Chapter 2

Kinematics in one dimension

Motion?  Motion itself  Why things move (Cause)?  Dynamics
Kinematics describes the motion not the cause

Describing motion  Location
Change in position with time

At time $t_0$

Position $x_0$
$x$

Change in position = final position – initial position
$= x - x_0$

Time elapsed  $= t - t_0$

Time of travel

Displacement  Shortest Distance traveled
A vector  m, cm

Speed

Example:
Mr. “X” travels 3 km (3000 m) from his home to university in 5 minutes (300 s).
His speed?

Average speed

Distance traveled divided by time of travel  m/s

Can he maintain this speed throughout the trip?
Car speedometer gives speed at every instant of time

Speedometer reads average value but time interval is very short. The speed practically remains unchanged in that interval

A car travels 12 km in half an hour, while a bicyclist sprints for 1 min at steady speed 24 km/hr. Which of the following is true:

1. The car has higher average speed.  
2. The bicycle has higher average speed.  
3. Both have same average speed.

In which of the following case/s is the car’s speed increasing?

a. A car covers equal distance in equal time intervals.

b. A car covers longer and longer distance in equal time intervals.

c. A car covers equal distance in longer and longer time intervals.

d. A car covers equal distance in shorter and shorter time intervals.
**Example:** Suppose we start traveling at t=0 s and take measurements after each second. The following data is obtained:

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td>2</td>
<td>8.0</td>
</tr>
<tr>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>4</td>
<td>22.0</td>
</tr>
<tr>
<td>5</td>
<td>22.0</td>
</tr>
<tr>
<td>6</td>
<td>29.0</td>
</tr>
<tr>
<td>7</td>
<td>37.0</td>
</tr>
<tr>
<td>8</td>
<td>40.0</td>
</tr>
</tbody>
</table>

What is average speed of the trip?

Average speed = Distance traveled / travel time

= \( \frac{(40 \text{ m} - 0 \text{ m})}{(8 \text{ s} - 0 \text{ s})} \)

What is speed between 4s and 5s?

Speed b/w 4 and 5s

= \( \frac{(22.0 \text{ m} - 22.0 \text{ m})}{(5 \text{ s} - 1 \text{ s})} \)

Instantaneous speed may be very different from average speed.

**Slop = 5m/s**
1. When a moving bus comes rapidly to a stop, why do the riders who are standing suddenly lurch towards the front of the bus?

2. Earth moves around the sun at a speed of 30 km per second (70,000 miles per hour). It seems as though birds, clouds and baseballs in flight should be left behind the moving earth, since they are not attached to the ground. How can they keep up with earth as earth moves through space?

3. From the graph find
   1. Average speed through out the trip.
   2. Average speed between 2s and 5s.
   3. Instantaneous speed between 1s and 2s.
   4. Speed between 5s and 6s.
Traveling  Direction
Driving at an average speed of 30 km/hr towards west or East

Speed with direction  **Velocity**

Magnitude of Velocity is ---------

**Speed**  how fast you move

**Velocity**  how fast and in what direction

**Average Velocity**

**Instantaneous Velocity**

Scalar Quantities
- Do not need direction

Vector Quantities
- Do need direction

Direction is also important for **Velocity**, vector quantity
Change of velocity is important

<table>
<thead>
<tr>
<th>Speed</th>
<th>Velocity</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>m/s</td>
<td>m/s</td>
<td>m/s/s or m/s²</td>
</tr>
</tbody>
</table>

Velocity may change in many ways:
- Increase
- Decrease
- Only change direction

Velocity
- Rate of change of displacement

Acceleration
- Rate of change of velocity

Deceleration
- Decreasing acceleration
  - Not necessarily negative velocity
Acceleration

Rate at which velocity changes (Velocity not speed)

we feel the effect of acceleration on our body

How do we find it? Stomach is an accelerator detector

Change in velocity divided by time elapsed.

\[ a = \frac{\Delta v}{\Delta t} \]

Direction of an acceleration

Direction is same as that of the change in velocity.

- If car is moving in a straight line and its velocity is increasing, the change in velocity is in the same direction as velocity itself.
- If the velocity is decreasing, the change in velocity points opposite direction to the two velocity vectors
- Can a car be accelerated when its speed is constant?
Equations of Kinematics with constant acceleration

Assuming object starts at $t_0 = 0$ s from origin $x_0 = 0$ m

\[ \Delta x = x - x_0 = x \quad \Delta t = t - t_0 = t \]

Average Acc

\[ a = \frac{v - v_0}{t - t_0} = \frac{v - v_0}{t} \]

\[ v = v_0 + a \times t \] --Eq-I

Average Velocity

\[ v = \frac{x - x_0}{t - t_0} = \frac{x}{t} \] --Eq-II

If velocity is increasing at constant rate

\[ -v = \frac{v + v_0}{2} \]

\[ x = \frac{1}{2} (v + v_0) t \] --Eq-III

Eq-I into Eq-III =>

\[ x = v_0 \times t + \frac{1}{2} a \times t^2 \]

From Eq-I

\[ t = \frac{v - v_0}{a} \]

Plugging into Eq-III

\[ 2 \ a \ x = v^2 - v_0^2 \]
\[ \begin{align*}
    v &= v_0 + a \times t \\
    x &= \frac{1}{2} (v + v_0) t \\
    x &= v_0 \times t + \frac{1}{2} a \times t^2 \\
    2a \times x &= v^2 - v_0^2 \\
    -v &= \frac{x - x_0}{t} = \frac{x}{t}
\end{align*} \]
Applications

• Decide positive and negative directions
• Decide positive and negative directions
• Deceleration --- not necessarily negative velocity
• Starting from rest => \( v_0 = 0 \)
• More than two answers --- use common sense

If acceleration changes

• Motion in segments --- final velocity of one segment will be the initial velocity of the next segment

• Make free body diagram
Free Falling Object

Effect of gravity

Things fall down

In the absence of air resistance

Different bodies fall with same acceleration
(if dropped at same location on earth)

Ideal fall

Air resistance is zero

Acceleration is constant

Free Fall

Acceleration is due to gravity
towards the center of the earth

\[ g = 9.8 \text{ m/s}^2 \]
\( v = v_0 + a \times t \)

\( v (t=3\text{ s}) = -29.4 \text{ m/s} \)

\( x = v_0 \times t + \frac{1}{2} a \times t^2 \)

\( x = y \)

\( y = -44.1 \text{ m} \)

g is always downward

If dropped will gain the downward velocity

If thrown upward will lose the velocity until turned around.
A ball is thrown upward with initial velocity of 5 m/s. How high will it go? How long will it be in the air?

Conceptual Questions: 1, 3, 10


Problem: A car starts from rest and accelerates at 2.01 m/s$^2$ for 7.0 s. Following this, its acceleration drops to 0.518 m/s$^2$ for next 6.0 s. It continues to move forward but slows down such that its acceleration becomes -1.49 m/s$^2$ for next 8.0 s. Find

a) Car’s velocity at 21.0 s.
b) Total distance car travels at the end of 21.0 s journey.