E.g. length of a race (which is a physical quantity) can be expressed in: meters (for sprinters) or kilometers (for long distance runners)

Without standardized units it would be extremely difficult to express and compare measured values in a meaningful way

We'll adopt the International System of Units

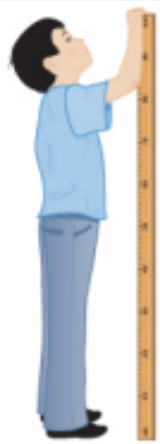
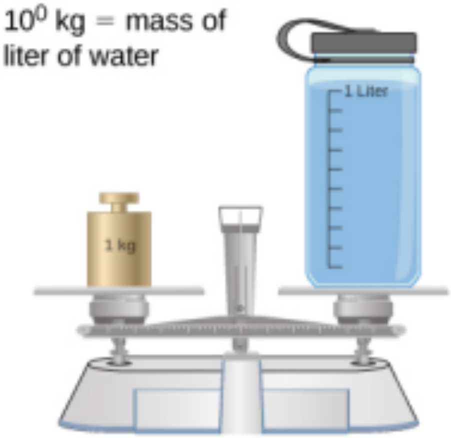
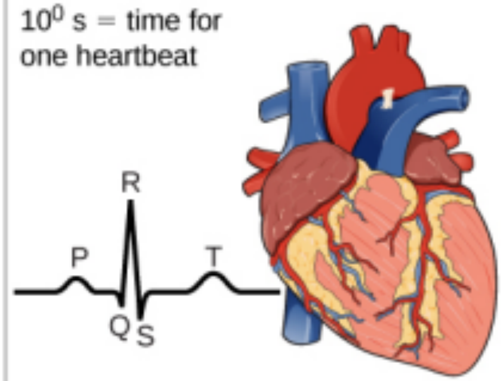
The Fundamental SI Units
(le Système International, SI)

SI UNITS OF MEASURE

SI Unit	Symbol
Mass	kg
Length	m
Volume	L
Time	sec
Count	mole
Temperature	Kelvin

Since 6/20/2019 all SI units are defined in terms of constants that describe the natural world

Orders of magnitude of length, mass, and time

Length in Meters (m)	Masses in Kilograms (kg)	Time in Seconds (s)
10^{-15} m = diameter of proton	10^{-30} kg = mass of electron	10^{-22} s = mean lifetime of very unstable nucleus
10^{-14} m = diameter of large nucleus	10^{-27} kg = mass of proton	10^{-17} s = time for single floating-point operation in a supercomputer
10^{-10} m = diameter of hydrogen atom	10^{-15} kg = mass of bacterium	10^{-15} s = time for one oscillation of visible light
10^{-7} m = diameter of typical virus	10^{-5} kg = mass of mosquito	10^{-13} s = time for one vibration of an atom in a solid
10^{-2} m = pinky fingernail width	10^{-2} kg = mass of hummingbird	10^{-3} s = duration of a nerve impulse
10^{0} m = height of 4 year old child 	10^{0} kg = mass of liter of water 	10^{0} s = time for one heartbeat 
10^{2} m = length of football field	10^{2} kg = mass of person	10^{5} s = one day
10^{7} m = diameter of Earth	10^{19} kg = mass of atmosphere	10^{7} s = one year
10^{13} m = diameter of solar system	10^{22} kg = mass of Moon	10^{9} s = human lifetime
10^{16} m = distance light travels in a year (one light-year)	10^{25} kg = mass of Earth	10^{11} s = recorded human history
10^{21} m = Milky Way diameter	10^{30} kg = mass of Sun	10^{17} s = age of Earth
10^{26} m = distance to edge of observable universe	10^{53} kg = upper limit on mass of known universe	10^{18} s = age of the universe

Measurement & Uncertainty

No measurement is exact

there is always some uncertainty

due to limited instrument accuracy and difficulty reading results

For example, it would be difficult to measure the width of this table to better than a millimeter

Measurement & Uncertainty

Estimated uncertainty is written with a ± sign

$$8.8 \pm 0.1\text{cm}$$

Percent uncertainty

ratio of uncertainty to measured value multiplied by 100

$$\frac{0.1}{8.8} \times 100\% \approx 1\%$$

A friend asks to borrow your precious diamond for a day to show her family

You are a bit worried, so you carefully have your diamond weighed on a scale which reads 8.17 g

Scale accuracy is claim to be $\pm$ 0.05 g.

Next day you weigh returned diamond again getting 8.09 g.

Is this your diamond?

Scale readings are measurements

Each measurement could have been high or low by up to 0.05 g

Actual mass of your diamond lies most likely between 8.12 g and 8.22 g

Actual mass of return diamond lies most likely between 8.04 and 8.14 g

These two ranges overlap so there is not a strong reason to doubt that return diamond is yours

Significant Figures

Number of significant figures:
number of reliably known digits in a number

It is usually possible to tell the number of significant figures by the way the number is written:

- 23.21 cm has 4 significant figures
- 0.062 cm has 2 significant figures (the initial zeroes don't count)
- 80 km is ambiguous- it could have 1 or 2 significant figures
  If it has 2 it should be written 80. km

Significant Figures

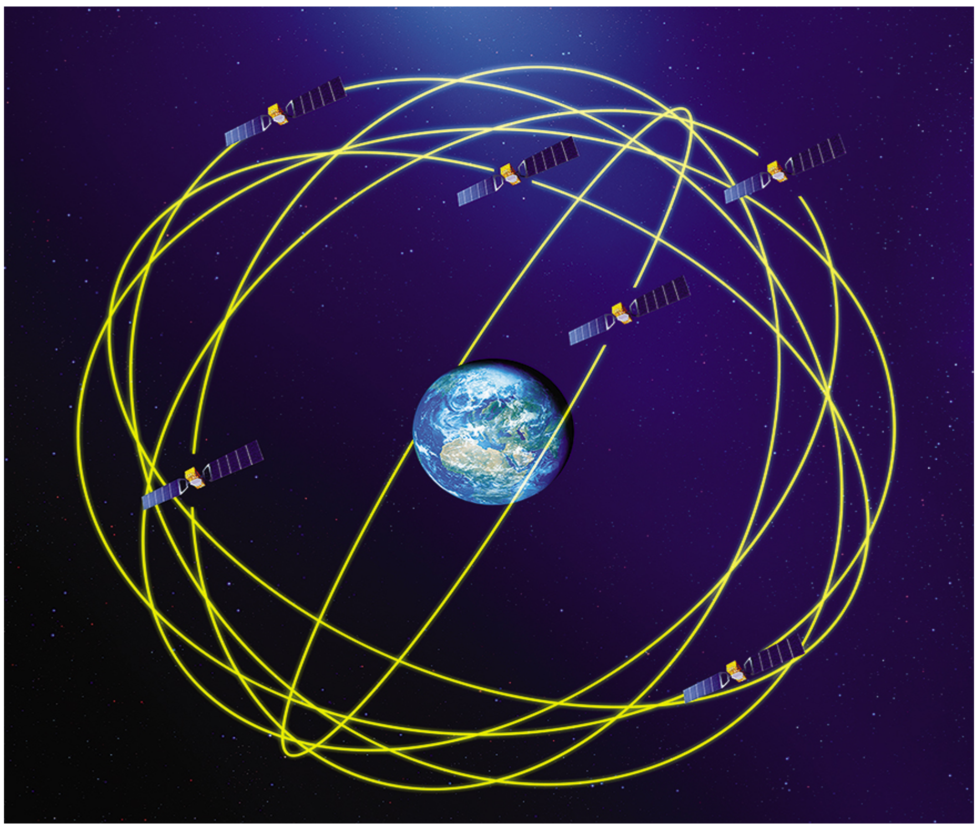
When multiplying or dividing numbers,
result has as many significant figures
as number used in calculation with fewest significant figures

Example: $11.3 \text{ cm} \times 6.8 \text{ cm} = 77\text{cm}$

When adding or subtracting
answer is no more accurate than the least accurate number used

Global positioning satellites (GPS) can be used to determine positions with great accuracy System works by determining distance between observer and each of several satellites orbiting Earth

If one of satellites is at a distance of 20,000 km from you, what percent accuracy in distance is required if we desired a 2 m uncertainty?
How many significant figures do we need to have in that distance?



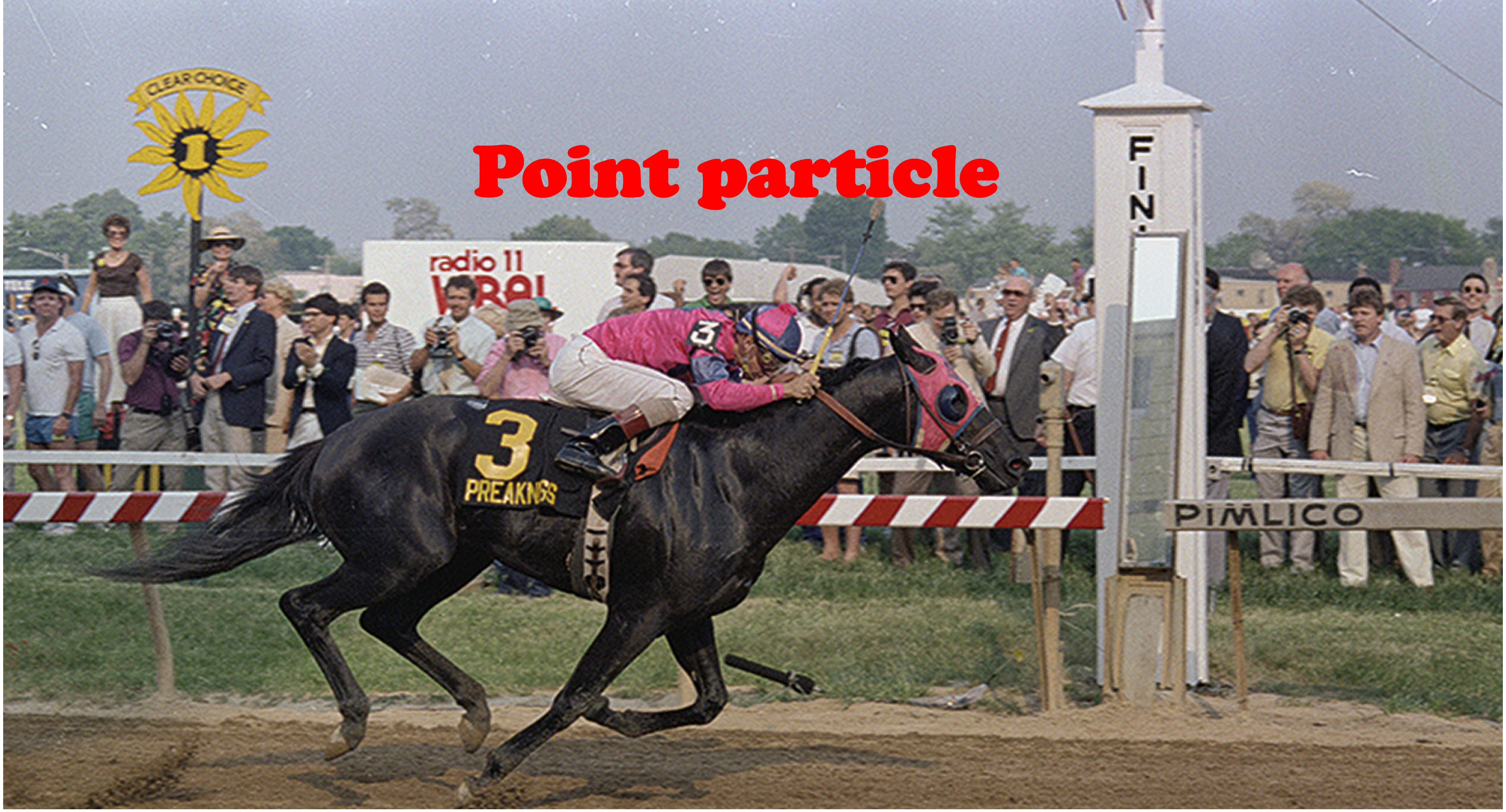
The percentage accuracy is

$$\frac{2\ \mathrm{m}}{2 \times 10^7\ \mathrm{m}} \times 100\% = 10^{-5}\%$$

The distance of 20,000,000 m needs to be distinguishable from 20,000,002 m which means that 8 significant figures are needed in distance measurements


Motion in one dimension

Point particle

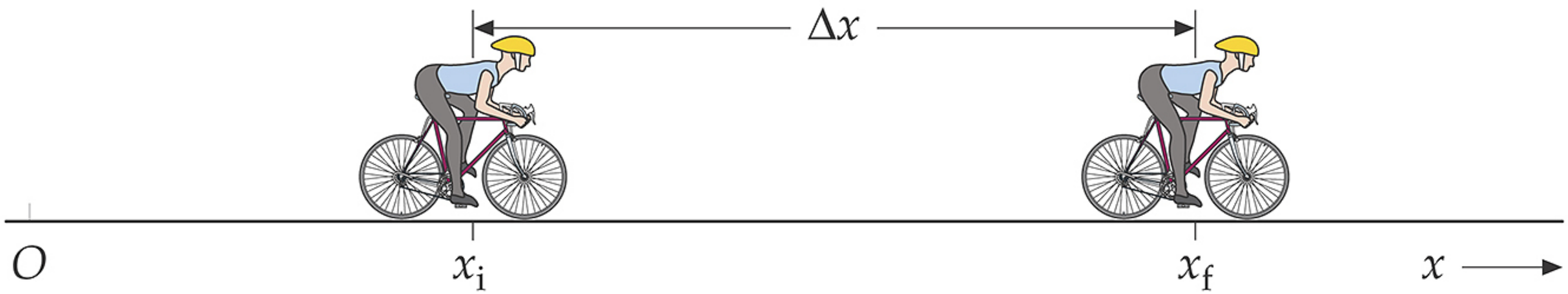


- In a horse race the winner is the horse whose nose first crosses the finish line

- One could argue that what really matters during the race is the motion of that single point of the horse

- In physics this type of simplification turns out to be useful for examining the motion of idealized objects called point particles

Position and Displacement

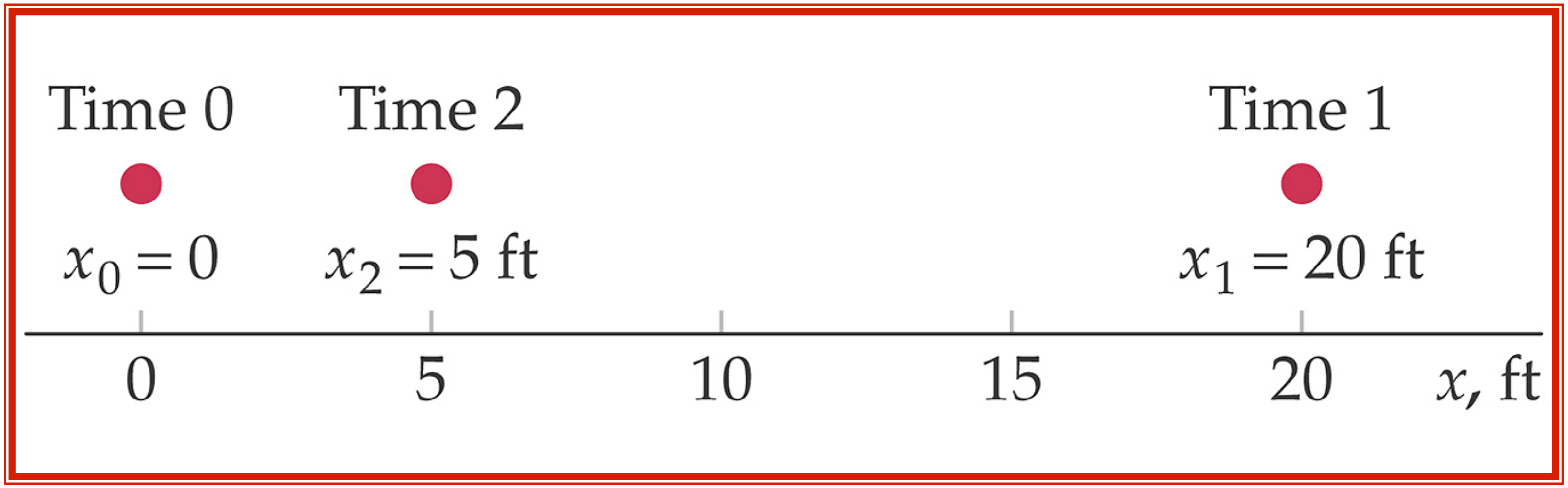


To describe motion of a particle we need to be able to describe position of particle and how that position changes as it moves

Change of bicycle's position is called a displacement

$$\Delta x = x_f - x_i$$

Distance & displacement of a dog



You are playing a game of catch with a dog

Dog is initially standing near your feet

Then he jogs 20 feet in a straight line to retrieve a stick

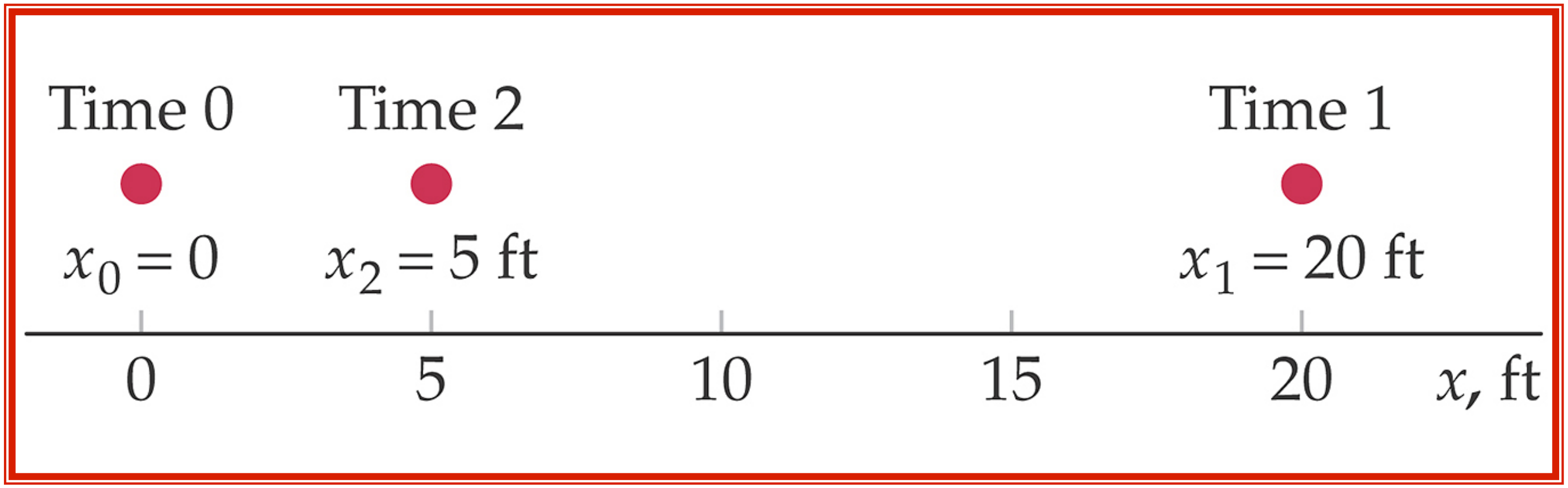
and carries stick 15 feet back towards you to chew stick

(a) What is total distance dog travels?

(b) What is displacement of dog?

(c) Show that net displacement for trip is sum of sequential displacements

Distance & displacement of a dog



You are playing a game of catch with a dog

Dog is initially standing near your feet

Then he jogs 20 feet in a straight line to retrieve a stick

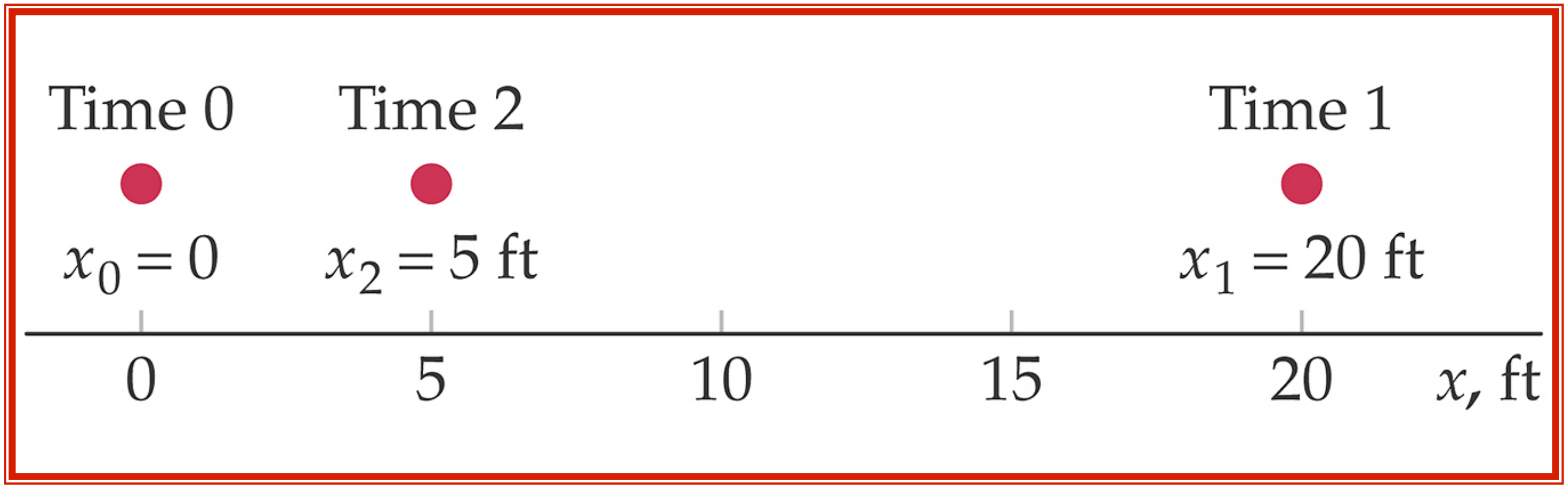
and carries stick 15 feet back towards you to chew stick

(a) What is total distance dog travels? **35 ft**

(b) What is displacement of dog?

(c) Show that net displacement for trip is sum of sequential displacements

Distance & displacement of a dog



You are playing a game of catch with a dog

Dog is initially standing near your feet

Then he jogs 20 feet in a straight line to retrieve a stick

and carries stick 15 feet back towards you to chew stick

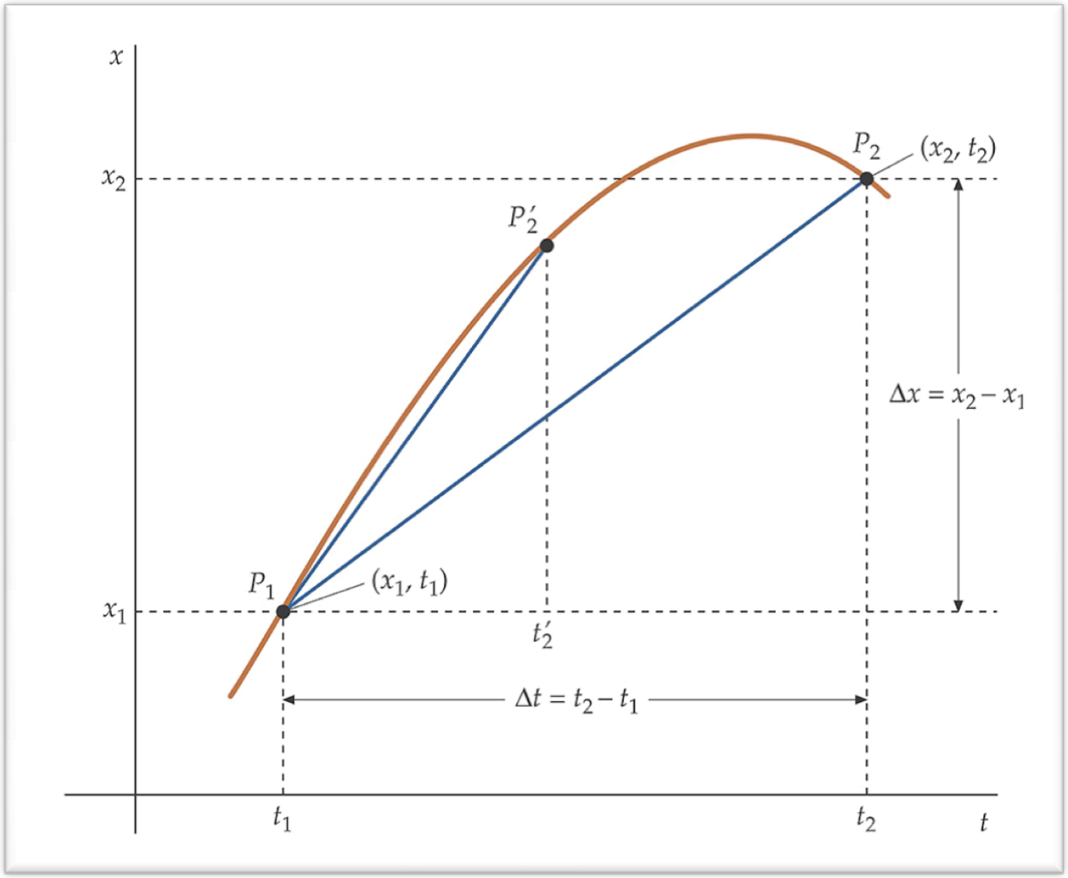
(a) What is total distance dog travels? **35 ft**

(b) What is displacement of dog? **5 ft**

(c) Show that net displacement for trip is sum of sequential displacements

Average Velocity & Speed

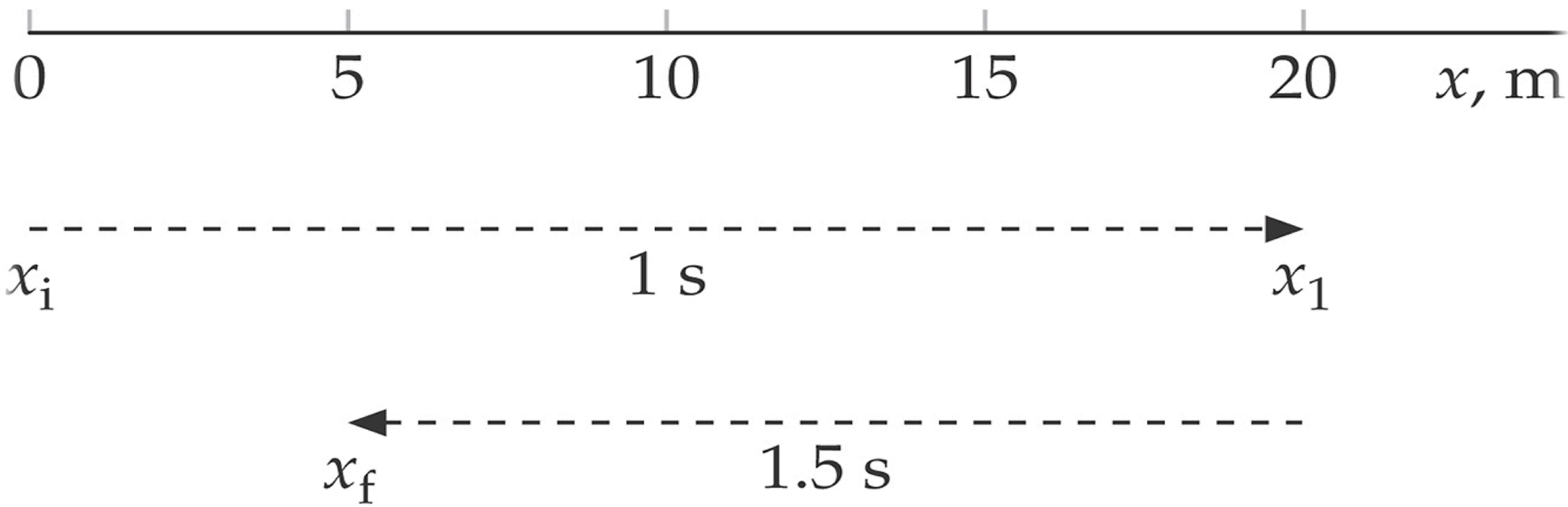
$$\text{Average speed} = \frac{\text{Total distance traveled by particle}}{\text{Total time from start to finish}}$$



$$\frac{\Delta x}{\Delta t} = \text{slope} = v_{x,\text{av}}$$

Average Velocity

Average Speed & Velocity of dog



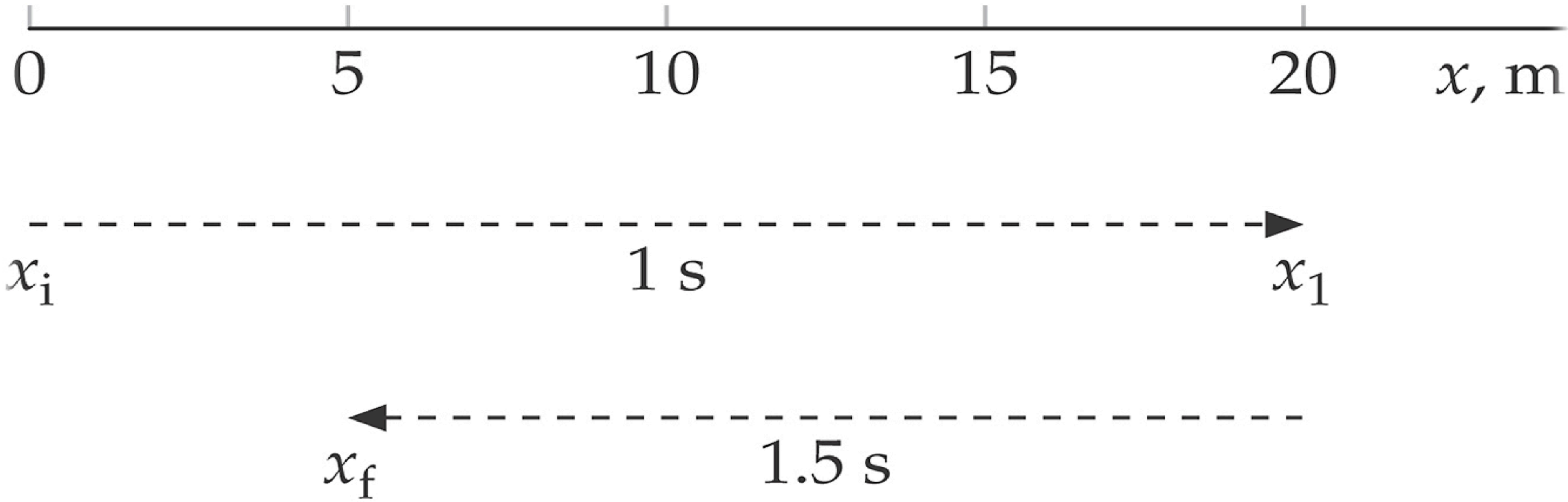
Dog that you were playing catch with jogged 20 ft away from you in 1s to retrieve stick and ambled back 15 ft in 1.5 s.

Calculate

(a) Dog's average speed

(b) Dog's average velocity for total trip

Average Speed & Velocity of dog



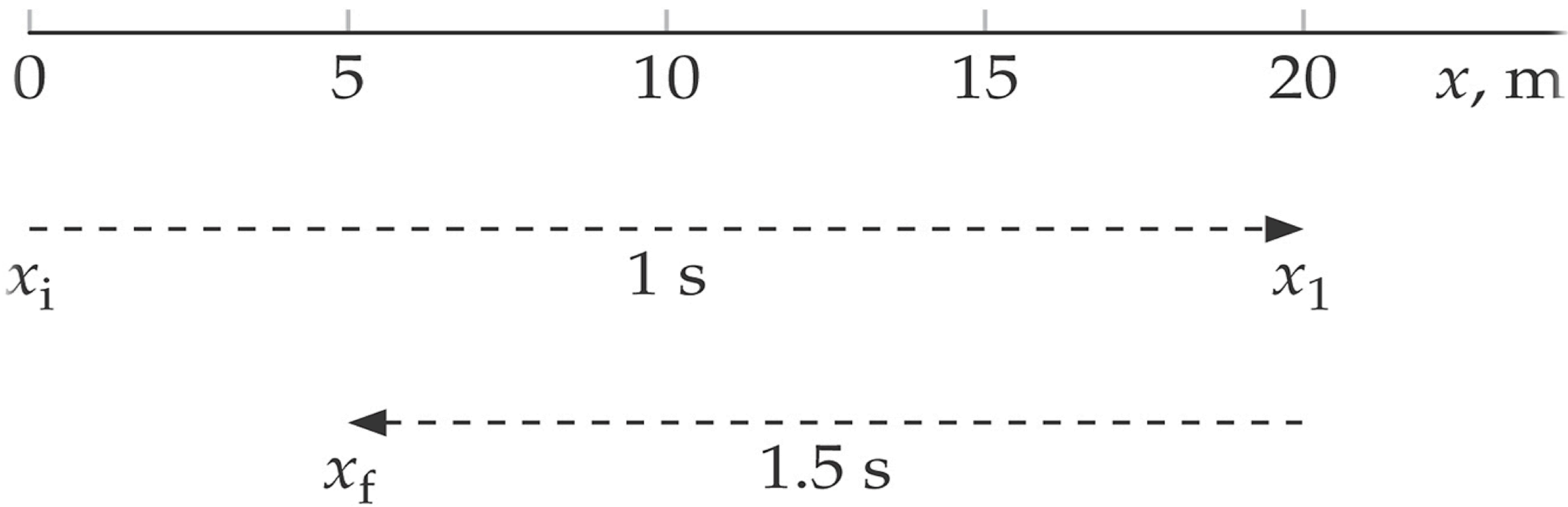
Dog that you were playing catch with jogged 20 ft away from you in 1s to retrieve stick and ambled back 15 ft in 1.5 s.

Calculate

(a) Dog's average speed $\boxed{\text{14 ft/s}}$

(b) Dog's average velocity for total trip

Average Speed & Velocity of dog



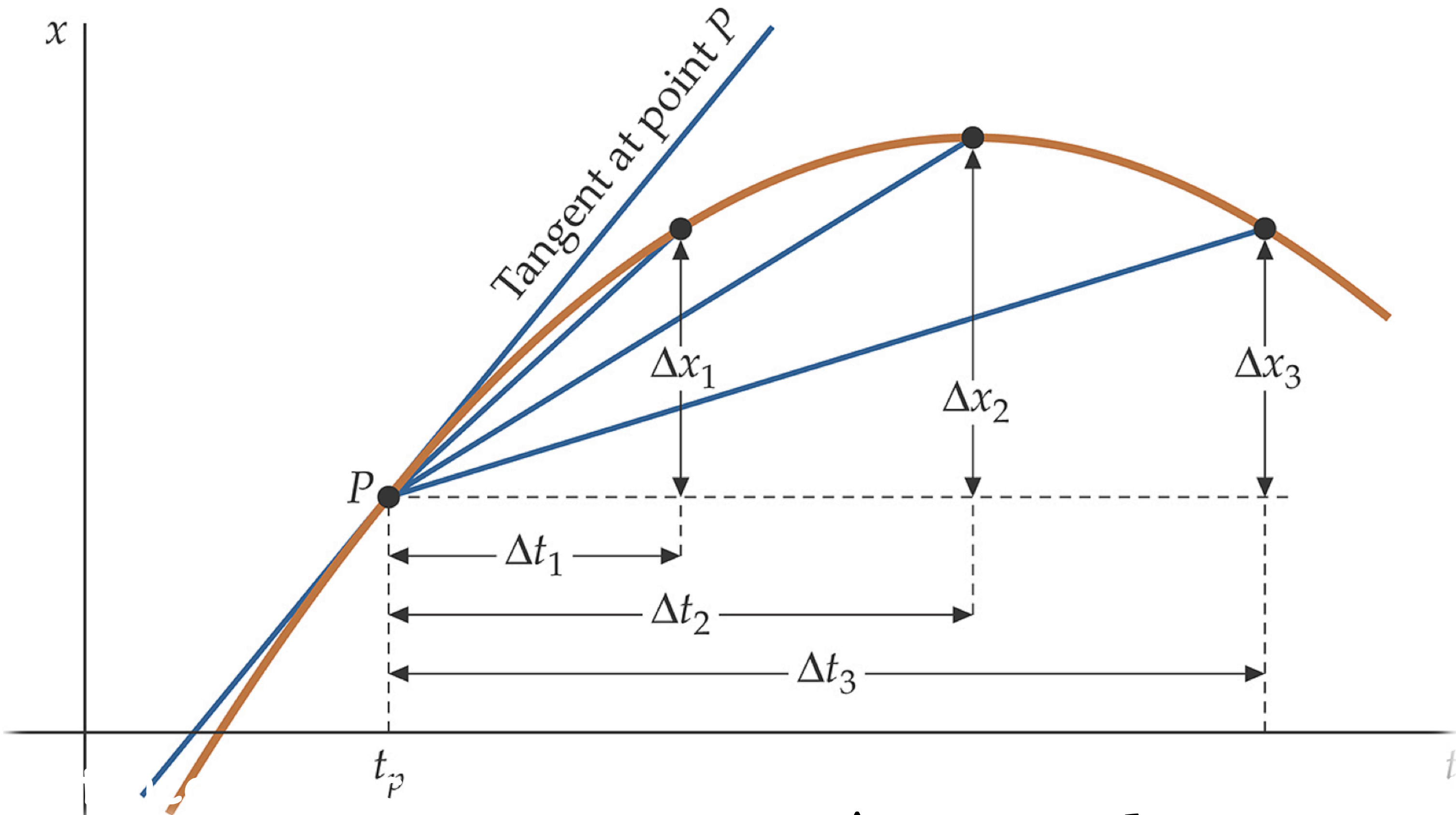
Dog that you were playing catch with jogged 20 ft away from you in 1s to retrieve stick and ambled back 15 ft in 1.5 s.

Calculate

(a) Dog's average speed **14 ft/s**

(b) Dog's average velocity for total trip **2 ft/s**

Instantaneous Velocity



$$v_x(t) = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

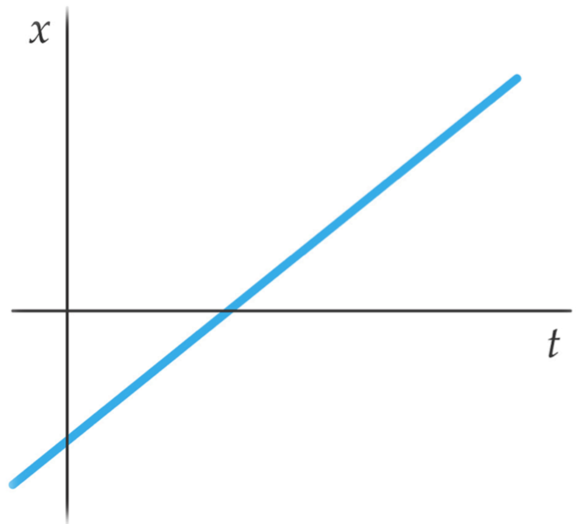
Instantaneous Velocity

In calculus limit that defines instantaneous velocity is called derivative of x with respect t

A line's slope may be positive, negative, or zero → instantaneous velocity in 1 dimension may be positive (x increasing), negative (x decreasing), or zero (no motion)

For an object moving with constant velocity → object's instantaneous velocity is equal to its average velocity

Position versus time of this motion will be a straight line



Instantaneous velocity is a vector and magnitude of instantaneous velocity is instantaneous speed

From now on: velocity → denotes instantaneous velocity

and speed → denotes instantaneous speed

Position of a particle as a function of time

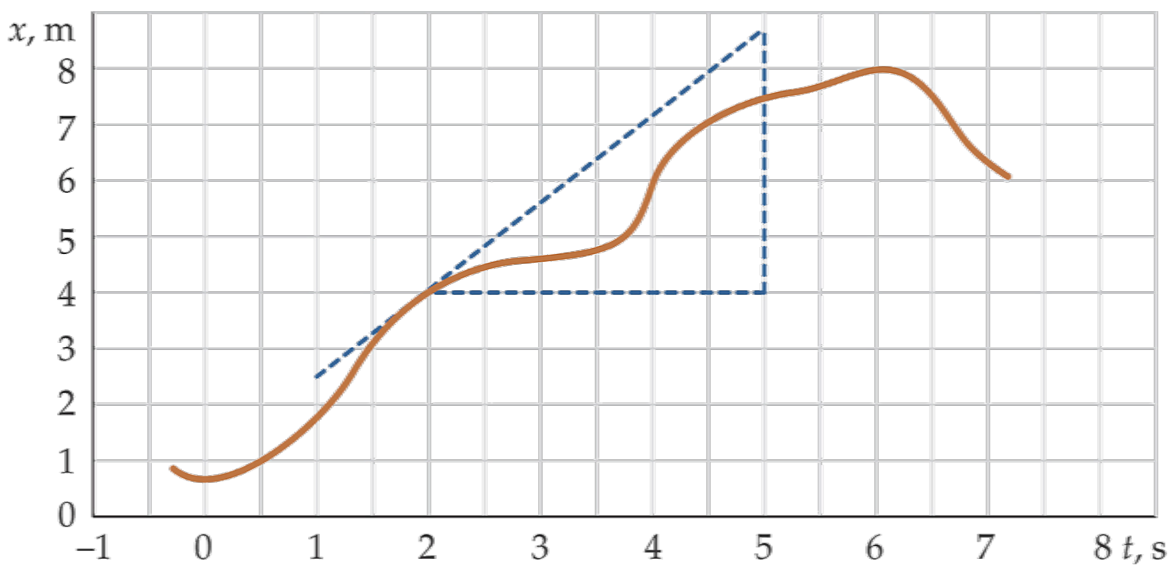


Figure shows position of a particle as a function of time

Find instantaneous velocity at t= 1.8 s?

When velocity is greatest?

When is it zero?

Is it ever negative?

Position of a particle as a function of time

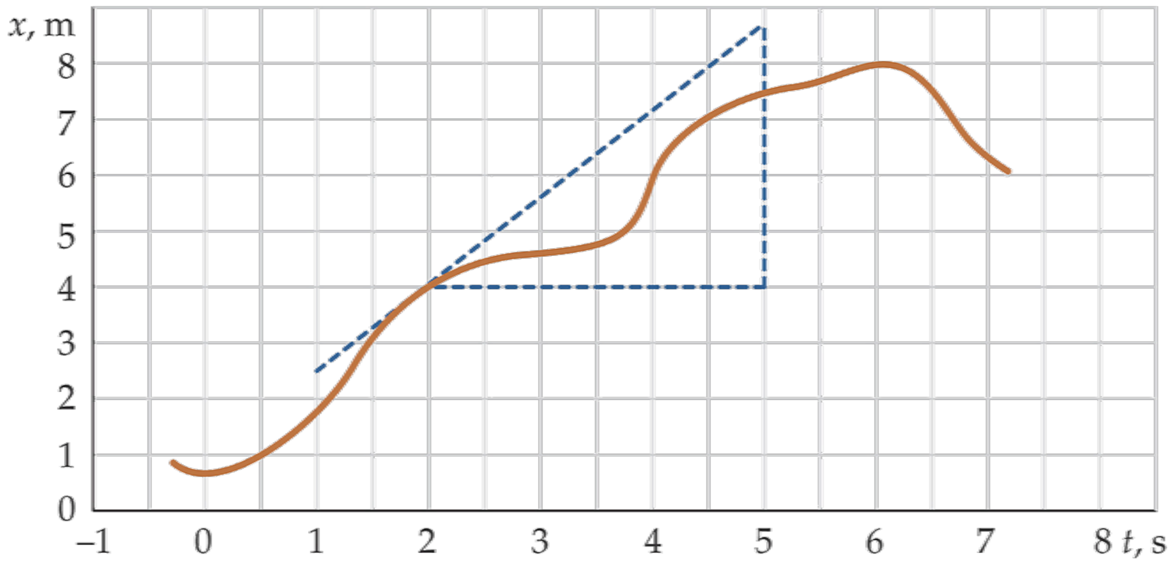


Figure shows position of a particle as a function of time

Find instantaneous velocity at t= 1.8 s?

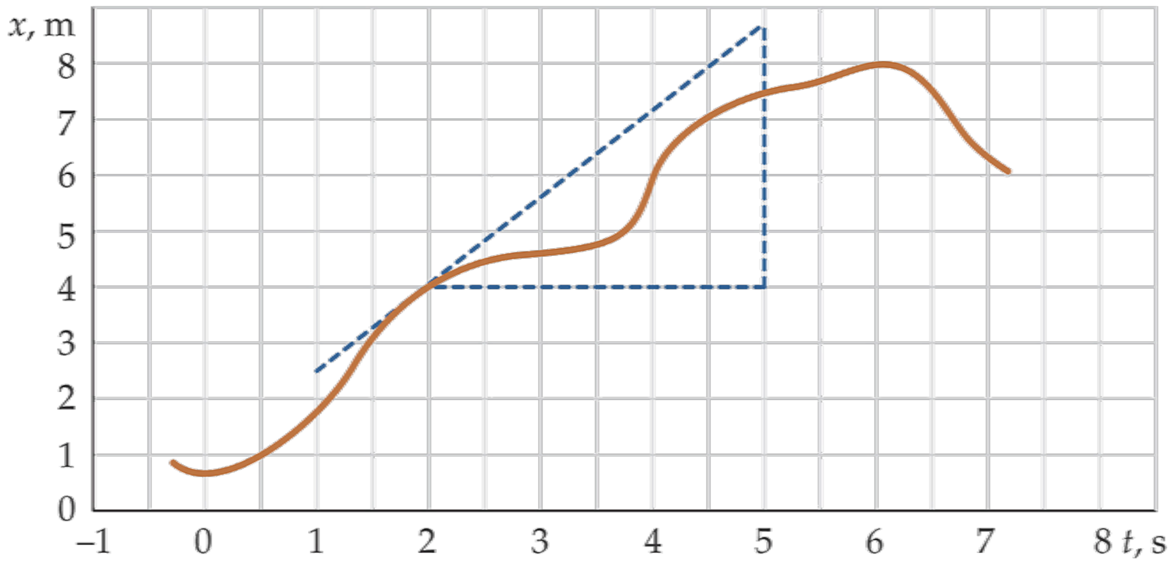
$$v_x = \text{slope} \sim (8.5\ \text{m} - 4.0\ \text{m})/(5.0\ \text{s} - 2.0\ \text{s}) = 1.5\ \text{m/s}$$

When velocity is greatest?

When is it zero?

Is it ever negative?

Position of a particle as a function of time



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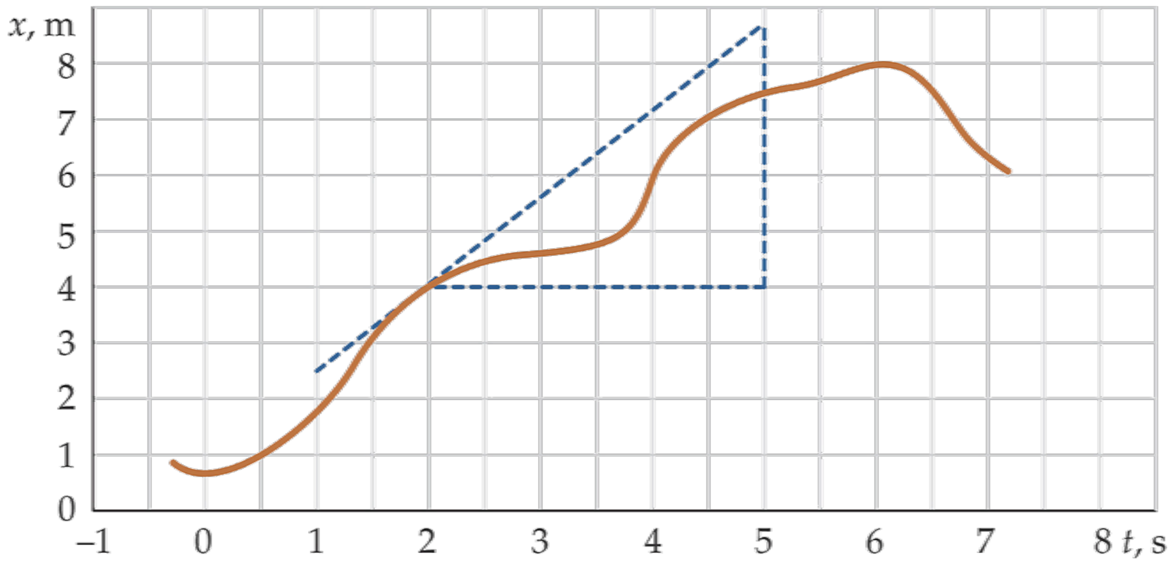
When velocity is greatest?

Tangent line is steepest and hence velocity is greatest at t~4 s

When is it zero?

Is it ever negative?

Position of a particle as a function of time



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When velocity is greatest?

Tangent line is steepest and hence velocity is greatest at t~4 s

When is it zero?

Velocity is zero at t=0 s and t=6 s

Is it ever negative?

Position of a particle as a function of time

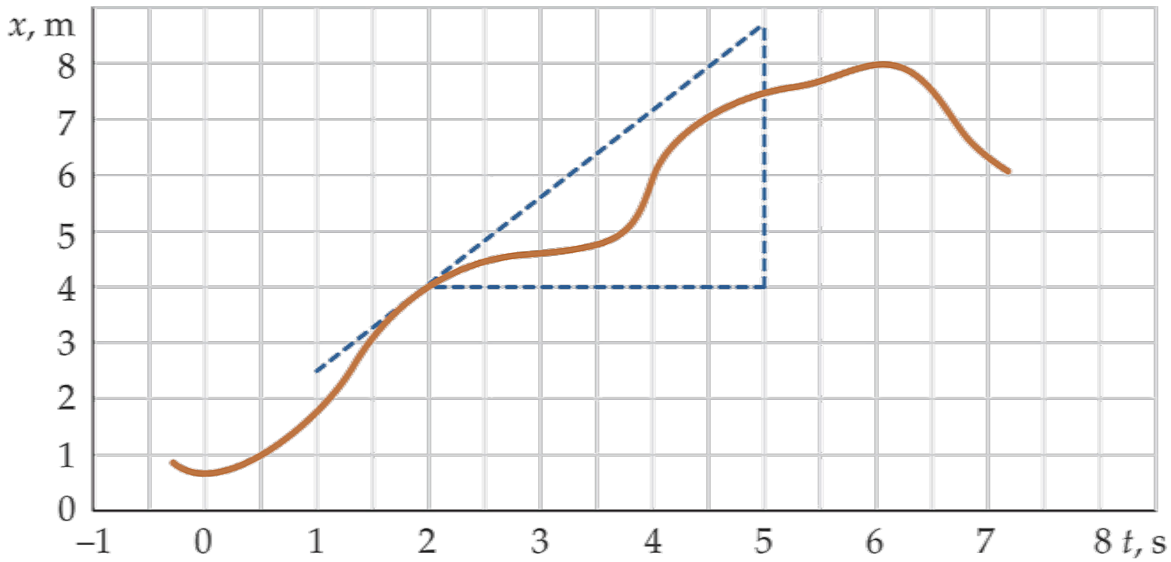

Figure shows position of a particle as a function of time

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When velocity is greatest?

Tangent line is steepest and hence velocity is greatest at t~4 s

When is it zero?

Velocity is zero at t=0 s and t=6 s

Is it ever negative?

Velocity is negative for t<0 s and t>6 s

Acceleration

Accelaration is rate of change of velocity with respect to time

Average acceleration

$$a_{x,\mathrm{av}} = \frac{\Delta v_x}{\Delta t} = \frac{v_{x,\mathrm{f}} - v_{x,\mathrm{i}}}{t_\mathrm{f} - t_\mathrm{i}}$$

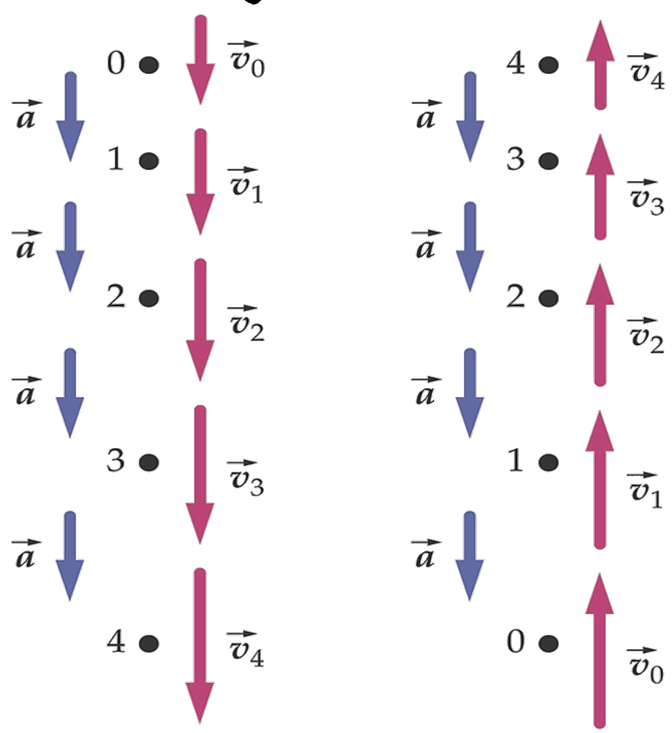
Instantaneous acceleration

$$a_x = \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt} = \frac{d(dx/dt)}{dt} = \frac{d^2x}{dt^2}$$

Motion with constant acceleration

$$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2 \qquad v(t) = v_0 + at$$

Motion diagrams: moving object is drawn at equally space time intervals

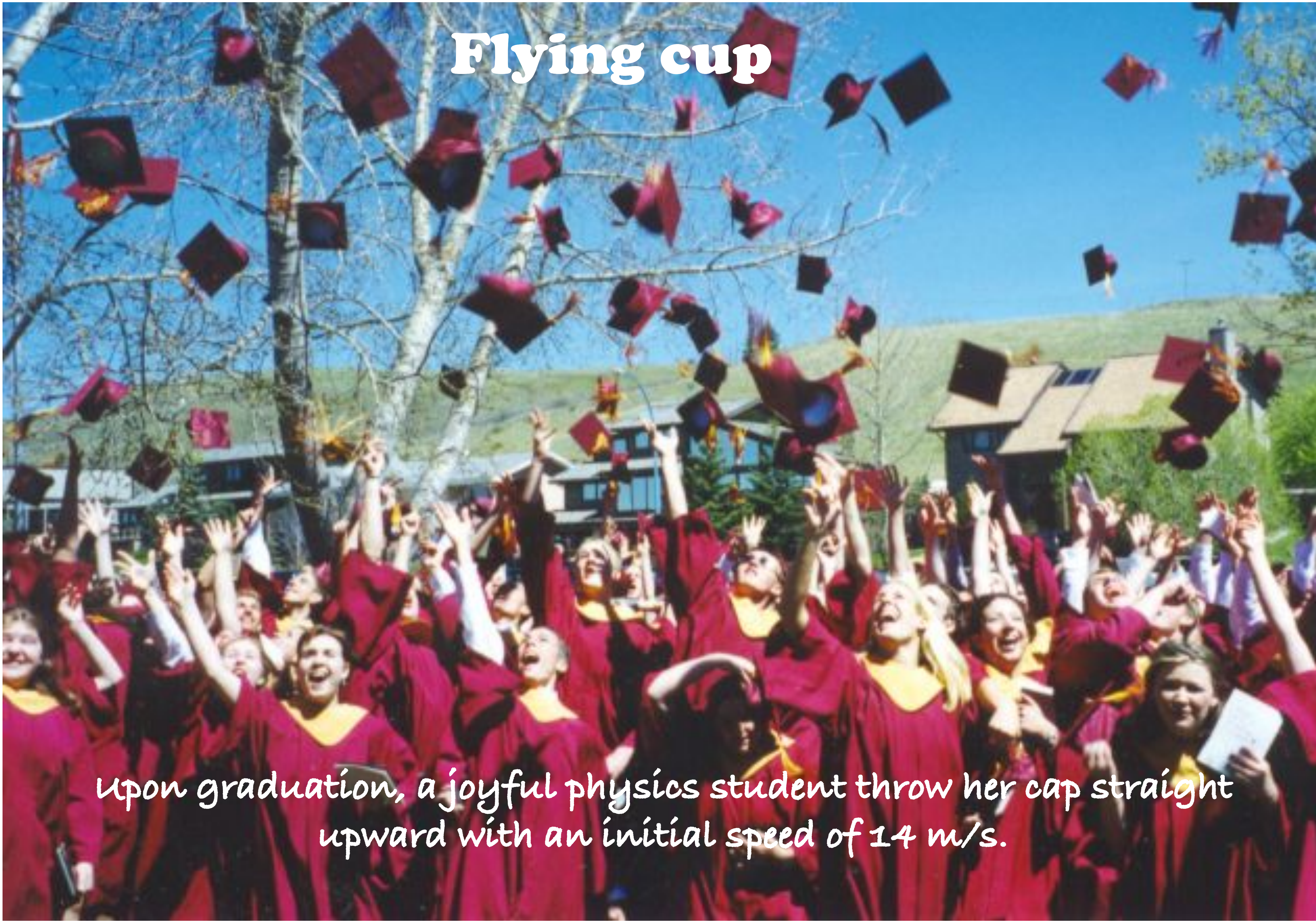


(a) (b)

(a) Velocity is increasing so acceleration is in direction of velocity vector

(b) Velocity vector is decreasing so acceleration is in direction opposite to that of velocity vector

Flying cup



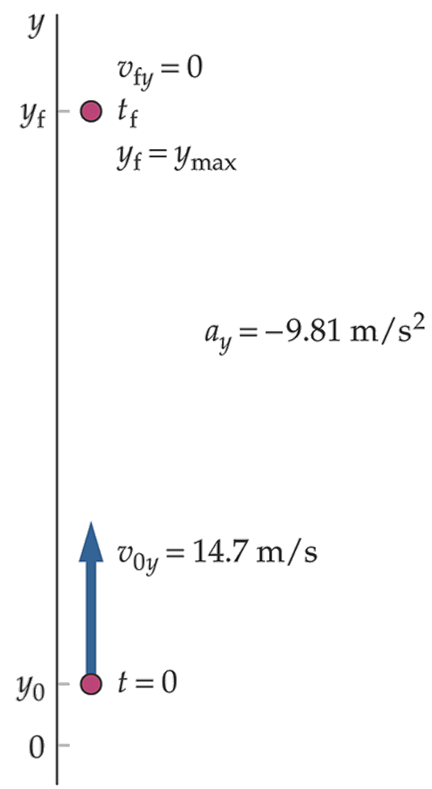
Upon graduation, a joyful physics student throw her cap straight upward with an initial speed of 14 m/s.

Flying cup

(a) How long does it take for cap to reach it highest point?

(b) What is distance to highest point?

(c) Assuming cap is caught at same height from which it was released, what is total time cap is in flight?



Start with

$$v_y(t) = v_{0_y} - gt$$

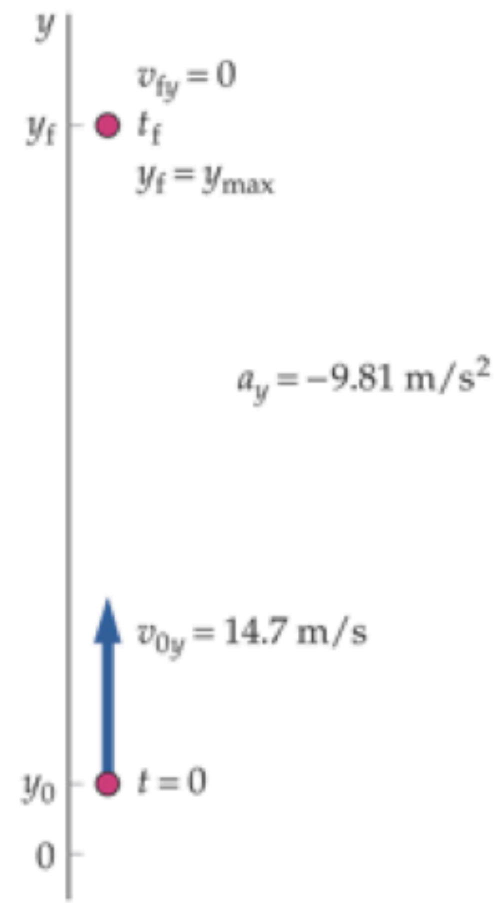
When the cap is at the top ☛ the instantaneous velocity is zero

$$t_{\text{max}} = \frac{v_{0_y}}{g} = 1.5 \text{ s}$$

$$y_{\text{max}} = v_{0_y} \; t_{\text{max}} - \frac{1}{2} \, g \, t_{\text{max}}^2 = 10 \text{ m}$$

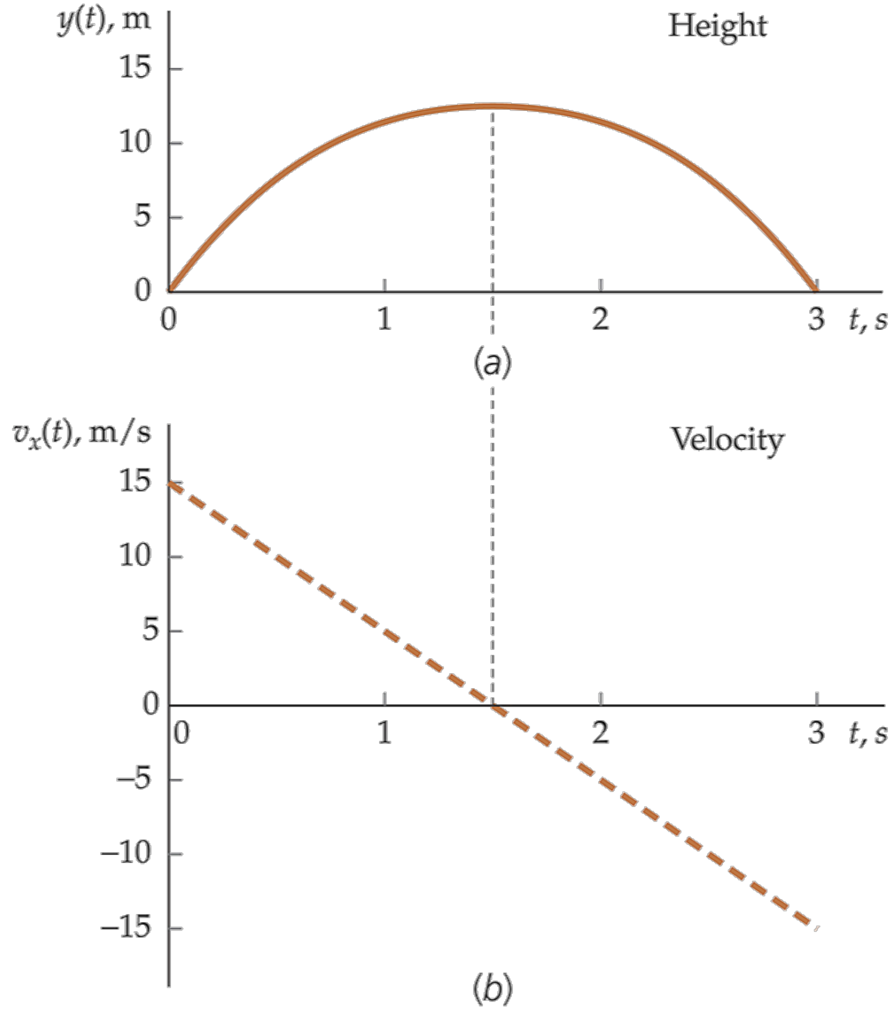
By symmetry

$$t_{\text{tot}} = 3 \text{ s}$$



Flying cup

Plot position as a function of time and velocity as a function of time



Note that slope is equal to instantaneous acceleration = 9.8 m/s²

Flying cup on Moon

Acceleration due to gravity on the Moon is about one sixth what it is on the Earth. If the cap is thrown vertically upward on the Moon, how many times higher will it go than it would on Earth, assuming the same initial velocity.

Choose the upward direction to be positive

and $y_0 = 0$ to be the level from which the object is thrown

The initial velocity is v_0 and the velocity at the top is zero

$$t_{\max} = \frac{v_0}{a} \Rightarrow y = \frac{v_0^2}{a} - \frac{1}{2}\ \frac{v_0^2}{a} = \frac{1}{2}\ \frac{v_0^2}{a}$$

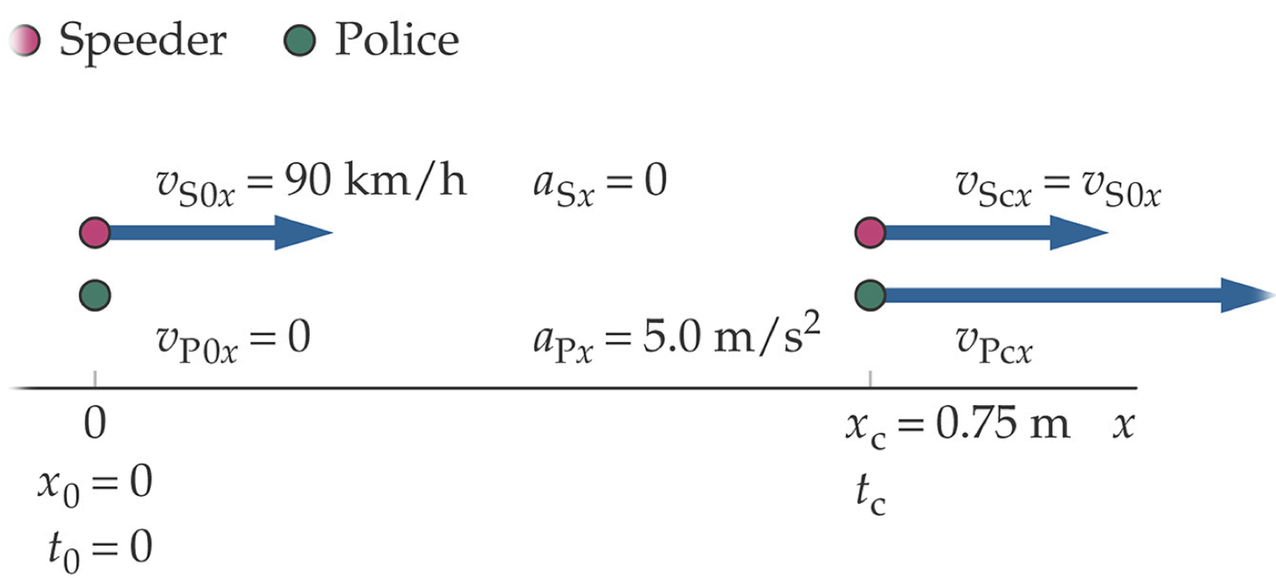
From this we see that the displacement is inversely proportional to the acceleration
and so if the acceleration is reduced by a factor of 6 by going to the Moon
and the initial velocity is unchanged the displacement increases by a factor of 6

Catching a speeding car

A car is speeding at constant 56 mi/h in a school zone. A police car starts from rest just as speeder passes by it and accelerates at constant rate of 5 m/s^2.

(a) When does police car catch speeding car?

(b) How fast is police car traveling when it catches up with speeder?



Equations for the speeding car and police car are

$$x_1 = v_0 t \qquad\qquad x_2 = \frac{1}{2}at^2$$

Catching equation

$$x_1 = x_2 \Rightarrow v_0 t = \frac{1}{2}at^2$$

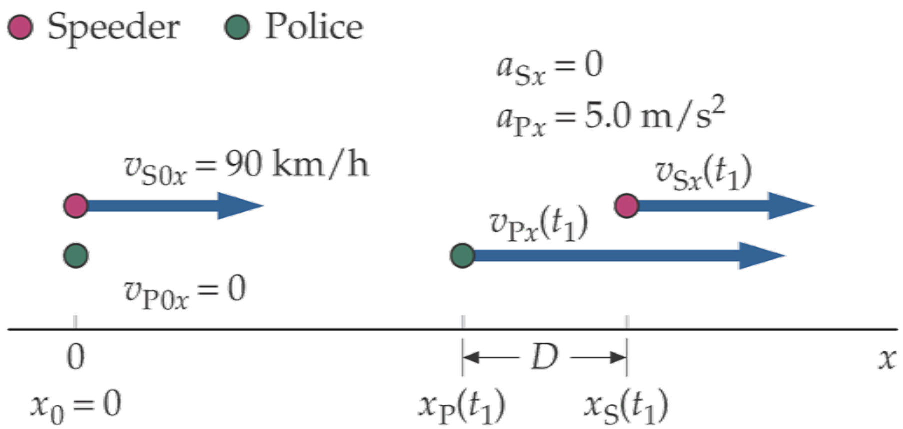
$$t = \frac{2v_0}{a} = 10 \text{ s}$$

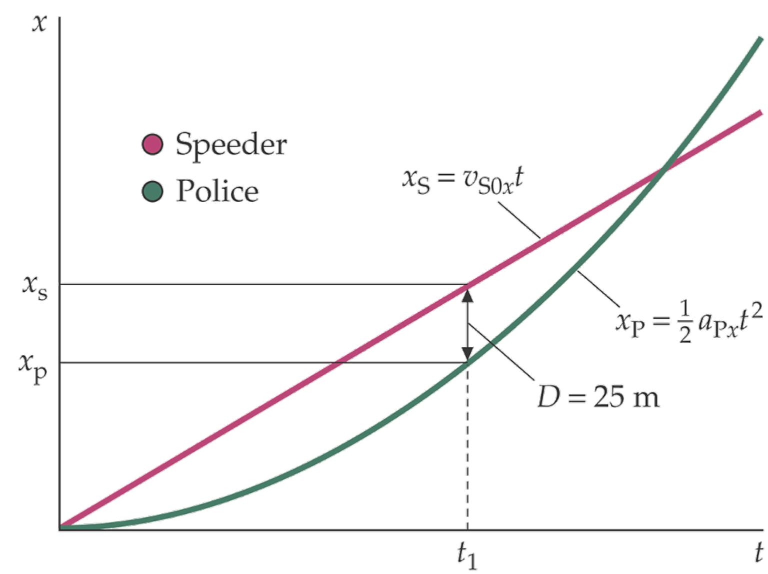
Velocity when catching the speeder

$$v = at = 50 \text{ m/s}$$

Catching a speeding car

How fast is police traveling when is 25 m behind speeding car





25 m behind equation

$$x_1 = x_2 + 25 \text{ m}$$

$$v_0 t = \frac{1}{2} a t^2 + 25 \text{ m}$$

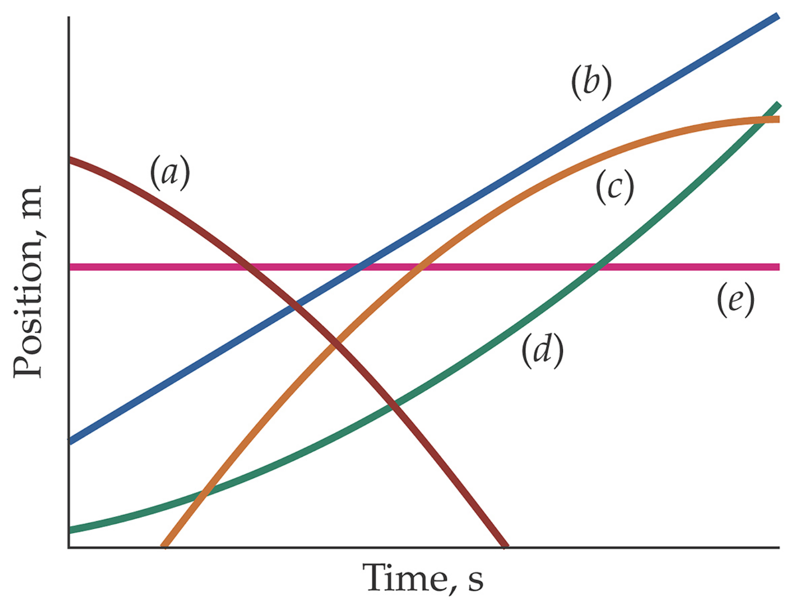
$$\frac{1}{2} a t^2 - v_0 t + 25 \text{ m} = 0$$

$$t = \frac{v_0 \pm \sqrt{v_0^2 - 50\ a\ \text{m}}}{a} = 5 \pm \sqrt{15} \text{ s}$$

$$v_{\text{pol}} = 5.64 \text{ m/s} \quad \textit{and} \quad v_{\text{pol}} = 44.4 \text{ m/s}$$

Homework 1

Which of position-versus-time curves in figure best shows motion of an object



(a) with positive acceleration

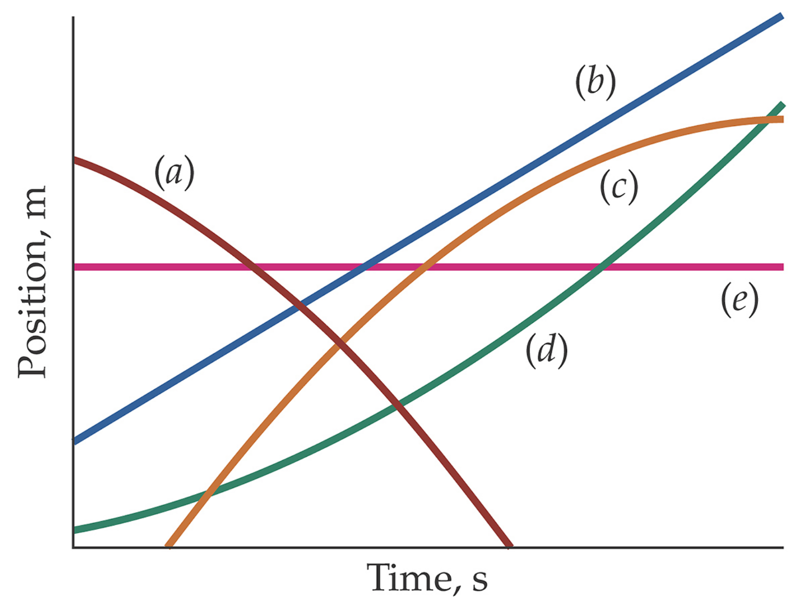
(b) with constant positive velocity

(c) that is always at rest

(d) with positive velocity and negative acceleration

Homework 1

Which of position-versus-time curves in figure best shows motion of an object



(a) with positive acceleration ☛ curve d

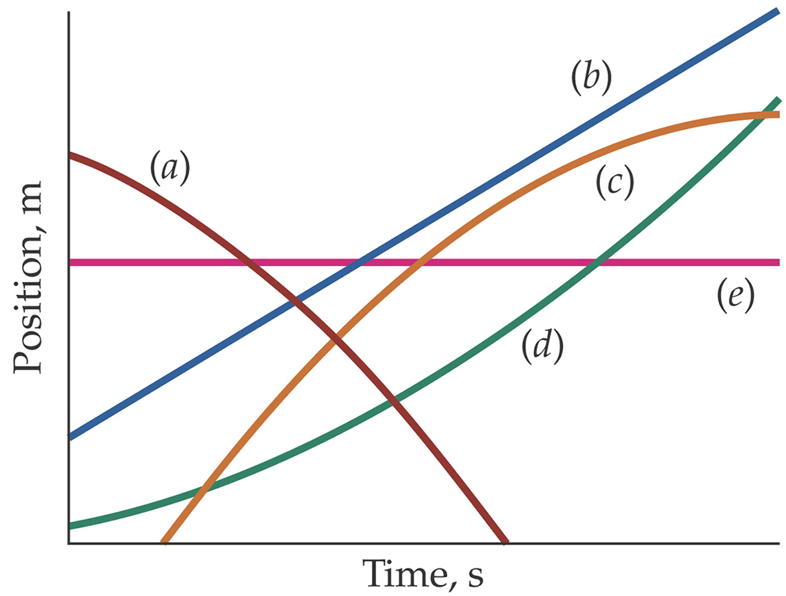
(b) with constant positive velocity

(c) that is always at rest

(d) with positive velocity and negative acceleration

Homework 1

Which of position-versus-time curves in figure best shows motion of an object



(a) with positive acceleration ☛ curve d

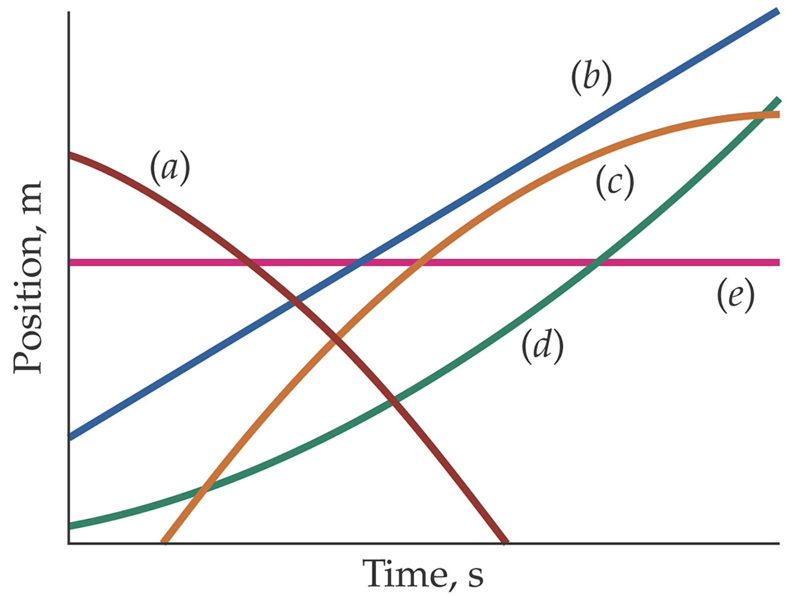
(b) with constant positive velocity ☛ curve b

(c) that is always at rest

(d) with positive velocity and negative acceleration

Homework 1

Which of position-versus-time curves in figure best shows motion of an object



(a) with positive acceleration ☛ curve d

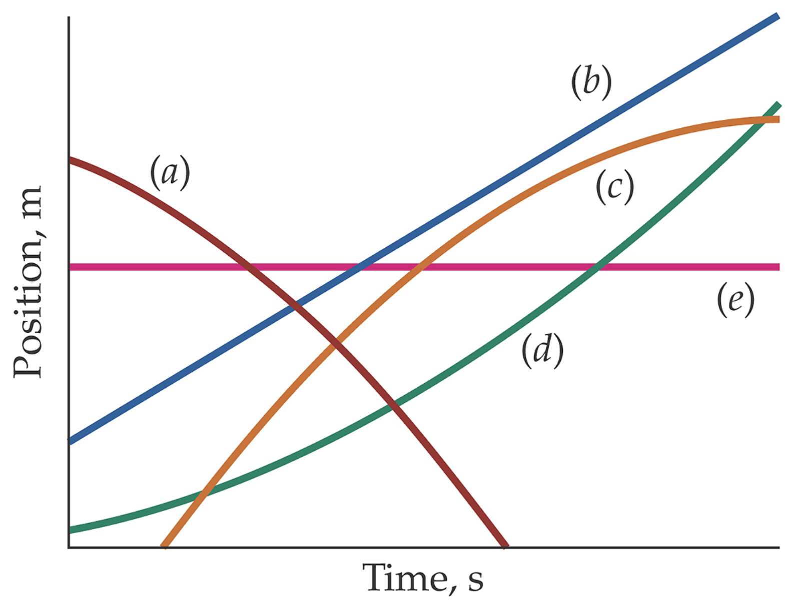
(b) with constant positive velocity ☛ curve b

(c) that is always at rest ☛ curve e

(d) with positive velocity and negative acceleration

Homework 1

Which of position-versus-time curves in figure best shows motion of an object



(a) with positive acceleration ☛ curve d

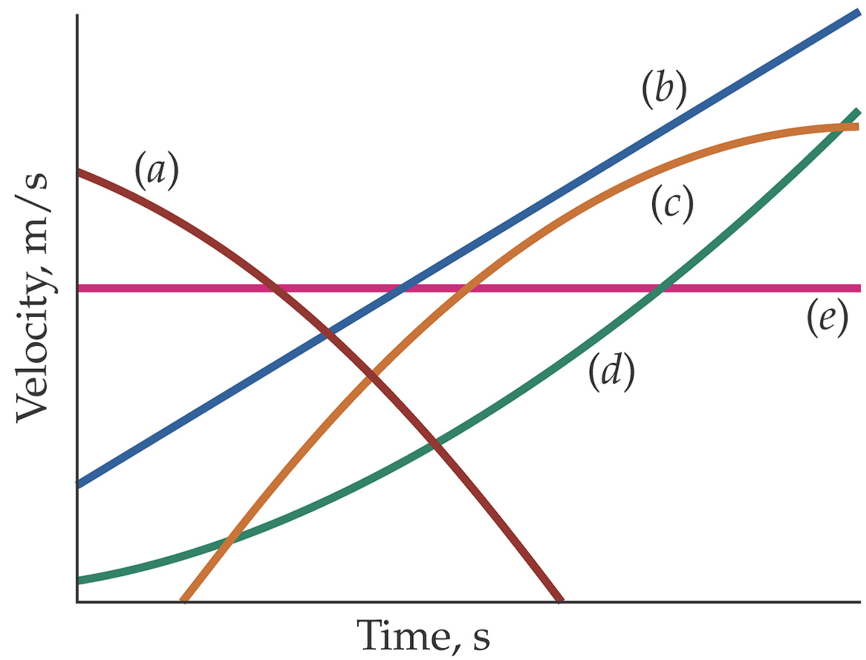
(b) with constant positive velocity ☛ curve b

(c) that is always at rest ☛ curve e

(d) with positive velocity and negative acceleration ☛ curve c

Homework 2

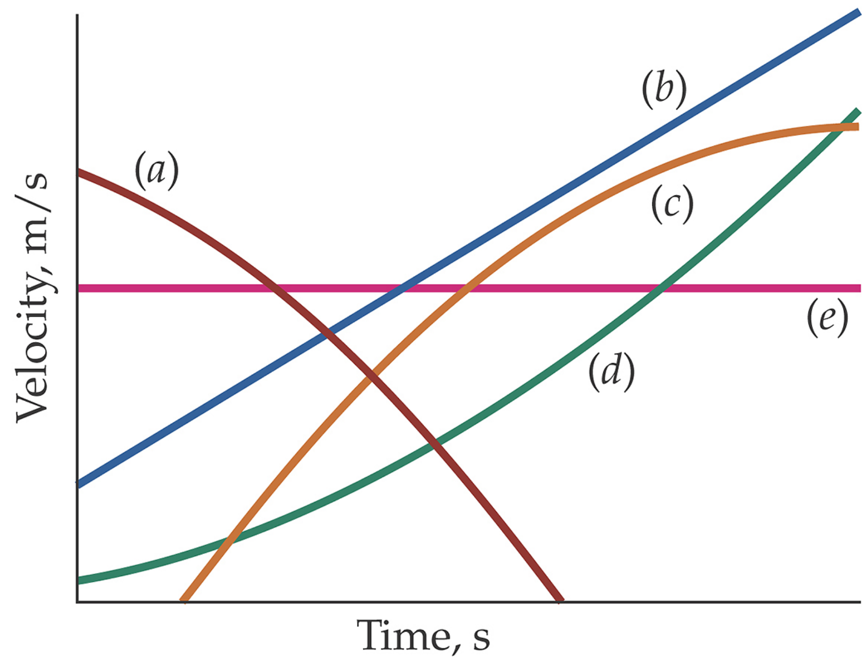
Which of velocity-versus-time curves in figure best describes motion of an object



(a) with constant positive acceleration
(b) with positive acceleration that is decreasing with time
(c) with positive acceleration that is increasing with time
(d) with no acceleration

Homework 2

Which of velocity-versus-time curves in figure best describes motion of an object



(a) with constant positive acceleration ☛ curve b
(b) with positive acceleration that is decreasing with time
(c) with positive acceleration that is increasing with time
(d) with no acceleration

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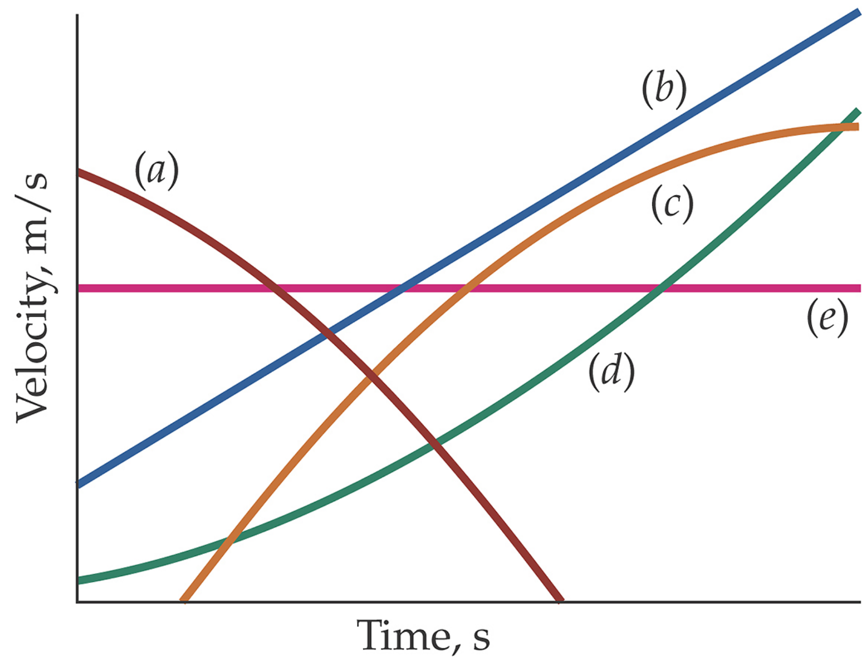

(a) with constant positive acceleration ☛ curve b

(b) with positive acceleration that is decreasing with time ☛ curve c

(c) with positive acceleration that is increasing with time

(d) with no acceleration

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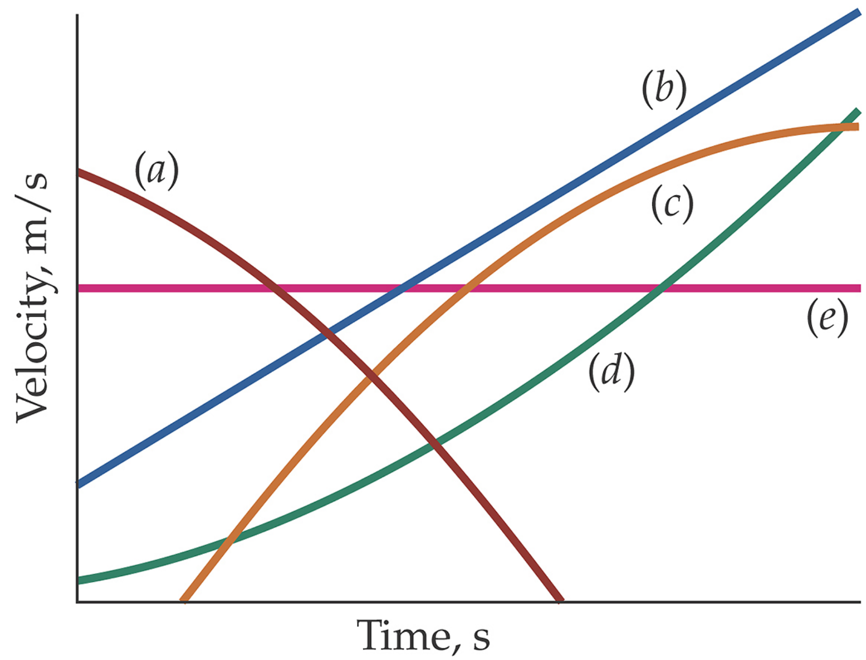

(a) with constant positive acceleration ☛ curve b
(b) with positive acceleration that is decreasing with time ☛ curve c
(c) with positive acceleration that is increasing with time ☛ curve d
(d) with no acceleration

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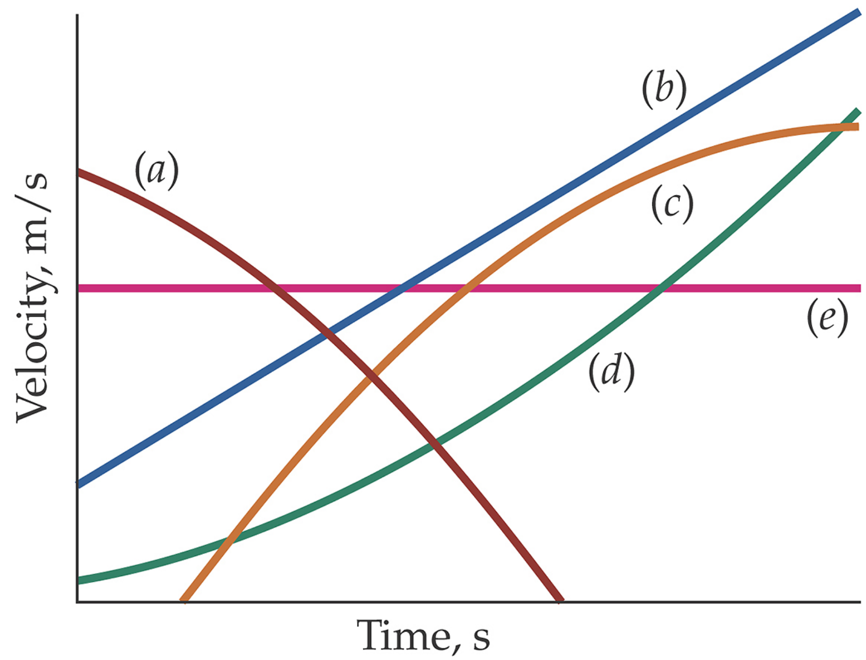

(a) with constant positive acceleration ☛ curve b

(b) with positive acceleration that is decreasing with time ☛ curve c

(c) with positive acceleration that is increasing with time ☛ curve d

(d) with no acceleration ☛ curve e

Thanks

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questions