Physics 111.01

Lecture 3 (Walker: 2.4-6)

Velocity and Acceleration

Sept. 2, 2009

Uniform Velocity

- Uniform velocity is constant velocity
  - Both the size and the direction of the velocity are constant
- In motion with uniform velocity, the instantaneous velocity is the same at all times
  - All the instantaneous velocities will also equal the average velocity
- **Newton's First Law** says that if there is no net force on an object, the object will have constant (uniform) velocity

1-D Motion with Constant Velocity

- $x = x_0 + v\,t$
  - x_0 is initial position
- Example: Runner B has a 12m head start at the beginning of race, and runs at 6 m/s. Runner A runs at 8 m/s. How long does it take for A to catch B? How far has A gone when she catches B?
  - – How do we write an equation for the condition “A catches B” ?

- $x_A = x_B$
- $x_{0A} + v_A t = x_{0B} + v_B t$
- 0 + (8 m/s)t = 12m + (6 m/s)t
- (2 m/s)t = 12m
- t = 6 s   Time for runner A to catch up to B

- Distance gone by A?
  x_A = 0 + (8 m/s)(6 s) = 48 m

Average Acceleration

- Changing velocity (non-uniform) means an **<u>acceleration</u>** is present. There is acceleration if either the <u>magnitude</u> or the <u>direction</u> of the velocity changes.
- Average acceleration is the rate of change of the velocity

$$\vec{a}_{average} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

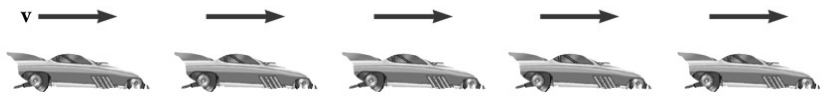
SI acceleration units: (m/s)/s = m/s^2

- Average acceleration is a vector quantity (i.e. described by both magnitude and direction). In 1-Dim., can use + or - to indicate direction.

Average Acceleration & Speed Change in 1-Dimensional Motion

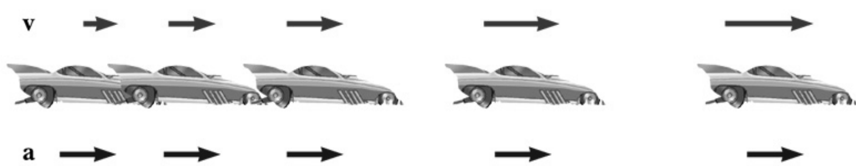
- When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
- When the sign of the velocity and the acceleration are opposite, the speed is decreasing
- Deceleration
  - refers to decreasing speed
  - is not the same as negative acceleration
  - occurs when velocity and acceleration have opposite signs
- If acceleration is positive, is speed increasing?

Example 1: Motion Diagrams



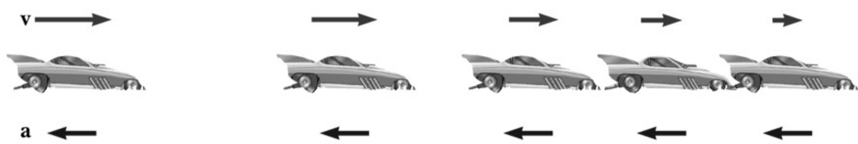
- Uniform velocity (shown by red arrows maintaining the same size)
- Acceleration equals zero

Example 2:



- 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)

Example 3:

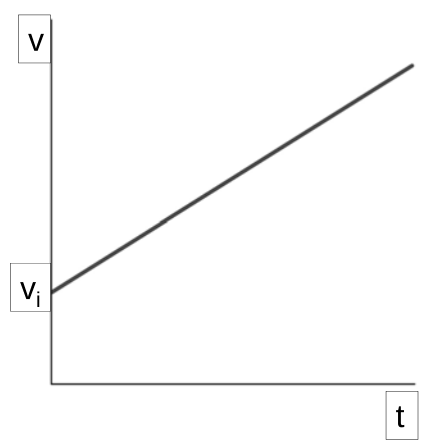


- Acceleration and velocity are in opposite directions
- Acceleration is uniform (blue arrows maintain the same length)
- Velocity is decreasing (red arrows are getting shorter)

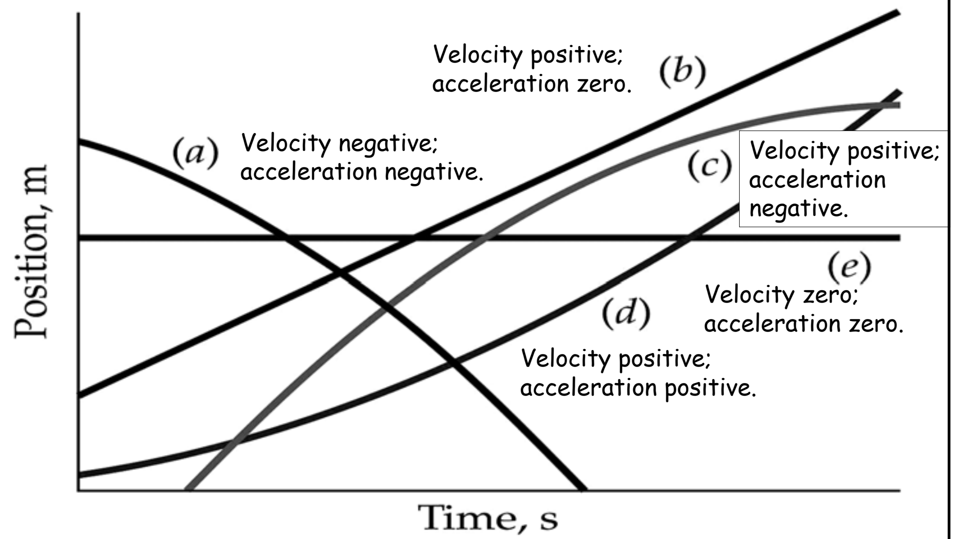
Constant Acceleration

Acceleration characterizes the change in velocity with time: $a = \Delta \mathbf{v} / \Delta \mathbf{t}$.

If acceleration is <u>constant</u> (both size & direction), then velocity is changing at a constant rate. The plot of velocity vs. time will be a straight line whose slope is the acceleration.



Position, Velocity, & Acceleration



Acceleration in 1-Dim

Average acceleration (1-D; + and - for direction):

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

Eqn. (2-5)

TABLE 2–3 Typical Accelerations (m/s^2)

Ultracentrifuge	3×10^6
Bullet fired from a rifle	4.4×10^5
Batted baseball	3×10^4
Click beetle righting itself	400
Acceleration required to deploy airbags	60
Bungee jump	30
High jump	15
Acceleration of gravity on Earth	9.81
Emergency stop in a car	8
Airplane during takeoff	5
An elevator	3
Acceleration of gravity on the Moon	1.62

Example – be careful with signs

A car moves from a position of +4 m to a position of –1 m in 2 seconds. The initial velocity of the car is –4 m/s and the final velocity is –1 m/s.

(a) What is the displacement of the car?

(b) What is the average velocity of the car?

(c) What is the average acceleration of the car?

Answer:

(a) $\Delta x = x_f - x_i = -1\text{ m} - (+4\text{ m}) = -5\text{ m}$

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(b) $v_{av} = \Delta x/\Delta t = -5\text{ m}/2\text{ s} = -2.5\text{ m/s}$

Velocity is negative because the car is going in the negative direction

Example – be careful with signs

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(c)

Instantaneous Acceleration

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

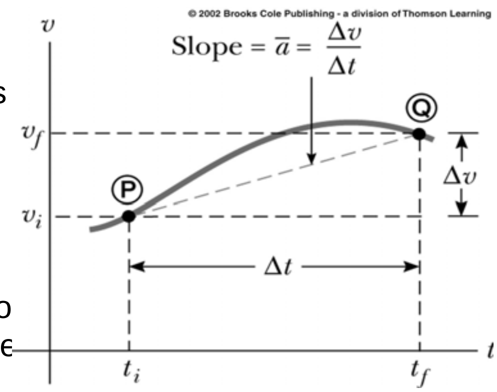
$$\vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \lim_{\Delta t \to 0} \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

- When the instantaneous accelerations are always the same, the acceleration will be uniform
  - The instantaneous accelerations will all be equal to the average acceleration

Graphical Interpretation of Acceleration

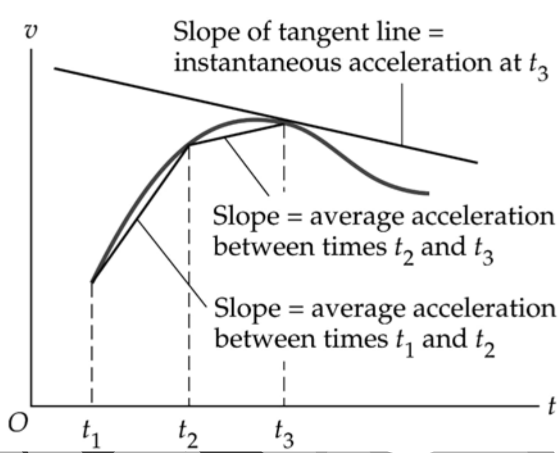
- Average acceleration is the slope of the line connecting the initial and final velocities on a velocity-time graph

- Instantaneous acceleration is the slope of the tangent to the curve of the velocity-time graph



Acceleration

Graphical Interpretation of Average and Instantaneous Acceleration:

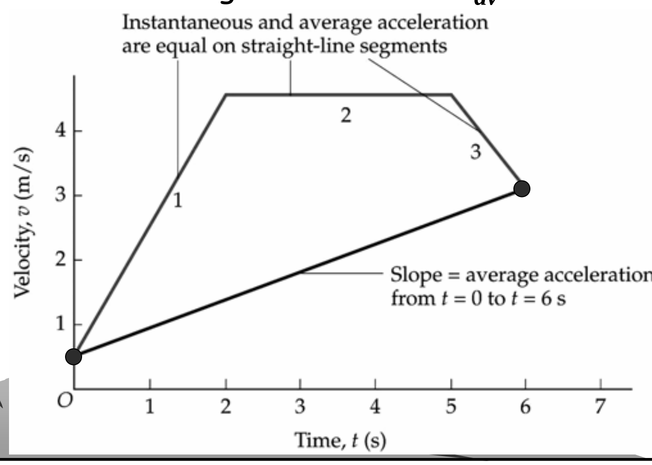


Example: An Accelerating Train

Train moving in straight line with initial velocity 0.50 m/s accelerates at 2.0 m/s^2 for 2.0 s, coasts with zero acceleration for 3.0 s, then accelerates at -1.5 m/s^2 for 1.0 s.

(a) What is the final velocity v_f of the train?

(b) What is the average acceleration a_{av} of the train?



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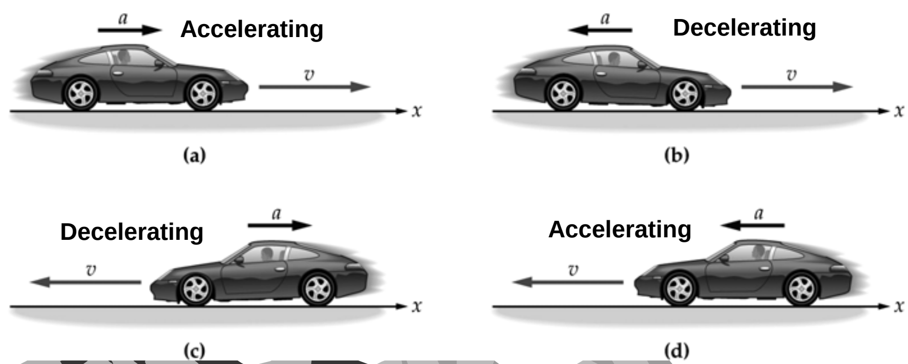
(a) What is the final velocity v_f of train?

(b) What is the average acceleration a_{av} of train?

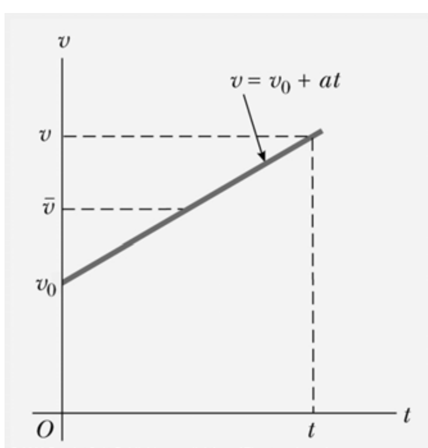
Acceleration

Acceleration (increasing speed) and deceleration (decreasing speed) should not be confused with the directions of velocity and acceleration:



1-D Motion With Constant Acceleration

- If acceleration is uniform (i.e.):



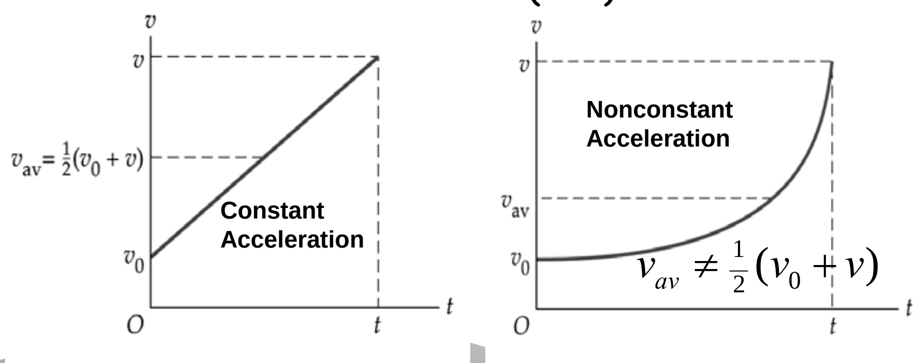
thus:

$$v_f = v_o + at$$

Motion with Constant Acceleration

If the acceleration is constant, the velocity changes linearly:

$$v = v_0 + at \quad \text{(2-7)}$$



(a) (b)

Motion with Constant Acceleration

Velocity: $v = v_0 + at$ (2-7)

Average velocity: $v_{av} = \frac{1}{2}(v_0 + v)$ (2-9)

Position as a function of time:

$$x = x_0 + \frac{1}{2}(v_0 + v)t \quad \text{(2-10)}$$

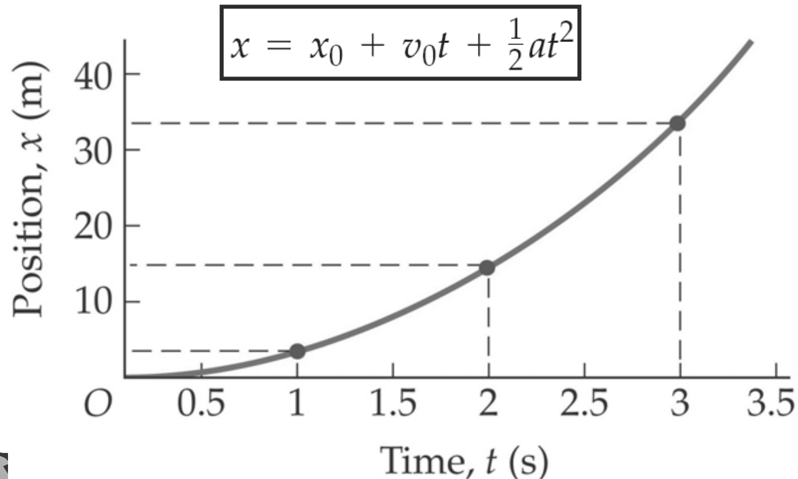
$$x = x_0 + v_0 t + \frac{1}{2}at^2 \quad \text{(2-11)}$$

Velocity as a function of position:

$$v^2 = {v_0}^2 + 2a(x - x_0) = {v_0}^2 + 2a\Delta x \quad \text{(2-12)}$$

Motion with Constant Acceleration

The relationship between position and time follows a characteristic curve.



Motion with Constant Acceleration

TABLE 2–4 Constant-Acceleration Equations of Motion

Variables related	Equation	Number
velocity, time, acceleration	$v = v_0 + at$	2–7
initial, final, and average velocity	$v_{av} = \frac{1}{2}(v_0 + v)$	2–9
position, time, velocity	$x = x_0 + \frac{1}{2}(v_0 + v)t$	2–10
position, time, acceleration	$x = x_0 + v_0t + \frac{1}{2}at^2$	2–11
velocity, position, acceleration	$v^2 = v_0^2 + 2a(x - x_0) = v_0^2 + 2a\Delta x$	2–12

Key Points of Lecture 3

Motion with constant velocity

Newton's First Law

Definition of Acceleration

Average and Instantaneous Acceleration

Motion with Constant Acceleration

- Before the next lecture, read *Walker* 2.7, 3.1-2.

- Homework Assignment #2b due by 11:00 PM on Wednesday, Sept. 9.