Chapter 3 – Kinematics

(A) Distance Vs Displacement

1. Compare distance and displacement in terms of:

(a) definition

- Distance is the total length of travel, irrespective of direction.
- Displacement is the length from an initial point to a final point, in a particular direction.

Comment:

√ *Unlike distance, displacement takes into consideration the direction of motion from the point of origin (where the object starts to move).*

(b) whether it is a scalar or vector quantity

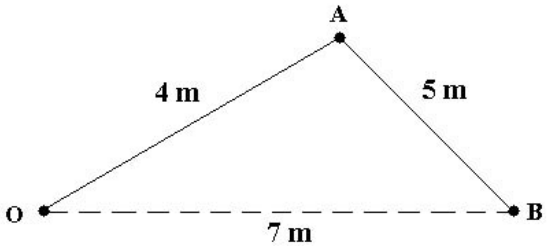
- Distance – scalar quantity
- Displacement – vector quantity

(c) SI units

- Distance – metre (m)
- Displacement – metre (m)

Eg **2. A body moves from point O to point A, and then to point B which is to the east of O.**

What is the distance and displacement travelled by the body?



- Distance = 4 + 5
  = 9 m
- Displacement = 7 m
  (to the east of point O)

Comments:

√ *The distance is the total length travelled.*
√ *The displacement is the length away from point O, which in this case is 7 m.*

3. Fill in the blanks:

An object is moving round in a circular path. It completes one revolution and goes back to its starting point.
The _____ is zero but the _____ travelled is the circumference of the circular path.

- ❖ displacement
- ❖ distance

4. Can distance and displacement decrease over time?

- ❖ Distance cannot decrease over time.
- ❖ Displacement can decrease over time.

Comments:

√ *As long as an object moves, the distance travelled by it will increase. If it stops moving, its distance will neither increase nor decrease. Under no situation will its distance decrease.*

√ *On the other hand, the displacement of an object can decrease if it moves backwards to its original starting point / position.*

5. Can distance and displacement be of a negative value?

- ❖ Distance cannot be negative.
- ❖ Displacement can be negative.

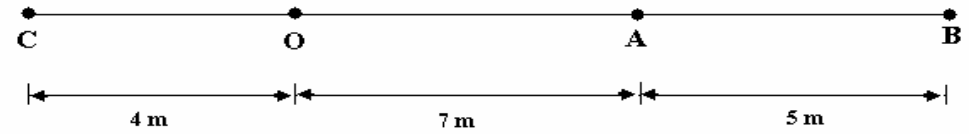
Comments:

√ *Distance is always positive because it is simply the total length moved by the object. Thus we just add up all the individual lengths; no subtraction will be performed.*

√ *In contrast, displacement can be negative if an object moves in the opposite direction past its starting point.*

Eg

6. The original position of object X is at O. X moves towards point A, and then towards point B. Next, it makes a U-turn, and travels in the opposite direction to reach point C.



What is the distance and displacement travelled by X when it first reaches:

(a) point A

- Distance = 7 m
- Displacement = 7 m (in a direction to the right)

(b) point B

- Distance = 7 + 5
  = 12 m
- Displacement = 7 + 5
  = 12 m (in a direction to the right)

(c) point C

- Distance = 7 + 5 + 5 + 7 + 4
  = 28 m
- Displacement = -4 m (in a direction to the right)
  [OR: 4 m (in a direction to the left)]

Comment:

√ *The value of the displacement in part (c) above is negative because the object is moving in the opposite direction from where it first started.*

(B) Speed Vs Velocity

7. Compare speed and velocity in terms of:

(a) definition

- Speed is the rate of change of distance.
- Velocity is the rate of change of displacement.

(b) whether it is a scalar or vector quantity

- Speed – scalar quantity
- Velocity – vector quantity

(c) SI units

- Speed – metre per second (m/s)
- Velocity – metre per second (m/s)

Comment:

√ *m/s can also be written as* ms^{-1}.

(d) formula for deriving the quantity.

- Speed = $\frac{\text{Distance travelled}}{\text{Time Taken}}$
- Velocity = $\frac{\text{Change in Displacement}}{\text{Time Taken}}$

8. Fill in the blanks:

As long as the _____ of an object changes, the velocity of the object will change. This is so even though the speed of the object _____.

- direction
- remains constant

9. When an object is under circular motion (i.e. moving in a circle), its speed is uniform but the velocity is changing. Explain.

- When an object is under circular motion, its direction of motion keeps changing.
- Speed involves only magnitude, which remains unchanged.
- In contrast, velocity involves both magnitude and direction. Since the direction is always changing, the velocity is not constant.

10. Ali Baba's donkey had travelled a distance of 2 km in 15 minutes at a constant speed. Suddenly, Ali spotted some masked assassins rushing in his direction, and he spanked his donkey so that it will go faster. The donkey was angry and instead moved 200 m in 5 minutes.

Calculate, in m/s, the speed of the donkey

(a) before Ali spotted the thieves

- Speed = Distance / Time
  = (2 x 1000 m) / (15 x 60 s)
  = 2.222
  = 2.22 m/s (3 sf)

(b) after Ali spotted the thieves.

- Speed = Distance / Time
  = (200 m) / (5 x 60 s)
  = 0.6666
  = 0.667 m/s (3 sf)

(B1) Average Speed & Velocity

11. Write down the formula for deriving:

(a) average speed.

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

(b) average velocity.

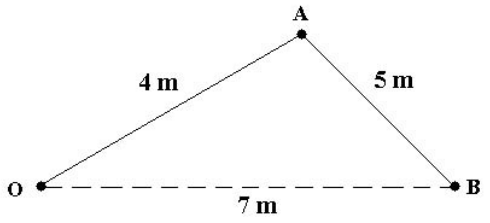
- Average velocity = $\frac{\text{Total Displacement}}{\text{Total Time}}$

12. Calculate the average speed of the donkey mentioned in question 10 above.

- Average speed = Total distance / Total time
  = (2 000 + 200 m) / [(15 + 5) x 60 s]
  = 1.833
  = 1.83 m/s (3 sf)

13. A body moves from point O to point A, and then to point B (to the east of O) in 5 s.

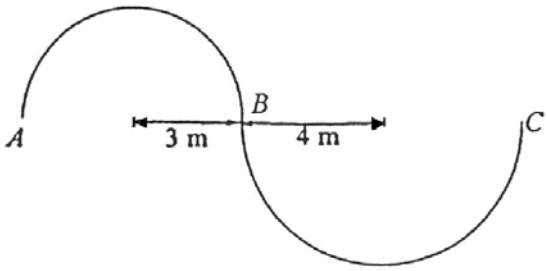
What is the average speed and average velocity of the body?



❖ Average speed = Total distance / Total time
= (4 + 5 m) / 5 s
= 1.8 m/s

❖ Average velocity = Total displacement / Total time
= 7 m / 5 s
= 1.4 m/s (to the east of point O)

14. A student walks along a curve ABC, which is made up of two semi-circular parts, AB and BC of radius 3 m and 4 m respectively. He takes 3 s to walk from A to B and 4.5 s to walk from B to C. Find the magnitude of his



(a) average speed

❖ Total distance travelled = Length of Arc AB + Length of Arc BC
= 0.5 (2 π r) + 0.5 (2 π R)
= 0.5 [2 π (3.0)] + 0.5 [2 π (4.0)]
= 21.991 m

❖ Average Speed = Total Distance ÷ Total Time
= 21.991 m ÷ (3 + 4.5 s)
= 2.932
= 2.93 m/s (3 sf)

(b) velocity from A to C.

❖ Total displacement = Length of line AC
= (3.0 x 2) + (4.0 x 2)
= 14 m

❖ Average velocity = Total Displacement ÷ Total Time
= 14 m ÷ (3 + 4.5 s)
= 1.866
= 1.87 m/s (in a direction to the right)

(C) Acceleration

15. Define acceleration.

- ❖ Acceleration is the rate of change of velocity.

16. Is acceleration a scalar or vector quantity?

- ❖ Vector quantity.

17. Fill in the blanks:

When the velocity of a body decreases, its acceleration is _____. Negative acceleration is known as _____.

- ❖ negative
- ❖ deceleration

(C1) Formula of Acceleration

18. Give the formula for calculating acceleration.

- ❖ Acceleration = $\frac{\text{Change in velocity}}{\text{Time taken}}$
- ⇨ Acceleration = $\frac{\text{Final Velocity – Initial Velocity}}{\text{Time taken}}$

Or simply: $a = \frac{v - u}{t}$

where a = acceleration
v = final velocity
u = initial velocity
t = time

19. What is the SI unit of acceleration?

- ❖ m/s^2

Eg **20. Gonzales moved from rest to a velocity of 100 m/s in 8 s. What was Gonzales' acceleration?**

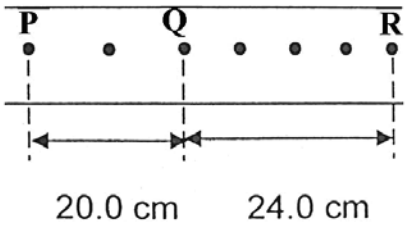
- ❖ $a = (v - u) / t$
  $= (100 \text{ m/s} - 0 \text{ m/s}) \div 8 \text{ s}$
  $= \underline{12.5 \text{ m/s}^2}$

21. Calculate the acceleration of a car starting from rest and accelerating to a velocity of 72 km/h in 20 s.

- 72 km/h = (72 x 1000 m) ÷ (1 x 3600 s)
  = 20 m/s

- $a = (v - u) / t$
  $= (20 \text{ m/s} - 0 \text{ m/s}) \div 20 \text{ s}$
  $= \underline{1 \text{ m/s}^2}$

22. A pupil uses a ticker-tape timer to investigate the movement of a trolley. The frequency of the timer is 50.0 Hz and the paper tape produced is as shown on the right. Calculate the average acceleration of the trolley in m/s^2.



- Time interval between 2 dots = 1 / 50.0
  = 0.02 s

- Average velocity from:

  - P to Q = Distance / Time
    = (20 ÷ 100 m) / (2 x 0.02 s)
    = 5 m/s

  - Q to R = Distance / Time
    = (24 ÷ 100 m) / (4 x 0.02 s)
    = 3 m/s

- Average acceleration = (v – u) / t
  = (5 m/s – 3 m/s) / (6 x 0.02 s)
  = 16.66
  = $\underline{16.7 \text{ m/s}^2}$ (3 sf)

(C2) Constant and Non-constant Acceleration

23. Fill in the blanks:

(a) Constant / uniform acceleration refers to a body's velocity _____ at a _____ rate.

- ❖ increasing
- ❖ constant

(b) Non-constant / non-uniform acceleration refers to a body's velocity _____ at a _____ rate.

- ❖ increasing
- ❖ increasing / decreasing

24. State whether a body (that starts from rest) is moving at constant or non-constant acceleration when its velocity is recorded as follows:

(a) 10 m/s in 1st second, 20 m/s in 2nd second, 30 m/s in 3rd second

- ❖ Constant acceleration.

Comment:

√ *The acceleration is constant at 10 m/s^2 during all 3 seconds.*

(b) 10 m/s in 1st second, 25 m/s in 2nd second, 50 m/s in 3rd second

- ❖ Non-constant (increasing) acceleration.

Comment:

√ *Acceleration during 0 and 1st second = (10 m/s – 0 m/s) / 1 s = 10 m/s^2*
√ *Acceleration during 1st and 2nd second = (25 m/s – 10 m/s) / 1 s = 15 m/s^2*
√ *Acceleration during 2nd and 3rd second = (50 m/s – 25 m/s) / 1 s = 25 m/s^2*

(c) 10 m/s in 1st second, 15 m/s in 2nd second, 18 m/s in 3rd second

- ❖ Non-constant (decreasing) acceleration

Comment:

√ *Acceleration during 0 and 1st second = (10 m/s – 0 m/s) / 1 s = 10 m/s^2*
√ *Acceleration during 1st and 2nd second = (15 m/s – 10 m/s) / 1 s = 5 m/s^2*
√ *Acceleration during 2nd and 3rd second = (18 m/s – 15 m/s) / 1 s = 3 m/s^2*

(C3) Acceleration Due to Free Fall

25. State the acceleration of free fall for a body near to the Earth.

- ❖ 10 m/s^2

Comments:

√ *A more exact value is 9.8 m/s^2.*
√ *In the absence of air-resistance, the acceleration of free fall will be constant at 10 m/s^2 (or 9.8 m/s^2)*

26. Fill in the blanks:

(a) The acceleration of a free-falling body on Earth is a result of the Earth's _____ pull on the object.

- ❖ gravitational

(b) The acceleration of a free-falling body on Earth is 10 m/s^2. This means that the _____ of the body increases by _____ in every second of its flight.

- ❖ velocity
- ❖ 10 m/s

27. How will the velocity of an object change when it is thrown vertically upwards?

- ❖ The velocity decreases by 10 m/s for every second of its flight.

Comment:

√ *When an object moves downwards (under free fall), its acceleration is 10 m/s^2. When it moves upwards, its acceleration is "the other way round", i.e. -10 m/s^2.*

28. Describe the motion of an object that is thrown vertically upwards and then allowed to drop and hit the ground.

- ❖ Moving up: Object is moving at constant acceleration of -10 m/s^2 (or constant deceleration of 10 m/s^2).
- ❖ At its highest point: Object is momentarily at rest.
- ❖ Moving down: Object is moving at constant acceleration of 10 m/s^2.

29. What is the velocity of a ball dropped from a height above the ground after 2 s?

- ❖ $a = (v - u) / t$
  $10\ m/s^2 = (v - 0\ m/s) / 2\ s$
  $v = \underline{20\ m/s}$

Comment:

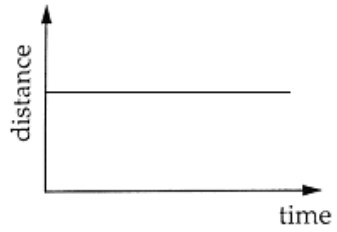
√ *Since the ball is in free-fall, it will have an acceleration of 10 m/s^2.*

(D) Graphs

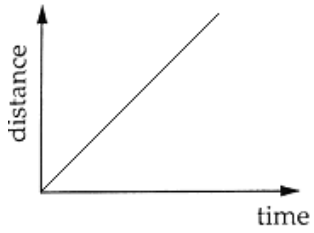
(D1) Distance-time Graphs

30. Draw distance-time graphs to represent the following motion of an object:

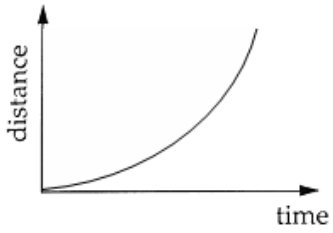
(a) At rest



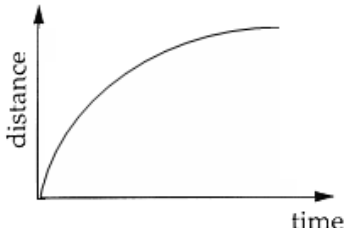
(b) Constant speed



(c) Accelerating



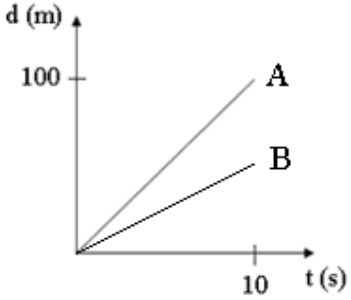
(d) Decelerating object



31. What does the gradient of a distance-time graph give us?

- Speed

Eg **32. The distance-time graph of two cars, A and B, is as shown below.**



(a) Describe qualitatively the motion of car A.

- From 0 – 10th second, the car moves at constant speed.
- It travels a total distance of 100 m after 10 seconds.

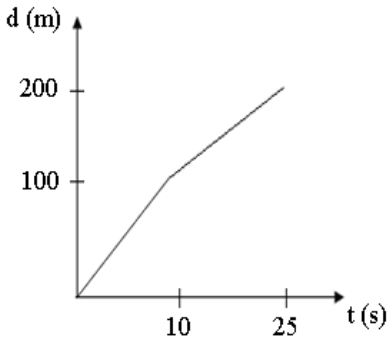
(b) Calculate the speed of car A during this time.

- Speed = Distance / Time
  = 100 m / 10 s
  = 10 m/s

(c) Which car moves at a faster speed? How can you tell?

- Car A.
- Because the gradient for car A is steeper.

33. The distance-time graph of a car is as shown below.



(a) Describe qualitatively the motion of the car.

- From 0 – 10th second, the car is moving at constant speed.
- It travels a distance of 100 m after 10 seconds.

- From 10th – 25th second, the car is moving at a constant speed, but at a smaller magnitude than that from 0 – 10th second.
- It travels a total distance of 200 m after 25 seconds.

(b) Calculate the average speed of the car during this time.

- Average Speed
  = Total Distance / Total Time
  = 200 m / 25 s
  = <u>8 m/s</u>

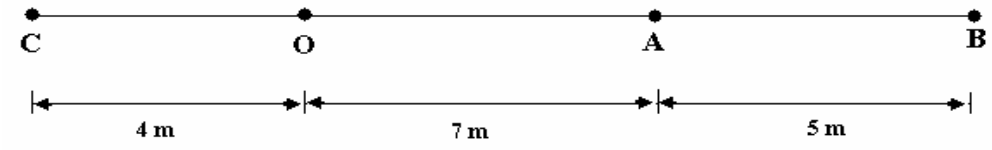
34. Distance is a scalar quantity whereas displacement is a vector quantity. Thus, state two differences between the two quantities important for distinguishing between distance-time graphs and displacement -time graphs.

- Distance cannot decrease in value whereas displacement can.
- Distance cannot assume a negative value whereas displacement can.

35. The gradient of a distance-time graph represents speed. What does the gradient of a displacement-time graph represent?

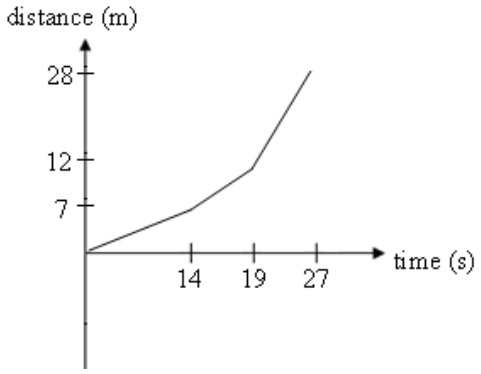
- Velocity

36. The original position of object X is at O. X takes 14 seconds to reach point A, and another 5 seconds to reach point B. Next, it makes a U-turn, and travels in the opposite direction to reach point C, taking a further 8 seconds.

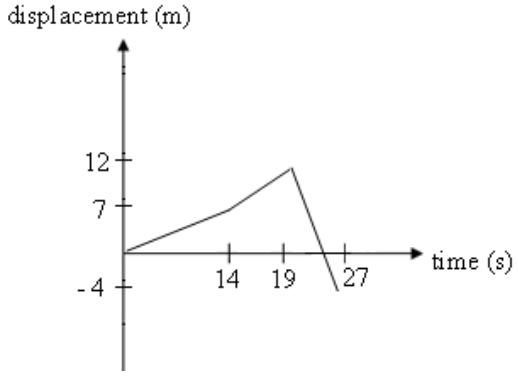


Sketch the distance-time and displacement-time graphs for the above scenario, given that X travels at constant speed throughout the journey.

❖ Distance-Time



❖ Displacement-Time



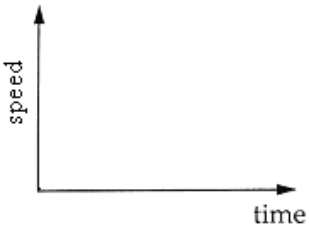
Comment:

√ *Distance will always be positive as it does not take into consideration the direction of the object. In contrast, displacement can be negative, such as in this case, where the object travels past its original position to a point 4 m away from where it starts off.*

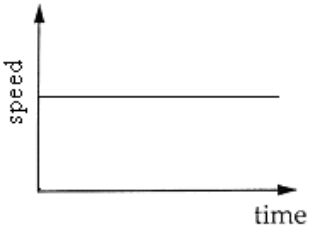
(D2) Speed-Time Graphs

37. Draw speed-time graphs to represent the following motion of an object:

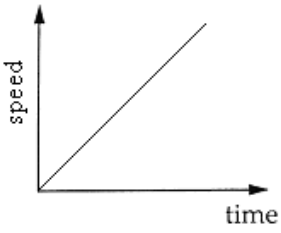
(a) At rest



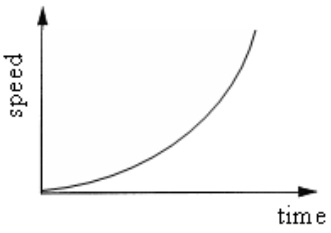
(b) Constant speed



(c) Constant acceleration

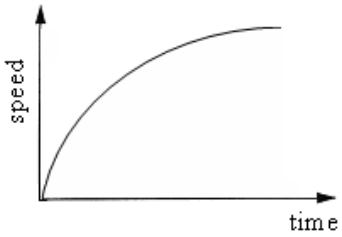


(d) Non-uniform acceleration



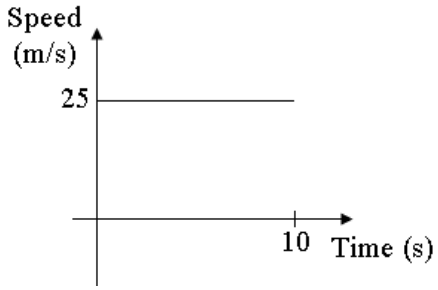
Increasing acceleration

OR:



Decreasing acceleration

38. The speed-time graph of a body is shown below.



(a) State whether the body is moving or at rest.

- The body is moving.

(b) What can you say about the motion of the body?

- The body moves at a constant speed of 25 m/s for 10 s.

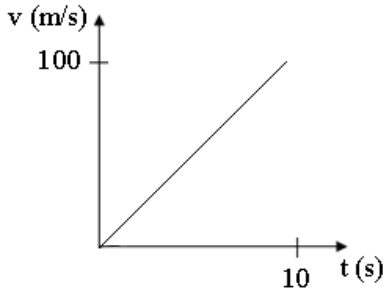
39. Speed is a scalar quantity whereas velocity is a vector quantity. Thus, state one difference between the two quantities important for distinguishing between speed-time graphs and velocity-time graphs.

- ❖ Speed cannot assume a negative value whereas velocity can.

40. What does the gradient of a velocity-time graph give us?

- ❖ Acceleration

Eg **41. The velocity-time graph of a car is as shown below.**



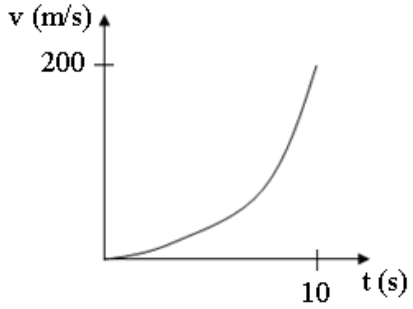
(a) Describe qualitatively the motion of the car.

- ❖ The car started from rest.
- ❖ From 0 – 10th second, the car is moving at a constant acceleration.
- ❖ Eventually, it reaches a velocity of 100 m/s at the 10th second.

(b) Calculate the car's acceleration from t = 0 - 10 s.

- ❖ $a = (v - u) / t$
  $= (100 \text{ m/s} - 0 \text{ m/s}) \div 10 \text{ s}$
  $= \underline{10 \text{ m/s}^2}$

Eg **42. The velocity-time graph of a car is as shown below.**



Describe qualitatively the motion of the car.

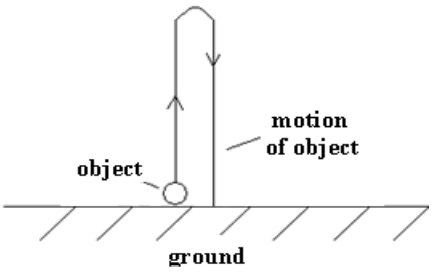
- ❖ The car started from rest.
- ❖ From 0 – 10th second, the car is moving at an increasing acceleration (i.e. the acceleration is not uniform).
- ❖ Eventually, it reaches a velocity of 200 m/s at the 10th second.

<u>Comment:</u>

√ *The <u>gradient</u> of the velocity-time graph represents the car's <u>acceleration</u>. Since the slope of the curve becomes increasingly steeper over the 10 s (i.e. the gradient is increasing), the car must be travelling with an increasing acceleration.*

Eg

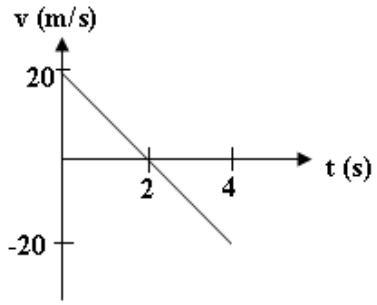
43. An object is being projected vertically upwards with an initial velocity of 20 m/s. It reaches its maximum height in 2 seconds, and then falls back to level ground as shown in the diagram. Sketch the following graphs to represent the object's motion.

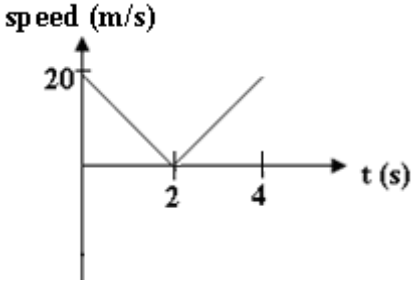


(a) Velocity-time graph

(b) Speed-time graph

❖ Answer:





Comments:

√ *When the stone reaches its maximum height of 2 m, it is momentarily at rest with a velocity is 0 m/s.*

√ *When the stone goes up, its direction of motion is upwards; when it goes down, its direction is downwards. Thus there is a change in direction. As velocity is a vector quantity, it will acquire a negative sign due to the change in direction. In contrast, speed is a scalar quantity, and is always positive.*

Eg **44. A car travels at a constant velocity of 10 m/s for 2 seconds, before decelerating to rest in 0.5 second. It then reverses its direction, accelerates for 0.5 second, and moves at a constant velocity of -10 m/s for 2 seconds.**

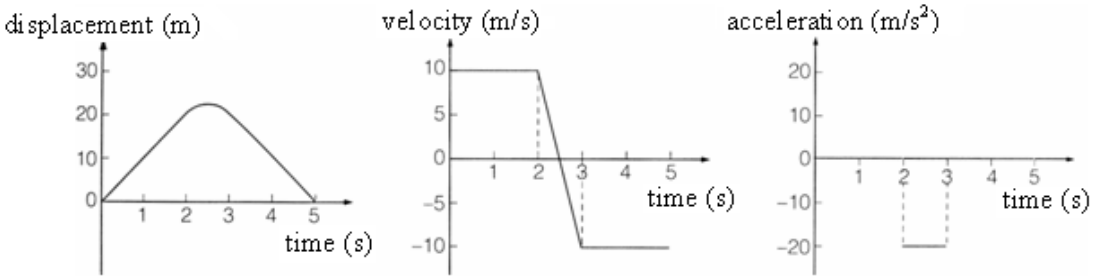
Represent the motion of the car with:

(a) a displacement-time graph

(b) a velocity-time, and graph

(c) an acceleration-time graph.

- Answer:



Comments:

(a) Displacement-Time graph

0 - 2 secs → Constant velocity → Straight line sloping upwards
2 – 2.5 secs → Decelerating → Curve with decreasing gradient (positive)
2.5 – 3 secs → Accelerating → Curve with increasing gradient (negative)
3 – 5 secs → Constant velocity → Straight line sloping downwards

(b) Velocity-Time graph

0 - 2 secs → Constant velocity → Straight horizontal line
2 – 2.5 secs → Decelerating → Straight line sloping downwards
2.5 – 3 secs → Accelerating (in opposite direction) → Straight line sloping downwards
3 – 5 secs → Constant velocity (in opposite direction) → Straight horizontal line

(c) Acceleration-Time graph

0 - 2 secs → Constant velocity → No acceleration → Straight horizontal line on x-axis.
2 – 2.5 secs → Constant deceleration → Straight horizontal line [(-10 – 0) / 0.5 = -20 m/s^2]
2.5 – 3 secs → Constant acceleration → Straight horizontal line [(0 – 10) / 0.5 = -20 m/s^2]
3 – 5 secs → Constant velocity → No acceleration → Straight horizontal line on x-axis.

(E) Area under Speed-Time / Velocity-Time Graph

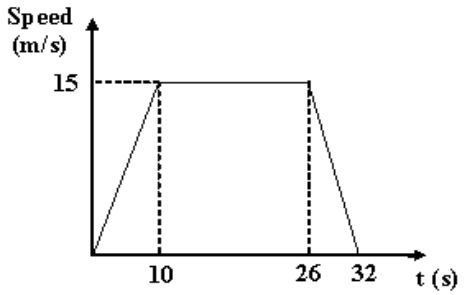
45. What does the area under a speed-time graph give us?

- ❖ Distance travelled by the object.

Eg **46. A car accelerates uniformly from rest to a speed of 15 m/s in 10.0 s. After travelling at his constant speed for another 16.0 s, it is brought to rest with a uniform deceleration in 6.0 s.**

(a) Draw a graph of speed against time to represent the car's motion.

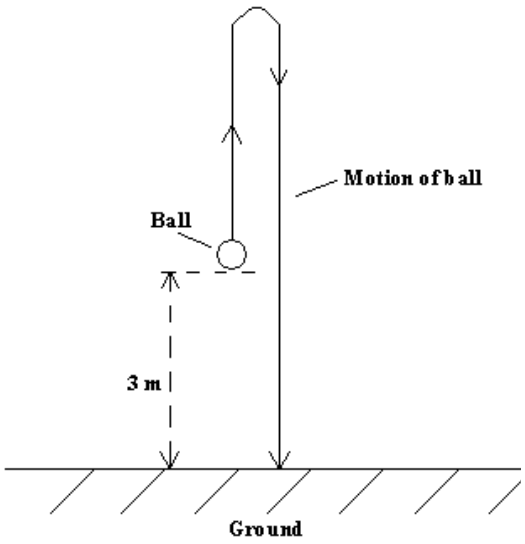
❖



(b) Calculate the total distance travelled by the car.

- ❖ Distance travelled = Area under the graph
  = ½ (15) (10) + (15) (16) + ½ (15) (6)
  = <u>360 m</u>

Eg **47. A tennis ball is being thrown vertically upwards at a speed of 25 m/s at a height of 3 m above ground level as shown in the diagram. Determine:**



(a) The time taken for it to reach the maximum height.

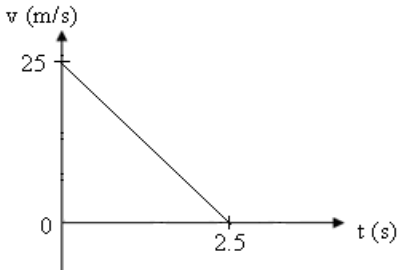
- ❖ The known values:
  $a = -10\ m/s^2$
  $u = 25\ m/s$
  $v = 0\ m/s$

- ❖ $a = (v - u) / t$
  $-10\ m/s^2 = (0\ m/s - 25\ m/s) / t$
  $t =$ <u>2.5 s</u>

<u>Comment:</u>

√ *The ball is moving upwards against the flow of gravity. Thus, its acceleration is negative.*

(b) The maximum height reached from where the ball is thrown.



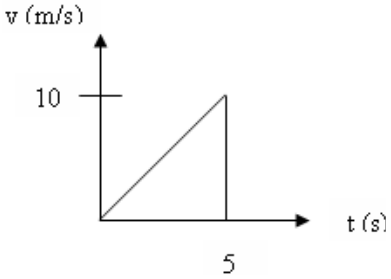
❖ Maximum height = Area under the graph
= ½ (25) (2.5)
= 31.25
= <u>31.3 m</u> (3 sf)

48. A cyclist moves from his initial rest position with a constant acceleration of 2 m/s^2.

(a) What velocity will he be travelling at after 5 s?

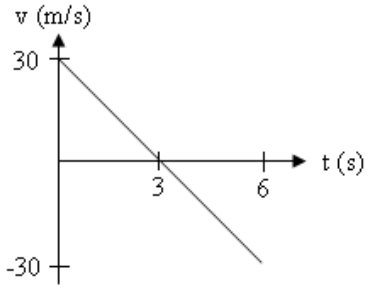
❖ $a = (v - u) / t$
$2 \text{ m/s}^2 = (v - 0 \text{ m/s}) / (5 \text{ s})$
$v = \underline{10 \text{ m/s}}$

(b) What is the distance travelled during 5 s?



❖ Distance travelled = Area under the graph
= 0.5 x 10 x 5
= <u>25 m</u>

49. Consider the velocity-time graph of a stone that is being thrown upwards.



(a) What can you say about the motion of the stone as it moves upwards?

❖ The stone moves at a constant deceleration of 10 m/s^2.

(b) Determine the maximum height reached by the stone.

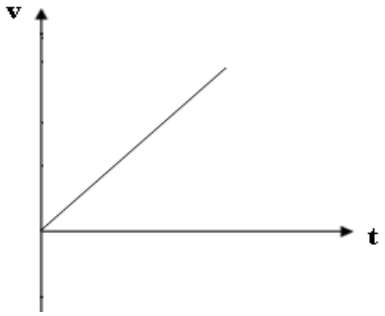
❖ Maximum height = Area under graph from t = 0 s to t = 3 s.
= ½ (30) (3)
= <u>45 m</u>

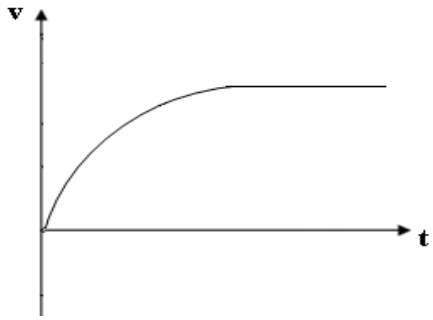
(F) Terminal Velocity

50(a) Sketch the velocity-time graph of a body released from rest, and allowed to fall downwards to the ground under the following scenario:

(i) Body does not experience air resistance **(ii) Body experiences air resistance.**

- Answer:





(b) Explain the difference between the two graphs in part (a).

- When there is no air resistance, a body will experience free fall with a constant acceleration of 10 m/s^2. Thus, the v-t graph is a straight line with a constant positive gradient.
- However, in the presence of air resistance, the body will slow down and fall with decreasing acceleration (i.e. velocity increases, but at a decreasing rate). Eventually, as its acceleration keeps decreasing, a point will be reached when its acceleration becomes 0 m/s^2. At this point, the body will move downwards at constant velocity. Thus, the v-t graph is a sloping curve with a decreasing gradient initially, before becoming a horizontal line.

51. When an object of constant weight falls downwards in the presence of air resistance, a point will be reached when the object no longer accelerates but moves downwards at constant velocity. What is the term given to this constant velocity?

- Terminal velocity

52. Sketch a velocity-time graph to illustrate terminal velocity.

- Answer: