# A Complete Course in Physics ( Graphs ) - Extended First Edition

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# Preface

The First Edition was a collection of tough problems but the file was small , only being 12 pages not meeting the Amazon crieteria of minimum 24 pages for paperback printing. Moreover, the toughness of problems required that answers be provided Intext.

Graphs is a very catchy topic for +1/+2 level and Competitive Exams, it is apparent that books in this particular topic would be written and available soon in the near future.

# Acknowledgements

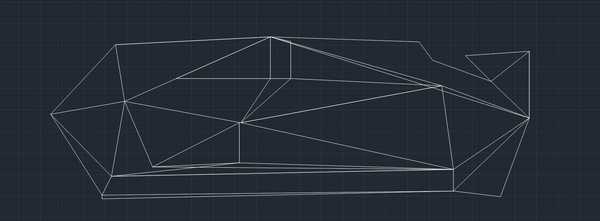
I first of all thank my son Manas Kalia for the love and support.

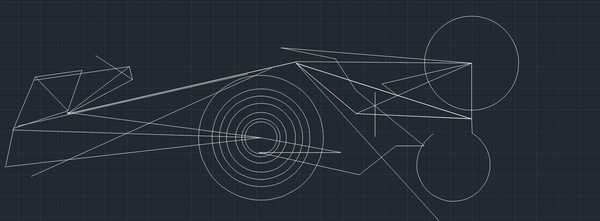
Today, he is writing an essay on “Myself” for all of us

1 My name is Manas.  
2 I am six years old.  
3 I study in KGF.  
4 I like to play ludo.  
5 I love my family.

I would also like to show few of his designs, he has made while playing on computer.











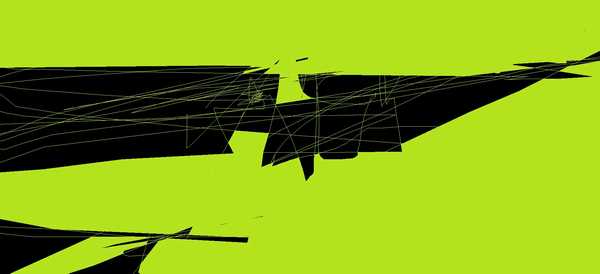


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# 1 Concepts of Graphs

## 1.1 The Equations of motion and the origin of Graph Handling

### 1.1.1 [↓](" \l "index-The-First-Equation)The First Equation

The Equation *v* = (*dx*)/(*dt*) in linear motion implies

i) The **Slope** of **Position-Time Graph** is **Instantaneous Velocity.**

ii) The **Area** under the **Velocity-Time Graph** is **Change in Position**.

{ The second one requires the manipulation , *dx* = *vdt* i.e. ∫*dx* = ∫*vdt* }

The equations can be further manipulated to obtain the Speed Time Graph , where

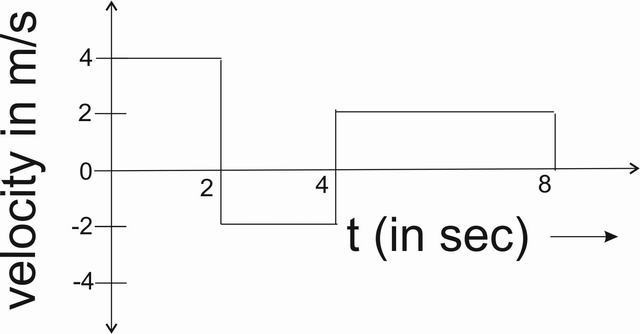
speed = rate of change of distance wrt time

Few of the following examples illustrate this concept:

Example: On a displacement-time graph, two straight lines make angles of 30° and 60° with the time-axis. The ratio of the velocities represented by them is

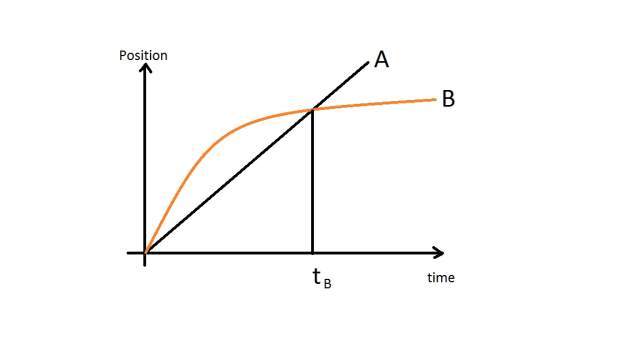
a) 1:√(3)  
b) 1:3  
c) √(3):1  
d) 3:1  
{ Hint: The velocity in a displacement-time is given by the slope of the curve. Slope = tan(gent) of angle of inclination of s-t graph. This gives the respective ratios tan 30*o* / tan 60*o*   
Answer: b) is the correct answer. }

Example: A body is moving in a straight line as shown in velocity-time graph. The displacement and distance travelled by body in 8 second are respectively:

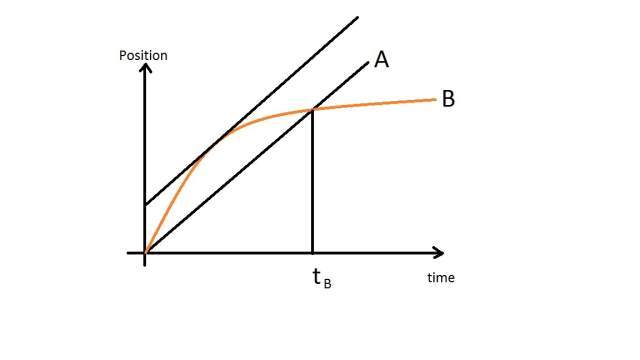


a) 12 m, 20 m  
b) 20 m, 12 m  
c) 12 m, 12 m  
d) 20 m, 20 m  
{ Hint: The displacement in a velocity-time graph is given by the area under the graph with proper signs. From 0s - to 2s , the area is 8m . From 2s - to 4s , the area is -4m . From 4s - to 8s , the area is 8m. Adding these 3 values , we get 8m + (-4m) + 8m = 12m. } The distance in a v-t graph is given by the absolute area under the graph. So, taking the absolute values of individual area divisions, we get 8m + 4m + 8m =20m  
Answer: a) is the correct answer. }

Example: The graph shows position as a function of time for two trains running on parallel tracks. Which statement is true?

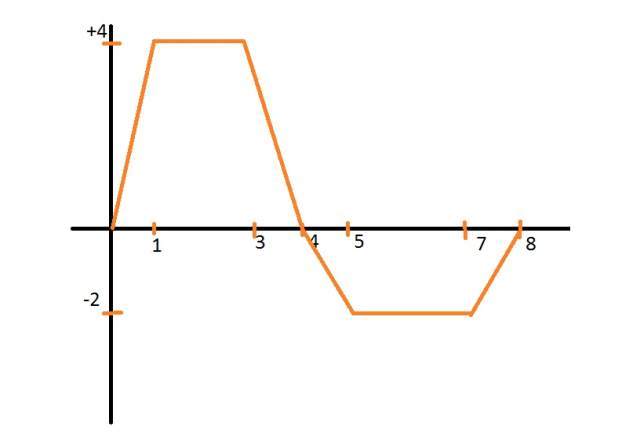


a) At time t*B* both trains have the same velocity.  
b) Both trains have the same velocity at some time after t*B* .  
c) Both trains have the same velocity at some time before t*B* .  
d) Somewhere on the graph, both trains have the same acceleration.  
{ Hint: Depending on the question requirements, we’ll have to check all the assertions one by one.  
a) In a position time graph, the slope gives velocity. It can be clearly seen that Graph B has a much lower slope than Graph A at time *tB*. So, the assertion is wrong.  
b,c) By drawing a line parallel to the line A which is a tangent to Graph B , it can be seen where the two graphs have same slope. It is clear that the graphs have same slope between 0 and *tB* as noted from the figure. So, assertion b is wrong while c is correct.



d) As the Graph A has a constant slope, so the acceleration of body A is zero. Whereas Graph B is constantly turning, so the slope can be assumed to be non-zero throughout. According to some revelations, however it is noted that the figure is not clear enough to show whether Graph B is straight after *tB* or bending. In case it is assumed to be straight, then after *tB* both trains will have same (zero) acceleration. Also at start both have large (infinite) accelration, in which case the ratio of the two large ( infinite ) values may be calculated if initial conditions are mentioned and is required.  
At our level we would assume this assertion to be wrong, however making a note that the image should have been more clearly presented.  
Answer: c) is the correct assertion. }

Example: The velocity-time graph of a particle in linear motion is as shown. Both v and t are in SI units. The displacement of the particle is



a) 6 m  
b) 8 m  
c) 16 m  
d) 18 m  
{ Hint : For displacement calculations, between 0 - to 4 , area of the positive trapesium = (4+2)X4 = 24  
between 4 - to 8, area of negative trapesium = (2+4)X(-2) = -12.  
So , the answer is +12 , which is not in the options.   
So , the anser is None of these. }

### 1.1.2 [↓](" \l "index-The-Second-Equation)The Second Equation

Proceeding similar to above, the equation *a* = (*dv*)/(*dt*) implies

i) The **Slope** of **Velocity-Time Graph** is **Instantaneous Acceleration**.

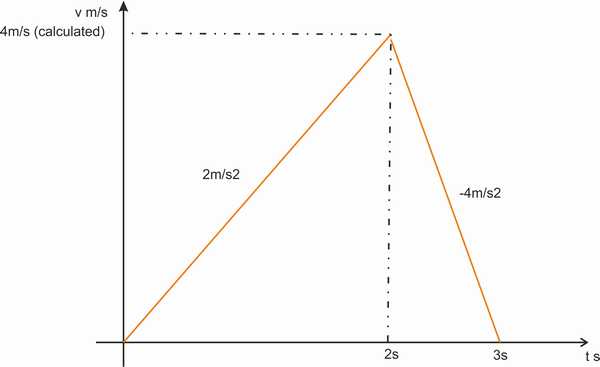
ii) The **Area** under **Acceleration-Time Graph** is **Change in Velocity**.

{ The second one requires the manipulation , *dv* = *adt* i.e. ∫*dv* = ∫*adt* }

A few of the following examples illustrate it.

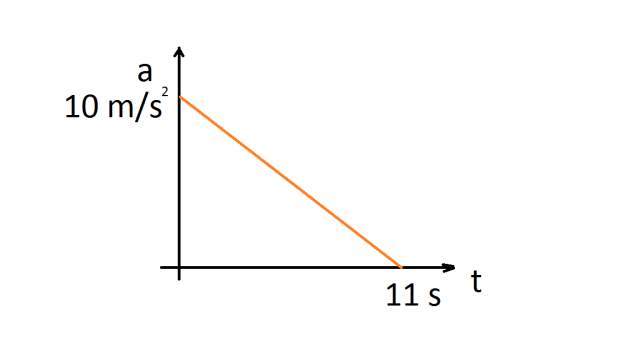
Example: A car starts from rest acquires a velocity v with uniform acceleration 2*ms*− 2 then it comes to stop with uniform retardation 4*ms*− 2 . If the total time for which it remains in motion is 3 sec, the total distance travelled is:

a) 2 m  
b) 3 m  
c) 4 m  
d) 6 m   
{Hint: For solving this problem, we draw the graph of the problem,



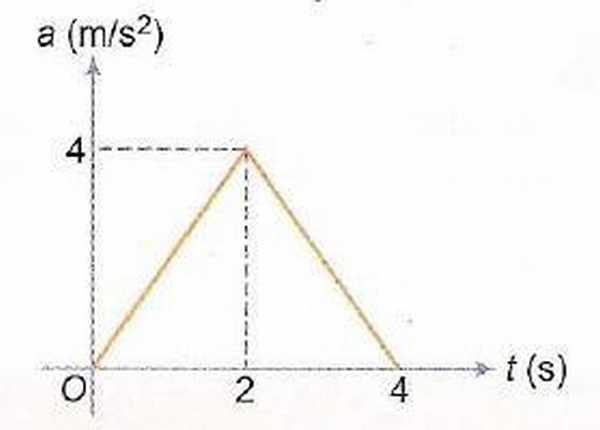
Accordning to graph, let the time when it reaches maximum velocity be T, and the maximum velocity be V.   
 ⇒ V = 2XT and also V = 4X(3-T)  
Equating the equations,  
2T = 12-4T = V  
 ⇒ 6T = 12  
 ⇒ T = 2  
 ⇒  V = 2T = 4  
Calculating the area under the graph using the calculated parameters, Area = 1/2 X 4 X 3 = 6m  
So , area under the graph is 6m = displacement . Also, as all the area is on the positive side, so distance = 6m.   
}

Example: A particle starts from rest. Its acceleration (a) vs time (t) is as shown in the Figure. The maximum speed of the particle will be

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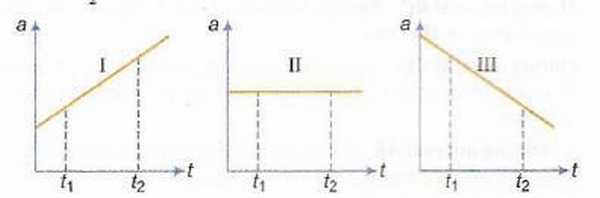
a) 110 m/s  
b) 55 m/s  
c) 550 m/s  
d) 660 m/s  
{ Hint : Writing the equation of the graph , we get (*a*)/(10) + (*t*)/(11) = 1  
 ⇒ *a* = (10)/(11)(11 − *t*)  
Integrating, ( we will assume initial velocity to be zero as the body starts from rest. )  
*v* = (10)/(11)(11*t* − (1)/(2)*t*2)  
Substituting *t* = 11*s*  
*v*11*s* = 55*m* ⁄ *s*  
Answer: b) is the correct answer }

Example: Acceleration-time graph of a particle moving in a straight line is shown in Figure. The velocity of particle at time t = 0 is 2 m/s. Velocity at the end of fourth second is

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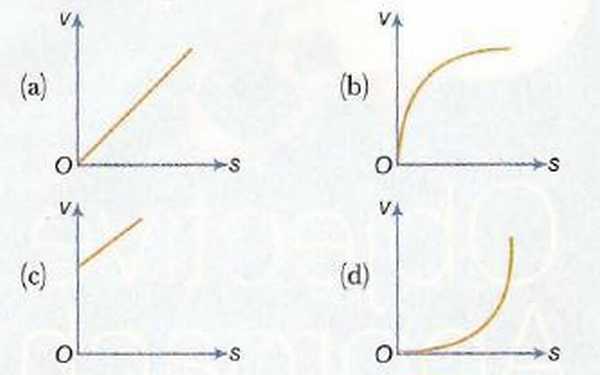
a) 8 m/s  
b) 10 m/s  
c) 12 m/s  
d) 14 m/s  
{ Hint: Area under the acceleration-time graph is change in velocity. Area of the triangle is Half ( into ) base ( into ) altitude = 8m/s. Adding the initial value of 2m/s , we get 2 + 8 = 10m/s.   
Answer: b) is the correct answer }

Example: Each of the three graphs represents acceleration vs time for an object that already has a positive velocity at time *t*1 . Which graph/graphs show an object whose speed is increasing for the entire time interva1 between *t*1 and *t*2 ?

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a) Graph I only  
b) Graphs I and II  
c) Graphs I and III  
d) Graphs I, II and III  
{Hint: Area under the acceleration time graphs give change in velocity. In all the three figures, the area under the graphs are +ve, hence velocity is increasing in all cases. As the initial velocity is +ve , in all three cases the velocity remains throughout positive. So , the speed is also increasing in all cases.}

Example: A body starts from rest and moves along a straight line with constant acceleration. The variation of speed v with distance s is given by the graph

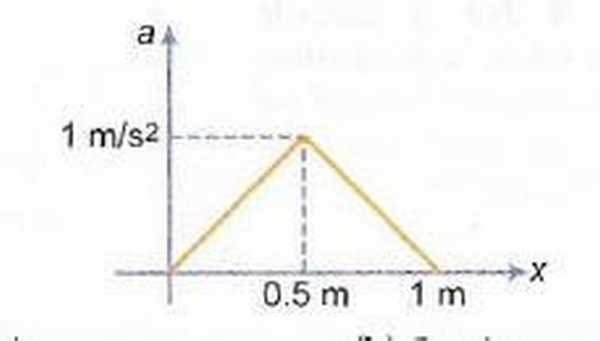
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{ Hint: The problem given has *vo*= 0   
Now acceleration = constant ( lets say k ) = (*dv*)/(*dt*)  
 ⇒ *k* = *v*(*dv*)/(*ds*)  
 ⇒ ∫0*vvdv* = ∫0*skds*  
 ⇒ *v* = √(2*ks*)  
The graph is proportional to square root function  
Hence , b (as it is the only graph with such a property )  
Answer : b) is the correct graph }

### 1.1.3 The Acceleration-Position Graph Variate

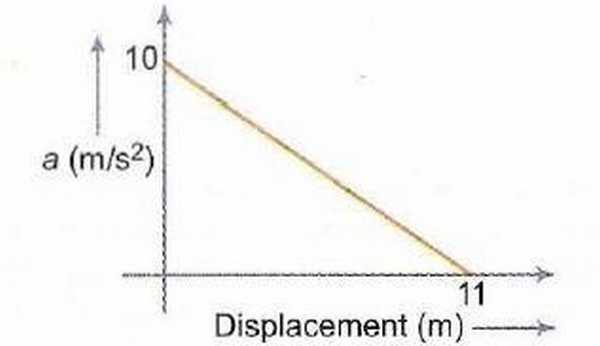
This kind of graph requires the manipulation of the Equation *a* = (*dv*)/(*dt*) as follows  
*a* = (*dv*)/(*dx*).(*dx*)/(*dt*)  
 ⇒ *a* = (*dv*)/(*dx*).*v*  
 ⇒  *adx* = *vdv* and integration can be performed to further solve it.

Example: A body, initially at rest, starts moving along x-axis in such a way that its acceleration vs displacement plot is as shown in the Figure. The maximum velocity of the particle is

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a) 1 m/s  
b) 6 m/s  
c) 2 m/s  
d) None of these  
{ Hint : The area under the a-x graph gives change in (*v*2)/(2) as can be evaluated by Integration method. The area of triange is (0.5) X (1) X (1) = 0.5  
 ⇒ v = 1m/s . Initial position is given to be 0 in the graph. Hence, we take only the positive sign.  
Answer : a) is the correct answer. }

Example : A particle initially at rest, it is subjected to a non-uniform acceleration a, as shown in the gure. The maximum speed attained by the particle is



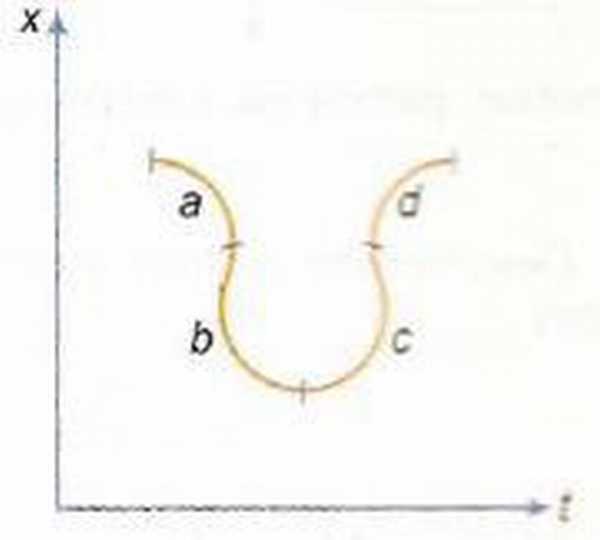
a) 605 m/s  
b) 110 m/s  
c) 55 m/s   
d) 110 m/s  
{ Hint: The answer is 55m/s as calculated in the example above(In the second equation section). Hence, c) is the correct response.  
Answer : c) is the correct answer. }

## 1.2 Other Types of Graphs

### 1.2.1 Sign of Acceleration from Position-Time Graph

The sign of Acceleration can be determined from the Position-Time Graph. The methodology involves of looking at the Concavity of the Graph  
i) If the graph is Concave-Up, the Acceleration is Positive.  
ii) If the graph is Concave-Down, the Acceleration is Negative.  
iii) If the graph is a straight line, the Acceleration is ZERO. { Irrespective of any other factor , such as the slope or direction of line}

Example: The graph given below is a plot of distance vs time. For which labelled region is the “Velocity Positive and the Acceleration Negative”

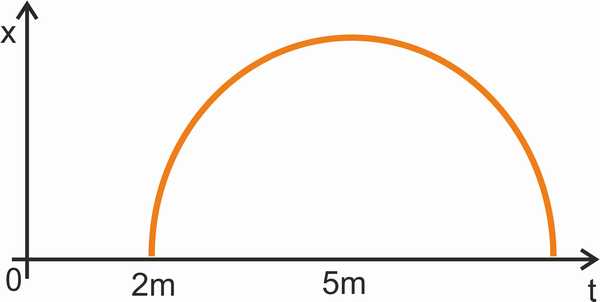


a) a  
b) b  
c) c  
d) d   
{ Hint: By the above mentioned propositions, d) is the required section with positive velocity and negative accleration. }

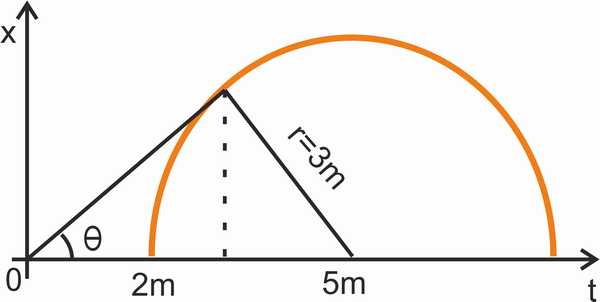
### 1.2.2 [↓](" \l "index-The-Average-Velocity-/-Instantane)The Average-Velocity / Instantaneous Velocity , Equal Case

We know , that ( in a x-t graph) the slope of the Secant is the Average Velocity , whereas the slope of Tangent is the Instaneous Velocity. The point where these two lines coincide, is the point where Average Velocity is equal to Instantaneous Velocity.

Example: Position-time graph is shown which is a semicircle from t = 2 to t = 8 s. Find time t at which the instantaneous velocity is equal to average velocity over first t seconds,



a) 4.8 s  
b) 3.2 s  
c) 2.4 s  
d) 5 s  
{ Hint: The tangent from 0 to the circle is drawn. It’s normal passes through the center of the circle. Time at this instant needs to be calculated.  
If H=5 , R = 3 , Length of tangent = 4. (By Pythagoras.)  
Angle which the tangent makes with the t axis is *θ* = *sin*− 1(3 ⁄ 5)  
So, the projection of tangent on t axis ( i.e. the required time ) = 4 cos *θ* = 4 × (4)/(5) = 3.2

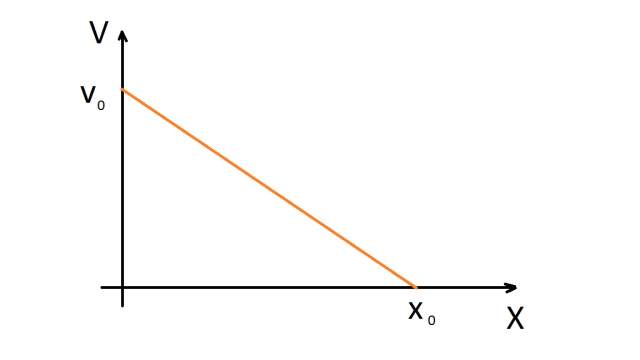


}

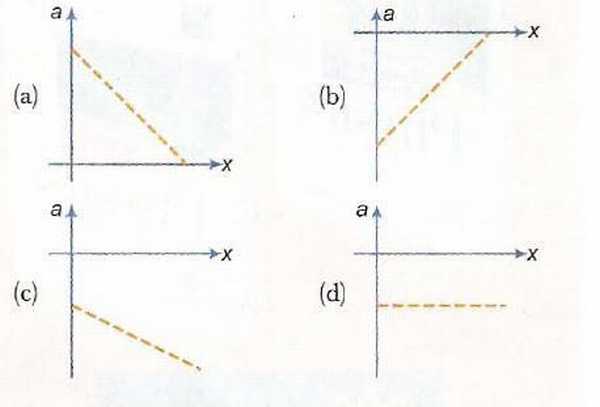
### 1.2.3 The Velocity-Displacement Case

This can be handled in a similar way as Acceleration-Displacement case by integrating the respective equation. Here the problem is of v = f(x) type, which can be integrated by writing (*dx*)/(*dt*) = *f*(*x*)  
i.e. dx = f(x)dt

Example: The velocity-displacement graph of a particle moving along a straight line is shown here.

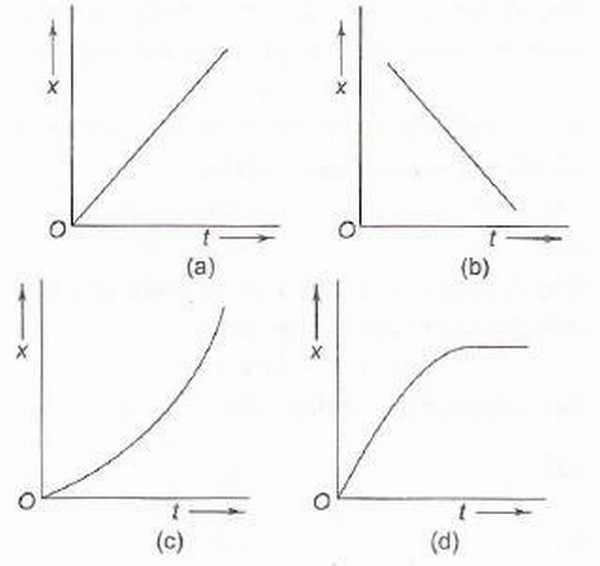
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The most suitable acceleration-displacement graph will be



{Hint: Using Co-Ordinate Geometry Result studied in +1 Mathematics, we get the equation of the graph  
(*v*)/(*vo*) + (*x*)/(*xo*) = 1  
We are supposed to find the a-x graph from this.  
So, we rewrite this equation as *v* = *vo*(1 − (*x*)/(*xo*))  
Differentiating, we get *a* =  − (*vo*)/(*xo*) = *constant*  
Hence d) is the requisite graph.  
Answer: d) is the correct answer. }

Example. The velocity (v) of a body moving along the postive x-direction varies with displacement (x) from the origin as p v = k x , where k is a constant. Which of the graphs shown in Fig. correctly represents the displacement-time (x - t) graph of the motion?

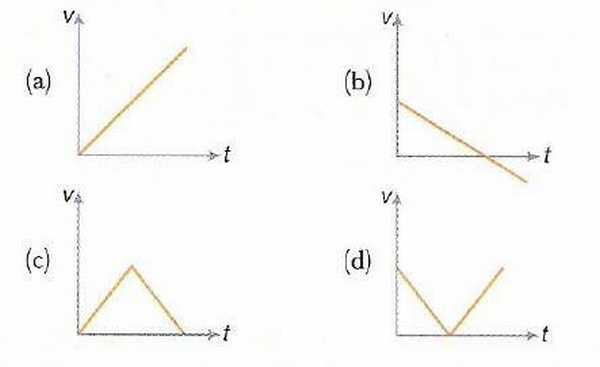
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{Hint: The variable p removes the dependence of v on x and gives emphasis only on the first condition that body is moving along positive x-direction. In Graphs a) ,c) body is moving along positive x-direction, However, a) is a specific case when p is proportional to x and not the general case. Only c) covers the general case of all possible p and still moving in positive x-direction. Hence c) is the correct answer  
Answer: c) is the required answer. }

### 1.2.4 [↓](" \l "index-Motion-Under-Free-Fall)Motion Under Free Fall due to Gravity

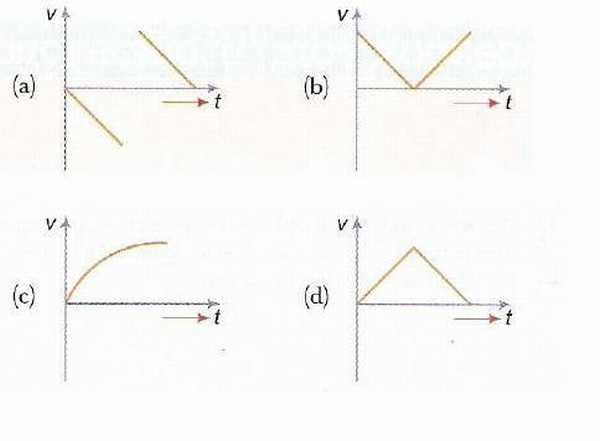
In such examples, the governing equations rule and the coordi-nate system needs to be properly chosen.

Example: Which of the following graphs correctly represents velocity-time relationship for a particle released from rest to fall freely under gravity?

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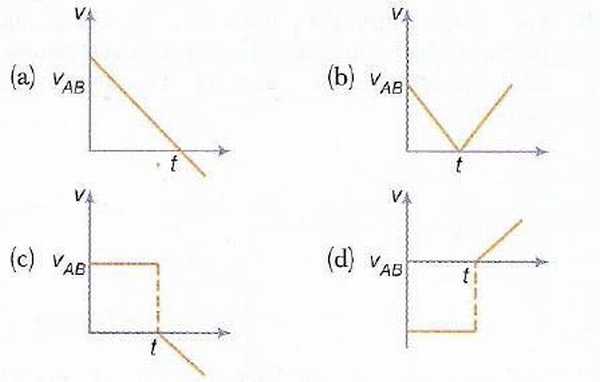
{ Hint: If we take the downward axis as positive, v will keep on increasing till the object hits something.   
So, a) is the correct answer.}

Example: The velocity-time graph of a body falling from rest under gravity and rebounding from a solid surface is represented by which of the following graphs?

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{ Hint: At rebound, the velocity would become negative of itself if the collision is perfectly elastic. Only in graph (a) such a thing is happening.   
a) is the correct answer.}

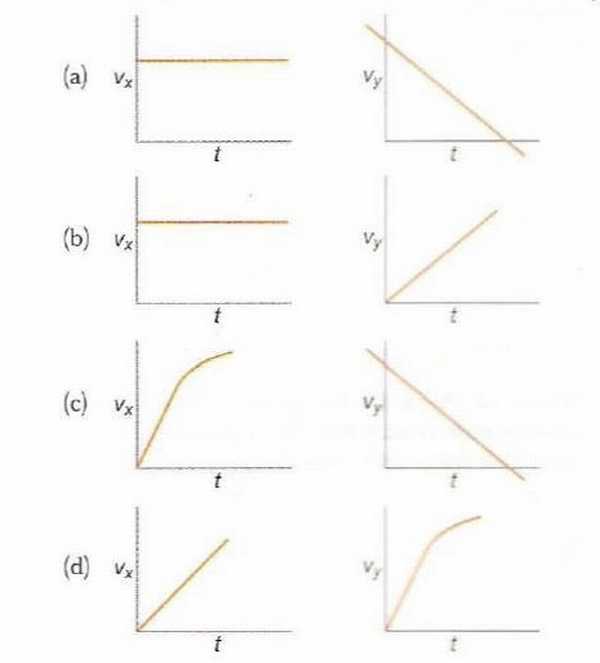
Example: A body A is thrown vertically upwards with such a velocity that it reaches a maximum height of h. Simultaneously another body B is dropped from height h. It strikes the ground and doesn’t rebound. The velocity of A relative to B vs time graph is best represented by (upward direction is positive.)

****

{ Hint: Before the strike, body A has velocity u-gt whereas body B has velocity -gt. So, a constant difference of u remains. Before strike, u-gto+gto=u . However , after that it is u-gt , the time being to=u/g of strike. So, the negative slope line starts from the x-axis and a discontinuity comes into picture.   
So , C) is the required graph.}

### 1.2.5 Projectile Motion

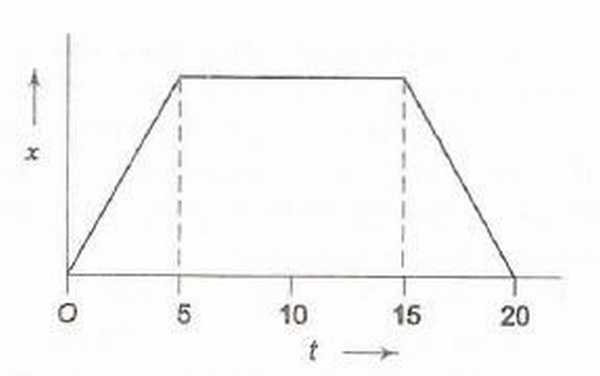
Example: A shell is fired from a gun at an angle to the horizontal. Graphs are drawn for its horizontal component of velocity *vx* and its vertical component of velocity *vy*.

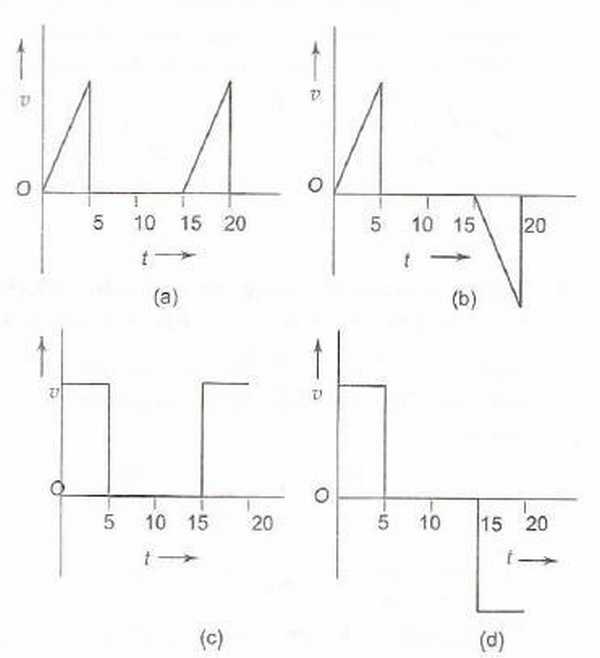
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{ Hint: *vx* would remain constant as ucos*θ* and *vy* would linearly decrease and go negative after maximum height is attained(if the fire angle is +ve).  
So, a) is the requisite graph.}

### 1.2.6 Miscelleneous

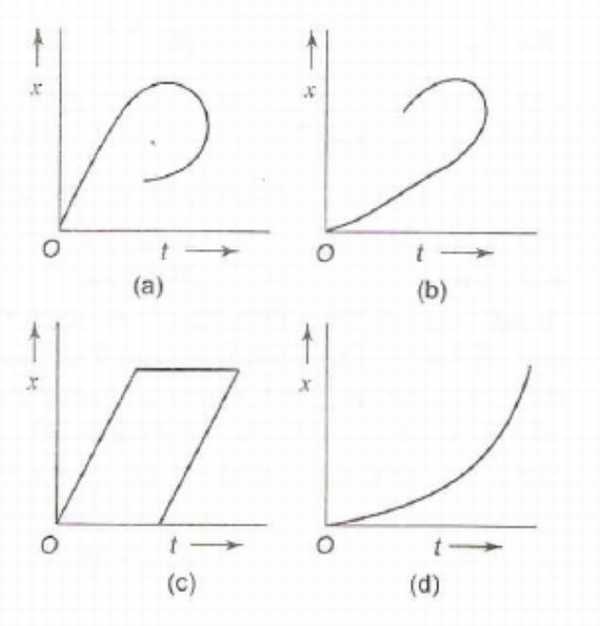
Example. Figure shows the displacement-time ( x-t ) graph of body moving in a straight line. Which one of the graphs shown in Fig. represents the velocity- time ( v-t ) graph of the motion of the body.

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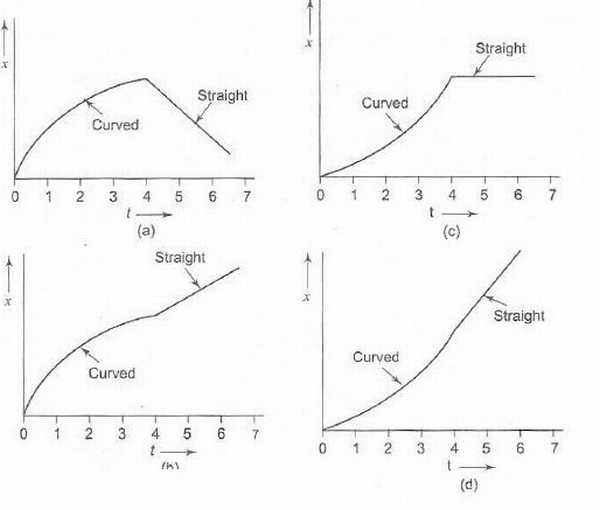
{ Hint: The graph has initially (0-5) a +ve slope, then zero slope and then (15-20) an equal -ve slope  
So, d) is the correct answer. }

Example. Which of the displacement-time (x−t) graphs shown in Fig. can possibly represent one dimensional motion of a particle?

****

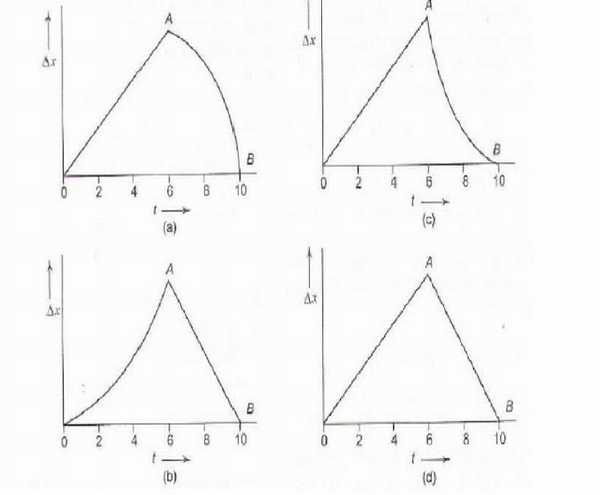
{ Hint: The object cannot be at two positions on a single time instant,  
So, d) is the correct option. }

Example. A car starts from rest, accelerates uniformly for 4 seconds and then moves with uniform velocity. Which of the (x-t) graphs shown in Fig. represents the motion of the car upto t = 7 s?

****

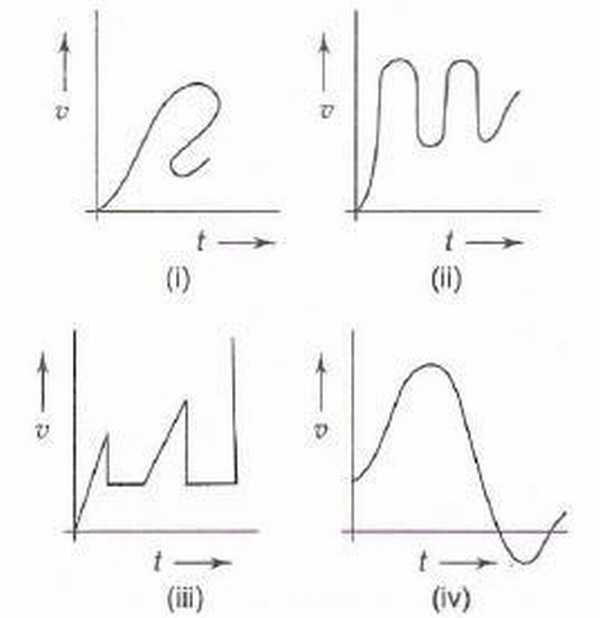
{ Hint: As the car is accelerating upto 4 seconds, the graph should be concave up. Further ahead , it moves with constant velocity , so a positive slope ahead of 4 seconds.   
d) is the correct answer. }

Example. Two stones are thrown up simultaneously with initial speeds of *u*1 and *u*2, (*u*2 > *u*1) . They hit the ground after 6 s and 10 s respectively. Which graph in Fig. correctly represents the time variation of △*x* = *x*2 − *x*1, the relative position of the second stone with respect to the first upto t = 10 s? Assume that the stones do not rebound after hitting the ground.

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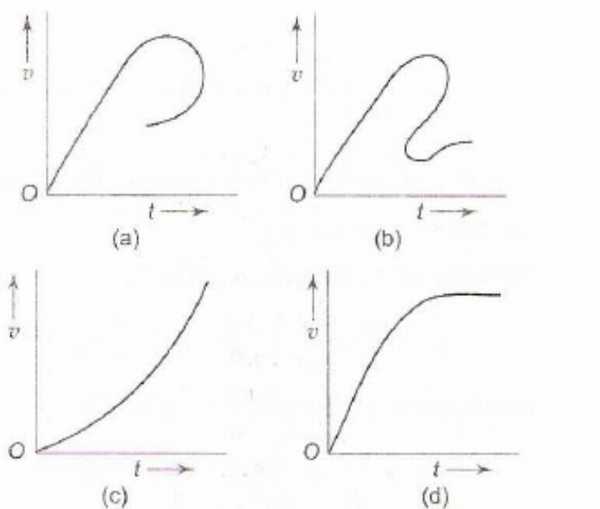
{ Hint : While both are in air, the differece of their velocity vectors would be a constant vector , so △*x* = *c*1*t* . Also, after the first stone hits ground, △*x* = *c*2*t* − *xo* as the velocity component in x direction of second stone is constant. There is no discontinutiy. So, both before and after one hits the ground , it would be a straight line.   
Hence, d) is the correct answer. }

Example. Figure shows the velocity-time (v - t) graphs for one dimensional motion. But only some of these can be realized in practice. These are

****

a) (i), (ii) and (iv) only  
b) (i), (ii) and (iii) only  
c) (ii) and (iv) only  
d) all  
{ Hint: At one particular instant, the object cannot have two different velocities.   
Hence, c) is the correct answer. }

Example. Which of the velocity-time (v-t) graphs shown in Fig. can possibly represent one-dimensional motion of a particle?

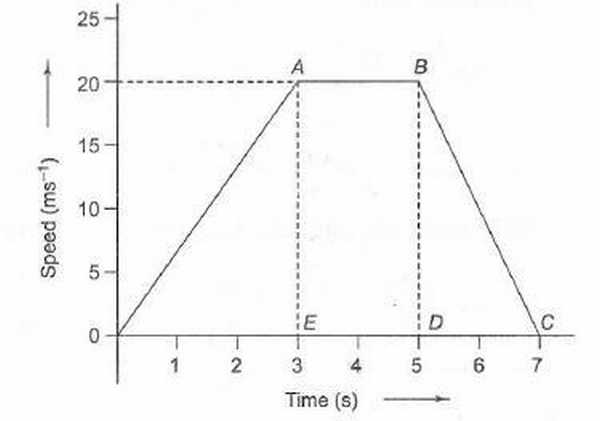
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{Hint: In c) , the particle is constantly increasing in one dimension, In d) , it stops near the end.  
c),d) are the correct answers. }

## 1.3 Question Types

### 1.3.1 Passage Type

Example: The speed-time graph of the motion of a body is shown in Fig.

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1. The accelerations of the body during the last 2 second is

a) (20)/(3)*ms*− 2  
b)  − (20)/(7)*ms*− 2  
c)  − 10*ms*− 2  
d) Zero

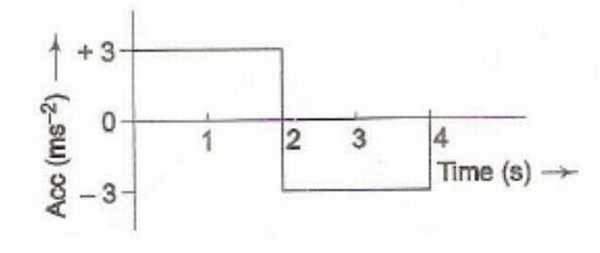
2. The ratio of distance travelled by the body during the last 2 seconds to the total distance travelled by it is

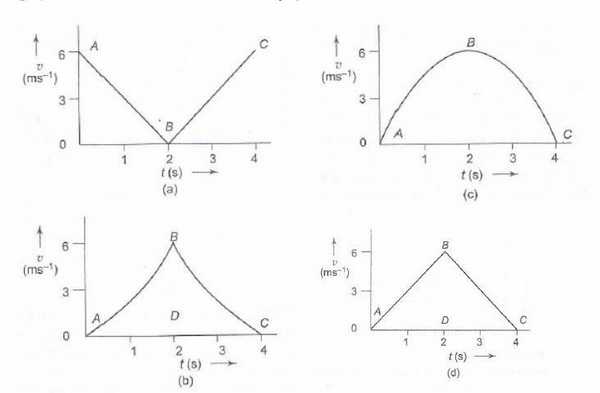
a) 1/9   
b) 2/9   
c) 3/9   
d) 4/9

3. The average speed of the car during the whole journey is

a) 10 m/s   
b) 20 m/s   
c) 90/7 m/s   
d) 40/7 m/s   
{Hint: 1. As no contradictory statements are present, we would take velocity as the value of speed only. Actually velocity is required for calculation of acceleration but here , speed doesn’t contradict anything so we’ll use it’s value for velocity.  
-10 from slope, c)  
2. Speed time graph’s area is distance. From area calculation, in last 2 seconds, the area is 20 and total area is 90.   
So, 2/9 is the required ration b)  
3. Total distance from area is 90, and total time is 7.   
So, 90/7. c)}

Example: A body starts from rest at time t = 0 and undergoes an acceleration as shown in Fig.Which of the graphs shown in Fig. represents the velocity-time (v-t) graph of the motion of the body from t = 0 s to t = 4 s?

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{Hint: d) is the v-t graph by calculating area function.}

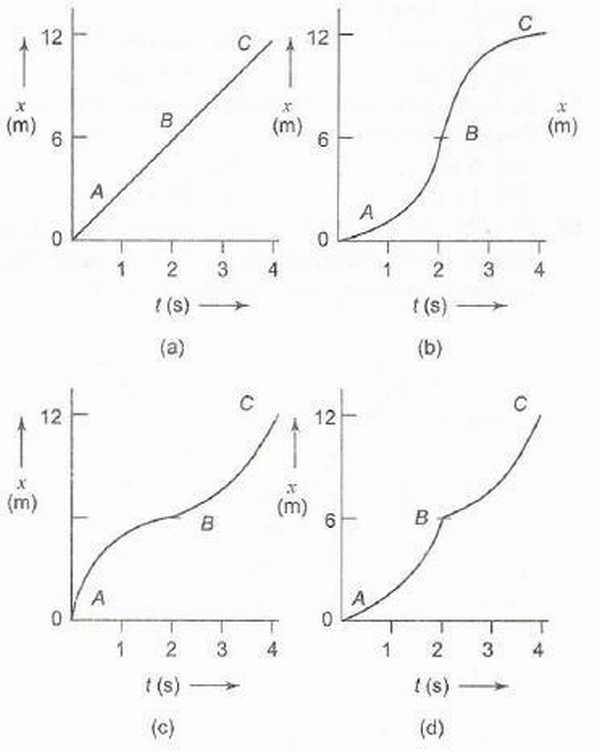
1. In Question above, what is the velocity of the body at time t = 2.5 s?

a) 2.5 m/s  
b) 3.5 m/s  
c) 4.5 m/s  
d) 5.5 m/s

2. In above question, how much distance does the body cover from t = 0 s to t = 4 s?

a) 6 m  
b) 9 m  
c) 12 m  
d) 15 m

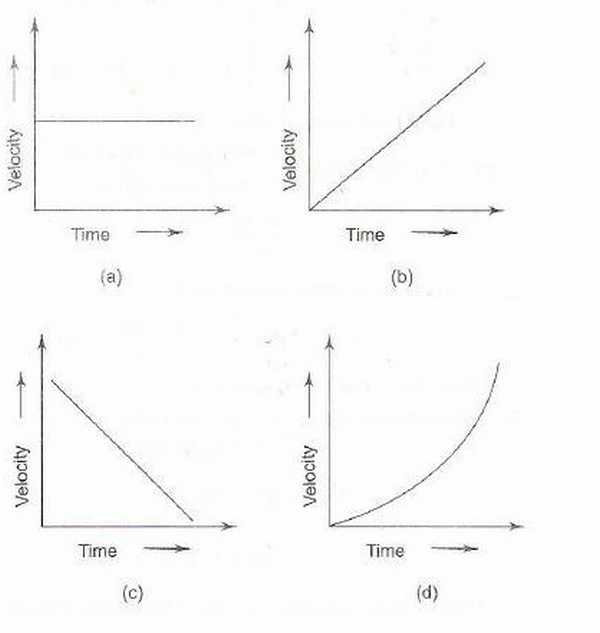
3 In above question, which of the graphs shown in Fig. represents the displacement-time (x-t) graph of the motion of the body from t = 0 s to t = 4 s?

****

{ Hint: 1. The area under the accln-time graph gives change in velocity. Till 2.5s, 6-1.5=4.5 is the required area.   
So, c)  
2. Area under the v-t graph d) is 12 till 4 seconds.   
So, c)  
3. Till 2 seconds , the graph should be concave-up while from 2 to 4 it should be concave-down.  
So, b)  
}

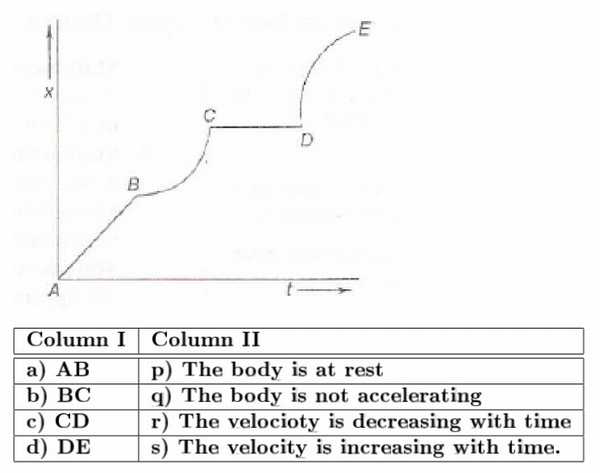
### 1.3.2 Matching

1. Match the graphs (a), (b), (c) and (d) shown in Fig. with the types of motions (p), (q), (r) and (s) that they represent

****

p) Motion with non-uniform acceleration  
q) Motion of a body covering equal distances in equal intervals of time  
r) Motion having a constant retardation  
s) Uniformly accelerated motion.  
{ Hint: p->d , q->a, r ->c , s->a,b,c }

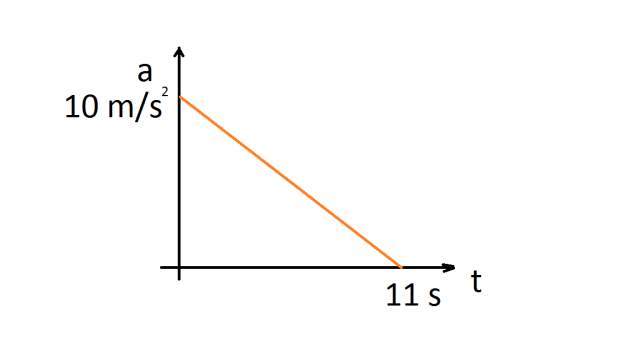
2. Figure shows the displacement ·time (x - t) graph of the m-tion of a body.

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{ Hint p->c, q->a,c, r-> d , s->b }

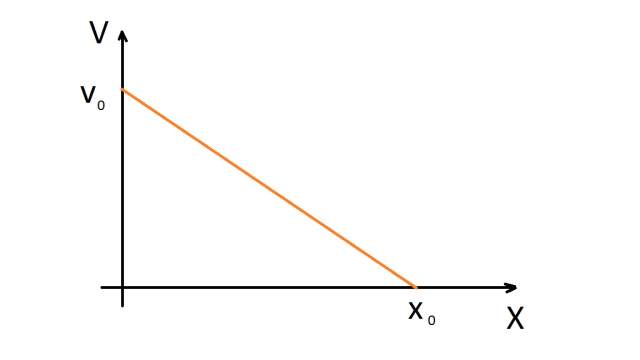
## 1.4 [↓](" \l "index-Previous-Year-Problems-IIT)Previous Year Problems IIT

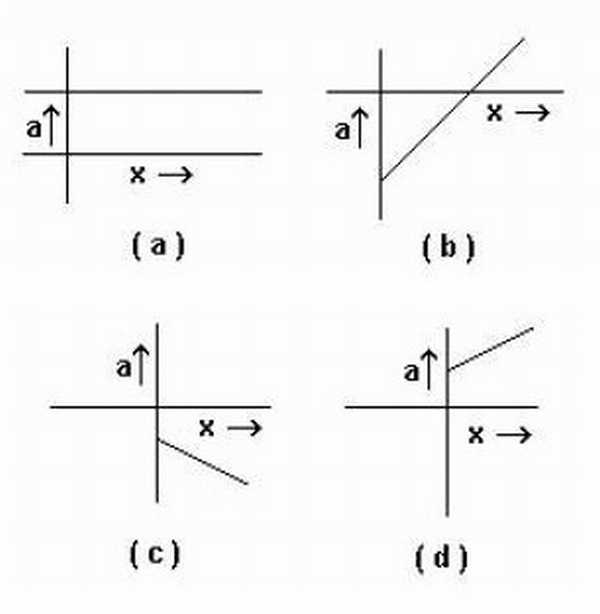
Q1: A particle starts from rest. Its acceleration ( a ) versus time ( t ) is as shown in the gure. The maximum speed of the particle will be

****

a ) 110 m /s   
b ) 55 m /s   
c ) 550 m /s   
d ) 660 m /s  
{ Hint : See In chapter examples for solution. }

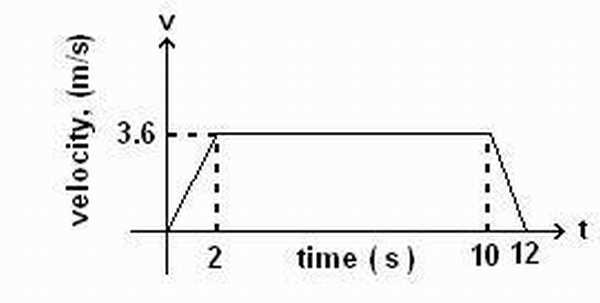
Q2: If graph of velocity vs. distance is as shown, which of the following graphs correctly represents the variation of acceleration with displacement ?

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****

{ Hint : The graph of the question is a straight line with the equation, (*x*)/(*xo*) + (*v*)/(*vo*) = 1   
This gives , *v* = *vo*(1 − *x* ⁄ *xo*)  
So, diffrentiating it, we get  
*a* =  − *vo* ⁄ *xo* which is a constant. Only in a) it is shown to be a constant.   
So, a) }

Passage A lift is going up. The variation in the speed of the lift is as given in the graph.

****

Q3: What is the height to which the lift takes the passengers ?

a ) 3.6 m   
b ) 28.8 m   
c ) 36 m  
d ) cannot be calculated from the above graph

Q4: In the above graph, what is the average velocity of the lift?

a ) 1 m/s   
b ) 2.88 m/s  
c ) 3.24 m/s   
d ) 3 m/s

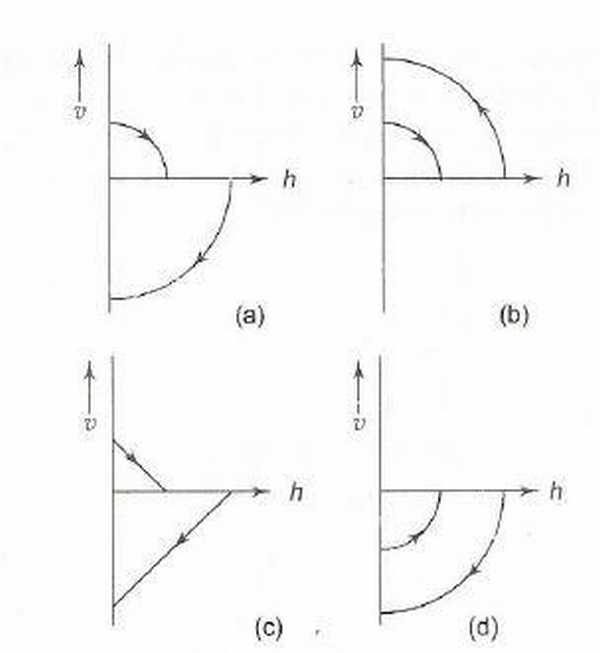
Q5: In the above graph , what is the average acceleration of the lift?

a ) 1.8*m* ⁄ *s*2   
b ) −1.8*m* ⁄ *s*2   
c ) 0.3*m* ⁄ *s*2   
d ) zero   
{Hint: Q3: Area under the graph is 36. Taking initial position as zero, c) is the best fit answer.  
Q4. For av. velocity, total displacement / total time should be calculated. which is 36/12 = 3m/s . d ) is the required answer.  
Q5. The accln is 1.8 from 0s to 2s, 0 from 2s to 10s and -1.8 from 10s to 12s. So, area under the a-t graph is zero. So av. accln is zero d)  
}

Q6: Four persons K, L, M and N are initially at the corners of a square of side of length d. If every person starts moving with velocity v such that K is always headed towards L, L towards M, M towards N and N towards K, then the four persons will meet after

a ) d/v s   
b ) d2/ v s   
c ) d / 2v s   
d ) d / 2v s  
{Hint: Not a graphs question, we’ll discuss it in kinematics book. Athough an easy one. It was mistakenly added to graphs book. Let’s use it to signify the fact that even if a diagram is made, it is still not a graph.}

Example. A ball is dropped vertically from a height h above the ground. It hits the ground and bounces up vertically to a height h/2. Neglecting subsequent motion and air resistance, its velocity v varies with the height h as (see Fig.) (l.l.T. 2000)

****

{ Hint : Case 1: Thrown from height h with zero initial velocity, v=-gt and h = *ho* − 1 ⁄ 2*gt*2, so eliminating t, we get *h* = *ho* − *v*2 ⁄ 2*g*. So, *v* =  − √(2*g*(*ho* − *h*))  
Case 2: We assume the opposite for solving purpose that the ball is now thrown from a height *ho* ⁄ 2 and replace ho only and see the effect. Taking upward velocity as positive , we get *v* = √(2*g*(*ho* ⁄ 2 − *h*))  
a) is the required answer. }

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