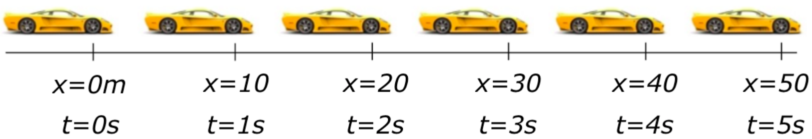
Subject Code PHY 1 **Physics 1**
Module Code 2.0 **Motion Graphs**
Lesson Code 2.1 **Position-Time Graphs**
Time Frame 30 minutes

<table>
<tr><th>Components</th><th>Tasks</th><th>TA[1] (min)</th><th>ATA[2] (min)</th></tr>
<tr><td>Target
</td><td>By the end of this learning guide, the student should be able to:
interpret position-time graphs
illustrate motion using position-time graphs</td><td>1</td><td></td></tr>
<tr><td>Hook
</td><td>In the previous lessons, we learned how to describe motion in terms of its change in position (displacement), in terms of its time rate of change in position (velocity), or how this rate changes over time (acceleration). More than these terms, we can also describe motion visually by merely observing an object’s change in position at various time intervals. In photography, we call this as stroboscopic images. Let’s assume the following as a stroboscopic image of a car moving at different time intervals.



It can be noticed from the diagram that the car is moving at a uniform rate. The car changes its position by 10 m for every 1-second interval. If we take all these position and time data and organize it in tabular form, it would look like this.

<table>
<tr><th>Time
(in s)</th><th>Position of the Car
(in m)</th></tr>
<tr><td>0</td><td>0</td></tr>
<tr><td>1</td><td>10</td></tr>
<tr><td>2</td><td>20</td></tr>
<tr><td>3</td><td>30</td></tr>
<tr><td>4</td><td>40</td></tr>
<tr><td>5</td><td>50</td></tr>
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[1] Time allocation suggested by the teacher.
[2] Actual time allocation spent by the student (for information purposes only).

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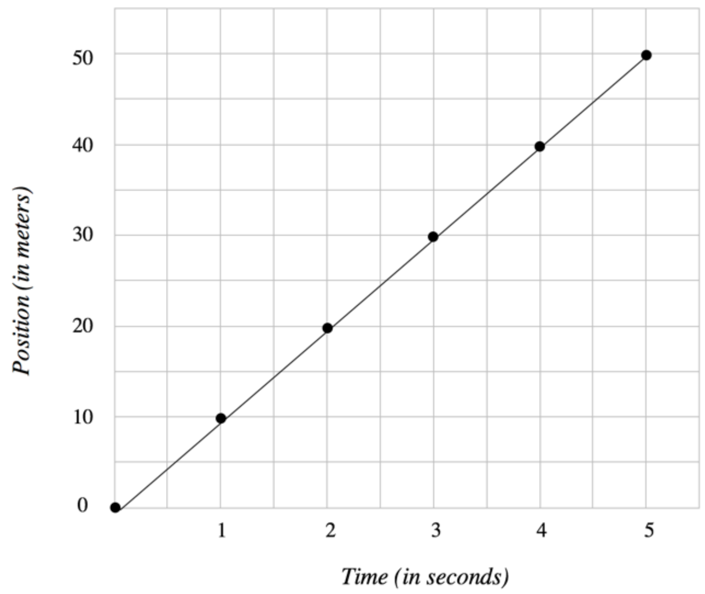
Note that both variables are quantitative and can be represented in another visual form – a graph. Since the position of the car is dependent on time, we designate time (as the independent variable) at the horizontal or x-axis of the line graph while the position of the car (as dependent variable) at the vertical or y-axis. By plotting our entries in the data set, we come up with the following line graph.



The graph above shows how the car's position changes over time. This visual representation of motion is one of the essential tools used to describe the state of motion of an object. We call this a **position-time graph** or an ***x-t* graph.**

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A position-time graph, or *x-t* graph, can tell us essential information about an object's pattern of motion. The behavior of the graph can be used to track whether an object is moving at uniform or varying velocities.

One way of describing *x-t* graphs is by exploring the **slope** of its line. In algebra, slope is defined as the rate of a line's rise over run. To describe the slope of a line, we need to set two points as our reference and then identify the change in the variable along *y* (Δy), or the rise, and change in the variable along *x* (Δx), or the run. Mathematically, we define slope using the following equation.

$$m = \frac{\Delta y}{\Delta x} = \frac{y - y_0}{x - x_0} \qquad \textit{Eq. 1. Slope of a line}$$

Using our previous graph, we can analyze the motion of the car by determining its slope. In this case, the slope will be the change

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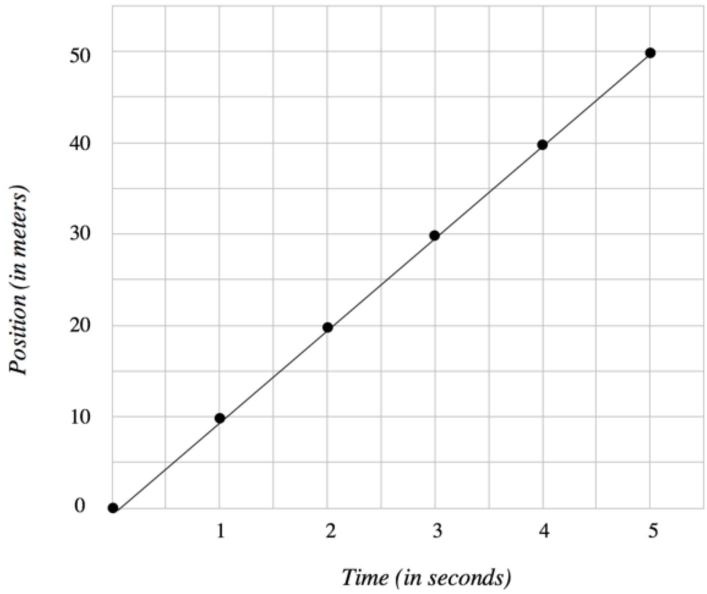
in position, plotted along the y-axis (vertical), over the time interval, plotted along the x-axis (horizontal). Therefore, *the slope of a position-time graph describes the average velocity of an object at a given time interval.*

Since a straight line is formed from the start to the fifth second, we use these two points as our reference.



The reference points will be (0 s, 0 m) and (5 s, 50 m), respectively. Substituting the values, we arrive at the following:

$$m = \frac{50\ m - 0\ m}{5\ s - 0\ s}$$

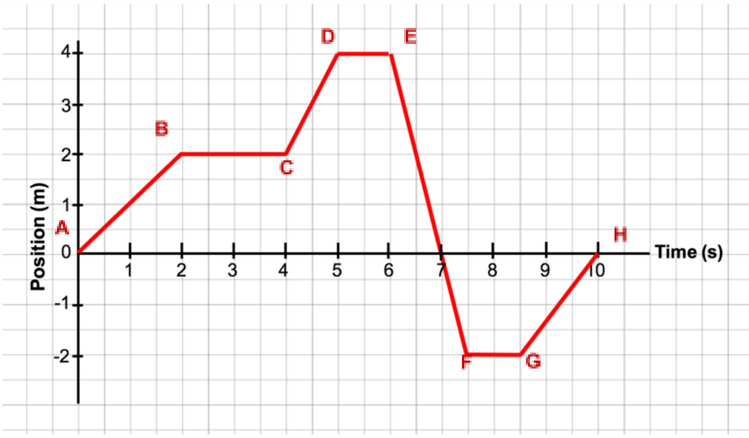
$$m = \frac{50\ m}{5\ s}$$

$$m = 10\ m/s$$

The slope of the line is 10 m/s. If you noticed, the slope of the line has a unit – it's m/s. This is a unit of velocity.

That the slope of position as a function of time, in this case, is positive and the same all throughout indicates uniform positive velocity or motion towards the positive direction with constant speed. In this case, the car moved at a uniform rate of 10 m/s.

In most cases, the velocity of an object during its course of motion is not constant. In this case, we cannot generate a single line but rather several line segments that have varying slopes. Let's take the example of the following *x-t* graph.



The graph shows the trends in the motion of a body in 10 seconds. Qualitatively, these line trends can tell us information about the velocity of the ball at various time intervals. Upward lines (with positive slope) connote positive values of velocity while downward lines (with negative slope) show negative values of velocity. A horizontal line, on the other hand, tells us that the slope is zero or the object is stationary. The following table shows the calculation of the slope of lines in the *x-t* graph above and the description of motion.

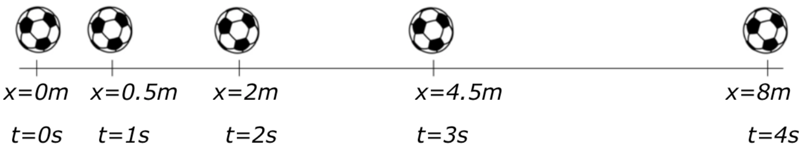
Points	Slope	Description
A to B	$m = \frac{2\,m - 0\,m}{2\,s - 0\,s} = 1\,m/s$	The object is moving 1 m/s. Positive direction.
B to C	$m = \frac{2\,m - 2\,m}{4\,s - 2\,s} = 0\,m/s$	The object is stationary (v = 0).
C to D	$m = \frac{4\,m - 2\,m}{5\,s - 4\,s} = 2\,m/s$	The object is moving 2 m/s. Positive direction.
D to E	$m = \frac{6\,m - 6\,m}{6\,s - 5\,s} = 0\,m/s$	The object is stationary (v = 0).
E to F	$m = \frac{-2\,m - 4\,m}{7.5\,s - 6\,s} = -\,4\,m/s$	The object is moving -4 m/s. Relatively faster compared from A to B but in the opposite direction.
F to G	$m = \frac{-2\,m - (-2\,m)}{8.5\,s - 7.5\,s} = 0\,m/s$	The object is stationary (v = 0).

G to H	$m = \frac{0-(-2\ m/s)}{10\ s - 8.5\ s} = 1.3\ m/s$	The object is moving 1.3 m/s. Positive direction.

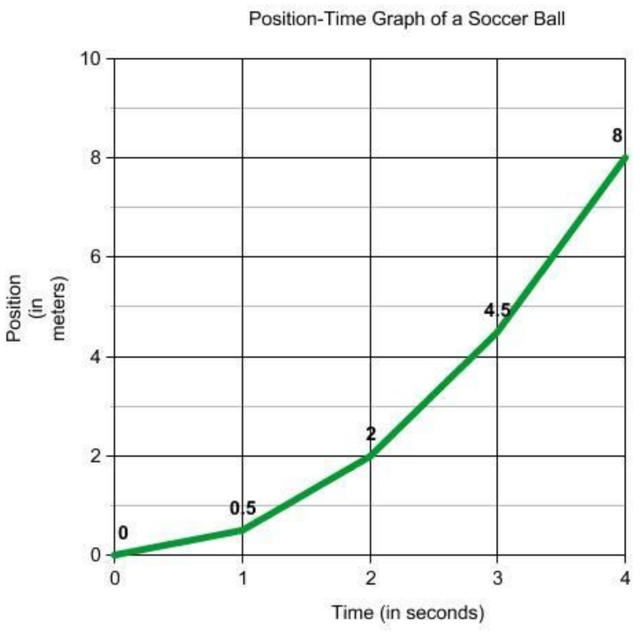
By merely observing the steepness of the lines, we can already determine at which time intervals in the graph there were greater changes in the position of a body. A very steep line in the case of *x-t* graphs connotes a large magnitude of velocity.

Another exciting thing about *x-t* graphs is that we can also find out an object's final position and displacement. Recall that displacement is a straight line that describes the change in position of a moving body concerning its origin. The abscissa of the final coordinate in an x-t graph denotes the object's final position. On the other hand, the difference between the abscissas of the first and last coordinates refers to the displacement of the object. In the case of this graph, we can say that the displacement traveled by the object is zero or that the object just returned to its starting point.

In other cases, *x-t* graphs do not generate perfectly straight lines. Instead, a curve can be noticed. Let's take the example of the following motion diagram of a soccer ball being kicked horizontally on a field.



Plotting our data on a plane coordinate system yields the following *x-t* graph.



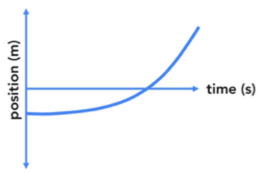
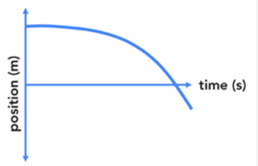
In this case, the *x-t* graph generates a particular curve called the parabola. It can be noticed that the slope of the curve varies over time indicating that velocity is not constant at different time intervals. This is clearly shown in the motion diagram of the ball.

There is also another piece of information about parabolic *x-t* graphs. If you further find the changes in velocities over time, you will find out that the rate of change in velocity over time is constant.

Time Intervals	Slope (Velocity)
0 to 1	$m = \frac{0.5\,m - 0\,m}{1\,s - 0\,s} = 0.5\,m/s$
1 to 2	$m = \frac{2\,m - 0.5\,m}{2\,s - 1\,s} = 1.5\,m/s$
2 to 3	$m = \frac{4.5\,m - 2\,m}{3\,s - 2\,s} = 2.5\,m/s$
3 to 4	$m = \frac{8\,m - 4.5\,m}{4\,s - 3\,s} = 3.5\,m/s$

For every 1-second interval, the velocity is increased by 1 m/s. This means that there is a constant rate of change in velocity or acceleration. Therefore, a parabola in an *x-t* graph implies that a body is moving at constant acceleration.

The following table shows the shapes of curves on an *x-t* graph and the information they convey about the motion of a body.

Shape of Curve	Description
	• The slope increases from zero to more positive values. • The object is speeding up in a positive direction.
	• The slope changes from zero to more negative values • The object is speeding up in a negative direction.

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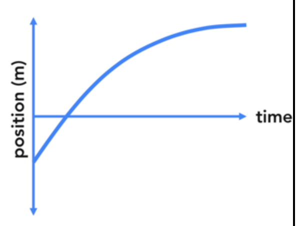
<td>
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- The positive slope is decreasing in magnitude.
- The object is traveling in a positive direction and slowing down (decelerating).

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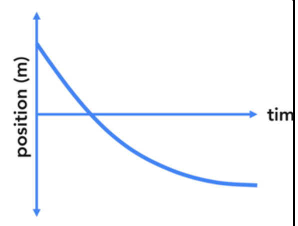
<td>
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- The negative slope is decreasing in magnitude.
- The object is traveling in a negative direction and slowing down (decelerating).

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Now that you're familiar with the features of an *x-t* graph, you can now describe an object's pattern of motion by analyzing an *x-t* graph.
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<td>Navigate</td>
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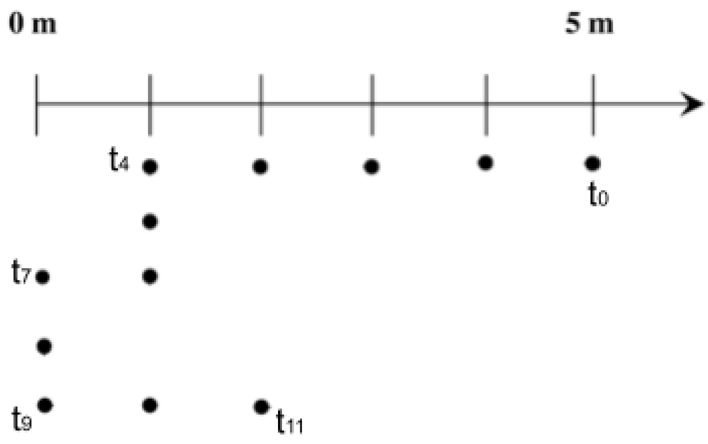
Work on the following exercises to find out if you understood the lesson on position-time graphs. Write your answers on a clean sheet of paper. Follow your teacher's instructions regarding submission.

1. Given the following motion map where each dot corresponds to one-second interval, construct its accompanying position-time graph.



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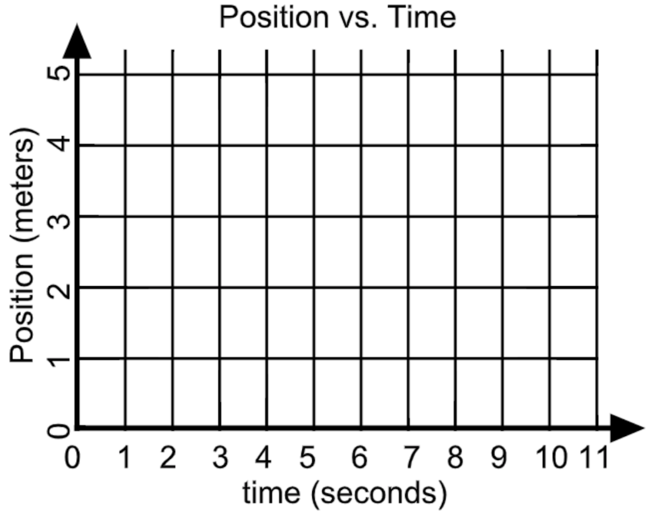
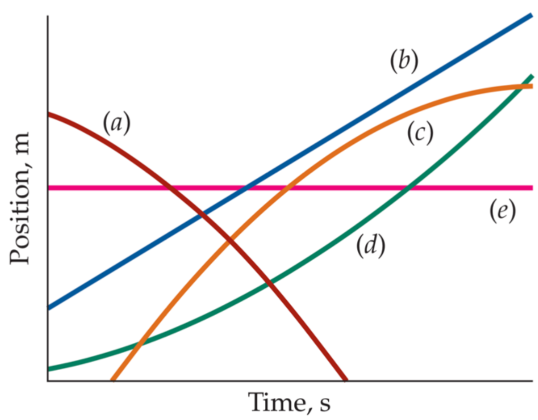


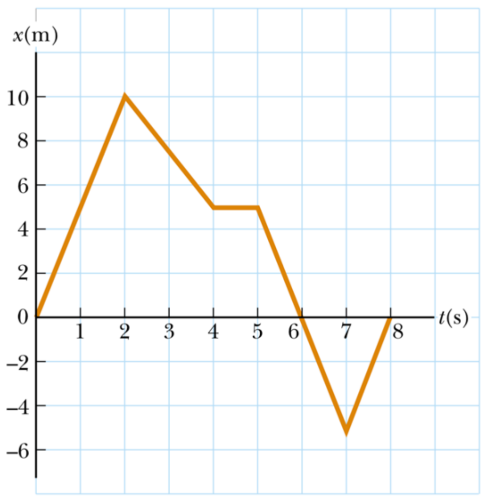
Describe the motion of the object at various time intervals.

2. Which of the following position-time curves best shows the motion of an object with the following descriptions (Tipler & Mosca, 2008).



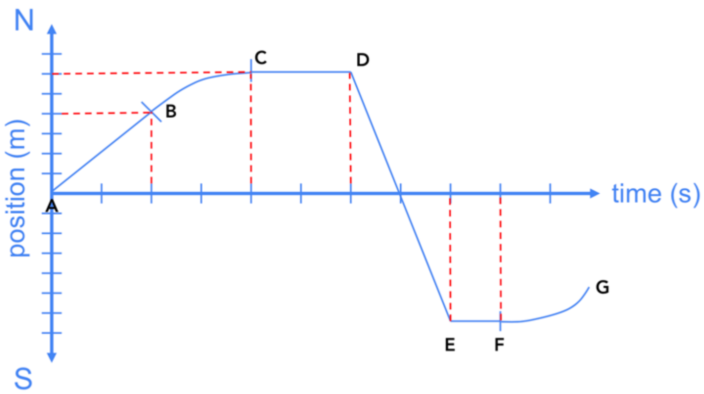
Description	*x-t* curve
(a) With constant positive velocity	
(b) With constant positive acceleration	
(c) That is always at rest	
(d) With negative acceleration	

3. The position-time graph of a moving object is shown below. Find the average velocity and describe the motion of the object in the following time intervals (a) 0 to 2 s, (b) 2 to 4 s, (c) 4 to 5 s, (d) 5 to 7 s, and (e) 0 to 8 s. (Serway & Jewett, 2004)



Section	Average Velocity	Description
a		
b		
c		
d		
e		

4. Describe the motion of the body indicated in the following position-time graph.



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<table>
<tr><th>Section</th><th>Description of Motion</th></tr>
<tr><td>A to B</td><td></td></tr>
<tr><td>B to C</td><td></td></tr>
<tr><td>C to D</td><td></td></tr>
<tr><td>D to E</td><td></td></tr>
<tr><td>E to F</td><td></td></tr>
<tr><td>F to G</td><td></td></tr>
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<td>Knot
</td>
<td>Here are some of the significant key ideas that you should remember about position-time graphs.

● Position-time or x-t graphs provide meaningful insights about the motion of an object.
● The slope of an x-t graph represents the velocity of an object at a specific time interval.
● The difference of the abscissas of the first and last coordinate in an x-t graph provides us the displacement of the moving object.
● A straight line on an x-t graph denotes constant velocity. Upward straight lines indicate constant positive velocity, while downward straight lines indicate constant negative velocity. A horizontal line indicates that the object is stationary.
● A parabolic curve on an x-t graph implies an object moving at constant acceleration.</td>
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References

1. Serway, R., & Jewett, J. (2004). *Physics for Scientists and Engineers.* Thomson Brooks/Cole.
2. Tipler, P., & Mosca, G. (2008). *Physics for Scientists and Engineers with Modern Physics.* W. H. Freeman and Company.

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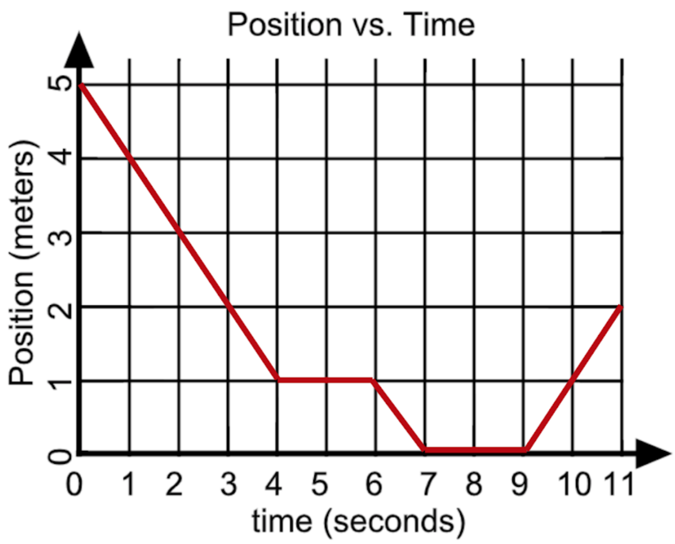
ANSWER KEY

NAVIGATE

1. The accompanying position-time graph for the motion diagram is as follows.



- The object has negative velocity between 0 to 4 seconds (-1 m/s) and 6 to 7 seconds (-1 m/s).
- The object is stationary between 4 to 6 seconds and 7 to 9 seconds.
- It has a positive velocity between 9 to 11 seconds (1 m/s).

2.

Description	***x-t* curve**
(a) With constant positive velocity	*b*
(b) With constant positive acceleration	*d*
(c) That is always at rest	*e*
(d) With negative acceleration	*a, c*

3.

Section	Average Velocity	Description
a	*5 m/s*	*The object is moving at 5 m/s. It has constant positive velocity (positive direction).*
b	*-2.5 m/s*	*The object is moving at -2.5 m/s (negative velocity). The rate is slower than the previous segment of the x-t graph and is moving opposite in terms of direction.*
c	*0*	*The object is stationary or at rest.*
d	*-5 m/s*	*There was an abrupt change in velocity. Negative since it is moving in the negative direction.*
e	*5 m/s*	*The object is moving with a positive constant velocity.*

4.

Section	Description of Motion
A to B	*The object is moving with constant positive velocity.*
B to C	*The object is slowing down but the motion is still in the positive direction.*
C to D	*The object is stationary or at rest.*
D to E	*The object is moving with constant negative velocity.*
E to F	*The object is stationary or at rest.*
F to G	*The object is accelerating to the positive direction.*