Theme 3: Motion

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Motion - inertia, uniform and non-uniform motion,
- Rate of motion - average speed, instantaneous velocity, average velocity, rate of change of velocity
- Graphical representation of motion - distance-time graph, velocity-time graph, equation for velocity-time relation

Road Accidents

One of the common forms of road accidents is a rear-end collision, where the vehicle at the back collides with the one in front. Although both the vehicles and the passengers inside are likely to undergo equal damage, the law in most countries considers the rear vehicle responsible for these accidents. One possible reason for this stand taken by the law is that the rear vehicle has full visibility or rather, is supposed to have the full visibility of the vehicle(s) in the front and maintain sufficient time and distance to react.

Fig. 3.1, Highway with two lanes, one for traffic in each direction

Shyam, with his three school friends, went on a road trip on a two-lane highway. Shyam feels it is better to keep a maximum gap of 4 m from the car in front as it helps him to overtake the car in front as soon as he finds a little gap in the traffic coming from the other direction.

But Rizwan believes that each individual has a different visual reaction time / response time, which is the time we need to respond after seeing an event. This time varies from person to person, as it depends on multiple factors such as age, sleep and other distractions around.

Case Study A - Reaction Time

One of the easiest ways to determine the nervous system reaction time is to catch a free-falling ruler dropped by another person. The time one takes to catch the ruler after seeing its movement is the visual response time.

Shyam and Rizwan perform this experiment.

Fig. 3.2, Shyam was asked to rest his hand on a surface and stretch his thumb and forefinger parallel to the zeroth mark of a 1 m ruler, held vertically by Rizwan.

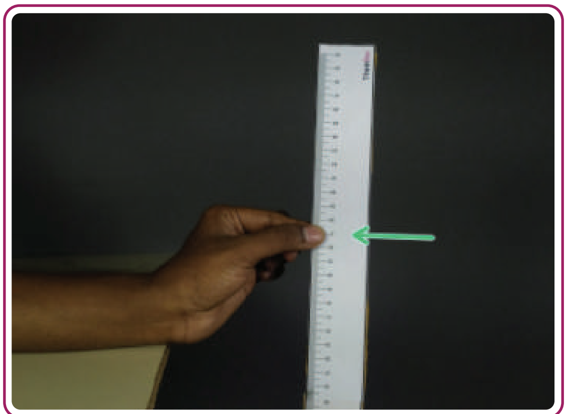


Fig. 3.3, Rizwan drops the ruler and Shyam holds it as soon as he sees the movement. The position where the ruler isheld is noted.

Answer the question below.

Question 1

Which of the following equations can Shyam and Rizwan use to calculate the response time?

a. $v = \frac{s}{t}$ where, v = Average speed s = Total distance travelled t = Total time taken	b. $v = u + at$ where, v = Final velocity u = Initial velocity a = Acceleration t = Time
c. $s = ut + \frac{1}{2}at^2$ where, s = Distance travelled u = Initial velocity a = Acceleration t = Time	d. $v^2 = u^2 + 2as$ where, v = Final velocity u = Initial velocity a = Acceleration s = Distance travelled

Answer

Question 2

Shyam and Rizwan continued with the experiment of measuring the distance after which Shyam caught the ruler. Two different experiments were conducted, as shown in Fig. 3.4-3.7:

Experiment 2

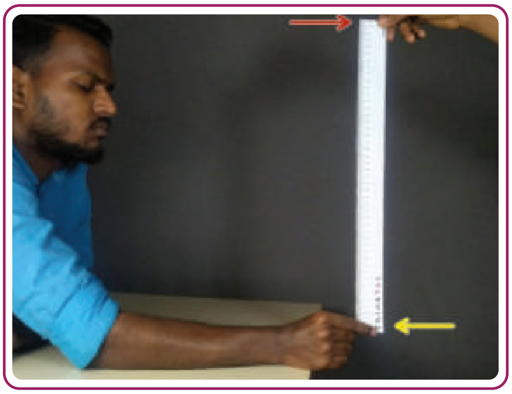


Fig. 3.4, Shyam kept his eyes closed

Fig. 3.5, Shyam detected the release of the rulerby Rizwan by listening to the sound made when the ruler was released.

Experiment 3

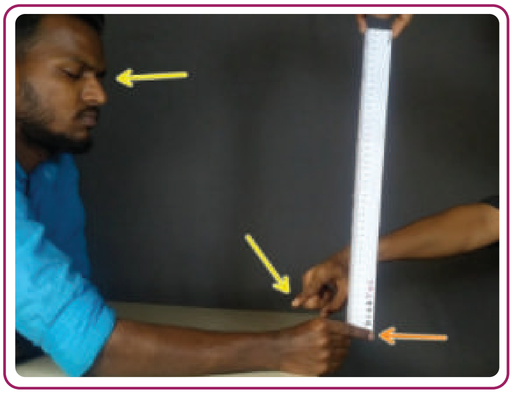


Fig. 3.6, Shyam kept his eyes closed

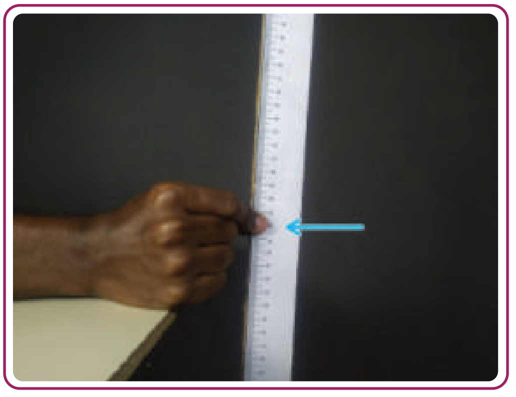


Fig. 3.7, Shyam detected the release of the ruler based on the signal given by Rizwan. Rizwan signalled the release by tapping on Shyam's hand.

Which type of response time is being measured by the two experiments? Fill in the blank space by choosing appropriate options out of these two - Touch Response Time, Auditory Response Time.

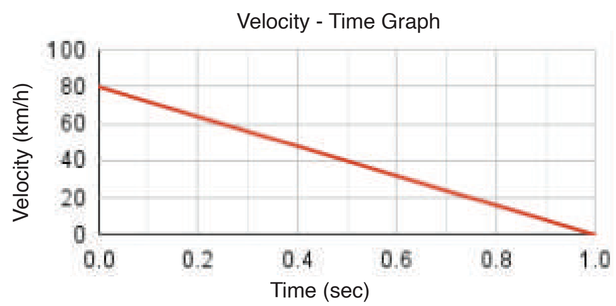
i. Response time measured by Experiment 2 is ______________________

ii. Response time measured by Experiment 3 is ______________________

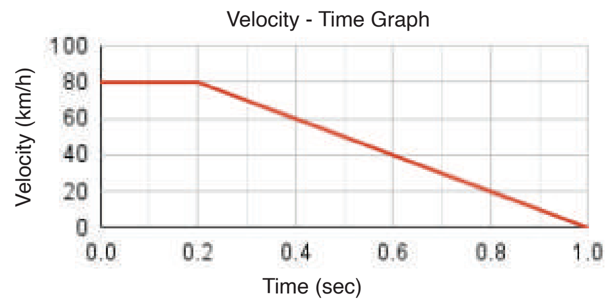
Question 3

If Shyam has a visual response time of 0.2 seconds and he takes 0.5 seconds to apply the brakes completely and it takes a total of 0.8 seconds for him to apply the brakes fully and the car to come to a halt after the brakes are applied, then which of the following velocity-time graphs correctly represents the situation? Assume the start time to be after Shyam sees the vehicle in front stop. Note that Shyam has been driving the car at a speed of 80 km/h.

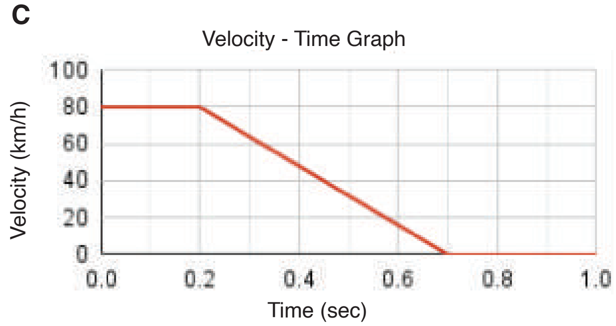
A



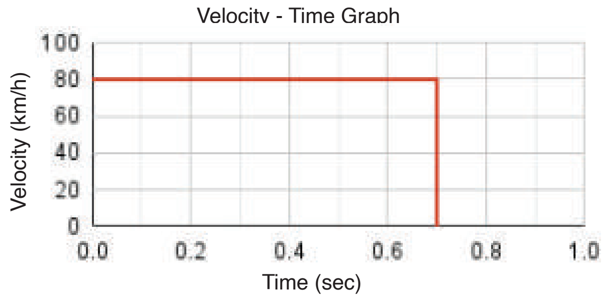
B



C



D



Answer

Question 4

How much distance will the car travel before coming to a halt? Write your answer in the space provided below.

Answer

Question 5

By looking at the value of the distance arrived based on these calculations, Shyam and Rizwan decided to refer to standard data and recommendations as well. They found a graph (see Fig. 3.8), which plots the distance a vehicle travels before coming to a halt (stoping distance), after the vehicle's driver identifies the need to apply brakes. The stopping distance varies depending on the type of vehicle and its speed at the time when the need to apply brakes is identified.

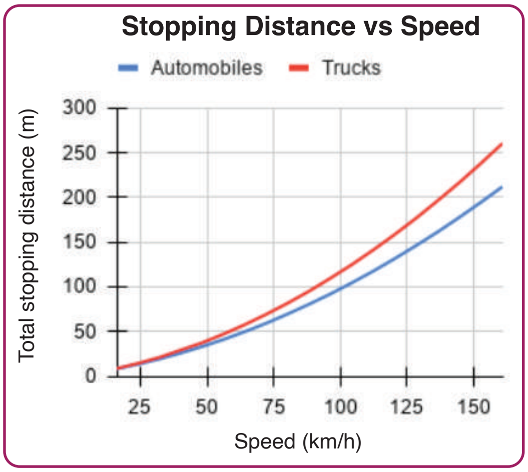


Fig. 3.8, The plot of total stopping distance vs speed of automobiles and trucks. Data sourced from Code of Virginia, The State of Virginia.

Choose the statements that can be interpreted from the graph shown in Fig. 3.8. More than one option may be correct.

a. For a given speed, a truck takes less time to stop when compared to a car.

b. Stopping distance increases with the speed of the vehicle

c. Shyam's estimate of 4 m as the safe distance matches with the safe distance which can be inferred from the graph. Recall that Shyam was driving at a speed of 80 km/h.

d. The safe distance also depends on the type of vehicle in front of us

Answer

Question 6

i. Based on the given graph, which vehicle would travel a longer distance after applying the brakes?

Answer

ii. Beyond which speed is this difference visible?

Answer

iii. Give a hypothesis explaining the difference in stopping distance between the two vehicles.

Answer

Case Study B - Rear-end Collision

When a vehicle undergoes a rear-end collision, the passengers inside experience a peculiar body movement. To study the impact, an experiment was conducted where the rear-end collision was simulated by moving the car abruptly with a high acceleration. A dummy was placed inside the car. The seat belt was fixed around the dummy, though there was no headrest. The speed and acceleration data was collected separately for the head and body of the dummy. The acceleration time graph was then plotted, based on the data collected.

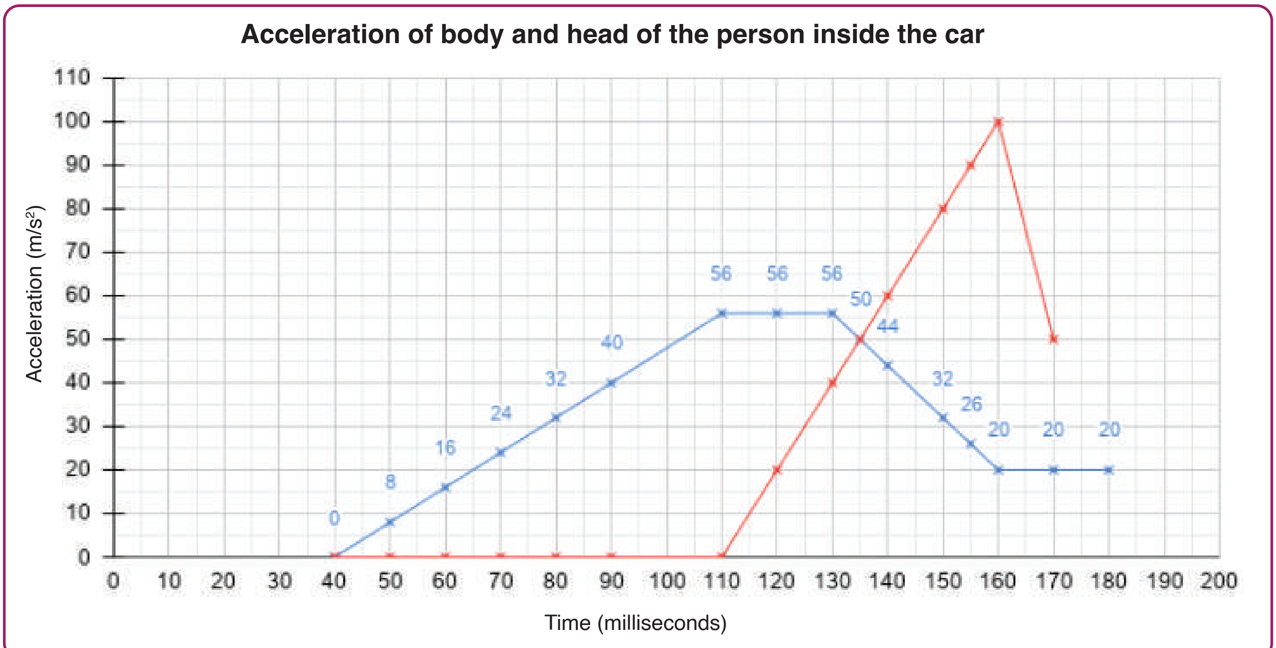


Fig. 3.9, The acceleration v/s time curve of head and torso of a person inside a car in a simulation of a rear-end collision

Question 7

Which of the two curves represents the movement of the head - the blue curve or the red curve? Justify your answer. Write your answer in the space provided below.

Answer

Question 8

With reference to the graph shown in Fig. 3.9, which of the options below correctly describes the position of the head immediately after the rear-end collision?

a. Can't be sure since Fig. 3.9 does not show the force of the rear-end collision

b. Behind the torso

c. Ahead of torso

d. In line with the torso (normal position)

Answer

Case Study C - Ticker Timer

The previous graph shows acceleration values collected every 10 milliseconds. The measurement of speed, distance and time at this level of precision requires sophisticated sensor-based setups. Light gates are set up such that the start of the movement is recognised when a light ray gets blocked. This triggers a signal to the timer, which counts till another light sensor sends a signal indicating that the object has travelled a known distance. To capture the signals from the light sensors and also display the time appropriately, some electronics need to be designed. The other option to conduct speed-distance-time experiments in laboratories is to use a ticker timer.

The ticker-timer is an instrument in which a metal arm is made to vibrate at a constant rate. This arm then creates dots on a strip of paper (with the help of a carbon sheet) that is run through the instrument. Fig. 3.10 to 3.13 show one of the ways a ticker timer is used. Here the ticker timer ticks 20 times in one second.

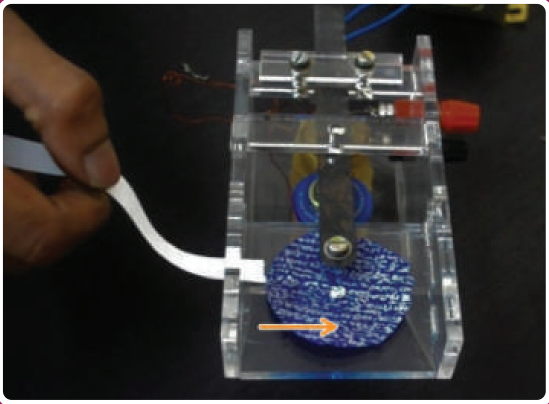


Fig. 3.10, Strip of paper being inserted under the screw, which ticks regularly on the carbon paper 20 times in one second.

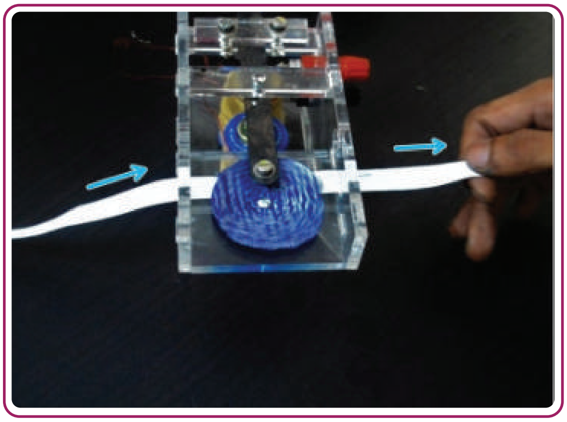


Fig. 3.11, The ink from carbon paper will create dots on the white strip of paper.

Fig. 3.12, Blue dots created on the strip of paper are counted.

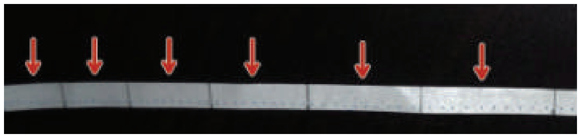


Fig. 3.13, Smaller pieces of paper with 10 dots on each are cut.

Question 9

If the strip of paper is cut into multiple strips, each carrying 10 dots, how much elapsed time does each strip represent? Write your answer in the space provided.

Answer

Question 10

In a strip of paper run through this ticker timer, if the distance between the dots starts increasing, what does it indicate about the speed at which the paper is being pulled through the ticker timer?

a. Speed has reduced
b. Speed has increased
c. It is not related to the speed at which paper is being pulled
d. Speed is constant

Answer

Question 11

A 2-metre long paper strip was pulled through the ticker timer. It was then cut into multiple pieces with each piece carrying 10 dots. These pieces were pasted on a graph paper, as shown in Fig. 3.14 and 3.15. Note that the starting of each paper strip was aligned with one horizontal line.

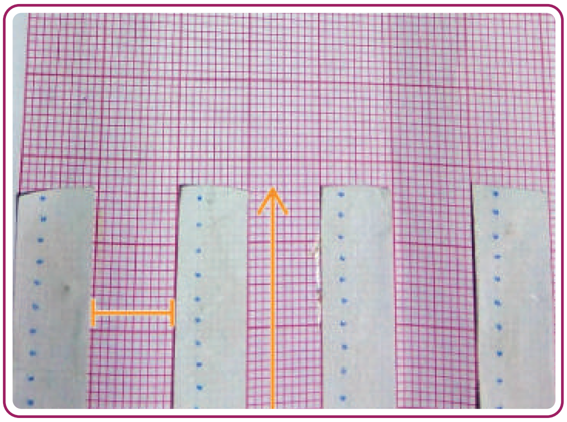


Fig. 3.14, Close-up view of 10 dots' paper pieces pasted on a graph paper

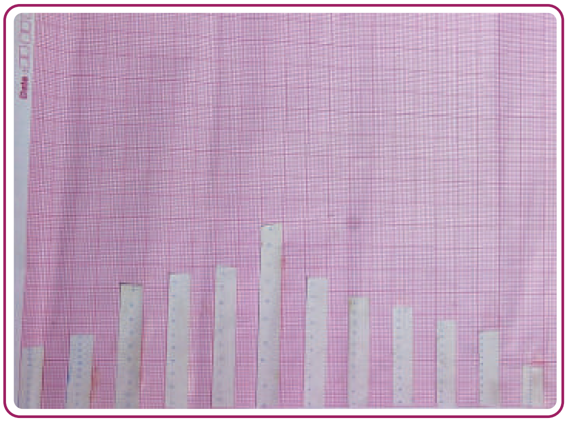


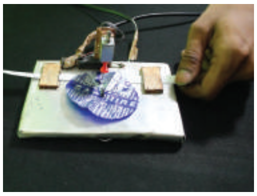
Fig. 3.15, Zoomed out view of the paper strips pasted on a graph paper

What do the cut strips pasted on the graph paper represent?

a. Velocity-time graph
b. Distance-time graph
c. Acceleration-time graph
d. Depends on how fast the paper strip is pulled out

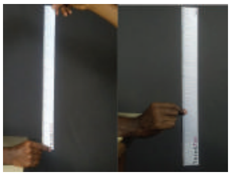
Answer

Exploration Pathway



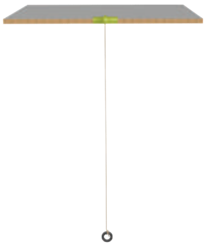
Ticker Timer - Speed

Any object in motion is said to have a "speed", i.e. the rate of change of its position. In this Ticker Timer TACtivity, ticker tape is pulled through the ticker timer and analysed. This is done by making strips of "10-tick" length, and placed sequentially as a histogram. Speed measurements can be made by dividing the length of each segment by the time taken for 10 ticks.



Nervous System - Reaction Time

While standing, hold a 1-m ruler with your left hand, raised up to your head level. Drop the ruler and catch it with your right hand. Where did you catch it? Now ask your friend to drop the ruler and try to catch it? Can you?



Motion - Periodic

In this splendidly simple and iconic TACtivity, you will make a classic pendulum, with a string and weight, used to measure time for centuries and the very basis of our “grandfather” clocks! Moreover, the constant to-and-fro motion, also known as Oscillatory Motion or Simple Harmonic Motion, is a wonderful phenomenon to experience and make measurements on.