Theme 2
Mechanics

Module T2M1:
Kinematics

T2M1 – Learning Objectives

- Take our day-to-day description of **motion** and shape these terms into well defined quantities.
- Visually represent motion by translating our spatial observations into a quantitative picture – a **graph**.
- **Extract information from graphs**, using our **kinematic definitions**.
- Define a model for **one dimensional motion** of an object that experiences a constant acceleration.
- Extend our model to **two dimensional motion** to see how the vector nature of the kinematic quantities can be used with the kinematic equations.

How we define motion

Term	Meaning	Notation
Position	Where is the object?	$\vec{x} \quad (\vec{x}_o, \vec{x}_i, \vec{x}_f, \vec{x}_3)$
Displacement	How far has the object moved from where it was before?	$\triangle\vec{x} = \vec{x}_f - \vec{x}_i$
Velocity	How quickly does the displacement occur?	$\vec{v} = \frac{\triangle\vec{x}}{\triangle t} = \frac{\vec{x}_f - \vec{x}_i}{t_f - t_i}$
Acceleration	Is the motion getting faster or slower?	$\vec{a} = \frac{\triangle\vec{v}}{\triangle t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$

Distance vs Displacement

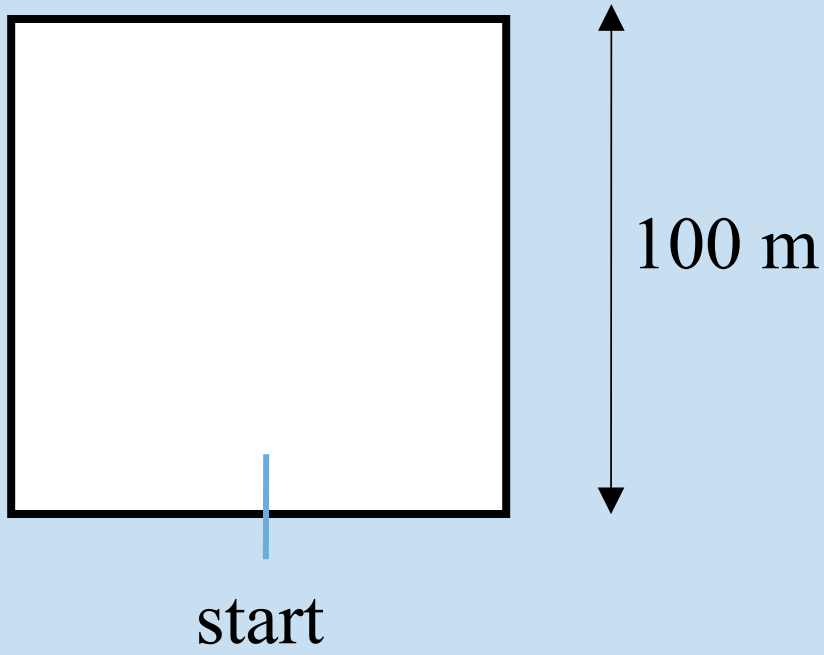
Take a Hike!: Walk from JHE to Tim Hortons in Mo-Mac (120 m), then to Health sciences bldg. (180 m), then back to class (130 m)

- What total distance did you walk? $\boldsymbol{d = 430\ m}$
- What was your total displacement? $\boldsymbol{\Delta\vec{r} = 0\ m}$

Clicker Quiz – 2D Motion

A jogger runs around a city block that is 100 m between stop signs. Starting at her apartment, she runs one and a half laps. What is her ***displacement*** from her starting point?

A. 0 m
B. 100 m
C. 200 m
D. 500 m
E. 600 m



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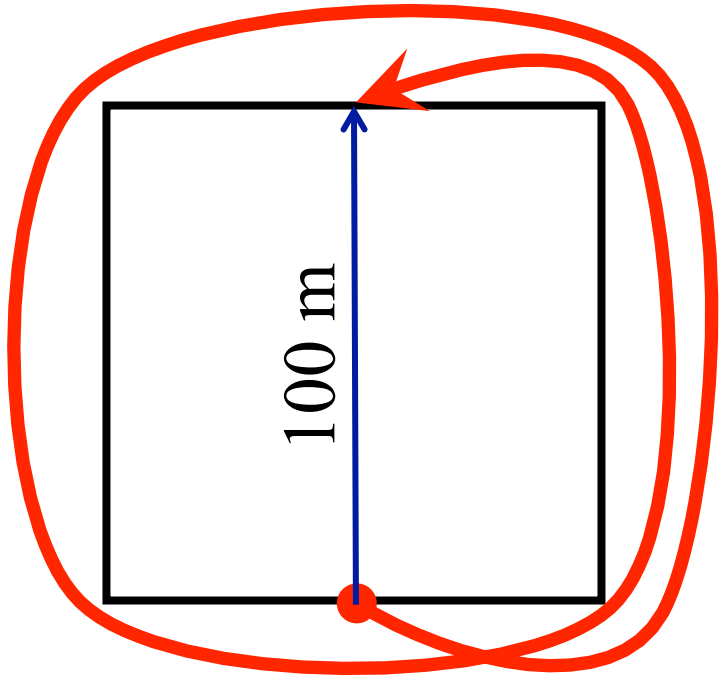

Answer B. 100 m

Clicker Quiz

- When an object moves, is there anything that can be said, ***in general***, about distance vs. displacement?

The magnitude of the DISPLACEMENT is ___ the DISTANCE.

A. Either greater than or equal to
B. Always greater than
C. Always equal to
D. Either smaller than or equal to
E. Always smaller than

Clicker Quiz

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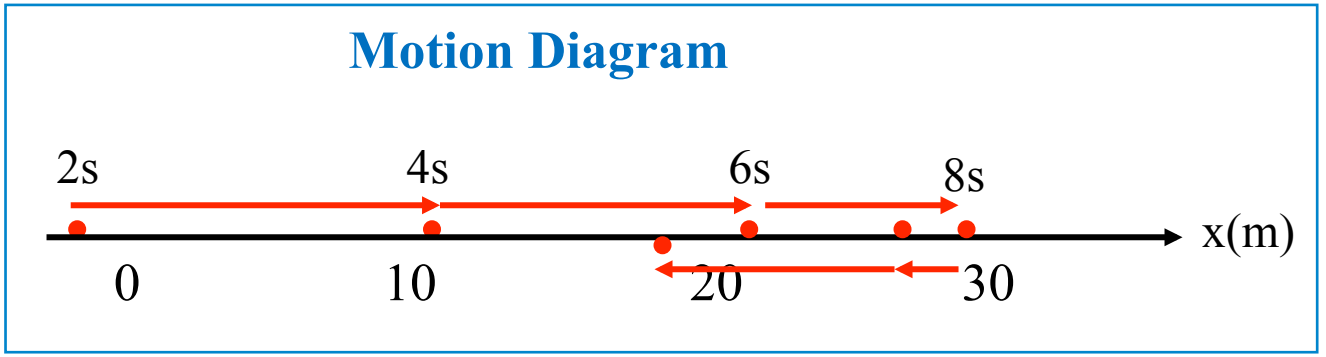
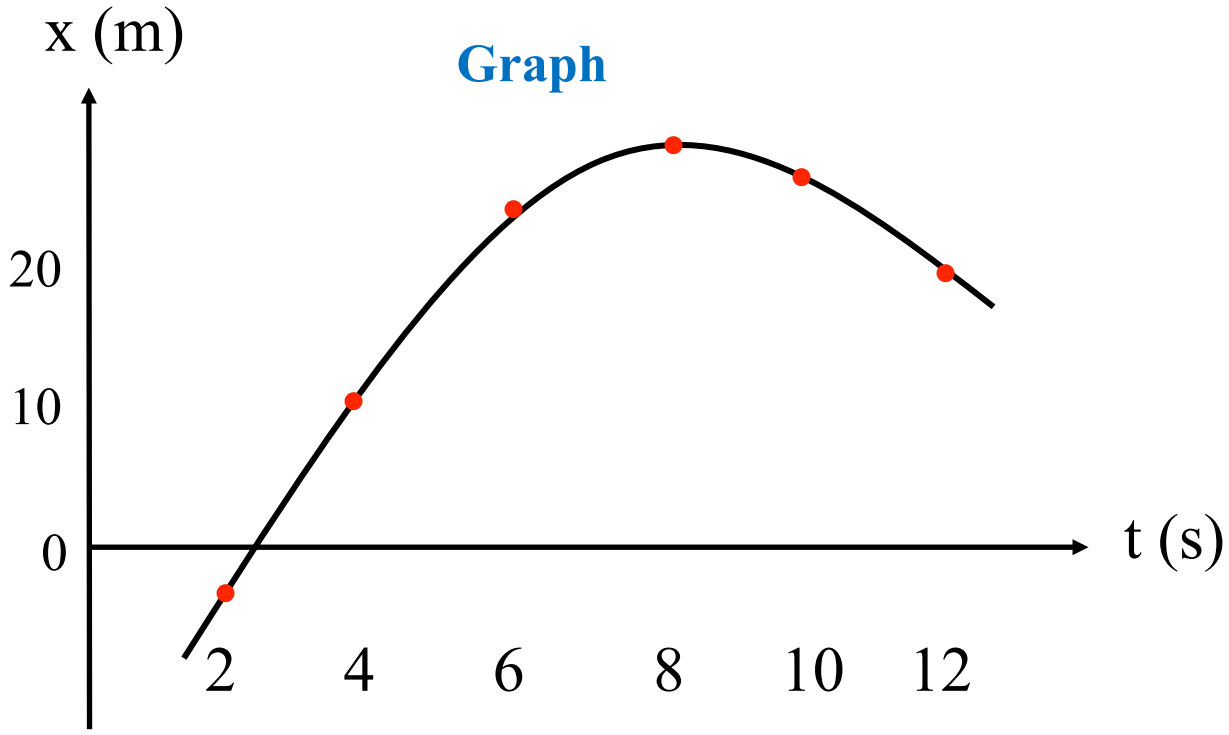
Plotting motion on a position-time graph

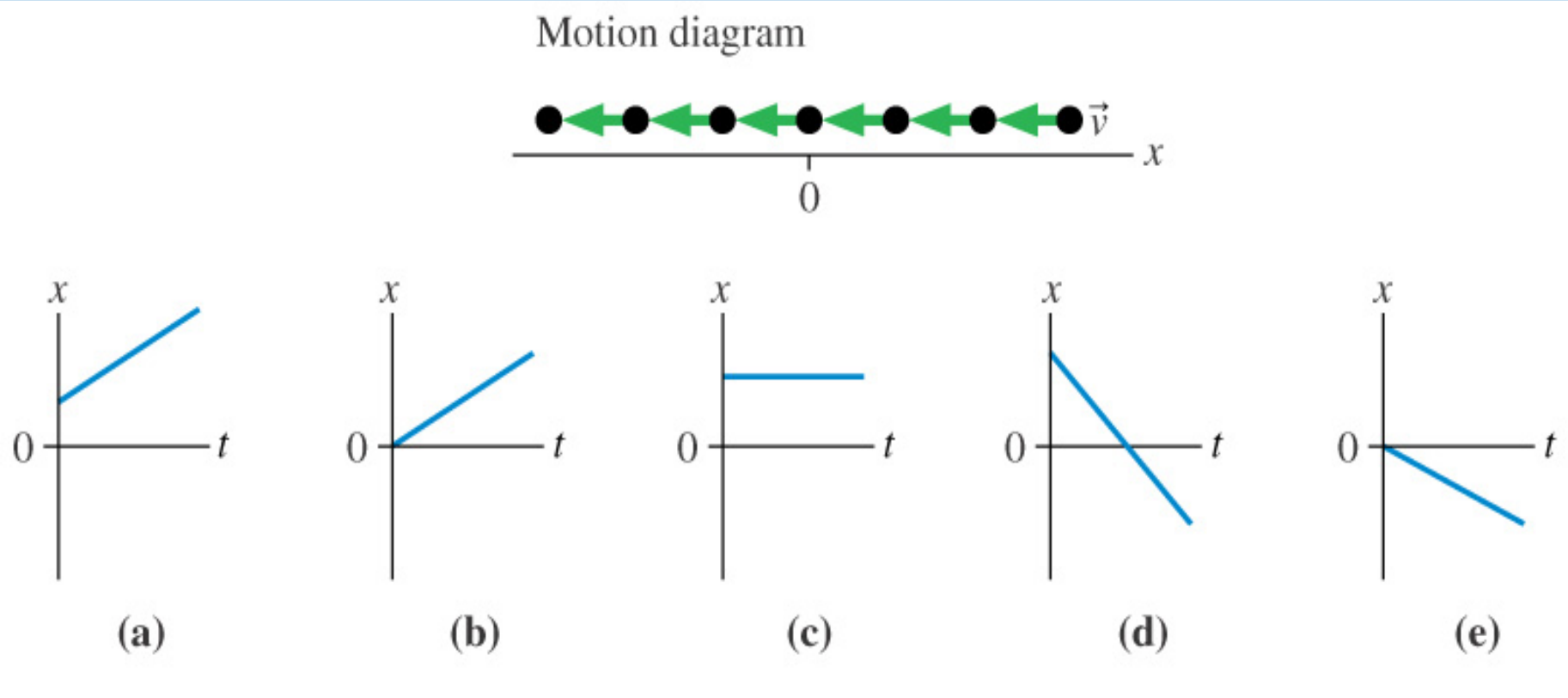
t(s)	x (m)
2	-2
4	10
6	24
8	29
10	27
12	19





Clicker Quiz

A ***motion diagram*** shows a moving object, with equal time intervals between successive positions. Which graph represents the motion shown in the diagram below?



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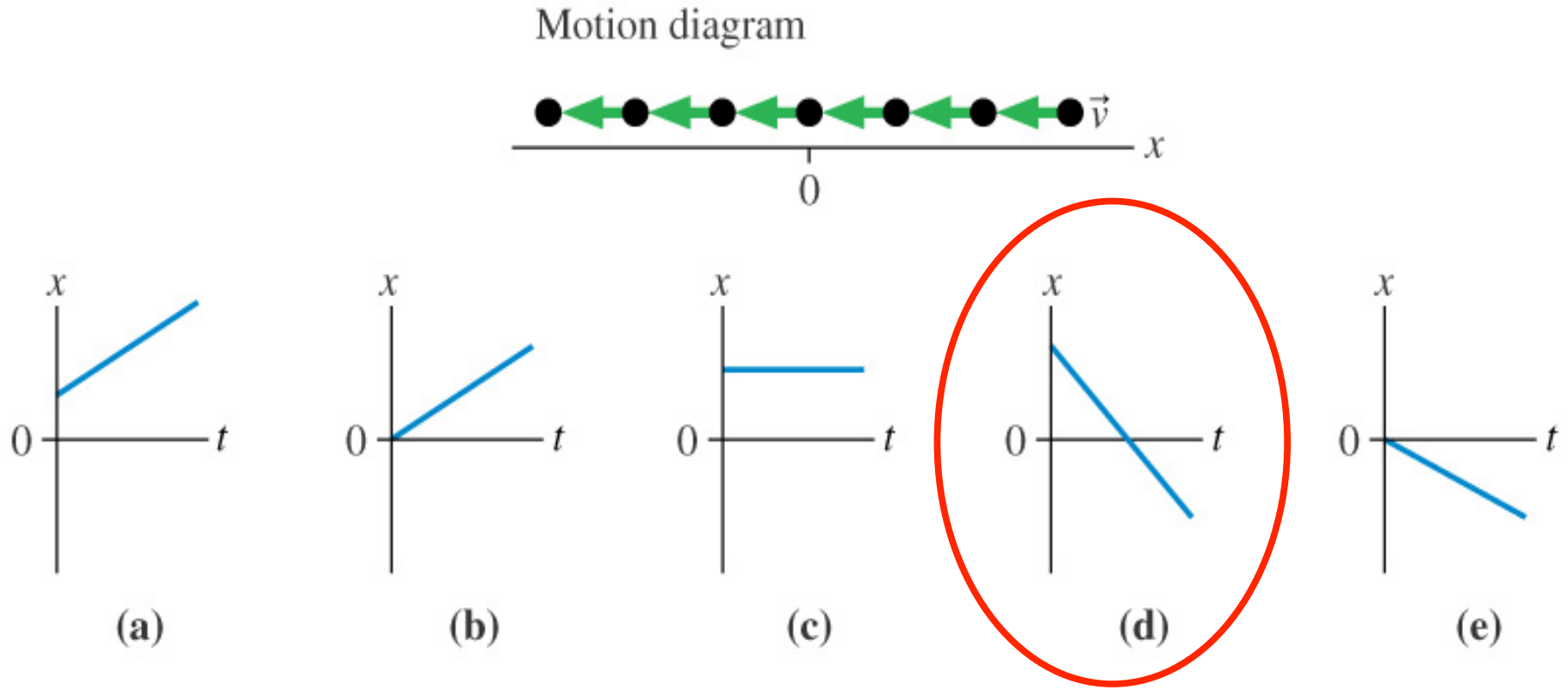
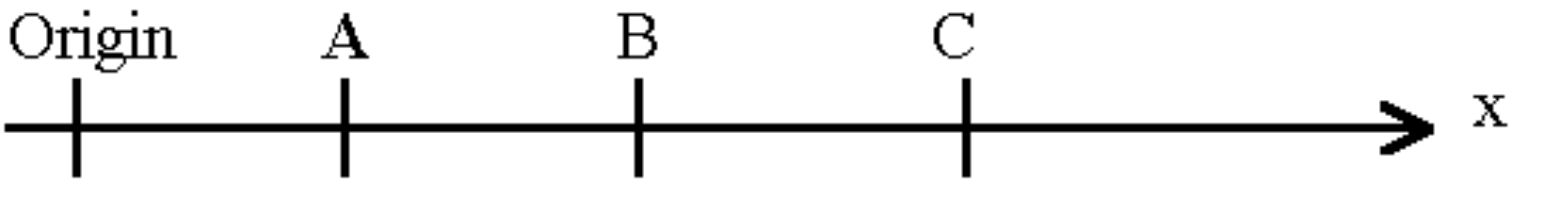
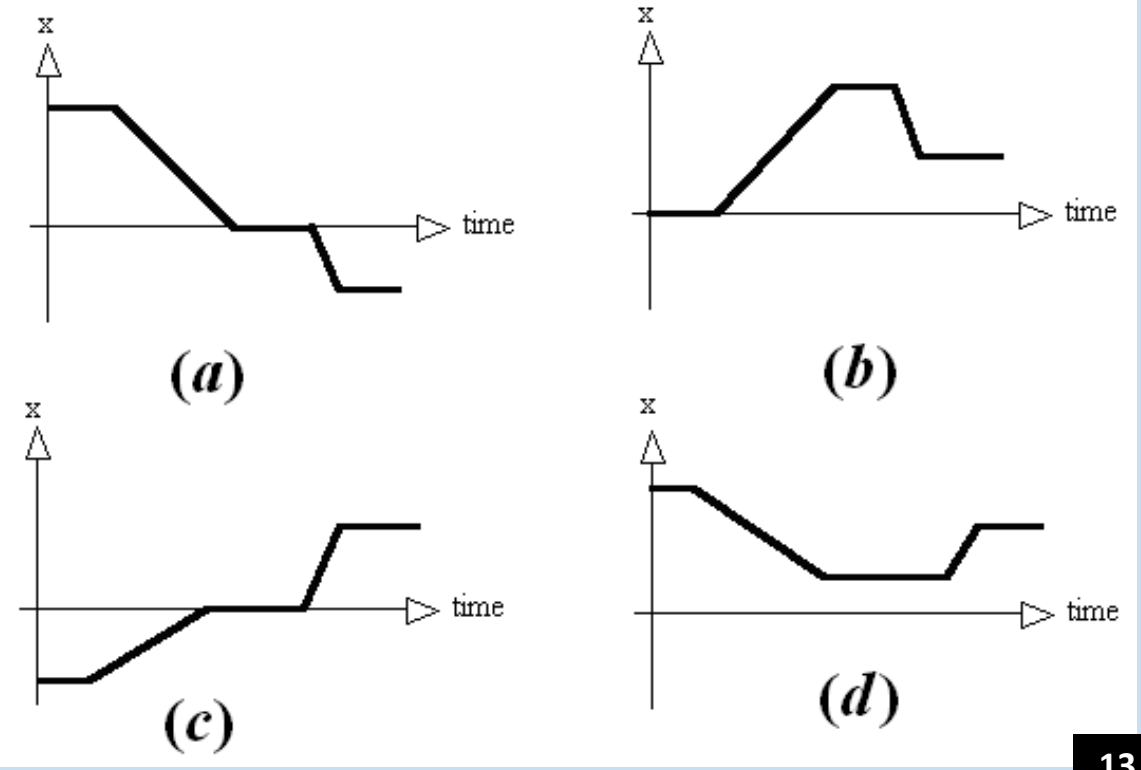


Clicker Quiz

- A person initially at point **C** on the x-axis stays there for a little while and then strolls along the x-axis to point **A**, stays there for a moment and then runs to point **B** and remains there.



- **Which graph correctly depicts this motion?**



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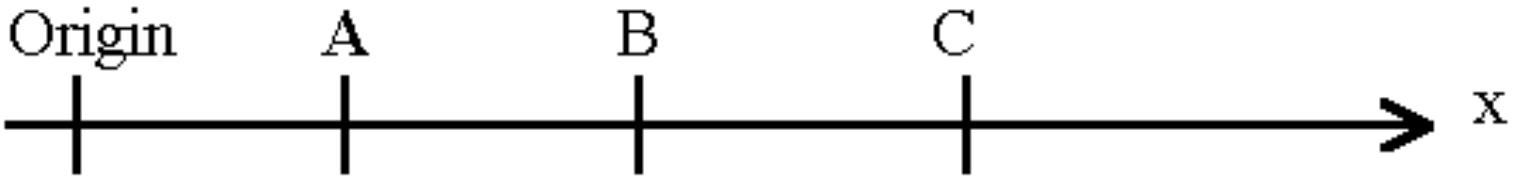

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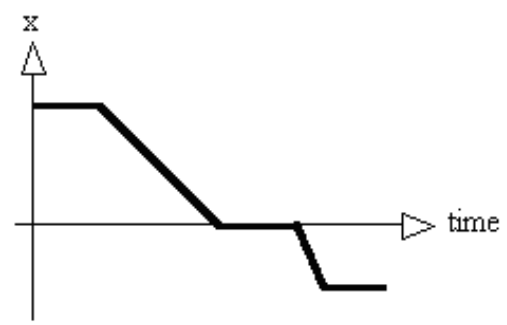
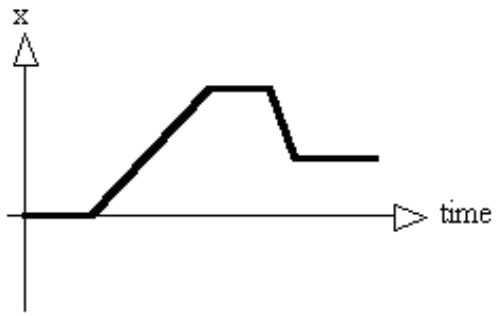
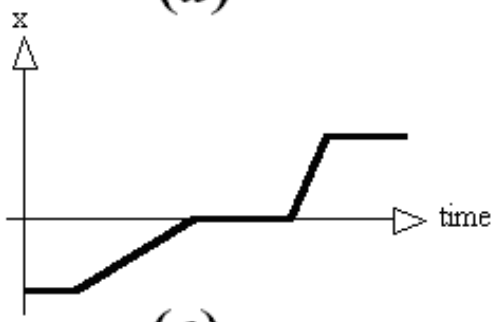


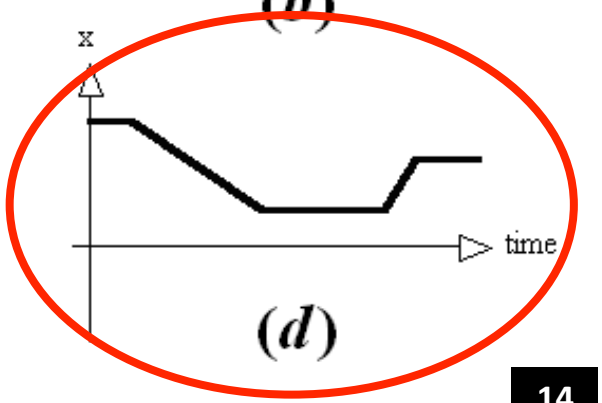
(a)



(b)



(c)



(d)

Speed vs Velocity

- Vector or scalar???
- Speed = distance/time

$$\text{speed}_{avg} = \frac{d}{\triangle t}$$

- Velocity = displacement/time

$$\vec{v} = \frac{\triangle \vec{x}}{\triangle t} = \frac{\vec{x}_f - \vec{x}_i}{t_f - t_i}$$

  - "How fast, and in which direction?"

Compare 50 km/h vs 50 km/h due north

Speed vs Velocity

You are walking down Main St. At 1:05 pm, you are 40 m east of campus. At 1:09 pm you are 60 m west of campus. What is your *average* velocity over the trip?

Let's define [east] as the positive direction

$$t_1 = 1{:}05 \qquad x_1 = 40 \text{ m } [\text{East}] = +40 \text{ m}$$

$$t_2 = 1{:}09 \qquad x_2 = 60 \text{ m } [\text{West}] = -60 \text{ m}$$

$$\vec{v} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{(-60 \text{ m}) - (40 \text{ m})}{1{:}09 - 1{:}05} = \frac{-100 \text{ m}}{4 \text{ min}}$$

$$= -25 \text{ m/min} = -0.42 \text{ m/s}$$

What about speed?

Clicker Quiz

You go out for a jog – you travel at 8 km/h for 2 hours, 6 km/h for 2 hours and then 4 km/h for 1 hour. What is your average speed?

A. 6 km/h
B. Less than 6 km/h
C. Greater than 6 km/h
D. Not enough information

Clicker Quiz

You go out for a jog – you travel at 8 km/h for 2 hours, 6 km/h for 2 hours and then 4 km/h for 1 hour. What is your average speed?

$$v_{ave} = (\text{total displacement})/(\text{total time})$$

$$\begin{aligned}\text{tot. disp.} &= (8\ \text{km/h})(2\ \text{h}) + (6\ \text{km/h})(2\ \text{h}) + (4\text{km/h})(1\text{h}) \\ &= 32\ \text{km}\end{aligned}$$

$$\text{total time} = 2\ \text{h} + 2\ \text{h} + 1\ \text{h} = 5\ \text{h}$$

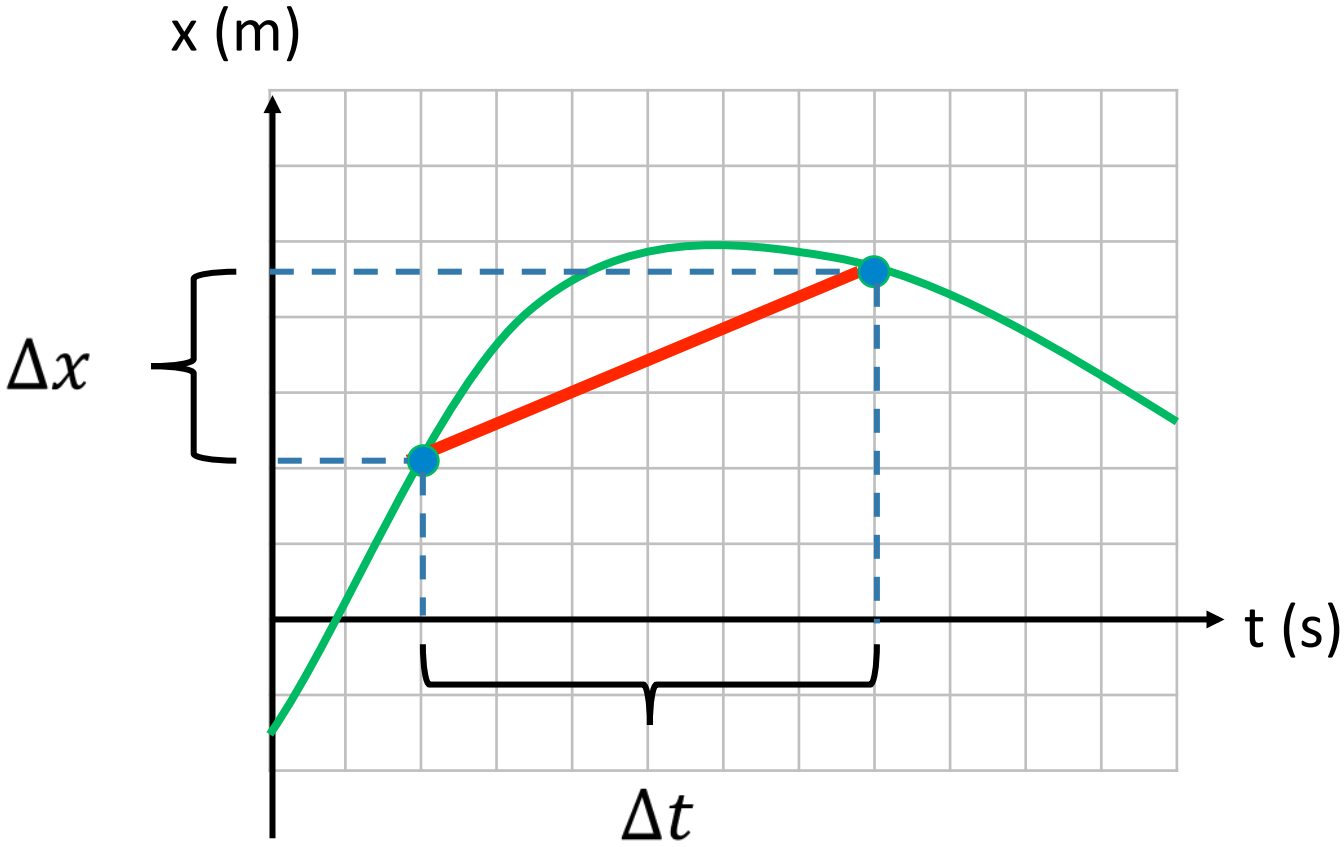
$$v_{ave} = (32\ \text{km})/(5\ \text{h}) = 6.4\ \text{km/h}$$

Answer C. Greater than 6 km/h

Position-time graphs and velocity

- The **SLOPE** of a position-time graph gives us velocity

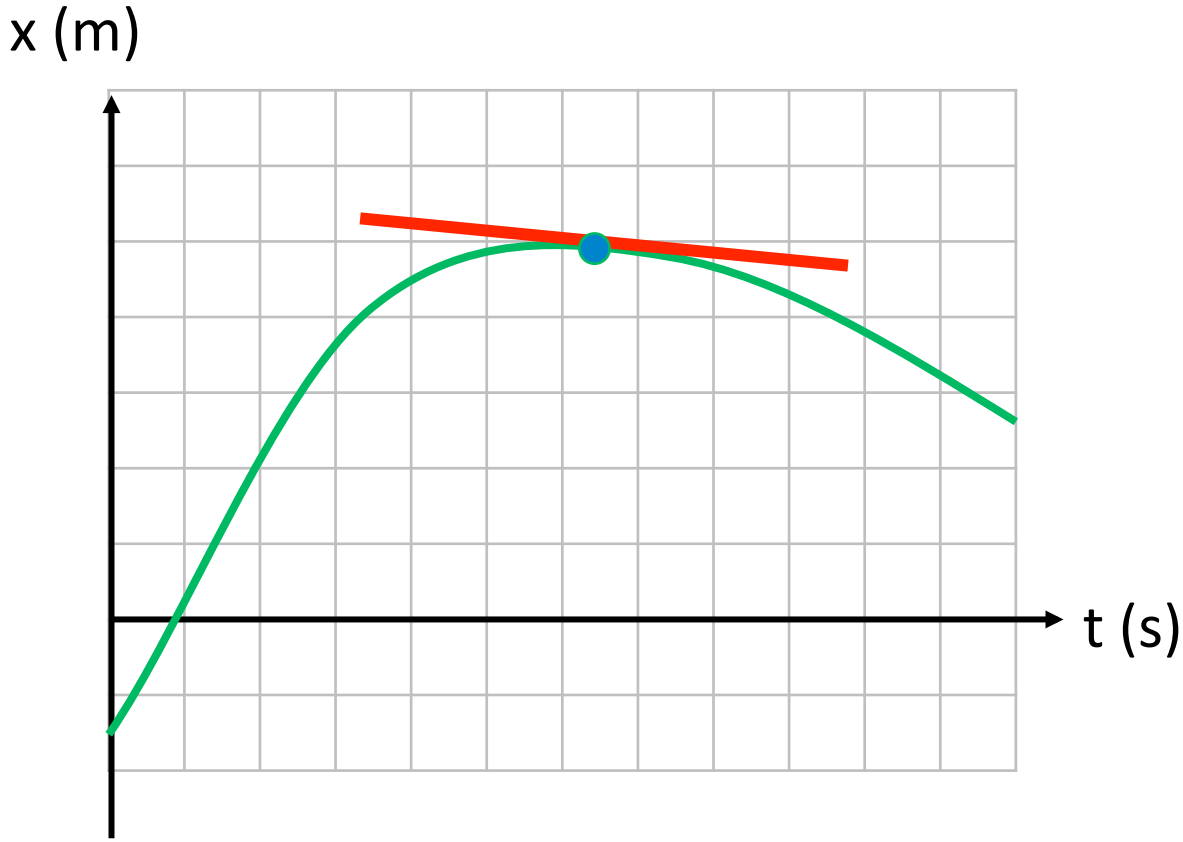
Average velocity: $v_{avg} = \frac{\Delta x}{\Delta t}$



Position-time graphs and velocity

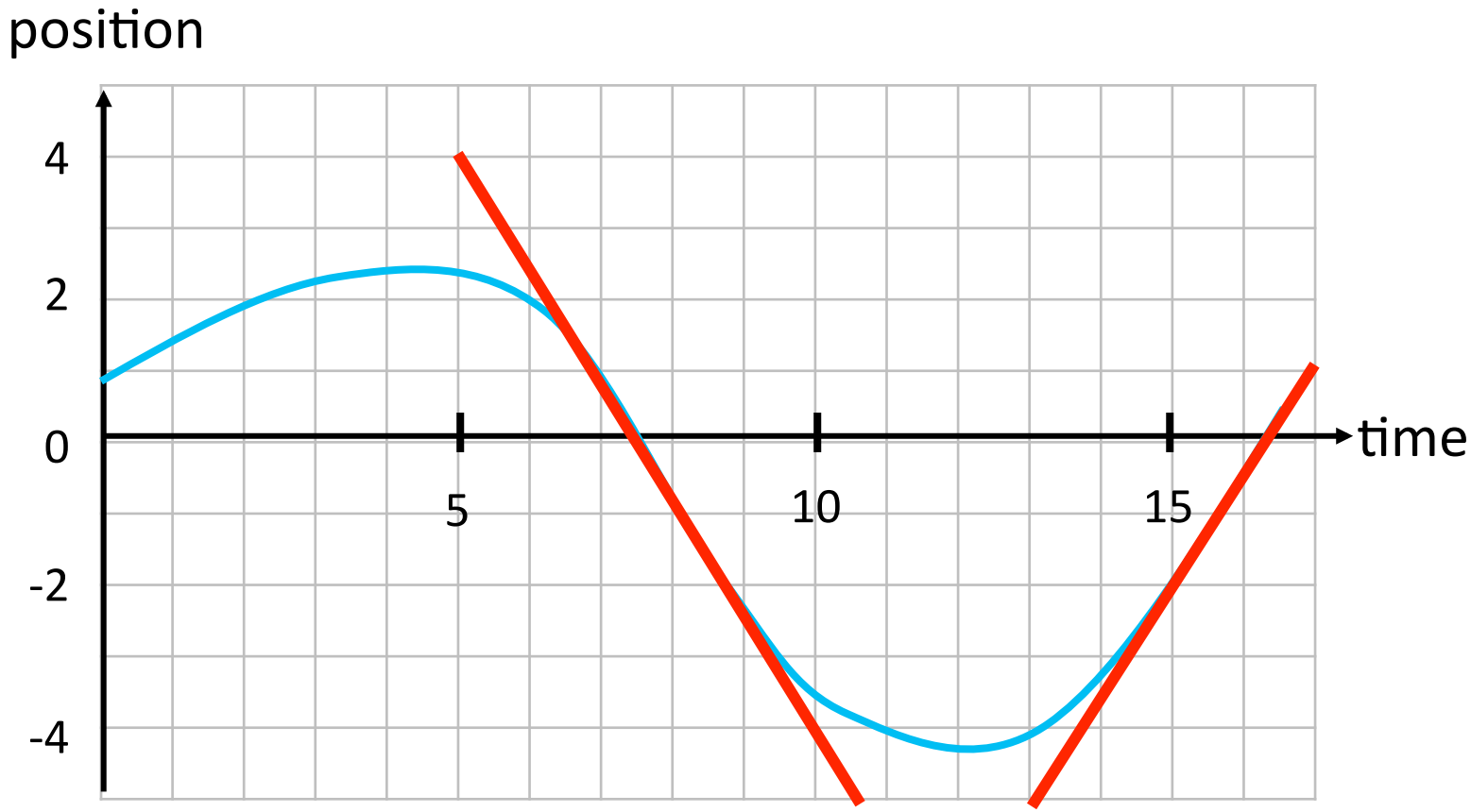
- The **SLOPE** of a position-time graph gives us velocity

Instantaneous velocity: $v_{inst} = \text{slope of tangent} \left(\frac{dx}{dt}\right)$



Average and instantaneous velocity

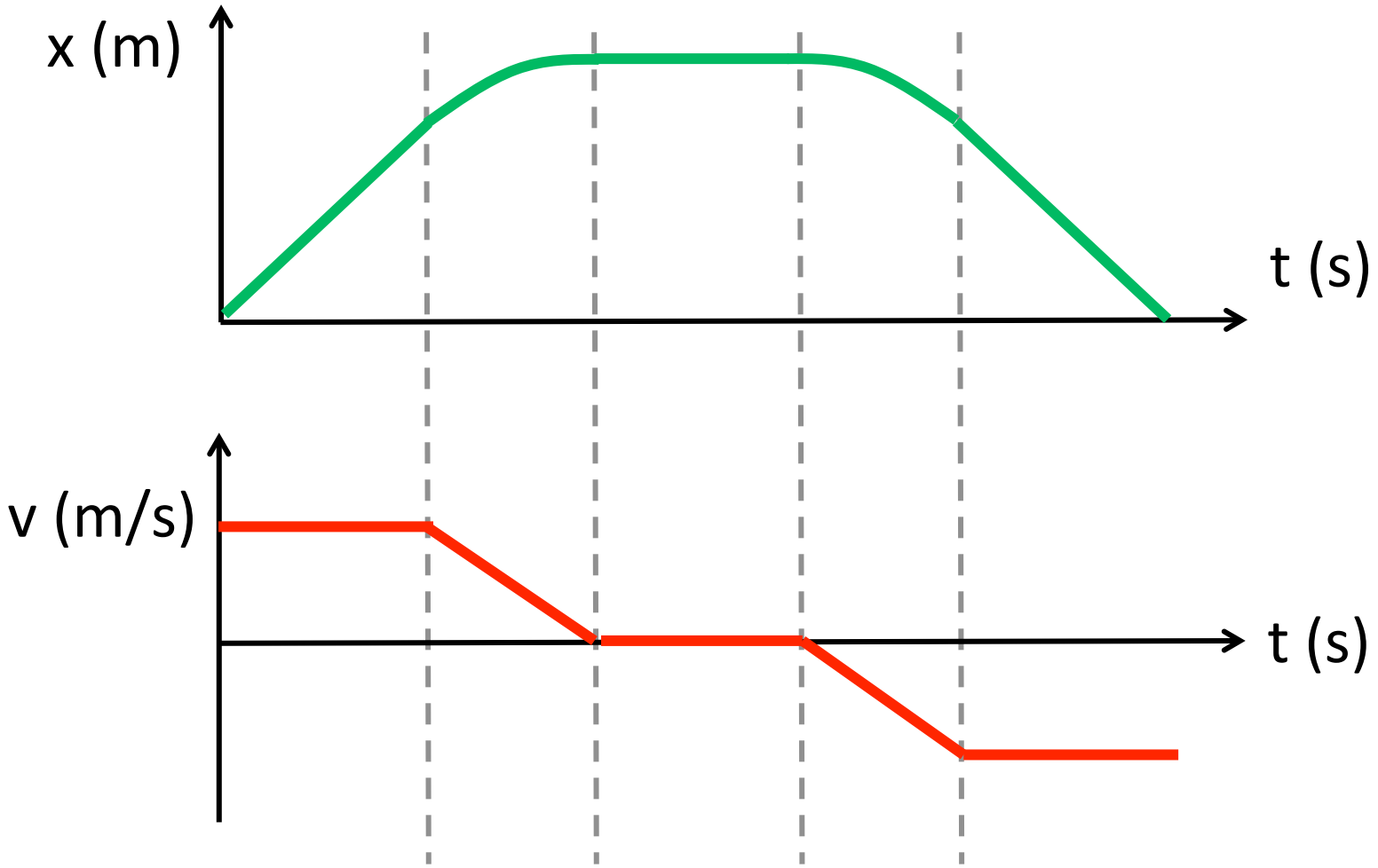
- The **SLOPE** of a position-time graph gives us velocity



1D kinematics in the real world?

Example

- We can evaluate the instantaneous velocity at any point on this graph.
  - Can we use this to make a plot of **velocity vs. time**?



Acceleration

- When velocity changes over a time interval ($t_1 \rightarrow t_2$), we define

- **Average acceleration** $$\vec{a}_{ave} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{t_2 - t_1}$$

- What graphical interpretation will give us acceleration?

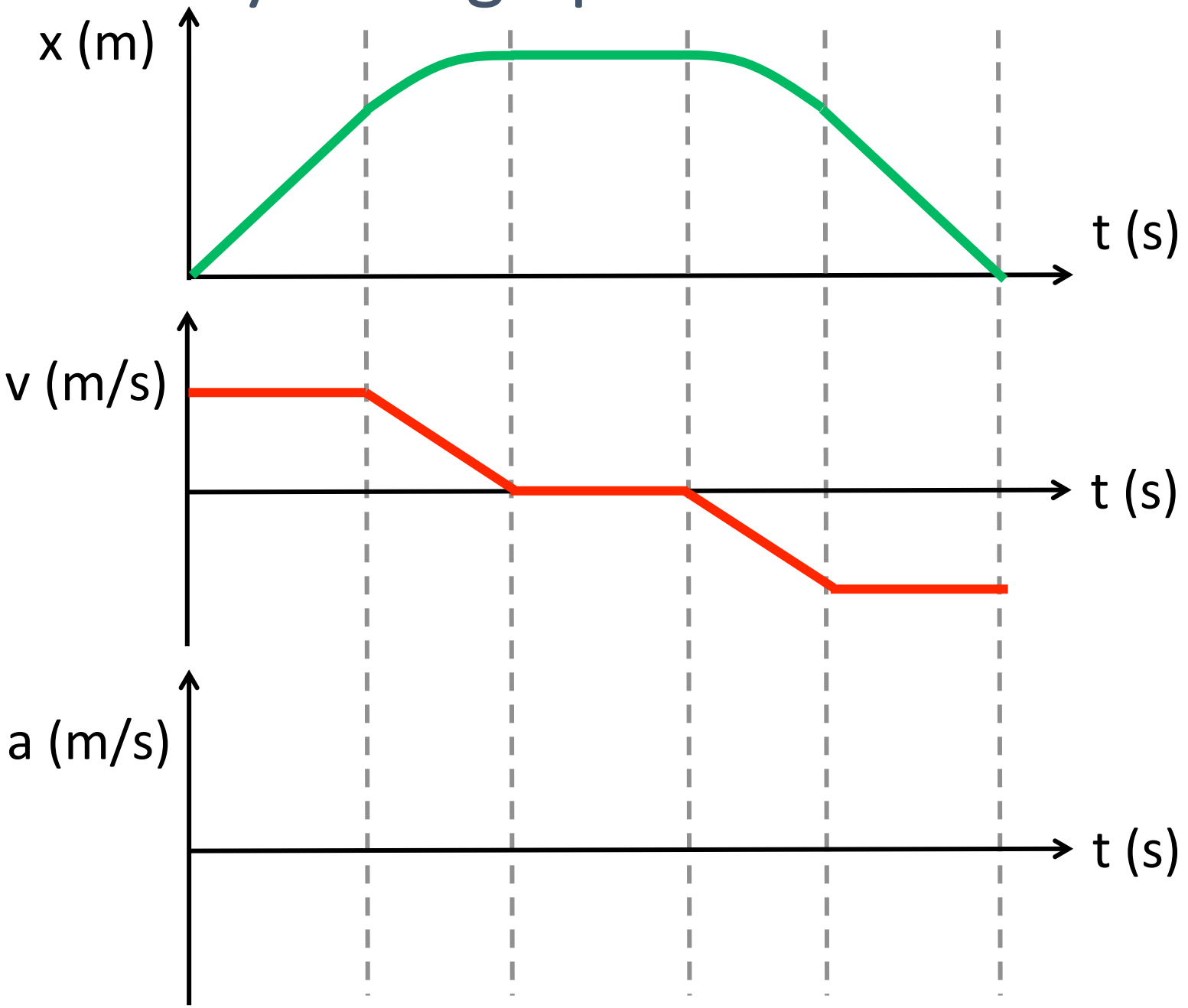
The SLOPE of a velocity-time graph gives acceleration

Determining acceleration from *v* vs. *t* graph

- **Average acceleration**
  - calculated over a finite period, from t_1 to t_2
  - use the slope of the line connecting the two points on the curve at t_1 and t_2.

- **Instantaneous acceleration**
  - calculated at one value of t
  - using the slope of the tangent line at that point.

Velocity-time graphs and acceleration



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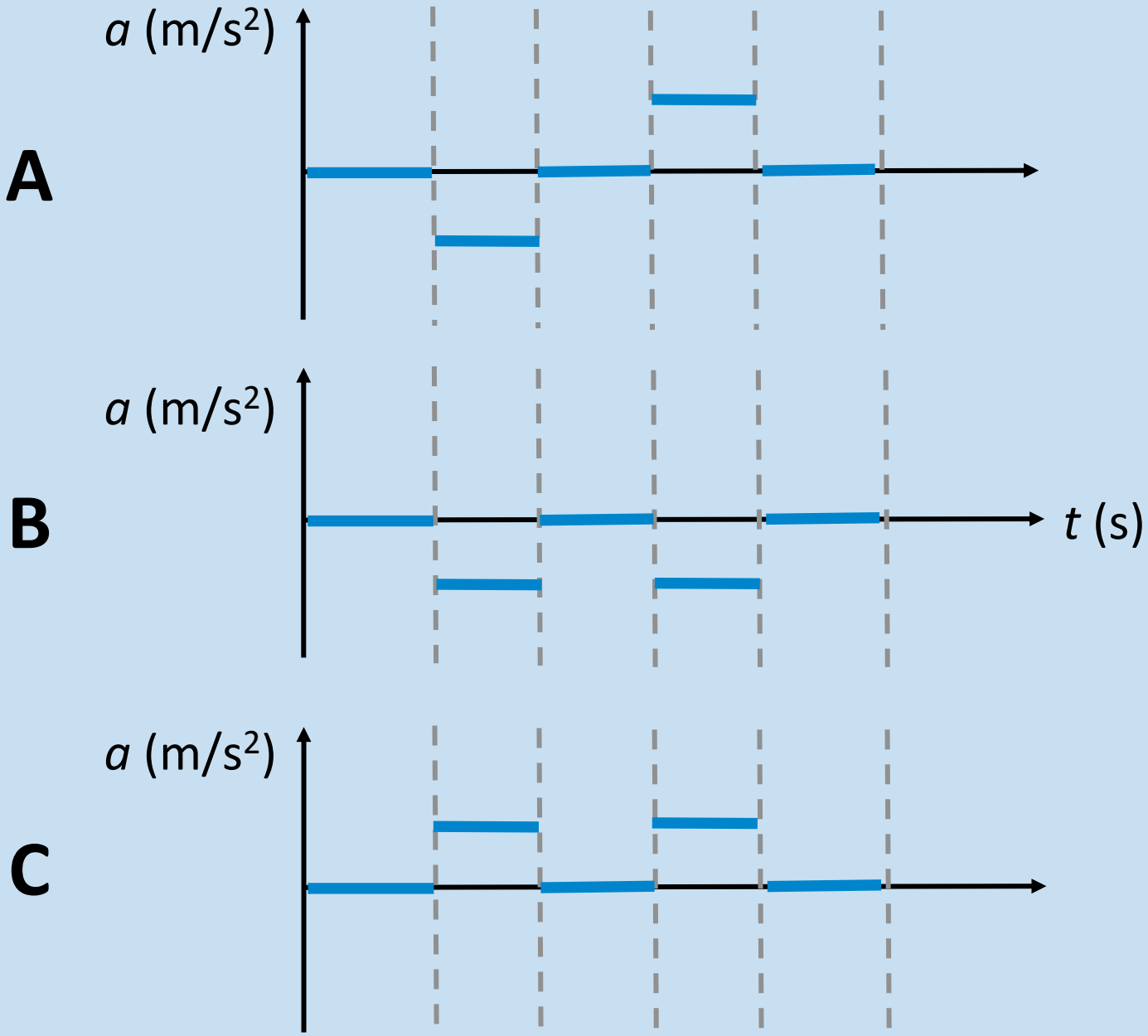
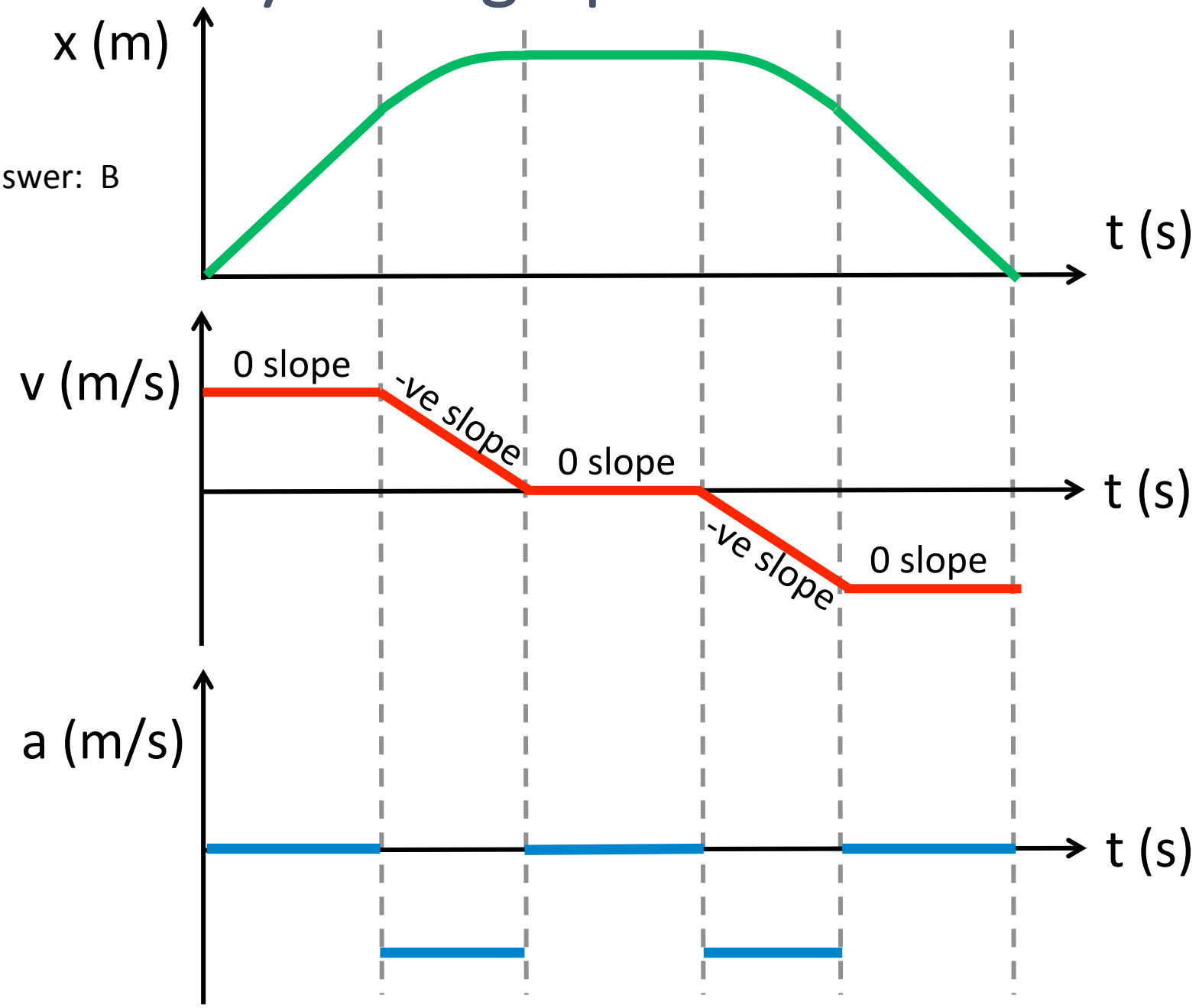


Velocity-time graphs and acceleration

Answer: B



Tricky acceleration!

- In previous example, there are two time intervals over which the object has negative acceleration.

1. **velocity is positive** and acceleration is negative
   - the object is slowing down.

2. **velocity is negative** and acceleration is negative
   - the object is speeding up (in the negative direction).

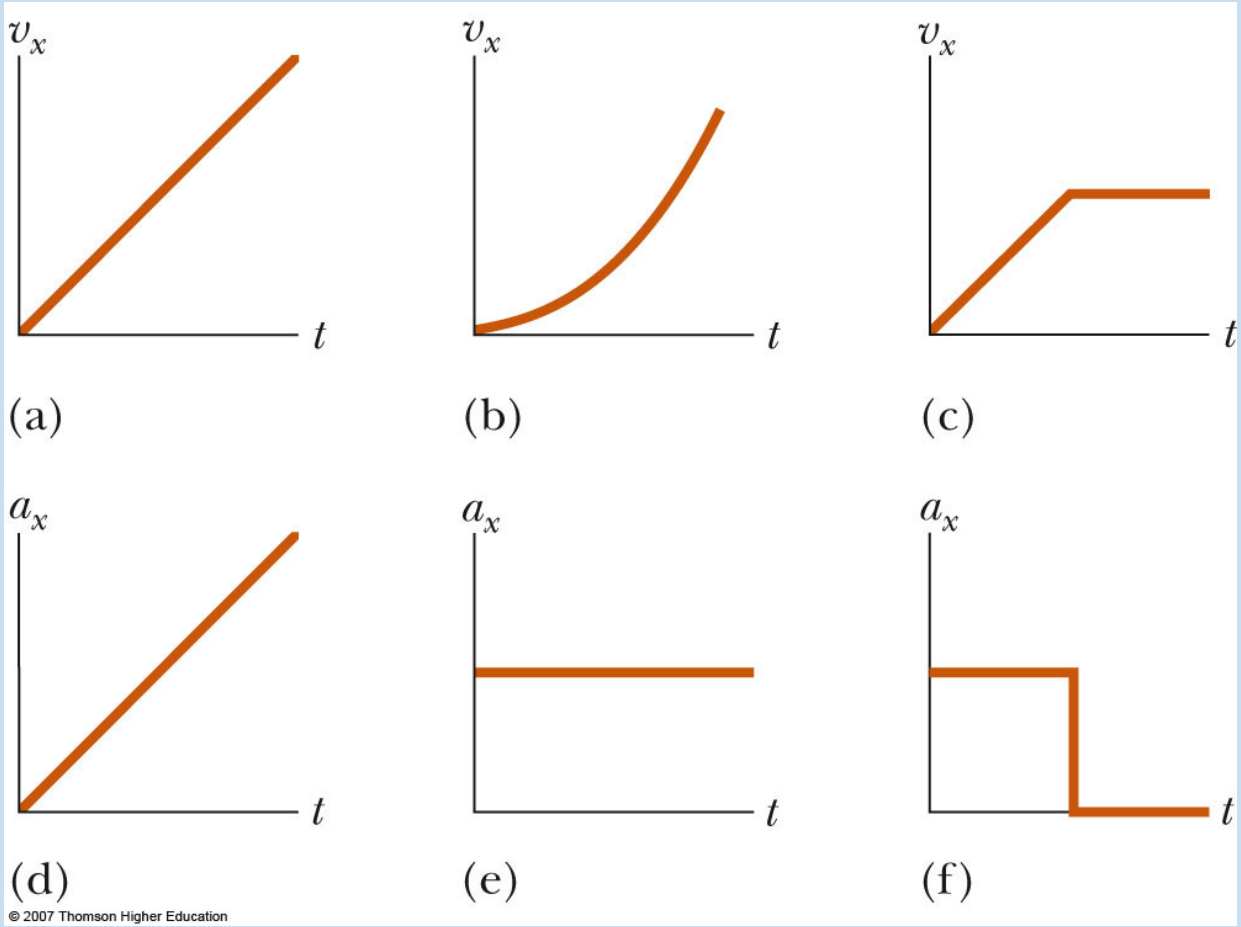
The Big Message:

Negative acceleration is NOT JUST slowing down

Clicker Quiz

- Match a given velocity graph with the corresponding acceleration graph

a. a-d, b-e, c-f
b. a-e, b-f, c-d
c. a-f, b-d, c-e
d. a-e, b-d, c-f
e. a-f, b-e, c-d



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Clicker Quiz

- Match a given velocity graph with the corresponding acceleration graph

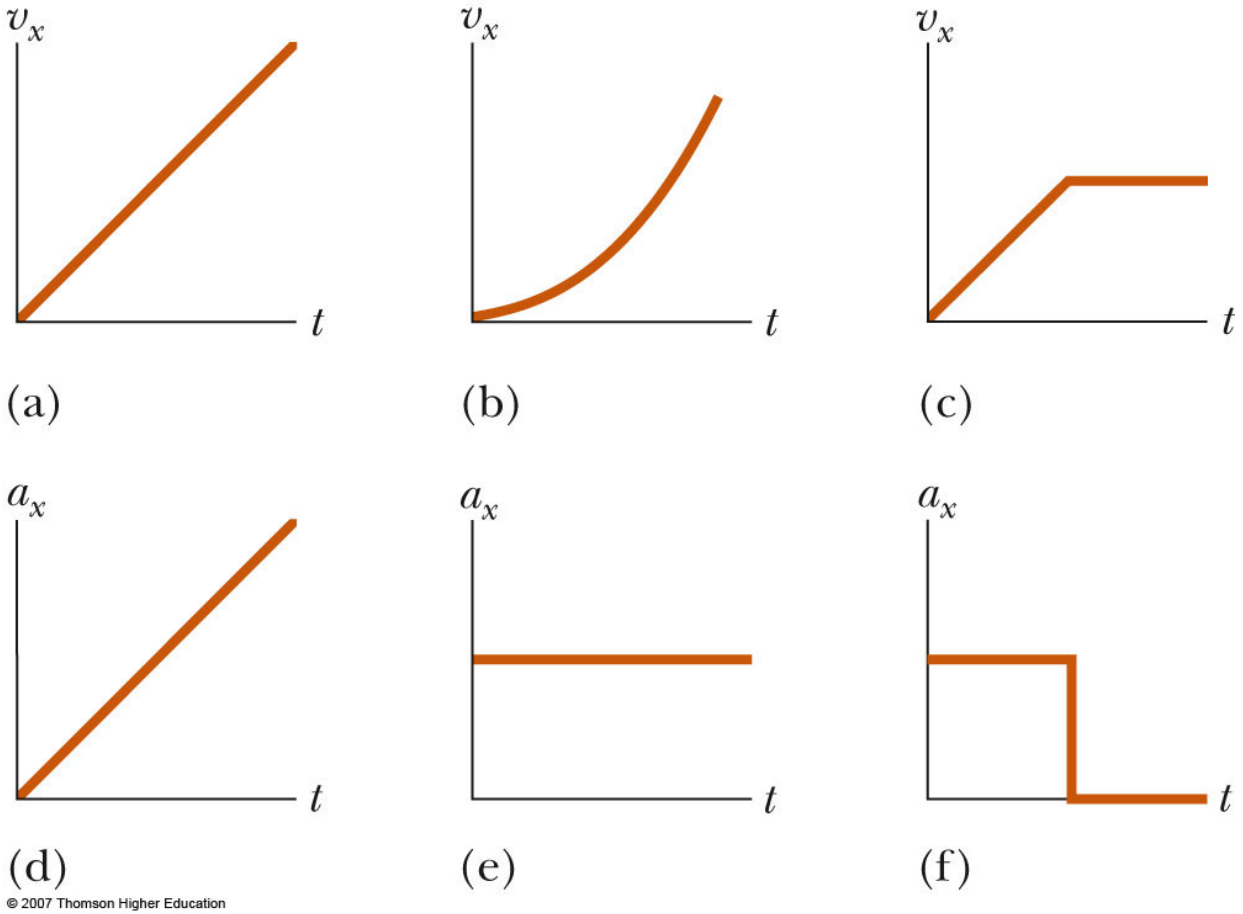
a. a-d, b-e, c-f

b. a-e, b-f, c-d

c. a-f, b-d, c-e

✔ **a-e, b-d, c-f**

e. a-f, b-e, c-d



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