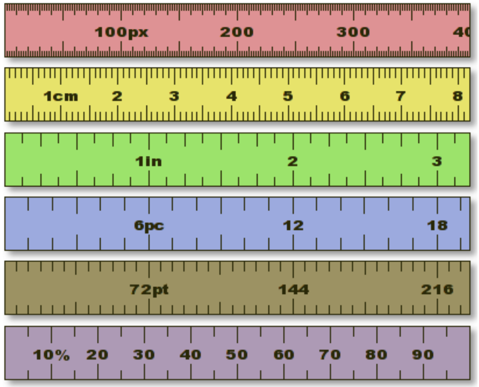
Physics 111: Mechanics
Lecture Week 1

Bin Chen

NJIT Physics Department

Introduction

- Physics 111 – Course Information
- Brief Introduction to Physics
- Chapter 1 – Measurements (sect. 1-6)
  - Measuring things
  - SI units
  - Unit conversion
  - Dimension
- Chapter 2 – 1D motion (sect. 1-5)
  - Displacement, Time and Average Velocity
  - Instantaneous Velocity
  - Average and Instantaneous Acceleration
  - Motion with Constant Acceleration
  - Free Falling Bodies



Course Information: Instructor

- Instructor: Prof. Bin Chen
- Office: Tiernan Hall, Room 101
- Office hour: Fridays 11:00 am-12:00 pm. Other time by appointment.
- Email: *bin.chen@njit.edu*
- Website: *http://web.njit.edu/~binchen/phys111*
  - *This is where I post my lecture slides!*

Course Information: Materials

- Class:
  - 04:00 pm – 05:20 pm, Tuesdays and Thursdays in Tiernan Hall 107
  - Lecture notes available at http://web.njit.edu/~binchen/phys111 (which will be uploaded after every lecture)
- Primary Textbook: *"Sears and Zumansky's University Physics with Modern Physics" by Young and Freedman (13th edition), available via NJIT Bookstore*
- Lab (required): Must register separately for Phys 111A

Course Information: Grading

- Common Exams (16% each, 48% total)
  - **Common Exam 1:** TBD 4:15 - 5:45 pm
  - **Common Exam 2:** TBD 4:15 - 5:45 pm
  - **Common Exam 3:** TBD 4:15 - 5:45 pm
- Final Exam (32%)
- Homework (10%)
- In-class Quizzes (10%)
- Final Letter Grade

A	**>85**
B+	**>80-85**
B	**>70-80**
C+	**>65-70**
C	**>55-65**
D	**>50-55**
F	**<50**

Course Information: Homework

- Homework problem assignments will be posted on-line using the Mastering Physics Homework System ("access code card" purchase with textbook)
- Homework Registration, Login, Problems:

  http://www.masteringphysics.com
- MasteringPhysics Course ID: **MPCHENFALL18**
- Homeworks are usually due on Sundays at 23:59 PM Eastern Time.

Doing homework is important!

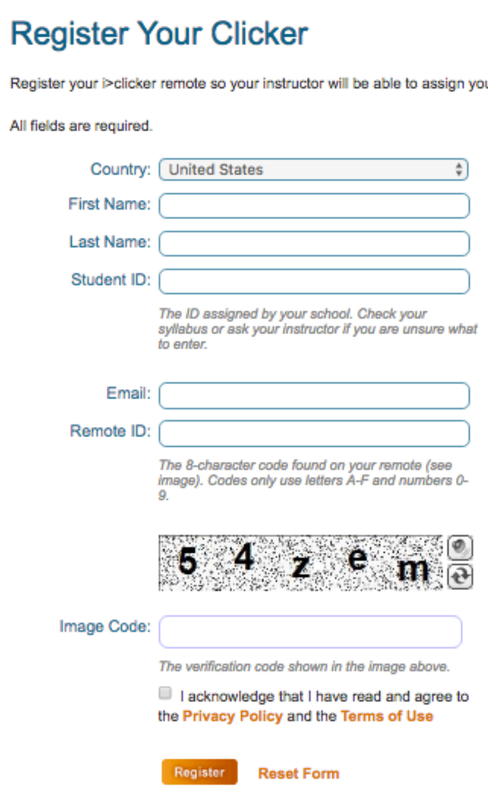
- Learning physics needs a lot of practice
- Gives you a chance to review the textbook
- Helps you understand the course material
- The **best** way to get a good grade!
  - Roughly **half** of all the exam questions (which are worth 80% of your total grade) are based on the homework questions!

In-Class Quiz: iClicker

- iClicker is **required** as part of the course
  - Similar to requiring a textbook for the course
  - Can be purchased/rented at the NJIT bookstore
  - Can't share with your classmate
- iClicker use will be integrated into the course
  - To be used during most or all lectures/discussions
  - iClicker questions will be worked into subject matter
- Watch out for slides with an iClicker symbol
- 10% of the final grade
- We will start to use it from the ***second*** week

Register your iClicker online

- https://www1.iclicker.com/register-clicker
- Use your 8-digit student ID
- Most importantly, enter your iClicker remote ID on the back
- Do this before the **second** week



Register Your Clicker

Register your i>clicker remote so your instructor will be able to assign you credit for using your clicker in class.

All fields are required.

Country: United States

First Name:

Last Name:

Student ID:

The ID assigned by your school. Check your syllabus or ask your instructor if you are unsure what to enter.

Email:

Remote ID:

The 8-character code found on your remote (see image). Codes only use letters A-F and numbers 0-9.

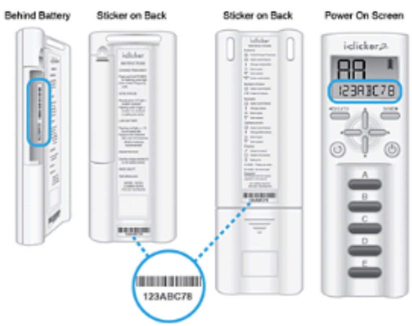
5 4 z e m

Image Code:

The verification code shown in the image above.

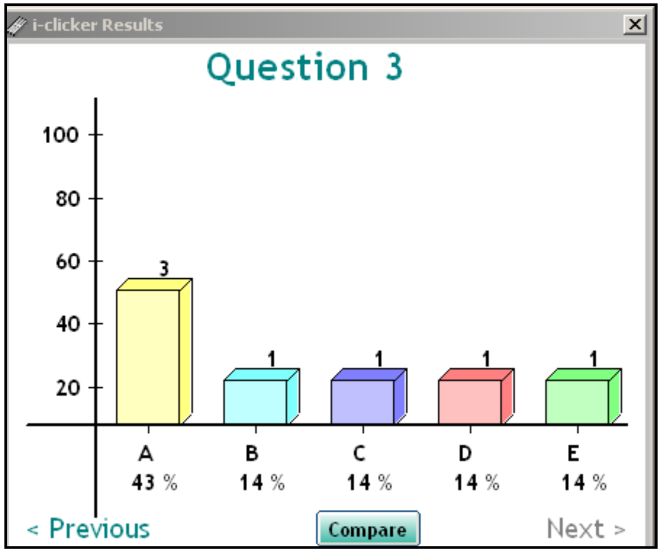
I acknowledge that I have read and agree to the Privacy Policy and the Terms of Use

Register Reset Form



How will we use the clicker?

- I post questions on the slide during lecture.
- You answer using your i-clicker remote.
- Class results are tallied.
- I can display a graph with the class results on the screen.
- We discuss the questions and answers.
- You can get points (for participating and/or answering correctly)! These will be recorded (e.g., for quizzes and attendance).



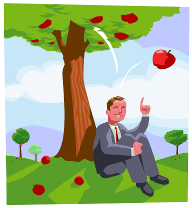
Course Information: Remarks

- This is one of the difficult 100-level courses – many students fail!
- To succeed, spending time/effort is crucial
- Taught at a much much faster pace than your high school
- Do not hesitate to get help!
  - Come to my office hour
  - Go to Phys Dept. tutoring sessions (time TBD)
  - Your fellow classmates

Physics and Mechanics

- **<u>Physics</u>** deals with the nature and properties of matter and energy. Common language is math (Co-Reqs: Math 111 or Math 132). Physics is based on experimental observations and quantitative measurements.
- The study of physics can be divided into six main areas:
  - <u>Classical mechanics – Physics I (Phys. 111)</u>
  - <u>Electromagnetism – Physics II (Phys. 121)</u>
  - Optics – Physics III (Phys. 234, 418)
  - Relativity – Phys. 420
  - Thermodynamics – Phys. 430
  - Quantum mechanics – Phys. 442



- **<u>Classical mechanics</u>** deals with the motion and equilibrium of material bodies and the action of forces.

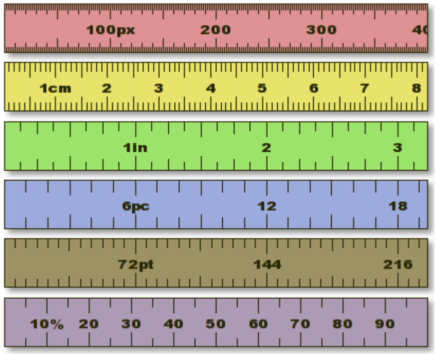
Measurement

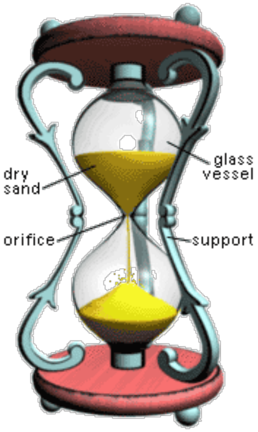
- Being quantitative in Physics requires measurements
- How tall is LeBron James? How about his weight?
  - Height: 2.03 m (6 ft 8 in)
  - Weight: 113.4 kg (250 lb)

- Number + Unit
  - "thickness is 10." has no physical meaning
  - Both numbers and units necessary for any meaningful physical quantities

SI Unit for 3 Basic Quantities

- Many possible choices for units of Length, Mass, Time (e.g. LeBron is 2.03 m or 6 ft 8 in)
- In 1960, standards bodies control and define Système Internationale (SI) unit as,
  - LENGTH: Meter
  - MASS: Kilogram
  - TIME: Second





Prefixes for SI Units

- 3,000 m = 3 x 1,000 m
  = 3 x 10^3 m = 3 km
- 1,000,000,000 = 10^9 = 1G
- 1,000,000 = 10^6 = 1M
- 1,000 = 10^3 = 1k

- 141 kg = ? g
- 1 GB = ? Byte = ? MB

If you are rusty with scientific notation, see appendix B.1 of the text

10^x	Prefix	Symbol
x=18	exa	E
15	peta	P
12	tera	T
9	giga	G
6	mega	M
3	kilo	k
2	hecto	h
1	deca	da

Prefixes for SI Units

10^x	Prefix	Symbol
x=-1	deci	d
-2	centi	c
-3	milli	m
-6	micro	μ
-9	nano	n
-12	pico	p
-15	femto	f
-18	atto	a

- 0.003 s = 3 x 0.001 s
  = 3 x 10^{-3} s = 3 ms
- 0.01 = 10^{-2} = centi
- 0.001 = 10^{-3} = milli
- 0.000 001 = 10^{-6} = micro
- 0.000 000 001 = 10^{-9} = nano
- 0.000 000 000 001 = 10^{-12}
  = pico = p
- 1 nm = ? m = ? cm
- 3 cm = ? m = ? mm

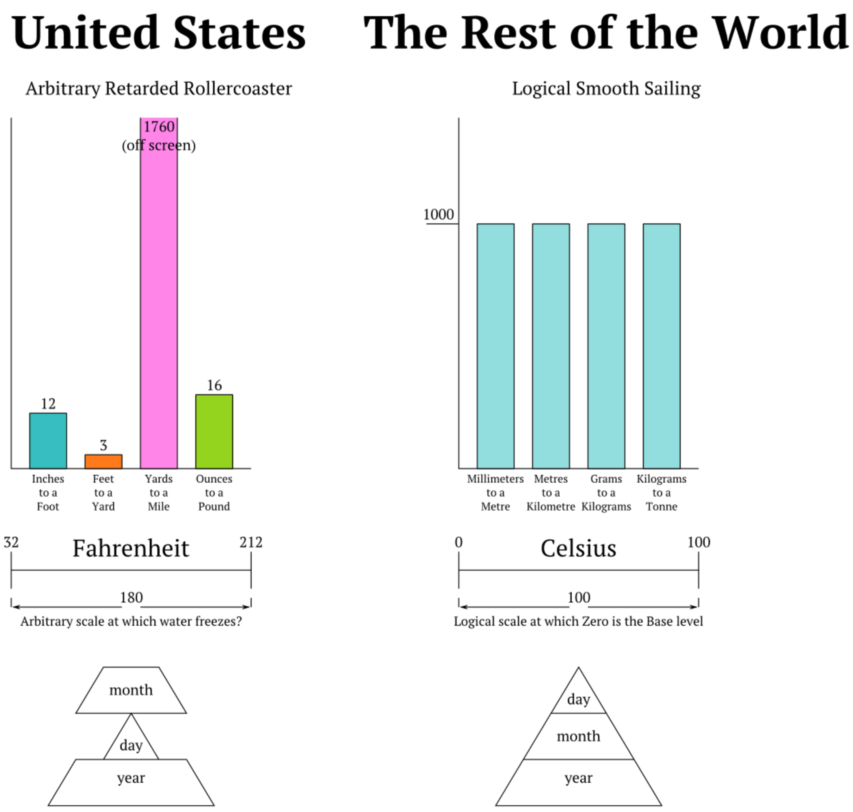
Derived Quantities and Units

- Multiply and divide units just like numbers
- Derived quantities: area, speed, volume, density …
  - Area = Length x Length SI unit = m^2
  - Volume = Length x Length x Length SI unit = m^3
  - Speed = Length / time SI unit = m/s
  - Density = Mass / Volume SI unit = kg/m^3

Other Unit System

- U.S. customary system (or imperial units): foot, slug, second
- CGS system: cm, gram, second (another variant of the metric system, heavily used in **astrophysics**)
- We will use SI units in this course, but it is useful to know conversions between systems.
  - 1 mile = 1609 m = 1.609 km   1 ft = 0.3048 m = 30.48 cm
  - 1 m = 39.37 in. = 3.281 ft   1 in. = 0.0254 m = 2.54 cm
  - 1 lb = 0.465 kg   1 oz = 28.35 g   1 slug = 14.59 kg
  - More can be found in Appendices A & D in your textbook.

Why metric is better?



"In metric, one milliliter of water occupies one cubic centimeter, weighs one gram, and requires one calorie of energy to heat up by one degree centigrade—which is 1 percent of the difference between its freezing point and its boiling point. An amount of hydrogen weighing the same amount has exactly one mole of atoms in it. Whereas in the American system, the answer to 'How much energy does it take to boil a room-temperature gallon of water?' is 'Go f**k yourself,' because you can't directly relate any of those quantities." – *Wild Thing* by Josh Bazell

Why should we care about units?

- Loss of NASA's Mass Climate Orbiter: https://www.youtube.com/watch?v=urcQAKKAAl0
- Official Announcements: http://mars.jpl.nasa.gov/msp98/orbiter

Unit Conversion

- Example: Is the driver speeding?
  - On the garden state parkway of New Jersey, a car is traveling at a speed of 38.0 m/s. Is the driver exceeding the speed limit?
  - Since the speed limit is in miles/hour (mph), we need to convert the units of m/s to mph. Take it in two steps.
  - Step 1: Convert m to miles. Since 1 mile = 1609 m, we have two possible conversion factors, 1 mile/1609 m = $6.215\text{x}10^{-4}$ mile/m, or 1609 m/1 mile = 1609 m/mile. What are the units of these conversion factors?
  - Since we want to convert m to mile, we want the m units to cancel => multiply by first factor: $38.0\,\frac{\cancel{m}}{s}\times\frac{1\,mile}{1609\,\cancel{m}}=\frac{38.0}{1609}\times\frac{mile}{s}=2.36\times10^{-2}\,mile/s$
  - Step 2: Convert s to hours. Since 1 hr = 3600 s, again we could have 1 hr/3600 s = $2.778\text{x}10^{-4}$ hr/s, or 3600 s/hr.
  - Since we want to convert s to hr, we want the s units to cancel =>

$$38.0m/s=2.36\times10^{-2}mile/s\times3600s/hr=85.0mile/hr=85.0mph$$

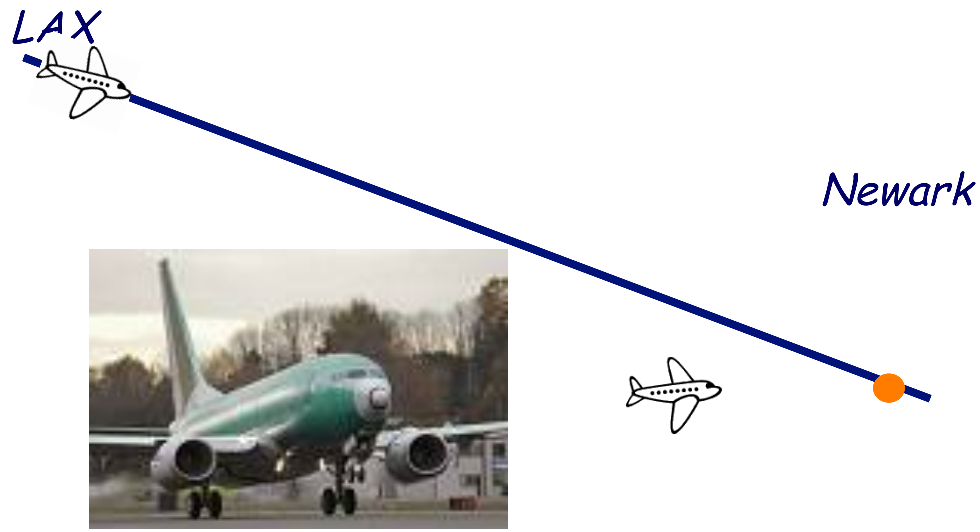
Summary – Part I

- The three fundamental physical quantities of mechanics are length, mass and time, which in the SI system have the units meter (m), kilogram (kg), and second (s), respectively.

- Units in physics equations must always be consistent. Converting units is a matter of multiplying the given quantity by a fraction, with one unit in the numerator and its equivalent in the other units in the denominator, arrange so the unwanted units in the given quantity are cancelled out in favor of the desired units.

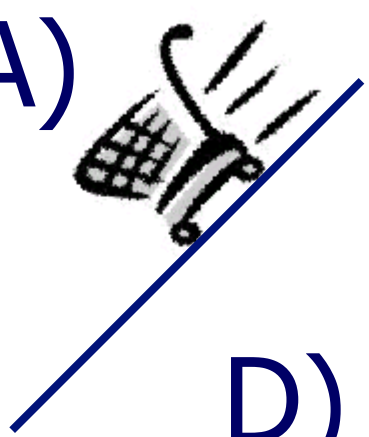
Chapt. 2: 1D Motion

- Everything moves! Motion is one of the main topics in Physics I
- Motion can be studied with **Kinematics** and **Dynamics**
- Simplification: Consider a moving object as a particle, i.e. it moves like a particle—a **"point object"**
- In the spirit of taking things apart for study, then putting them back together, we will first consider only **motion along a straight line: one dimensional motion**

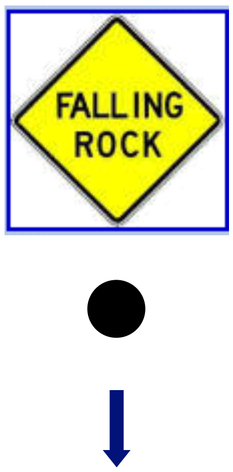


Straight Line

Which case is a motion along a straight line?

A) 

B) 

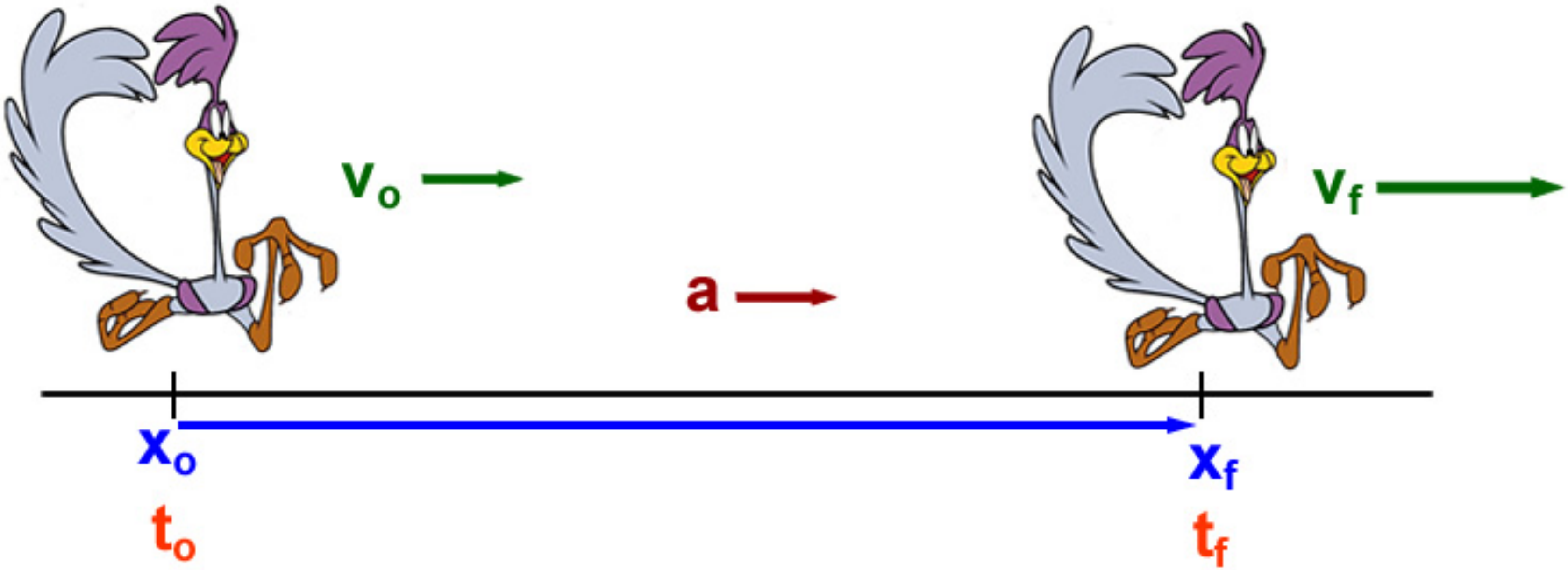
C) 

D) All of the above

- This is the simplest type of motion.
- Straight line can be oriented along any direction: Horizontal, vertical, or at some angle.
- It lays the groundwork for more complex motion.

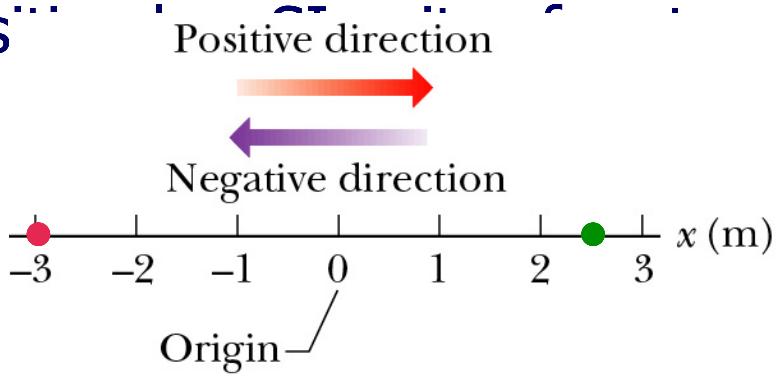
Basic Quantities in Kinematics

Displacement*, *Velocity*, *Time* and *Acceleration



One Dimensional Position x

- Motion can be defined as the change of position over time.
- How can we represent position along a straight line?
- Position definition:
  - Defines a starting point: origin ($x = 0$), x relative to origin
  - Direction: positive (usually right or up), negative (usually left or down)
  - It depends on time: $t = 0$ (start clock), $x(t=0)$ does not have to be zero.
- Pos .

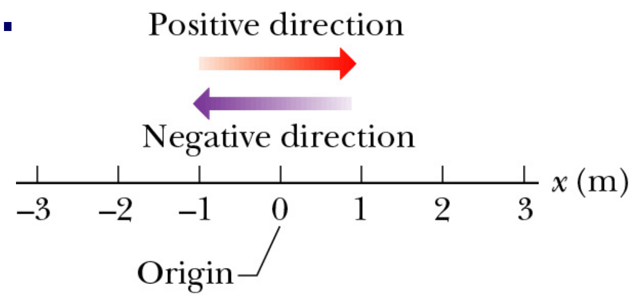


$x = + 2.5$ m

$x = - 3$ m

Vector and Scalar

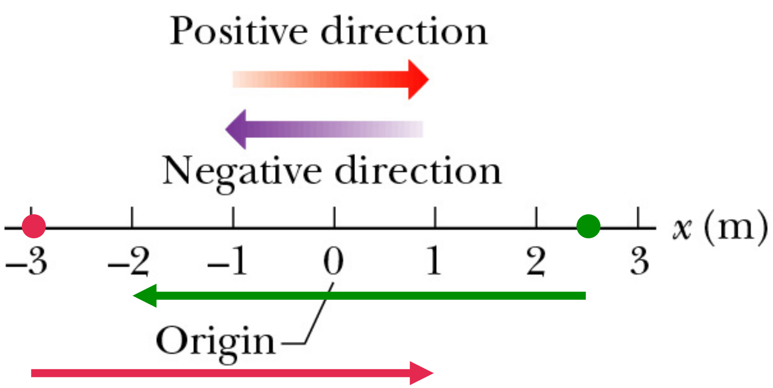
- A vector quantity is characterized by having both a magnitude and a direction.
  - Displacement, Velocity, Acceleration, Force …
  - Denoted in boldface type $\mathbf{v}$, $\mathbf{a}$, $\mathbf{F}$ … or with an arrow over the top $\vec{v}$, $\vec{a}$, $\vec{F}$ … .
- A scalar quantity has magnitude, but no direction.
  - Distance, Mass, Temperature, Time …
- For motion along a straight line, the direction is represented simply by + and – signs.
  - + sign: Right or Up.
  - − sign: Left or Down.
- 1-D motion can be thought of as a component of 2-D and 3-D motions.



Displacement

- Displacement is a change of position in time
- Displacement: $x = x_f(t_f) - x_i(t_i)$

  f stands for final and i stands for initial
- It is a vector quantity
- It has both **magnitude** and **direction** (+ or – sign)
- SI unit: meter



$x_1(t_1) = +\ 2.5$ m
$x_2(t_2) = -\ 2.0$ m
$\Delta x = -2.0$ m $- 2.5$ m $= -4.5$ m

$x_1(t_1) = -\ 3.0$ m
$x_2(t_2) = +\ 1.0$ m
$\Delta x = +1.0$ m $+ 3.0$ m $= +4.0$ m

Distance and Position-time graph

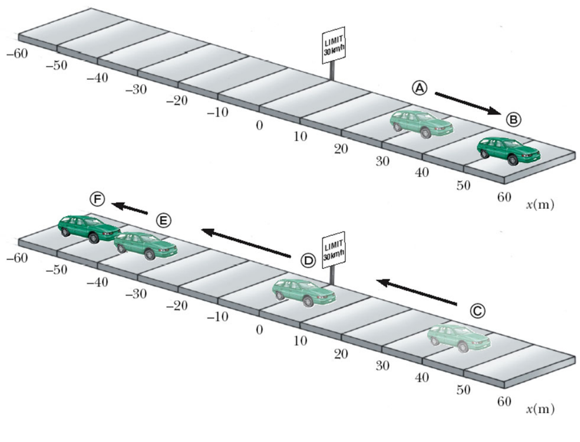
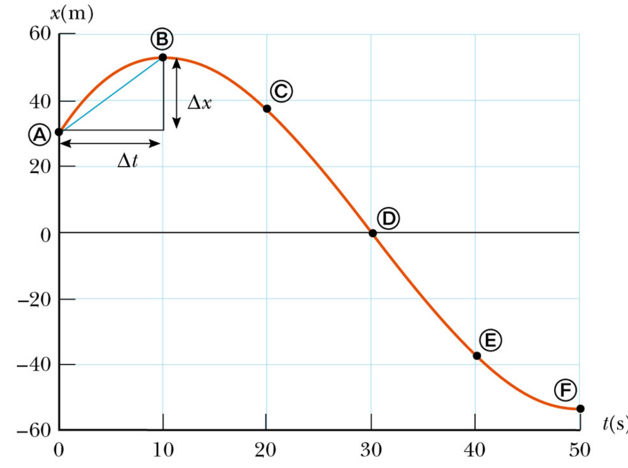


TABLE 2.1

Position of the Car at Various Times

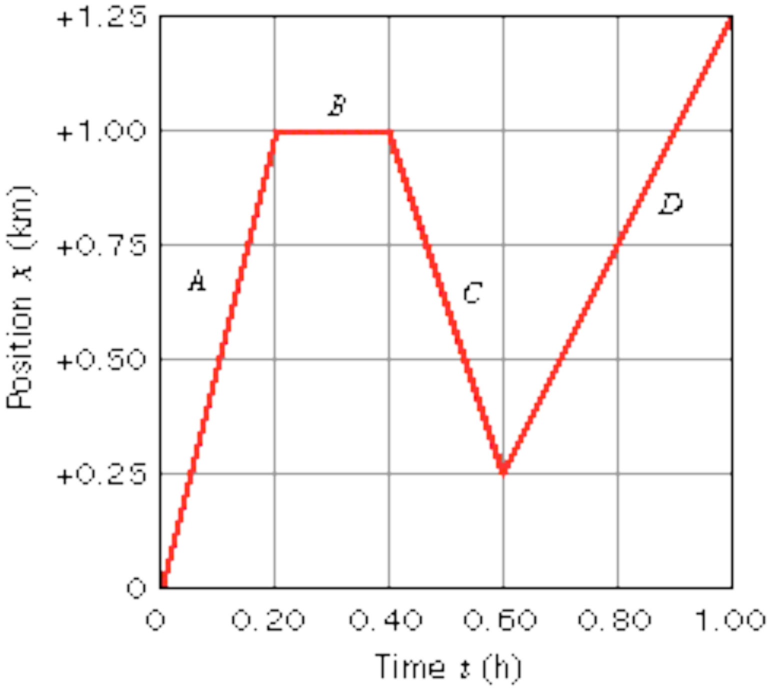
Position	t (s)	x (m)
Ⓐ	0	30
Ⓑ	10	52
Ⓒ	20	38
Ⓓ	30	0
Ⓔ	40	− 37
Ⓕ	50	− 53



- Displacement in space
  - In 10 s: $\Delta x = x_B - x_A = 52\text{ m} - 30\text{ m} = 22\text{ m}$
  - In 20 s: $\Delta x = x_C - x_A = 38\text{ m} - 30\text{ m} = 8\text{ m}$
- Distance is the length of a path followed by an object
  - In 10 s: $d = |x_B - x_A| = |52\text{ m} - 30\text{ m}| = 22\text{ m}$
  - In 20 s: $d = |x_B - x_A| + |x_C - x_B| = 22\text{ m} + |38\text{ m} - 52\text{ m}| = 36\text{ m}$
- **Displacement is not Distance**

Position-time graph

- A person who walks for exercise produces the position-time graph as below. Which segment represents that the person remains at rest?



- In 0.6 hr, what's the person's displacement?
- In 0.6 hr, what's the distance the person has travelled?

Recap Problems 1: Who is faster?

- Kangaroo vs. Usain Bolt
  - Kangaroos can hop at a speed of 40 mph
  - Bolt set the 100-m world record of 9.58 s in 2009
  - Break it down…
    - 1 mile = ? m, given there are 5280 feet/mile and 3.28 feet/m
    - 1 hr = ? s
    - 1 mph = ? m/s

Velocity

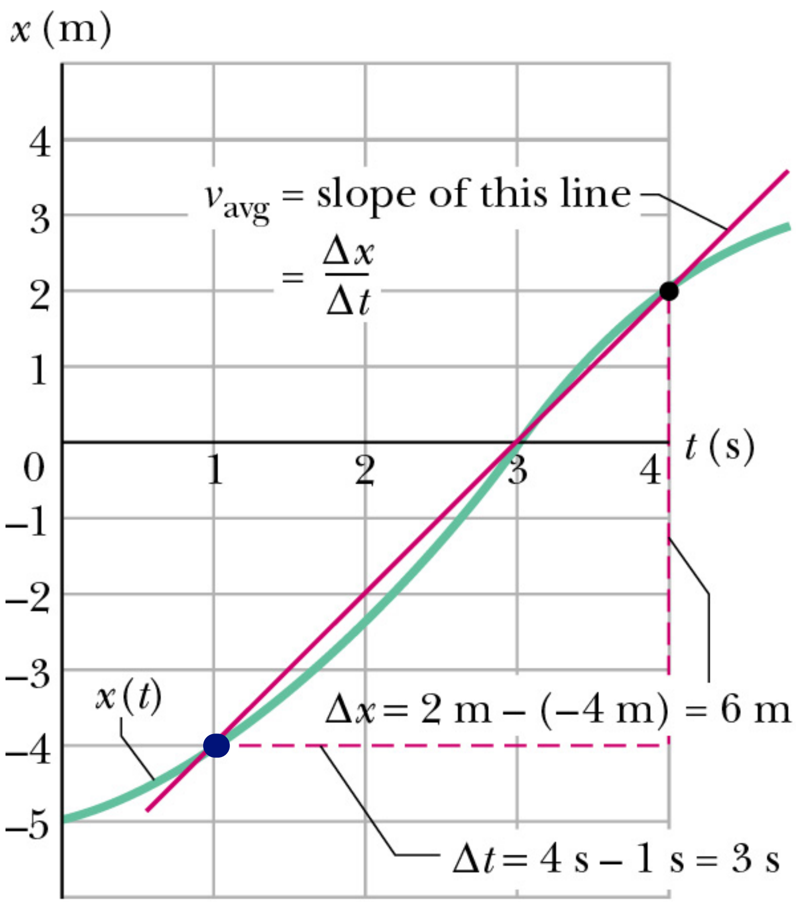
- Velocity is the rate of change of position.
- Velocity is a vector quantity.
- Velocity has both magnitude and direction.
- Velocity has a SI unit of meter/second.
- We will be concerned with three quantities, defined as:
  - Average velocity $$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$$
  - Average speed $$s_{\text{avg}} = \frac{\text{total distance}}{\Delta t}$$
  - Instantaneous velocity $$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

displacement

distance

displacement

Average Velocity

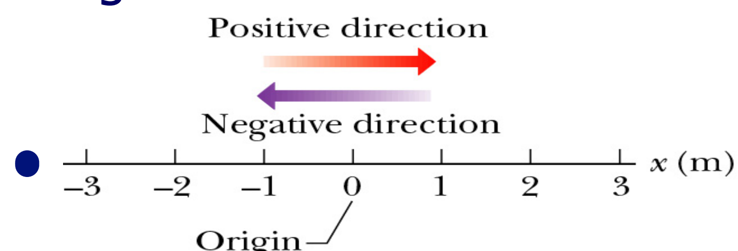


- Average velocity

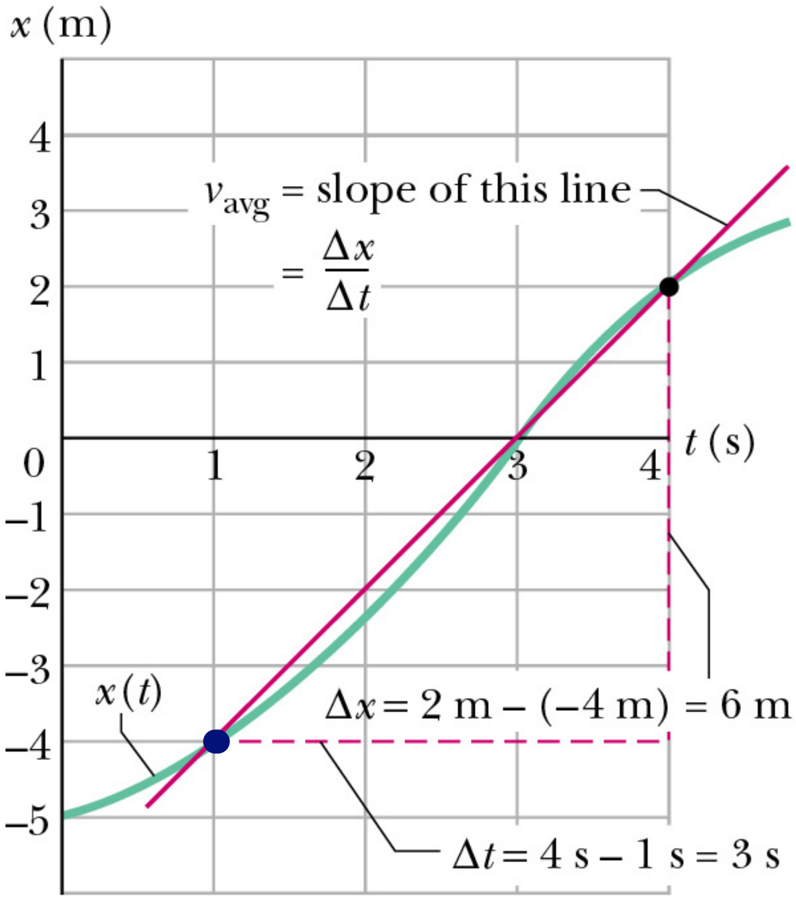
$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$$

is the slope of the line segment between end points on a graph.

- SI unit: m/s.
- It is a vector (i.e. is signed), and displacement direction sets its sign.



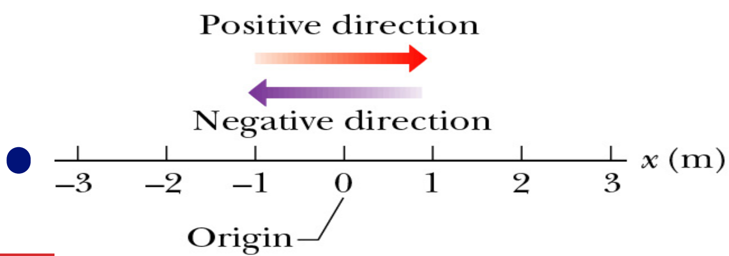
Average Speed



- Average speed

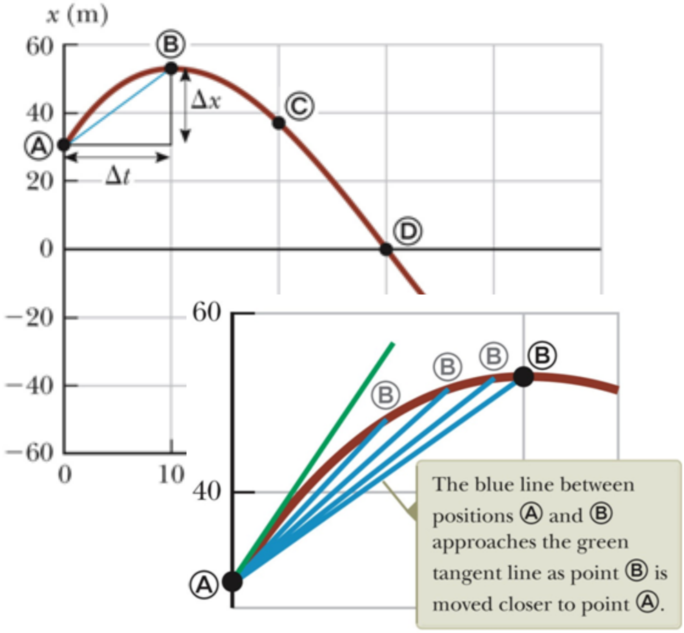
$$s_{\text{avg}} = \frac{\text{total distance}}{\Delta t}$$

- Dimension: length/time, [m/s].
- Scalar: No direction involved.
- Not necessarily close to V_{avg}:
  - S_{avg} = (6m + 6m)/(3s+3s) = 2 m/s
  - V_{avg} = (0 m)/(3s+3s) = 0 m/s



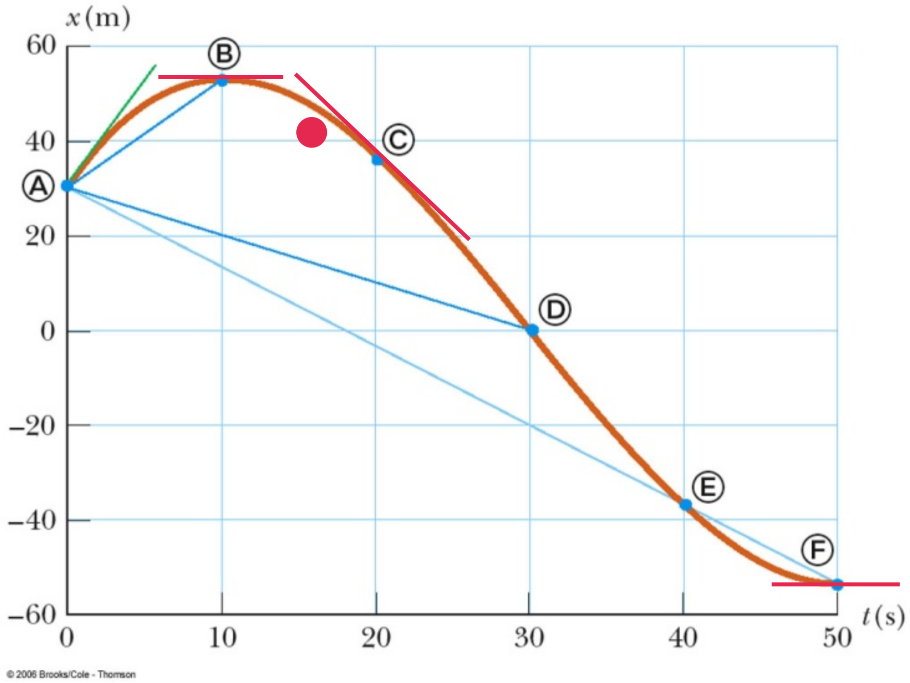
Instantaneous Velocity

- Instantaneous means "at some given instant". The instantaneous velocity indicates what is happening at every point of time.
- Limiting process:
  - Chords approach the tangent as $\Delta t \Rightarrow 0$
  - Slope measure rate of change of position
- Instantaneous velocity: $$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$
- It is a vector quantity.
- SI unit: m/s.
- It is the slope of the tangent line x(t).
- Instantaneous velocity v(t) is a function of time.



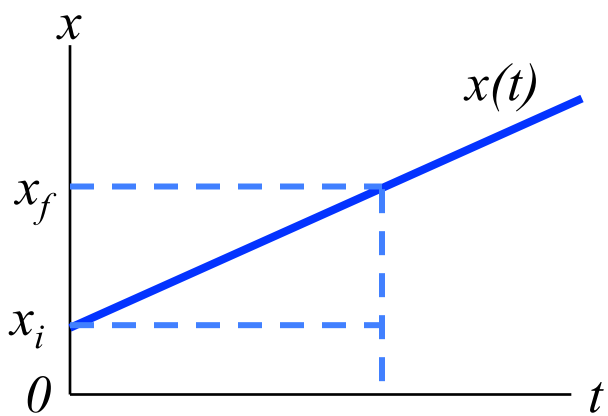
Instantaneous Velocity

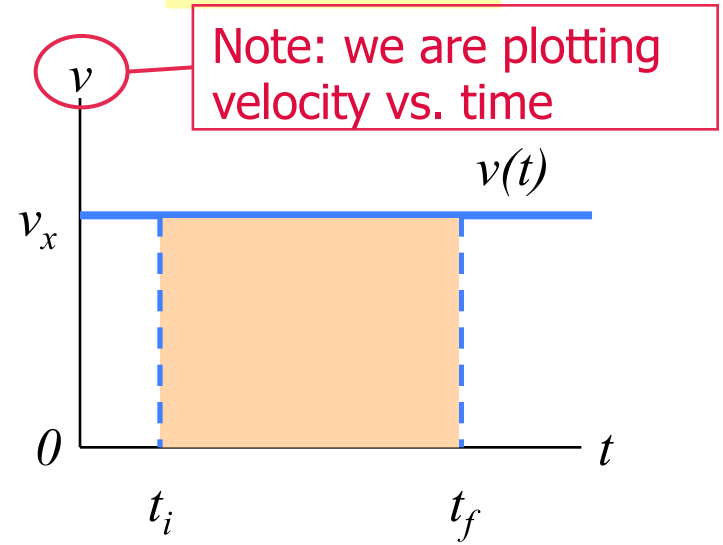
- At which time(s) the instantaneous velocity v(t) is zero?



Uniform Velocity

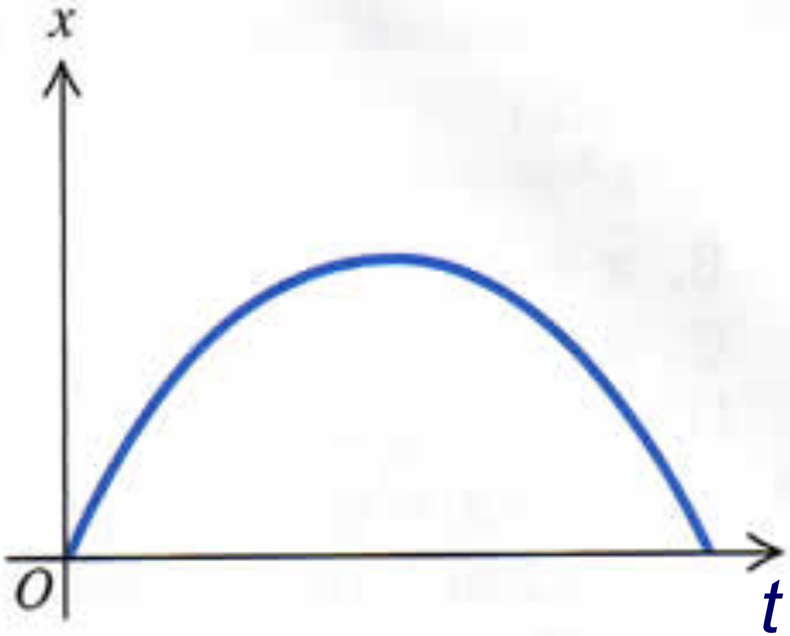
- Uniform velocity is the special case of constant velocity
- In this case, instantaneous velocities are always the same, all the instantaneous velocities will also equal the average velocity
- Begin with $v_x = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$ then $x_f = x_i + v_x \Delta t$





Position-time graph

Figure 2.33 shows the graph of an object's position x as a function of time t. (a) Does this object ever reverse its direction of motion? If so, where? (b) Does the object ever return to its starting point? (c) Is the velocity of the object constant? (d) Is the object's speed ever zero?



▲ **FIGURE 2.33** Question 16.

Video Time!

- Lighting seen in slow-motion (1 s in 6-min video footage):

https://www.youtube.com/watch?v=W9xzU0xjlhE

- Average velocity of a lighting leader (order of magnitude estimation)
  - $v_{avg} = \Delta x / \Delta t$
  - Δx?
  - Δt?

Average Acceleration

- Changing velocity (non-uniform) means an acceleration is present.
- Acceleration is the rate of change of velocity.
- Acceleration is a vector quantity.
- Acceleration has both magnitude and direction.
- Acceleration has a dimensions of length/time^2: [m/s^2].
- Definition:
  - Average acceleration $$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$
  - Instantaneous acceleration $$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d}{dt}\frac{dx}{dt} = \frac{d^2 v}{dt^2}$$

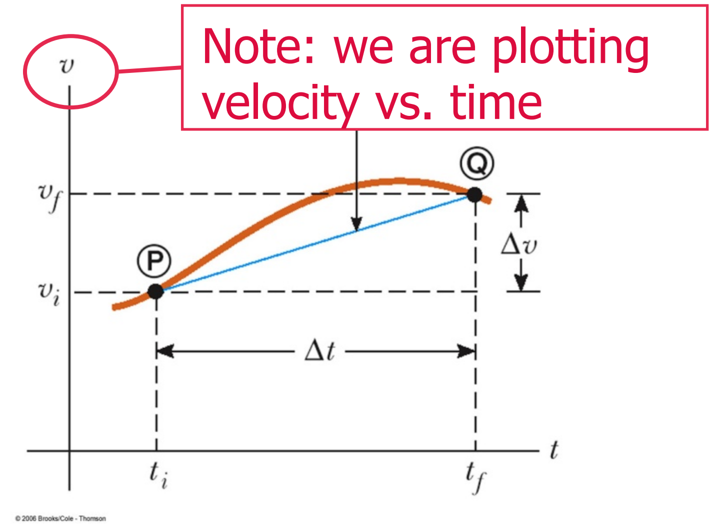
Average Acceleration

- Average acceleration

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

- Velocity as a function of time

$$v_f(t) = v_i + a_{avg}\Delta t$$



- It is tempting to call a negative acceleration a "deceleration," but note:
  - When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
  - When the sign of the velocity and the acceleration are in the opposite directions, the speed is decreasing
- Average acceleration is the slope of the line connecting the initial and final velocities on a velocity-time graph

Acceleration of the Tesla Model S P100D

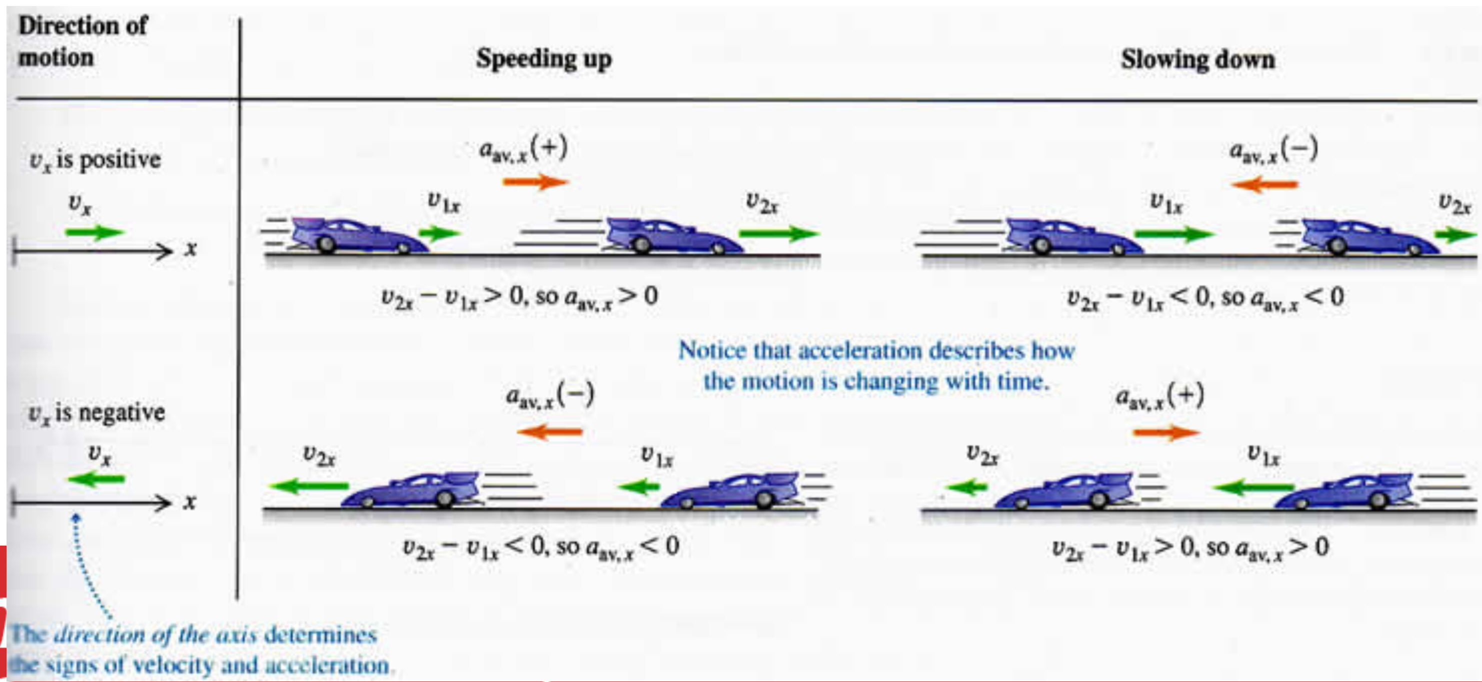
- Elon Musk claims that his Tesla Model S P100 D can accelerate from 0–60 mph in 2.5 s, becoming the third-fastest-acceleration production car in the world. If so, what is the acceleration in m/s^2?

$$a_{avg} = \Delta v / \Delta t = (v_f - v_i)/(t_f - t_i) = 60 mph / 2.5 s$$

$$= 60 \times 0.45 m/s / 2.5 s = 10.8 m/s^2$$

Speed up and Slow down

- Velocity as a function of time $$v_f(t) = v_i + a_{avg}\Delta t$$
- When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
- When the sign of the velocity and the acceleration are in the opposite directions, the speed is decreasing

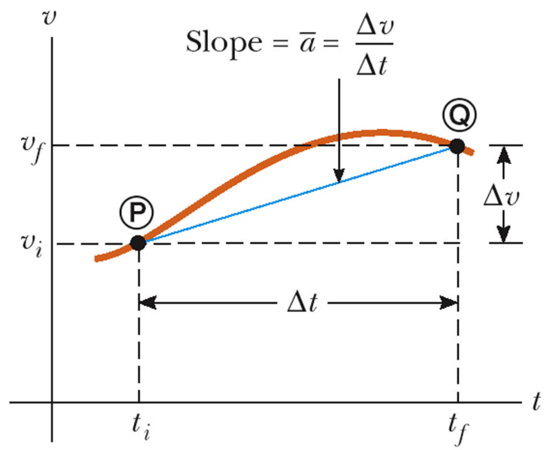


Instantaneous and Uniform Acceleration

- The limit of the average acceleration as the time interval goes to zero

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d}{dt}\frac{dx}{dt} = \frac{d^2 v}{dt^2}$$

- When the instantaneous accelerations are always the same, the acceleration will be uniform. The instantaneous acceleration will be equal to the average acceleration
- Instantaneous acceleration is the slope of the tangent to the curve of the velocity-time graph



Acceleration

- An object travels 3 m in the 1st second of travel, 3 m again during the 2nd second of travel, and 3 m again during the 3rd second. What is the approximate average acceleration of the object during this time interval?

A) 3 m/s^2

B) 6 m/s^2

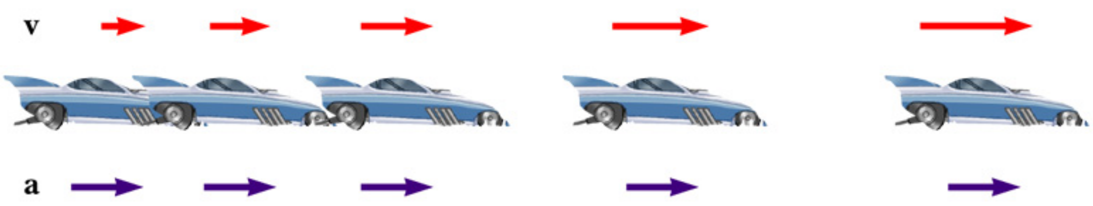
C) 9 m/s^2

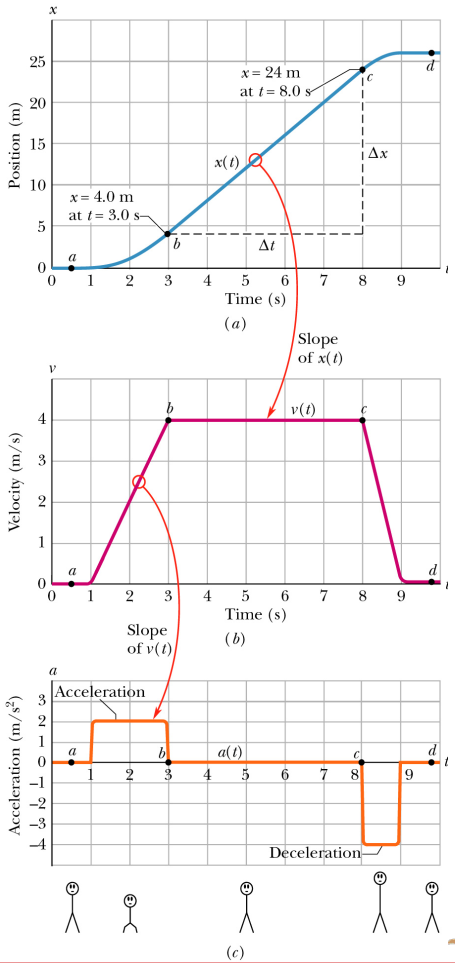
D) 0 m/s^2

E) unable to determine

Relationship between Acceleration and Velocity

- Velocity and acceleration are in the same direction
- Acceleration is uniform (blue arrows maintain the same length)
- Velocity is increasing (red arrows are getting longer) $v_f(t) = v_i + at$
- Positive velocity and positive acceleration

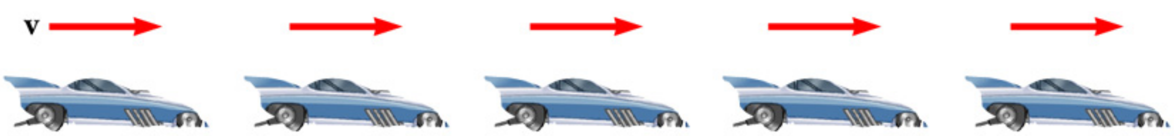


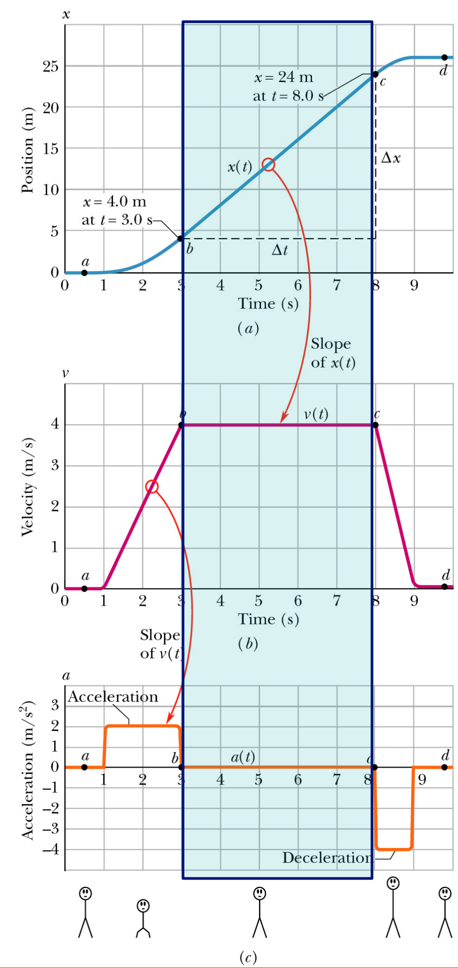


Relationship between Acceleration and Velocity

- Uniform velocity (shown by red arrows maintaining the same size)
- Acceleration equals zero

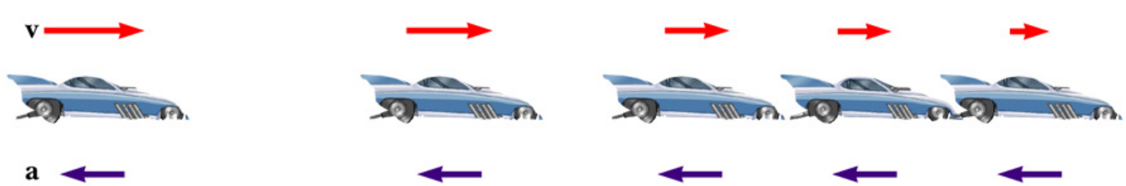
$$v_f(t) = v_i + at$$

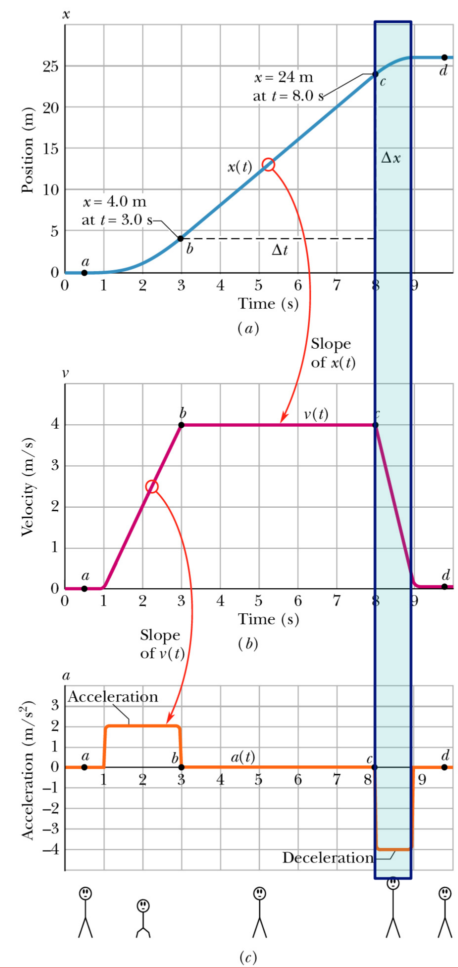




Relationship between Acceleration and Velocity

- Acceleration and velocity are in opposite directions
- Acceleration is uniform (blue arrows maintain the same length)
- Velocity is decreasing (red arrows are getting shorter) $v_f(t) = v_i + at$
- Velocity is positive and acceleration is negative





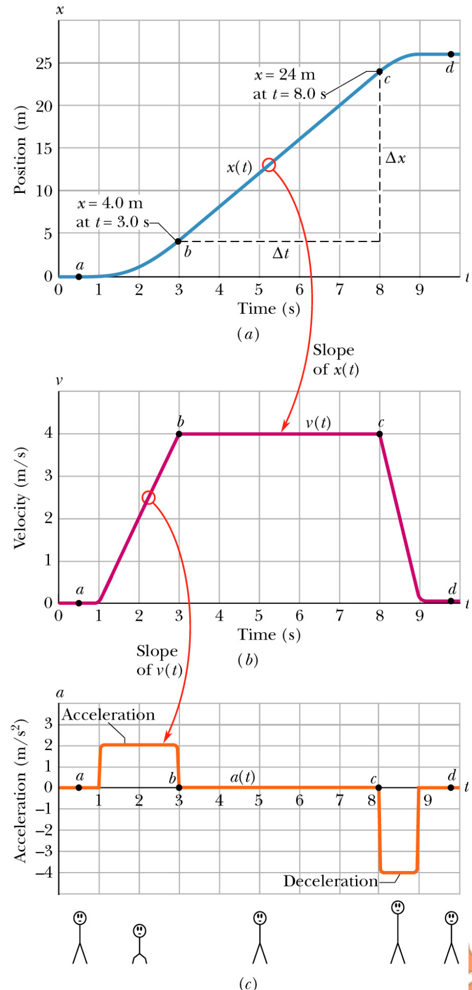
Kinematic Variables: *x(t), v(t), a*

- Position is a function of time: $x = x(t)$
- Velocity is the rate of change of position.
- Acceleration is the rate of change of velocity.

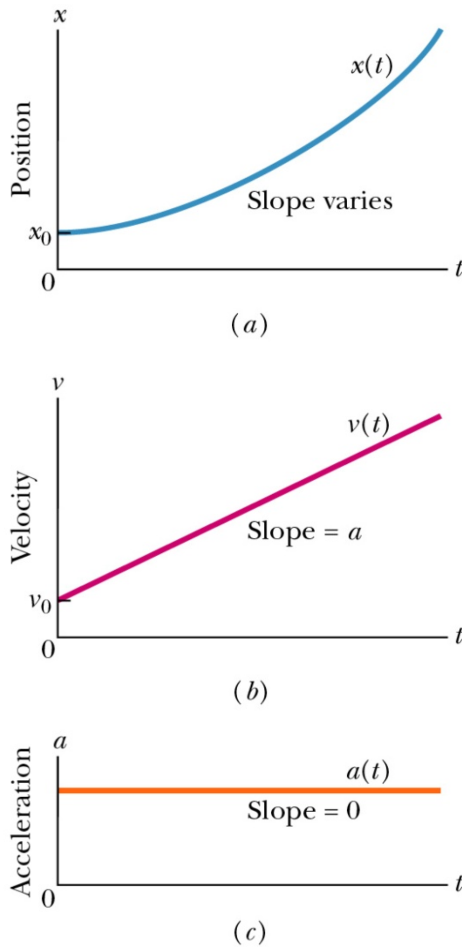
$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} \qquad a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

- Position $\xrightarrow{\frac{d}{dt}}$ Velocity $\xrightarrow{\frac{d}{dt}}$ Acceleration
- Graphical relationship between x, v, and a

An elevator is initially stationary, then moves upward, and then stops. Plot *v* and *a* as a function of time.



Special Case: Motion with Uniform Acceleration (our typical case)



- Acceleration is a constant
- Kinematic Equations (which we will derive in a moment)

$$v = v_0 + at$$

$$\Delta x = \bar{v}t = \frac{1}{2}(v_0 + v)t$$

$$\Delta x = v_0 t + \tfrac{1}{2}at^2$$

$$v^2 = v_0{}^2 + 2a\Delta x$$

Derivation of the Equation (1)

- Given initial conditions:
  - $a(t) = \text{constant} = a$, $v(t=0) = v_0$, $x(t=0) = x_0$
- Start with definition of average acceleration:

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v - v_0}{t - t_0} = \frac{v - v_0}{t - 0} = \frac{v - v_0}{t} = a$$

- We immediately get the first equation

$$v = v_0 + at$$

- Shows velocity as a function of acceleration and time
- Use when you don't know and aren't asked to find the displacement

Derivation of the Equation (2)

- Given initial conditions:
  - $a(t) = \text{constant} = a,\ v(t=0) = v_0,\ x(t=0) = x_0$
- Start with definition of average velocity:

$$v_{avg} = \frac{x - x_0}{t} = \frac{\Delta x}{t}$$

- Since velocity changes at a constant rate, we have

$$\Delta x = v_{avg} t = \frac{1}{2}(v_0 + v)t$$

- Gives displacement as a function of velocity and time
- Use when you don't know and aren't asked for the acceleration

Derivation of the Equation (3)

- Given initial conditions:
  - $a(t) = \text{constant} = a$, $v(t=0) = v_0$, $x(t=0) = x_0$
- Start with the two just-derived equations:

$$v = v_0 + at \qquad \Delta x = v_{avg}t = \frac{1}{2}(v_0 + v)t$$

- We have $\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2}(v_0 + v_0 + at)t$ $\quad \Delta x = x - x_0 = v_0 t + \frac{1}{2}at^2$
- Gives displacement as a function of all three quantities: time, initial velocity and acceleration
- Use when you don't know and aren't asked to find the final velocity

Derivation of the Equation (4)

- Given initial conditions:
  - $a(t) = \text{constant} = a$, $v(t=0) = v_0$, $x(t=0) = x_0$
- Rearrange the definition of average acceleration

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v - v_0}{t} = a$$

to find the time

$$t = \frac{v - v_0}{a}$$

- Use it to eliminate t in the second equation:

$$\Delta x = \frac{1}{2}(v_0 + v)t = \frac{1}{2a}(v + v_0)(v - v_0) = \frac{v^2 - v_0^{\ 2}}{2a}$$

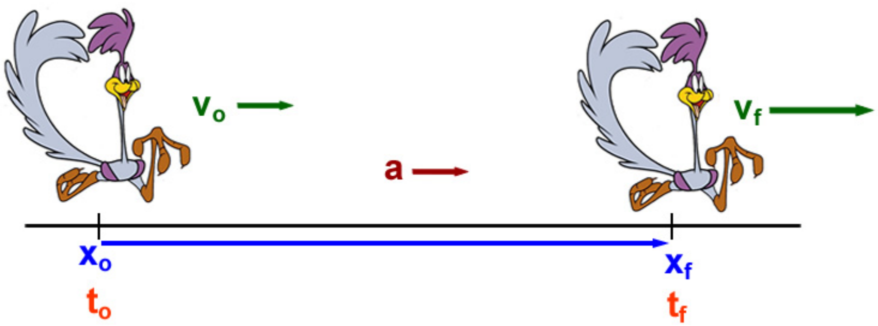
, rearrange to get

$$v^2 = v_0^{\ 2} + 2a\Delta x = v_0^{\ 2} + 2a(x - x_0)$$

- Gives velocity as a function of acceleration and displacement
- Use when you don't know and aren't asked for the tim

Problem-Solving Hints

- Read the problem
- Draw a diagram
  - Choose a coordinate system, label initial and final points, indicate a positive direction for velocities and accelerations



- Label all quantities, be sure all the units are consistent
  - Convert if necessary
- Choose the appropriate kinematic equation
- Solve for the unknowns
  - You may have to solve two equations for two unknowns
- Check your results

Example

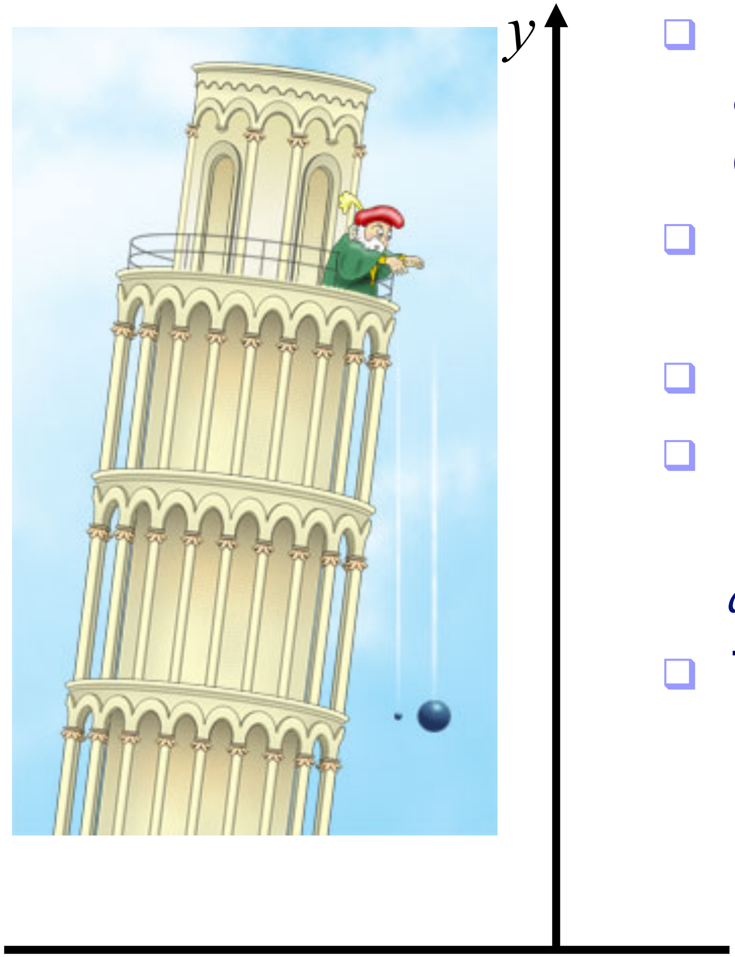
- An airplane has a lift-off speed of 30 m/s after a take-off run of 300 m, what minimum constant acceleration?

$$v = v_0 + at \qquad \Delta x = v_0 t + \tfrac{1}{2} a t^2 \qquad v^2 = v_0^2 + 2a\Delta x$$

- What is the corresponding take-off time?

$$v = v_0 + at \qquad \Delta x = v_0 t + \tfrac{1}{2} a t^2 \qquad v^2 = v_0^2 + 2a\Delta x$$

Free Fall Acceleration

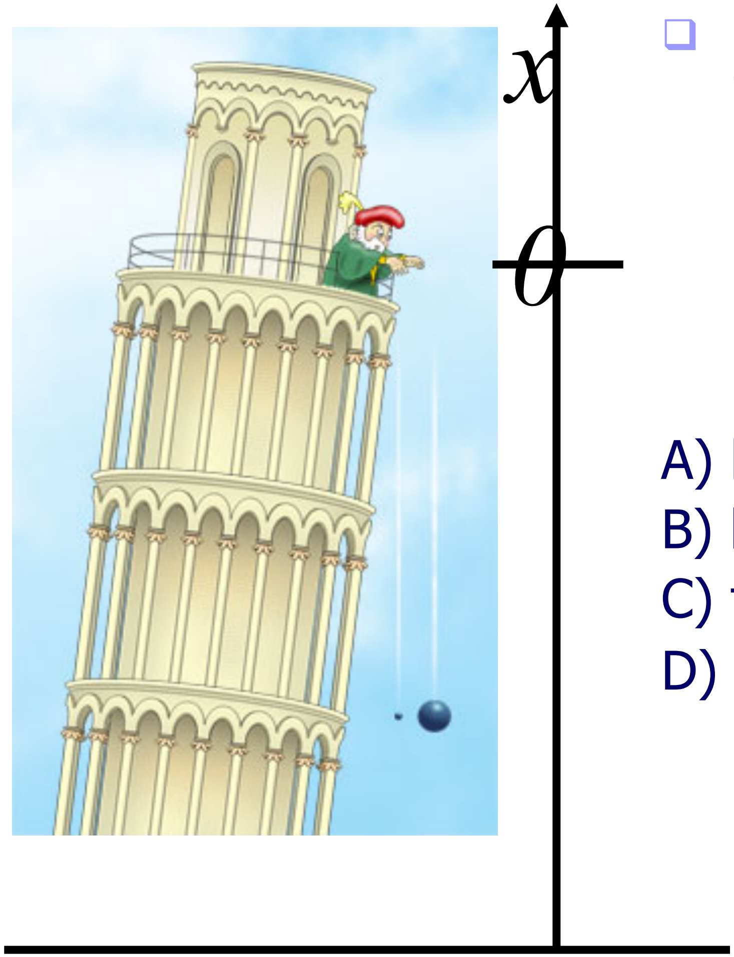


- Earth gravity provides a constant acceleration. Most important case of constant acceleration.
- Free-fall acceleration is independent of mass.
- Magnitude: $|a| = g = 9.8\ \mathrm{m/s^2}$
- Direction: always downward, so a_g is negative if we define "up" as positive,

  $a = -g = -9.8\ \mathrm{m/s^2}$
- Try to pick origin so that $y_i = 0$

$$v = v_0 - gt \qquad y - y_0 = v_0 t - \frac{1}{2} g t^2$$

Free Fall Acceleration



- In 1600, Italian physicist Galileo performed a famous experiment on the top of the Leaning tower of Pisa. He dropped two balls with different weights simultaneously. If air resistance is negligible, which ball hit the ground first?

$$x - x_0 = v_0 t - \frac{1}{2} g t^2$$

A) heavy ball hit the ground firs

B) light ball hit the ground first

C) they hit the ground at the same time

D) unable to determine

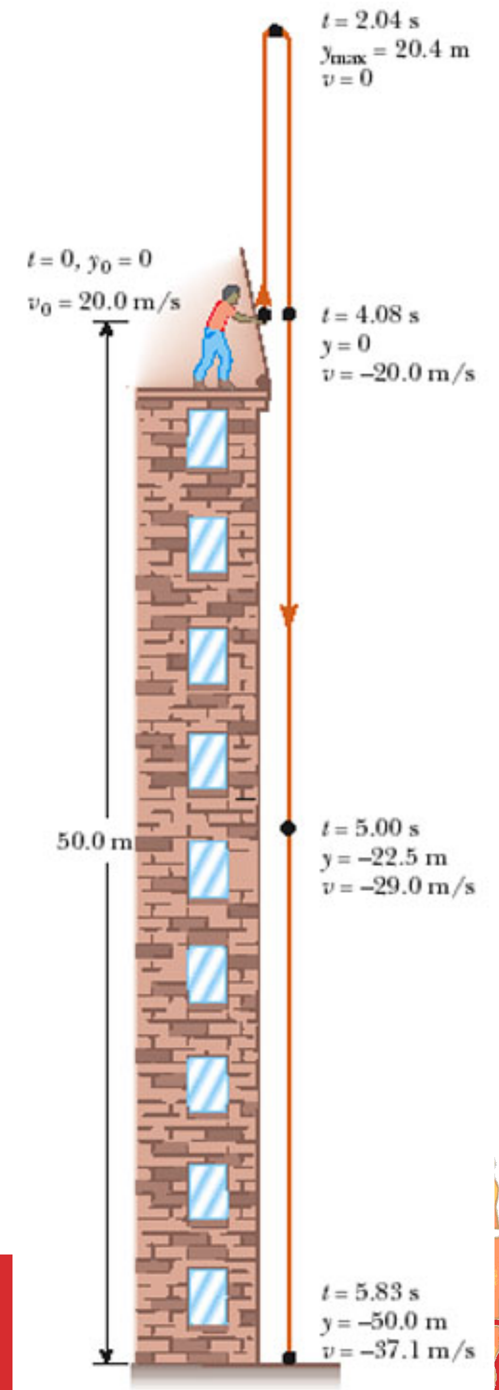
Begin with $t_0 = 0$, $v_0 = 0$, $x_0 = 0$

So, $t^2 = 2|x|/g$ same for two balls!

Assuming the leaning tower of Pisa is 150 ft high, $t = (2 \text{x} 150 \text{x} 0.305/9.8)^{1/2} = 3.05$ s

Free Fall for Rookie

- A stone is thrown from the top of a building with an initial velocity of 20.0 m/s straight upward, at an initial height of 50.0 m above the ground. The stone just misses the edge of the roof on the its way down. Determine
- (a) the time needed for the stone to reach its maximum height.
- (b) the maximum height.
- (c) the time needed for the stone to return to the height from which it was thrown and the velocity of the stone at that instant.
- (d) the time needed for the stone to reach the ground
- (e) the velocity and position of the stone at t = 5.00s



Summary

- This is the simplest type of motion
- It lays the groundwork for more complex motion
- Kinematic variables in one dimension

Position	$x(t)$	m	L
Velocity	$v(t)$	m/s	L/T
Acceleration	$a(t)$	m/s^2	L/T^2

  - All depend on time
  - All are vectors: magnitude and direction vector:
- Equations for motion with constant acceleration: missing quantities

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