المحاضره الاولى / الحركه في بعد واحد
Physics for Scientists and Engineers
by Serway

## Chapter 1

## (Measurements)

To describe natural phenomena, we must make measurements of various aspects of nature. Each measurement is associated with a physical quantity, such as the length of an object. The laws of physics are expressed as mathematical relationships among physical quantities. In 1960, an international committee established a set of standards for the fundamental quantities of science. It is called the SI (System International), and its fundamental units of length, mass, and time are the meter, kilogram, and second, respectively. Other standards for SI fundamental units established by the committee are those for temperature (kelvin), electric current (ampere), luminous intensity (candela), and the amount of substance (mole).

In mechanics, the fundamental quantities are length, mass, and time. All other quantities in mechanics can be expressed in terms of these three.

Most other variables are derived quantities, those that can be expressed as a mathematical combination of fundamental quantities. Common examples are area (a product of two lengths) and speed (a ratio of a length to a time interval). Another example of a derived quantity is density.

The density $\rho$ (Greek letter rho) of any substance is defined as its mass per unit volume.

$$
\rho=\frac{m}{V}
$$



## Chapter 2

## (Motion in One Dimension)

### 2.1 Position, Velocity, and Speed

- A particle's position (x) is (The location of the particle with respect to a chosen reference point that we can consider to be the origin of a coordinate system).
- The displacement $(\Delta x)$ of a particle is defined as (its change in position in some time interval). As the particle moves from an initial position $\left(x_{i}\right)$ to a final position $\left(x_{f}\right)$, its displacement is given by:

$$
\begin{equation*}
\Delta x=x_{f}-x_{i} \quad \text { Displacement } \tag{2.1}
\end{equation*}
$$

We use the capital Greek letter delta $(\Delta)$ to denote the change in a quantity.

- From this definition, we see that $(\Delta x)$ is positive if $\left(x_{f}\right)$ is greater than $\left(x_{i}\right)$ and negative if $\left(x_{f}\right)$ is less than $\left(x_{i}\right)$.

It is very important to recognize the difference between displacement and distance traveled.

- Distance (is the length of a path followed by a particle).
- Distance is always represented as a positive number, whereas displacement can be either positive or negative.
- Displacement is an example of a vector quantity. Many other physical quantities, including position, velocity, and acceleration, also are vectors.
- In general, a vector quantity requires the specification of both direction and magnitude. Scalar quantity has a numerical value and no direction.

- The average velocity ( $v_{x \text {,avg }}$ ) of a particle is defined as (the particle's displacement ( $\Delta x$ ) divided by the time interval ( $\Delta t$ ) during which that displacement occurs):

$$
\begin{equation*}
v_{x, \text { avg }}=\frac{\Delta x}{\Delta t} \tag{2.2}
\end{equation*}
$$

Where, the subscript ( $x$ ) indicates motion along the ( $x$-axis).
From this definition we see that average velocity has dimensions of length divided by time, or meters per second ( $\mathrm{m} / \mathrm{s}$ ) in SI units.

- The average velocity of a particle moving in one dimension can be positive or negative, depending on the sign of the displacement.
- The time interval $(\Delta t)$ is always positive.

If the velocity of a particle is constant, its instantaneous velocity at any instant during a time interval is the same as the average velocity over the interval. That is, $\boldsymbol{v}_{\boldsymbol{x}}=\boldsymbol{v}_{\boldsymbol{x} \text { arag }}$.

$$
v_{x}=\frac{\Delta x}{\Delta t}
$$

Remembering that $\Delta x=x_{f}-x_{i}$, we see that $\boldsymbol{v}_{\boldsymbol{x}}=\left(x_{f}-\boldsymbol{x}_{i}\right) / \Delta \boldsymbol{t}$, or

$$
x_{f}=x_{i}+v_{x} \Delta t
$$

In practice, we usually choose the time at the beginning of the interval to be $t_{i}=0$ and the time at the end of the interval to be $t_{f}=t$, so our equation becomes: $\quad \boldsymbol{x}_{\boldsymbol{f}}=\boldsymbol{x}_{\boldsymbol{i}}+\boldsymbol{v}_{\boldsymbol{x}} \boldsymbol{t}$ (for constant $v_{x}$ )

- The average speed ( $v_{\text {avg }}$ ) of a particle, a scalar quantity, is defined as (the total distance (d) traveled divided by the total time interval required to travel that distance):

$$
\begin{equation*}
v_{\mathrm{avg}}=\frac{d}{\Delta t} \quad \text { (Average speed) } \tag{2.4}
\end{equation*}
$$

The SI unit of average speed is the same as the unit of average velocity: (meters per second)( $\mathrm{m} / \mathrm{s}$ ).

- Average speed has no direction and is always expressed as a positive number.



### 2.2 Instantaneous Velocity and Speed

- The instantaneous velocity $\left(v_{x}\right)$ equals the limiting value of the ratio $(\Delta x / \Delta t)$ as ( $\Delta \mathrm{t}$ ) approaches zero:

$$
\begin{equation*}
v_{\mathrm{x}}=\lim _{\Delta t \rightarrow 0} \frac{\Delta x}{\Delta t} \tag{2.5}
\end{equation*}
$$

In calculus notation, this limit is called the derivative of $(x)$ with respect to $(t)$, written $(d x / d t)$ :

$$
\begin{equation*}
v_{\mathrm{x}}=\frac{d x}{d t} \quad \text { (instantaneous velocity) } \tag{2.6}
\end{equation*}
$$

The instantaneous velocity can be positive, negative, or zero.

- The instantaneous speed of a particle is defined as (the magnitude of its instantaneous velocity). As with average speed, instantaneous speed has no direction associated with it.


## Example (2.1):

A particle moves along the ( $x$ - axis). Its position varies with time according to the expression: $\left(x=-4 t+2 t^{2}\right)$, where $(x)$ is in meters and $(t)$ in seconds.
(A) Determine the displacement of the particle in the time intervals $(t=0)$ to $(t=1 \mathrm{~s})$ and $(t=1 \mathrm{~s})$ to $(t=3 \mathrm{~s})$.
(B) Calculate the average velocity during these two time intervals.
(C) Find the instantaneous velocity of the particle at $(t=2.5 \mathrm{~s})$.

## Solution:

(A): In the first time interval, $(t=0)$ to $(t=1 \mathrm{~s})$ :

$$
\begin{gathered}
\Delta x=x_{f}-x_{i} \\
\Delta x=\left[-4(1)+2(1)^{2}\right]-\left[-4(0)+2(0)^{2}\right]=-2 \mathrm{~m} .
\end{gathered}
$$

For the second time interval $(t=1 \mathrm{~s})$ to $(t=3 \mathrm{~s})$ :

$$
\Delta x=\left[-4(3)+2(3)^{2}\right]-\left[-4(1)+2(1)^{2}\right]=+8 \mathrm{~m} .
$$

(B): In the first time interval, use equation (2.2) with $\Delta t=t_{f}-t_{i}=1 \mathrm{~s}$ :


$$
v_{x, \text { avg }}=\frac{\Delta x}{\Delta t}=\frac{-2 m}{1 s}=-2 \mathrm{~m} / \mathrm{s}
$$

In the second time interval, $\Delta t=t_{f}-t_{i}=2 \mathrm{~s}$ :

$$
v_{x, a v g}=\frac{\Delta x}{\Delta t}=\frac{8 m}{2 s}=+4 \mathrm{~m} / \mathrm{s}
$$

( C ): Instantaneous velocity $\quad v_{\mathrm{x}}=\frac{d x}{d t}, x=-4 t+2 t^{2}$

$$
\begin{gathered}
v_{\mathrm{x}}=\frac{d x}{d t}=-4+4 t, \text { at } t=2.5 \mathrm{~s}: \\
v_{\mathrm{x}}=-4+4(2.5)=+6 \mathrm{~m} / \mathrm{s}
\end{gathered}
$$

### 2.3 Acceleration

- When the velocity of a particle changes with time, the particle is said to be accelerating.
- The average acceleration ( $a_{x, \text { avg }}$ ) of the particle is defined as (The change in velocity ( $\Delta v_{\mathrm{x}}$ ) divided by the time interval ( $\Delta t$ ) during which that change occurs):

$$
\begin{equation*}
\boldsymbol{a}_{x, \text { avg }}=\frac{\Delta v_{x}}{\Delta t}=\frac{v_{x f}-v_{x i}}{t_{f}-t_{i}} \quad \text { Average acceleration } \tag{2.7}
\end{equation*}
$$

The unit of acceleration is meters per second squared $\left(\mathrm{m} / \mathrm{s}^{2}\right)$.

- The instantaneous acceleration equals the derivative of the velocity with respect to time:

$$
\begin{equation*}
a_{x}=\frac{d v_{x}}{d t} \quad \text { Instantaneous acceleration } \tag{2.8}
\end{equation*}
$$

- For the case of motion in a straight line, the direction of the velocity of an object and the direction of its acceleration are related as follows: When the object's velocity and acceleration are in the same direction, the object is speeding up. On the other hand, when the object's velocity and acceleration are in opposite directions, the object is slowing down.
- Because $v_{\mathrm{x}}=\frac{d x}{d t}$, the acceleration can also be written as:

$$
\begin{equation*}
a_{x}=\frac{d v_{x}}{d t}==\frac{d}{d t}\left(\frac{d x}{d t}\right)=\frac{d^{2} x}{d t^{2}} \tag{2.9}
\end{equation*}
$$

That is, in one-dimensional motion, the acceleration equals the second derivative of $(x)$ with respect to time.

## Example (2.2):

The velocity of a particle moving along the ( $x$ - axis) varies according to the expression $\left(v_{x}=40-5 t^{2}\right)$, where $v_{x}$ is in meters per second and $(t)$ in seconds.
(A) Find the average acceleration in the time interval $(t=0$ to $t=2 \mathrm{~s})$.
(B) Determine the acceleration at $t=2 \mathrm{~s}$.

## Solution:

(A) $v_{x 1}=40-5 t^{2}=40-5(0)^{2}=40 \mathrm{~m} / \mathrm{s}$

$$
v_{x 2}=40-5 t^{2}=40-5(2)^{2}=20 \mathrm{~m} / \mathrm{s}
$$

$$
a_{x, \mathrm{avg}}=\frac{\Delta v_{x}}{\Delta t}=\frac{20-40}{2-0}=-10 \mathrm{~m} / \mathrm{s}^{2}
$$

The negative sign indicates that the particle is slowing down.
(B)

$$
\begin{aligned}
& a_{x}=\frac{d v_{x}}{d t}, v_{x}=40-5 t^{2} \\
& a_{x}=-10 t=-10(2)=-20 \mathrm{~m} / \mathrm{s}^{2}
\end{aligned}
$$

### 2.4 Particles under Constant Acceleration

If the acceleration of a particle varies in time, its motion can be complex and difficult to analyze. A very common and simple type of onedimensional motion, however, is that in which the acceleration is constant. In such case, the average acceleration ( $a_{x, \text { avg }}$ ) over any time interval is numerically equal to the instantaneous acceleration $\left(a_{x}\right)$ at any instant within the interval, and the velocity changes at the same rate throughout the motion. This situation is considered to be the particle under constant acceleration.

If we replace $\left(a_{x, \text { avg }}\right)$ by $\left(a_{x}\right)$ in equation (2.7) and take $t_{i}=0$ and $\left(t_{f}\right)$ to be any later time ( $t$ ), we find that:


$$
a_{x}=\frac{v_{x f}-v_{x i}}{t-0}
$$

$$
\begin{equation*}
\boldsymbol{v}_{\boldsymbol{x f}}=\boldsymbol{v}_{\boldsymbol{x} \boldsymbol{i}}+\boldsymbol{a}_{\boldsymbol{x}} \boldsymbol{t} \quad\left(\text { for constant } a_{x}\right) \tag{2.10}
\end{equation*}
$$

We can express the average velocity in any time interval:

$$
\begin{equation*}
\boldsymbol{v}_{x, \text { ave }}=\frac{\boldsymbol{v}_{x i}+\boldsymbol{v}_{x f}}{2} \quad\left(\text { for constant } a_{x}\right) \tag{2.11}
\end{equation*}
$$

Notice that this expression for average velocity applies only in situations in which the acceleration is constant.

We can now use equations $2.1,2.2$, and 2.11 to obtain the position of an object as a function of time. Recalling that $\Delta x$ in equation (2.2) represents $\left(x_{f}-x_{i}\right)$ and recognizing that $\Delta t=t_{f}-t_{i}=t-0=t$, we find that:

$$
\begin{equation*}
x_{f}-x_{i}=v_{x, a v e} t=\frac{1}{2}\left(v_{x i}+v_{x f}\right) t \tag{2.12}
\end{equation*}
$$

$\boldsymbol{x}_{f}=\boldsymbol{x}_{\boldsymbol{i}}+\frac{1}{2}\left(\boldsymbol{v}_{x i}+\boldsymbol{v}_{\boldsymbol{x f}}\right) \boldsymbol{t} \quad$ (for constant $a_{x}$ )
This equation provides the final position of the particle at time $(t)$ in terms of the initial and final velocities.

We can obtain another useful expression for the position of a particle under constant acceleration by substituting equation (2.10) into equation (2.12):

$$
\begin{array}{r}
x_{f}=x_{i}+\frac{1}{2}\left[v_{x i}+\left(v_{x i}+a_{x} t\right)\right] t \\
\left.x_{f}=x_{i}+v_{x i} t+\frac{1}{2} a_{x} t^{2} \quad \text { (for constant } a_{x}\right) \tag{2.13}
\end{array}
$$

This equation provides the final position of the particle at time $(t)$ in terms of the initial position, the initial velocity, and the constant acceleration. Finally, we can obtain an expression for the final velocity that does not contain time as a variable by substituting the value of $(t)$ from equation (2.10) into equation (2.12):

$$
\begin{array}{r}
x_{f}=x_{i}+\frac{1}{2}\left(v_{x i}+v_{x f}\right)\left(\frac{v_{x f}-v_{x i}}{a x}\right)=x_{i}+\left(\frac{v_{x f}^{2}-v_{x i}^{2}}{2 a x}\right) \\
v_{x f}^{2}=v_{x i}^{2}+2 a_{x}\left(x_{f}-x_{i}\right) \tag{2.14}
\end{array}\left(\text { for constant } a_{x}\right)
$$

This equation provides the final velocity in terms of the initial velocity, the constant acceleration, and the position of the particle.

When the acceleration of a particle is zero, its velocity is constant and its position changes linearly with time.

Equations (2.10), (2.12), (2.13), and (2.14) are called
Kinematic Equations for motion of a particle under constant acceleration. These equations are listed in the table below:

| Equation | Information Given by <br> Equation |
| :---: | :---: |
| $v_{x f}=v_{x i}+a_{x} t$ | Velocity as a function of time |
| $\left.x_{f}=x_{i}+\frac{1}{2} v_{x i}+v_{x f}\right) t$ | Position as a function of velocity and time |
| $x_{f}=x_{i}+v_{x i} t+\frac{1}{2} a_{x} t^{2}$ | Position as a function of time |
| $v_{x f}{ }^{2}=v_{x i}{ }^{2}+2 a_{x}\left(x_{f}-x_{i}\right)$ | Velocity as a function of position |

## Example (2.3):

A car traveling at a constant speed of ( $45 \mathrm{~m} / \mathrm{s}$ ) passes a trooper on a motorcycle hidden behind a billboard. One second after the speeding car passes the billboard; the trooper sets out from the billboard to catch the car, accelerating at a constant rate of $\left(3 \mathrm{~m} / \mathrm{s}^{2}\right)$. How long does it take him to overtake the car?

## Solution:



