Phys 103

Chapter 2

Motion in One Dimension

By

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LECTURE OUTLINE

- **2.1 Position, Velocity, and Speed**
- **2.2 Instantaneous Velocity and Speed**
- 2.3 Acceleration
- 2.5 One-Dimensional Motion with Constant Acceleration
- 2.6 Freely Falling Objects

Introduction

Kinematics:

Describes motion while ignoring the external agents that might have caused or modified the motion

For now, will consider motion in one dimension

Along a straight line

Motion represents a continuous change in the position of an object.

Introduction

Types of Motion

Translational

- An example is a car traveling on a highway.

Rotational

- An example is the Earth’s spin on its axis.

Vibrational

- An example is the back-and-forth movement of a pendulum.

Introduction

Particle Model

We will use the particle model.

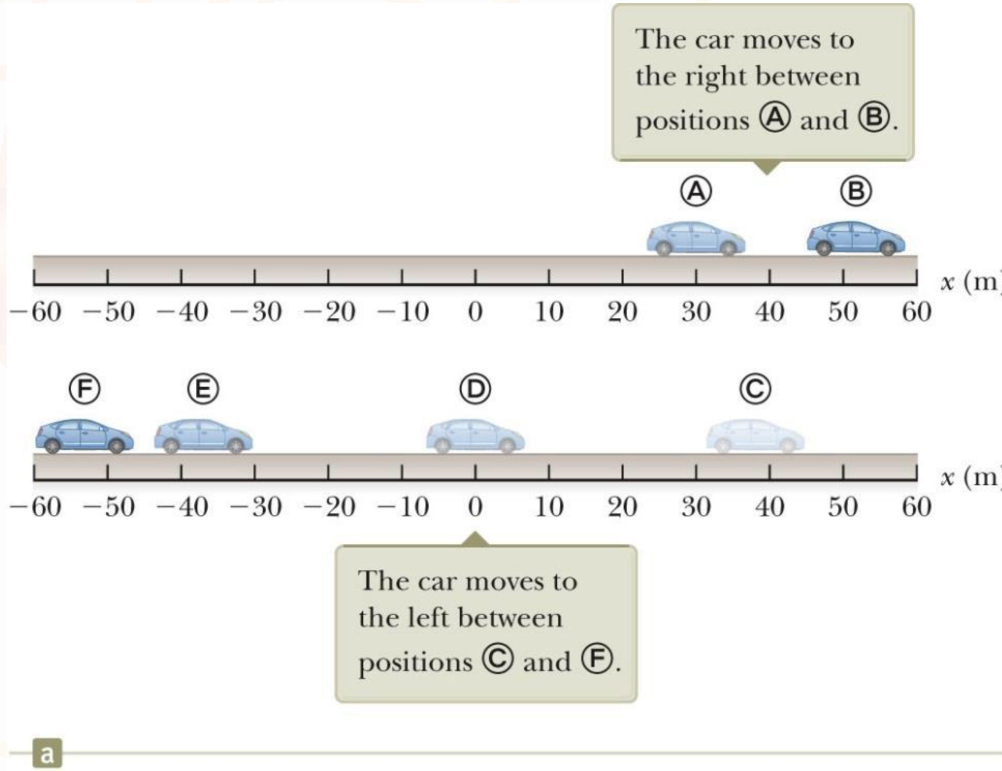
In general, a particle : is a point-like object—that is, an object with mass but having infinitesimal size.

2.1 Position, Velocity, and Speed

- **Position**

The object's position is its location with respect to a chosen reference point.

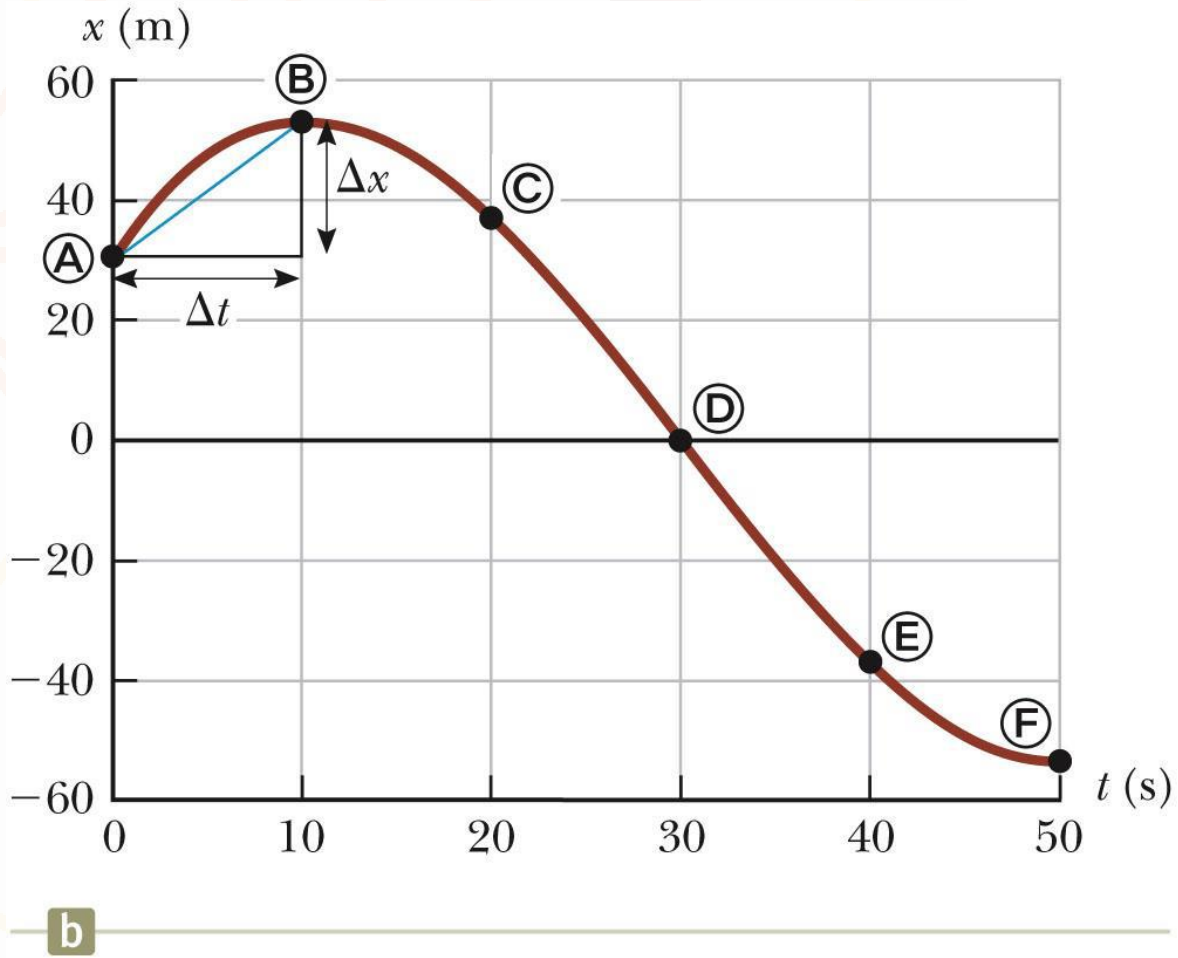
❖ Consider the point to be the origin of a coordinate system. Only interested in the car's translational motion, so model as a particle



2.1 Position, Velocity, and Speed

- **Position-Time Graph**

The position-time graph shows the motion of the particle (car). The smooth curve is a guess as to what happened between the data points.



2.1 Position, Velocity, and Speed

- **Displacement**

The displacement of a particle is defined as its change in position in some time interval.

$$\Delta x = x_f - x_i \begin{cases} \Delta x > 0 \ or \ x_f > x_i \text{ :motion to the right } \rightarrow + \\ \Delta x < 0 \ or \ x_f < x_i \text{ :motion to the left } \leftarrow - \\ \Delta x = 0 \ or \ x_f = x_i \text{ :object returned to} \\ \text{its initial position,or there was no motion} \end{cases}$$

<u>Displacement is an example of a vector quantity.</u>

(requires the specification of both direction and magnitude)

- **Distance**

Distance is the length of a path followed by a particle.

<u>Distance is an example of a scalar quantity.</u>

(scalar quantity has a numerical value and no direction.)

2.1 Position, Velocity, and Speed

- **Average velocity**

The average velocity $\overline{v_x}$ of a particle is defined as the particle's displacement Δx divided by the time interval Δt during which that displacement occurs:

$$\overline{\boldsymbol{v}_x} = \frac{\Delta \boldsymbol{x}}{\Delta \boldsymbol{t}} = \frac{x_f - x_i}{\Delta \boldsymbol{t}}$$

<u>The average velocity has dimensions of length divided by time (L/T)—meters per second in SI units</u>

(The average velocity of a particle moving in one dimension can be positive or negative, depending on the sign of the displacement , a vector quantity)

Average speed

The average speed of a particle, is defined as the total distance traveled divided by the total time interval required to travel that distance:

$$\textbf{Average speed} = \frac{\textbf{Total Distance}}{\textbf{Total Time}}$$

<u>The SI unit of average speed is the same as the unit of average velocity</u>

- **(The average speed of a particle, a scalar quantity=** *no direction* and hence carries *no algebraic sign*)

Notice the distinction between average velocity and average speed—average velocity is the *displacement* divided by the time interval, while average speed is the *distance* divided by the time interval.

2.1 Position, Velocity, and Speed

- **Average velocity and Average speed**

Example 2.1 Calculating the Average Velocity and Speed

Find the displacement, average velocity, and average speed of the car in Figure 2.1a between positions Ⓐ and Ⓕ.

Solution From the position–time graph given in Figure 2.1b, note that $x_A = 30$ m at $t_A = 0$ s and that $x_F = -53$ m at $t_F = 50$ s. Using these values along with the definition of displacement, Equation 2.1, we find that

$$\Delta x = x_F - x_A = -53 \text{ m} - 30 \text{ m} = \boxed{-83 \text{ m}}$$

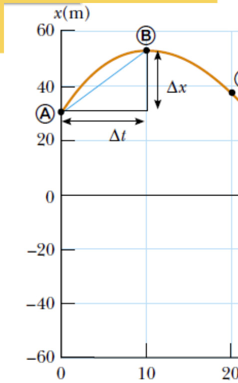
This result means that the car ends up 83 m in the negative direction (to the left, in this case) from where it started. This number has the correct units and is of the same order of magnitude as the supplied data. A quick look at Figure 2.1a indicates that this is the correct answer.

It is difficult to estimate the average velocity without completing the calculation, but we expect the units to be meters per second. Because the car ends up to the left of where we started taking data, we know the average velocity must be negative. From Equation 2.2,

$$\bar{v}_x = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} = \frac{x_F - x_A}{t_F - t_A}$$

$$= \frac{-53 \text{ m} - 30 \text{ m}}{50 \text{ s} - 0 \text{ s}} = \frac{-83 \text{ m}}{50 \text{ s}}$$

$$= \boxed{-1.7 \text{ m/s}}$$



We cannot unambiguously find the average speed of the car from the data in Table 2.1, because we do not have information about the positions of the car between the data points. If we adopt the assumption that the details of the car's position are described by the curve in Figure 2.1b, then the distance traveled is 22 m (from Ⓐ to Ⓑ) plus 105 m (from Ⓑ to Ⓕ) for a total of 127 m. We find the car's average speed for this trip by dividing the distance by the total time (Eq. 2.3):

$$\text{Average speed} = \frac{127 \text{ m}}{50 \text{ s}} = \boxed{2.5 \text{ m/s}}$$

2.2 Instantaneous Velocity and Speed

- **Instantaneous Velocity**

The limit of the average velocity as the time interval becomes infinitesimally short, or as the time interval approaches zero.

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

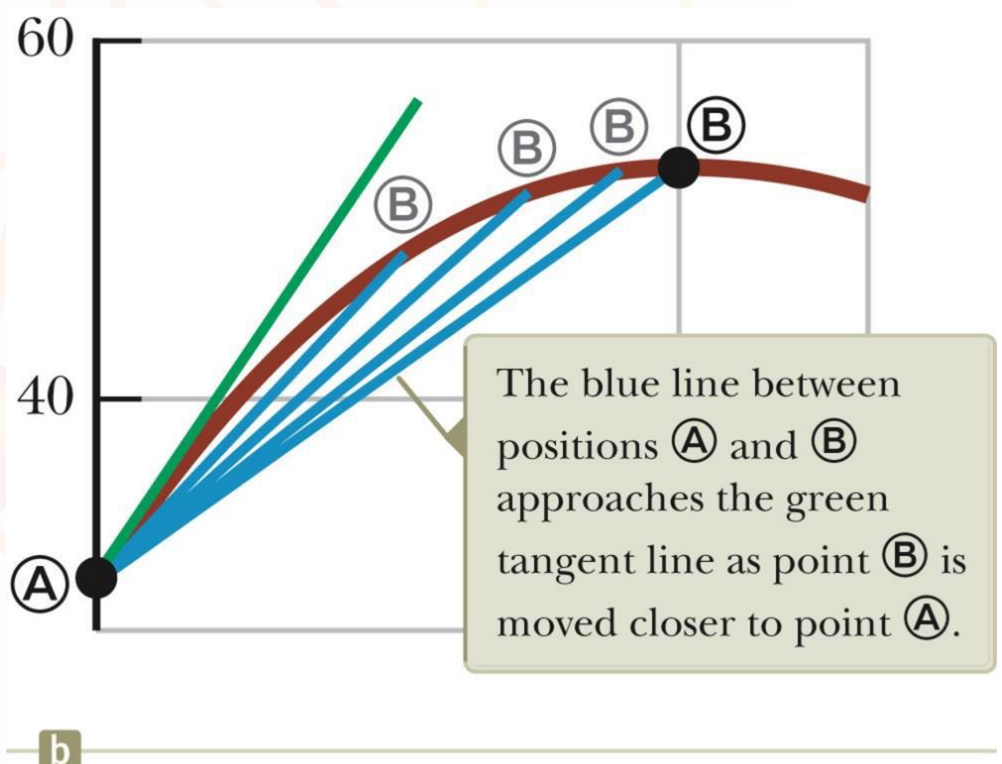
$v_x = 0$ (at maxima or minima) particle is momentarily at rest

this limit is called the *derivative* of *x* with respect to *t*

The instantaneous velocity indicates what is happening at every point of time.

The instantaneous velocity is the slope of the line tangent to the x vs. t curve.

This would be the green line. The light blue lines show that as Δt gets smaller, they approach the green line.



The slope of a graph of physical data represents the ratio of change in the quantity represented on the vertical axis to the change in the quantity represented by the horizontal axis.

2.2 Instantaneous Velocity and Speed

- **Instantaneous Speed**

The instantaneous speed is the magnitude of the instantaneous velocity.

The instantaneous speed has no direction associated with it and hence carries no algebraic sign**.**

we use the word *velocity* to designate instantaneous velocity. When it is *average velocity* we are interested in, we shall always use the adjective *average*.

2.2 Instantaneous Velocity and Speed

Example 2.3 **Average and Instantaneous Velocity**

A particle moves along the x axis. Its position varies with time ccording to the expression $x = -4t + 2t^2$ where x is in meters and t is in seconds. The position–time graph for this motion is shown in Figure . Note that the particle moves in the negative x direction for the first second of motion, is momentarily at rest at the moment $t = 1$ s, and moves in the positive x direction at times $t > 1s$.

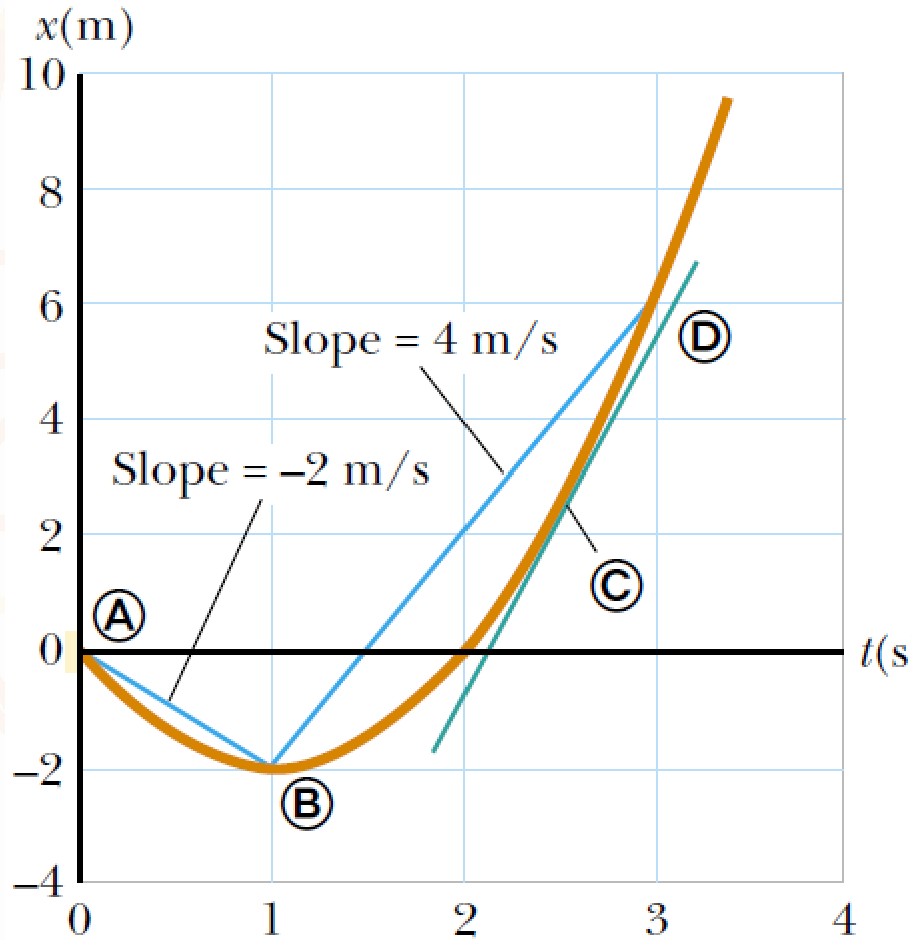


Figure 2.4 (Example 2.3) Position–time graph for a particle having an x coordinate that varies in time according to the expression $x = -4t + 2t^2$.

2.2 Instantaneous Velocity and Speed

Example 2.3 **Average and Instantaneous Velocity**

(A) Determine the displacement of the particle in the time intervals $t = 0$ to $t = 1$ s and $t = 1$ s to $t = 3$ s.

Solution During the first time interval, the slope is negative and hence the average velocity is negative. Thus, we know that the displacement between Ⓐ and Ⓑ must be a negative number having units of meters. Similarly, we expect the displacement between Ⓑ and Ⓓ to be positive.

In the first time interval, we set $t_i = t_A = 0$ and $t_f = t_B = 1$ s. Using Equation 2.1, with $x = -4t + 2t^2$, we obtain for the displacement between $t = 0$ and $t = 1$ s,

$$\begin{aligned} \Delta x_{A \to B} &= x_f - x_i = x_B - x_A \\ &= [-4(1) + 2(1)^2] - [-4(0) + 2(0)^2] \\ &= \boxed{-2 \text{ m}} \end{aligned}$$

To calculate the displacement during the second time interval ($t = 1$ s to $t = 3$ s), we set $t_i = t_B = 1$ s and $t_f = t_D = 3$ s:

$$\begin{aligned} \Delta x_{B \to D} &= x_f - x_i = x_D - x_B \\ &= [-4(3) + 2(3)^2] - [-4(1) + 2(1)^2] \\ &= \boxed{+8 \text{ m}} \end{aligned}$$

These displacements can also be read directly from the position–time graph.

2.2 Instantaneous Velocity and Speed

Example 2.3 **Average and Instantaneous Velocity**

(B) Calculate the average velocity during these two time intervals.

Solution In the first time interval, $\Delta t = t_f - t_i = t_B - t_A = 1\text{ s}$. Therefore, using Equation 2.2 and the displacement calculated in (a), we find that

$$\bar{v}_{x(A \to B)} = \frac{\Delta x_{A \to B}}{\Delta t} = \frac{-2\text{ m}}{1\text{ s}} = -2\text{ m/s}$$

In the second time interval, $\Delta t = 2\text{ s}$; therefore,

$$\bar{v}_{x(B \to D)} = \frac{\Delta x_{B \to D}}{\Delta t} = \frac{8\text{ m}}{2\text{ s}} = +4\text{ m/s}$$

These values are the same as the slopes of the lines joining these points in Figure 2.4.

2.2 Instantaneous Velocity and Speed

Example 2.3 **Average and Instantaneous Velocity**

(C) Find the instantaneous velocity of the particle at $t = 2.5$ s.

Solution We can guess that this instantaneous velocity must be of the same order of magnitude as our previous results, that is, a few meters per second. By measuring the slope of the green line at $t = 2.5$ s in Figure 2.4, we find that

$$v_x = \boxed{+6 \text{ m/s}}$$

[3] Simply to make it easier to read, we write the expression as $x = -4t + 2t^2$ rather than as $x = (-4.00 \text{ m/s})t + (2.00 \text{ m/s}^2)t^{2.00}$. When an equation summarizes measurements, consider its coefficients to have as many significant digits as other data quoted in a problem. Consider its coefficients to have the units required for dimensional consistency. When we start our clocks at $t = 0$, we usually do not mean to limit the precision to a single digit. Consider any zero value in this book to have as many significant figures as you need.

Lecture Summary

- **After a particle moves along the x axis from some initial position x_i to some final position x_f, its displacement is**

$$\Delta x = x_f - x_i$$

- **The average velocity of a particle during some time interval is the displacement Δx divided by the time interval Δt during which that displacement occus:**

$$\overline{v_x} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$$

- **The average speed of a particle is equal to the ratio of the total distance it travels to the total time interval during which it travels that distance:**

$$\text{Average speed} = \frac{\text{Total Distance}}{\text{Total Time}}$$

Lecture Summary

- **The instantaneous velocity of a particle is defined as:**

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

The instantaneous speed of a particleis equal to the magnitude of its instantaneous velocity.

Thank You

ACKNOWLEDGEMENTS