Chapter 1
Motion in a straight line

Mechanics is the Study of objects in motion

Mechanics is divided into two Parts

Kinematics & Dynamics

Kinematics describes *HOW* objects move

Dynamics shows *WHY* objects move

1.2 Displacement; Average Velocity

❖ Vector and Scalar quantities

Vector: any physical quantity which has magnitude and Direction (Angle) the angle is measured from a reference axis

Scalar: any physical quantity that has magnitude only

❖ Displacement

Displacement is a vector quantity which defines the change in the position of an object measured from a reference point and is expressed in unit of meter

Displacement can be positive or negative

$$\Delta x = x_f - x_i$$

Example 1.1

Starting at home, a student walked to college for his physics lecture and then walked back home . He then walked to the university bookshop in the main university building. The lecture room is located exactly north of his home and the bookshop is located exactly south of his home. If the lecture room is 500 m away from his home and the university bookshop is 300 m from his home. What is:

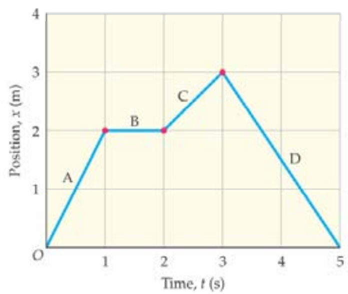
1) His displacement from home when he was in the lecture room?
2) His displacement from home when he was in the bookshop?
3) His displacement when he returned home?

❖ Average Velocity

Average velocity is defined as the displacement ($\Delta X = X_f - X_i$) divided by the elapsed time (Δt)

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

Displacement-time graphs



These graphs show how an object's position changes with time. From this graph we can read the position of the object at any time t.

The average velocity of an object between tow instants of time can be calculated using the position of the object at these times as given by the equation above as shown in the following figures 1.2 and 1.3.

Figure 1.2

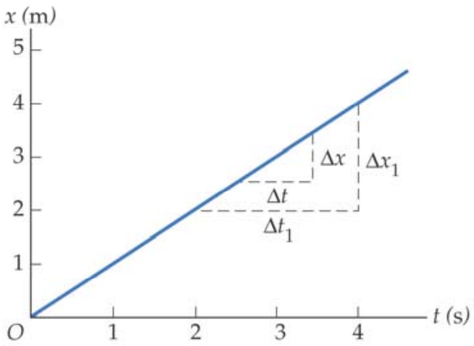
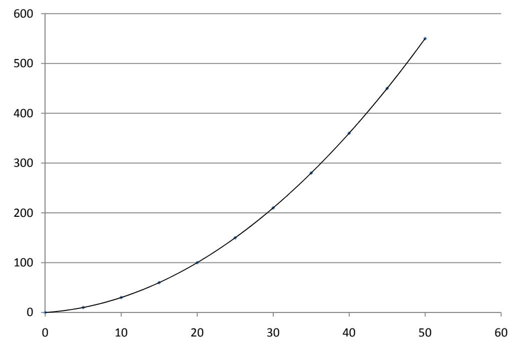


Figure 1.3



❖ Distance and speed

Distance is a scalar quantity measured in unit of meter and is always positive

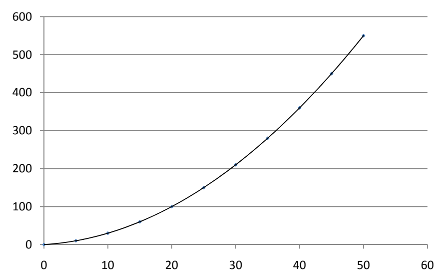
Example 1.2:

Starting at home, a student walked to college for his physics lecture and then walked back home . He then walked to the university bookshop in the main university building. The lecture room is located exactly north of his home and the bookshop is located exactly south of his home. If the lecture room is 500 m away from his home and the university bookshop is 300 m from his home. What is:

1) The distance travelled from home to the lecture room?
2) The distance travelled from home to the bookshop?
3) The total distance travelled when he came back to the house?

❖ Examples 1.3

Use the figure to calculate the average velocity during the period from t = 20 to 40 s



Example: 1.4

At t_1= 5 s, a car is at x_1 600 m and at t_2= 15 s, it is at x_2 500 m. Calculate its average velocity.

Example: 1.5

Use figure 1.3 to calculate the average velocity of the moving object during the periods from t = 0 to t = 20 s and from t = 20 s to t= 30 s

Example: 1.6

A car moved at an average velocity of 100km/h for two hours.

a) How far would the car travel during this time?

b) How long would it take to travel a distance of 350 km

Summary

Displacement can be positive, negative or zero

Average velocity can be positive, negative or zero

Distance is always positive

Average speed is always positive

Motion of any object can be represented by a graph of Displacement verses Time

The displacement at any instant can be read directly from the graph

The average velocity can also be calculated using the graphs

Quiz (1)

A car moved 20 km north and turned back and moved 50 km south. What is the distance travelled and its displacement?

Homework:

Questions: 1-16 and 1-17 page 14

Motion in a Straight Line

1.3 Instantaneous Velocity

- **Instantaneous velocity is defined as the velocity of an object at a given instant**

- **It can be calculated in two ways:**

a) **Mathematical (differentiation)**

$$v = \lim_{\Delta t \to 0}\left(\frac{\Delta x}{\Delta t}\right) = \frac{dx}{dt}$$

Example 1.9

From figure 1.3 ($x = bt^2$, $b = 1\ ms^{-2}$), find the average velocity between the periods:

a) **3 s to 3.1 s**

b) **3 s to 3.01 s**

c) **3 s to 3.001 s**

Answer: using the equation of the line the average velocity is found to be 6.1 m/s, 6.01 m/s and 6.001 m/s respectively.

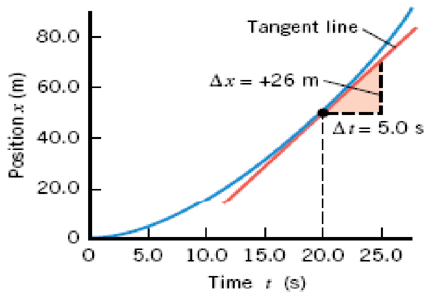
This shows that as Δt get smaller the average velocity get closer to the velocity at t =3 s which is equal to 6 m/s

ie: the instantaneous velocity at t =3 s is 6 m/s

From example 1.9 we found that as Δt goes to zero the average velocity goes to the instantaneous velocity which leads us the idea of differentiation

b) Graphical (tangent)

The instantaneous velocity can be found graphically by drawing a tangent (straight line) to the curve at the instant of time when the velocity is to be found as shown in the figure



1.4 Acceleration

❖ **Average acceleration**

Average acceleration is defined as the change of velocity ($\Delta v = v_f - v_i$) divided by the elapsed time (Δt)

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

❖ **Instantaneous acceleration**

Instantaneous acceleration is defined as the acceleration of an object at a given instant

$$a = \lim_{\Delta t \to 0}\left(\frac{\Delta v}{\Delta t}\right) = \frac{dv}{dt}$$

Acceleration can be either Constant or Variable.

In this course acceleration is constant

Summary

- Average velocity is defined
- Instantaneous velocity is obtained:
  - a) mathematically (differentiation)
  - b) graphically (tangent)
- Average acceleration is defined
- Instantaneous acceleration is defined
- In this course only motion with constant acceleration is considered

Quiz (1)

A car moved 120 km north in 2 hours and turned back and moved 250 km south in three hours. What is the average speed and average velocity of the car?

Quiz (2)

A car's displacement is represented by the equation:

$x = 3t^2 + 2$. Find

1) The car's displacements at t =5 s and 15 s
2) The average velocity of the car

Quiz (3)

A car's displacement is represented by the equation:

$x = 2t^2 + 5t + 5$. What is the car's velocity at t =1 s and 5 s ?

Quiz (4)

A car's velocity is represented by the equation:

$v = 5t^2 + 6t + 3$. What is the average acceleration between t =3s and t = 5 s ?

Home work:

26, 28, 33 and 38 (pages 22 and 23)

Motion in a Straight Line

1.5 Finding the motion of an object at constant acceleration

The motion of an object can be described by a number of equations called the Equations of motion (Kinematics):

Considering an object moving with initial velocity v_0 and constant acceleration a, for a time interval Δt.

The final velocity v, can be found using the definition of the acceleration: $a = \frac{\Delta v}{\Delta t}$ where $\Delta v = a\Delta t$ is the change in the

Velocity which can be expressed as:

$$\Delta v = v - v_0$$

Hence the first equation of motion can be written as:

$$v = v_0 + a\Delta t \qquad (1)$$

The average velocity for a moving object between two points can be written as:

$$\bar{v} = \frac{1}{2}(v_0 + v)$$

The average velocity for a moving object can be written as defined before:

$$\bar{v} = \frac{\Delta x}{\Delta t}$$

This leads to the second equation of motion:

$$\Delta x = \frac{1}{2}(v + v_0)\Delta t \qquad (2)$$

Δx can also be obtained by substituting the first equation into the second (eliminating v). The third equation of motion is obtained as follow:

$$\Delta x = \frac{1}{2}((v_0 + a\Delta t) + v_0)\Delta t$$

This leads to the third equation which is:

$$\Delta x = v_0\Delta t + \frac{1}{2}a(\Delta t)^2 \qquad (3)$$

Using Δt in equation (1) and substituting it in equation (2) we obtain:

$$\Delta x = \frac{1}{2}(v + v_0)(\frac{v - v_0}{a})$$

The fourth equation of motion is found to be:

$$v^2 = +v_0^2 + 2a\Delta x \qquad (4)$$

Motion with constant acceleration

$$v = v_0 + a\Delta t \qquad (1)$$

$$\Delta x = \frac{1}{2}(v + v_0)\Delta t \qquad (2)$$

$$\Delta x = v_0\Delta t + \frac{1}{2}a(\Delta t)^2 \qquad (3)$$

$$v^2 = +v_0^2 + 2a\Delta x \qquad (4)$$

$$\bar{v} = \frac{1}{2}(v_0 + v)$$

Conceptual questions

Q1: Is it possible for an object to have a zero acceleration and a non-zero velocity?

YES!!

If the object is moving at a constant velocity, the acceleration vector is zero!

Q2: Are the velocity and the acceleration always in the same direction?

NO!!

If the object is slowing down, the acceleration vector is in the opposite direction of the velocity vector!

Example 1.16:

What is the position and velocity after 4 s, of a car starting from rest with an acceleration of 2 m/s^2

Solved in the course's text book

Example 1.17:

A car accelerating at 2 m/s^2 , reaches a velocity of 20 m/s. How far will it travel if it's initial velocity is:

a) zero

b) 10 m/s

Solved in the course's text book

Example 1.18:

A car starts moving from rest with an acceleration of 2m/s^2 on to a highway where the traffic is moving at 24 m/s.

a) How long will it take the car to reach the velocity of the traffic at the highway

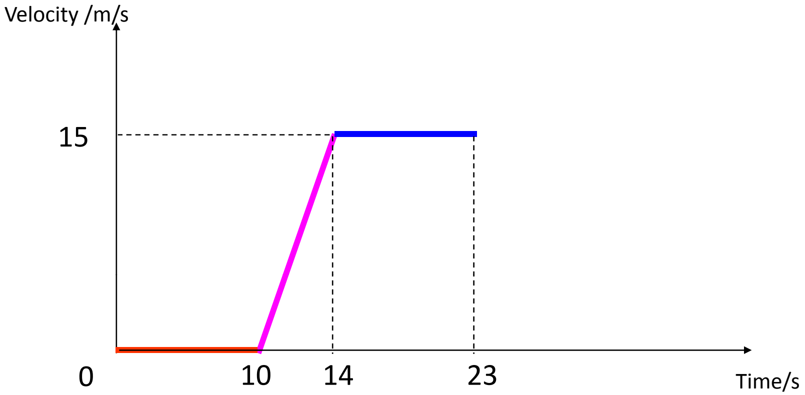
b) How far will it travel during that time

C) How large is the break in the traffic the car's driver need to have if he want the car behind him to be 20 m away at the time he reaches the traffic's velocity

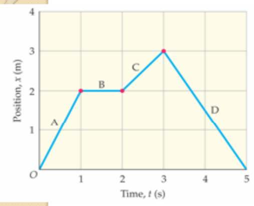
Solved in the course's text book

Example:

The velocity–time graph represents the motion of a bus. Calculate the distance travelled by the bus



What are the velocities?



(a) $\frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t} = \frac{2-0}{1-0} = 2m/s$

(b) 0 m/s

(c) 1 m/s

(d) $\frac{0-3}{5-3} = \frac{-3}{2} = -1.5m/s$

Summary

- Average velocity and acceleration
- Instantaneous velocity and acceleration
- Scalar and Vector quantities
- Motion with constant acceleration
- Equations of motion and applications

Quiz (1)

What is the final velocity of a particle if accelerated for 3 s with an acceleration of 4 m/s^2 if it's initial velocity was 13 m/s?

Quiz (2)

A car started to accelerate (3 m/s^2) from rest. Another car moving at 20 m/s passed the first car as it started to accelerate.

1- How long will it take the first car to reach the speed of the other car?

2- How far will the first car travel before reaching the second car?

3- How long would it take the first car to catch up with the second car?

Quiz (3)

What is the average velocity of a particle if accelerated for 3 s with an acceleration of 4000 km/s^2 if it's initial velocity was 1130 km/s?

Home work:

43, 71, 72, 78 and 80 pages 23-26