Motion and Time

Speed

Sourabh and Apurva go to school on their bicycles. Sourabh covers 200 m in 4 minutes and Apurva covers the same distance in 5 minutes. **Who cycles faster?**

In this section, we will discuss the concept of speed and how it is used in solving various problems in our daily life.

Speed

The slowness or fastness of an object can be related with the help of their speeds. **The speed of a moving object is defined as the distance covered by it in unit time.** For example, if a car covers a distance of 25 km in one hour, then it is said that the car is moving with a speed of 25 km per hour. The speed of a vehicle can be measured by dividing the total distance covered by it by the total time it takes to cover that distance.

$$\text{Speed} = \frac{\text{Total distance covered } (d)}{\text{Total time taken } (t)}$$

You may have observed many times that the speed of your school bus keeps changing its motion along a straight path because of heavy traffic, traffic signals, etc. This is an example of **non-uniform motion**. In this type of motion, a vehicle's speed keeps changing with time. In this case, the speed can be determined in terms of its "**average**" speed. Average speed is determined by dividing the total distance covered by the total time taken.

In the case of **uniform motion**, a vehicle moves with constant speed along a straight path. Hence, its average speed is the same as its actual speed.

- An object that takes the minimum amount of time to cover a given distance is the one moving with the highest speed, whereas an object that takes the maximum amount of time to cover the same distance is the one moving with the slowest speed.

The times taken by each cyclist to complete one round of a racing circuit are given in the table.

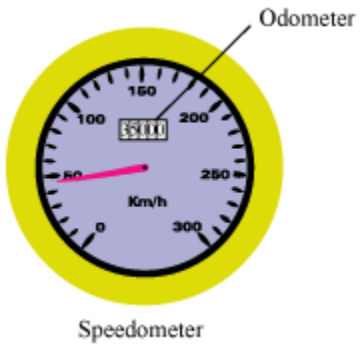
Who is the fastest cyclist?

Participant	**Time taken (in seconds)**
Rajesh	12

Manish	22
Sujoy	12
Anuj	10
Pawan	8
Gaurav	9
Samik	17
Biswas	16

Do You Know:

Maglev trains are one of the fastest trains in the world. They can move at an average speed of 450 km/h i.e., they can cover a distance of 450 km in just an hour!



Speedometer

Modern vehicles use **speedometers** that measure speed in units of km/h. They also include **odometers** that record the total distance travelled by vehicles in units of kilometre (km). A simple speedometer with an odometer is shown in the given figure.

Calculation of Speed

Atul takes 3 minutes to travel a distance of 300 m to reach his school. Can you determine his speed?

In this section, we will learn to solve problems related to speed.

We know that the speed of a body in motion is represented by the given relation.

$$\text{Speed} = \frac{\text{Distance covered}}{\text{Time taken}}$$

In the question given above, we have

Distance covered = 300 m

Time taken = 3 minutes = 180 s

$$\text{Speed} = \frac{300\ \text{m}}{180\ \text{s}}$$

$$= \frac{5}{3}$$

$$= 1.67\ \text{m/s}$$

In the same way, the speed of a moving body can also be expressed in km/hr. However, that depends on the requirement of the situation.

The unit of speed is metre per second (m/s) or kilometre per hour (km/h).

Example: A school bus covers a distance of 5 km between a student's house and the school in 30 minutes. What is the speed of the bus?

Solution:

The speed of the bus between the student's house and the school can be determined by dividing the total distance covered by the total time taken by the bus.

$$\text{Speed} = \frac{\text{Total distance covered}}{\text{Total time taken}}$$

Since the total distance between the student's house and the school is 5 km and the time taken by the bus is 30 minutes,

$$\text{Speed} = \frac{5\ \text{km}}{30\ \text{minutes}}$$

$$(\because 1\,\text{h} = 60\,\text{minutes})$$

$$= \frac{5\,\text{km}}{0.5\,\text{h}}$$

$$= \frac{5 \times 10}{5}$$

$$\text{Speed} = 10\,\text{km/h}$$

Hence, the speed of the bus between the student's house and the school is 10 km/h.

A train crosses a tunnel of length 100 m in 9 seconds. What is its speed in km/h?

To solve such a problem, one should know the concept of conversion between m/s and km/hr.

- **To convert km/hr into m/sec, we multiply the quantity with $\frac{5}{18}$.**

- **To convert m/sec into km/hr, we multiply the quantity with $\frac{18}{5}$.**

  Hence,

  Distance = 100 m

  Time = 9 s

  Speed = $\frac{100}{9}$ m/s

  In terms of kilometre per hour, this speed can be written as

  Speed = $\frac{100}{9} \times \frac{18}{5} = 40$ km/h

  = 40 km/h

  Now, try to do this yourself.

  A car travels a distance of 105 km in 3 hours. Calculate its speed in m/s.

  Measurement of Time

  Before going into the subject, let us look at this animation.

  So, you have learned the importance of measuring time. You also have learned about some time-measuring instruments, some from ancient and medieval ages and some from modern times.

  Let us learn about the units of time in detail.

  Units of Time

  In ancient times, people used large units for measuring time. For example, the time interval between two consecutive sunrises was considered **a day**. However, they were not able to accurately measure the time taken by relatively shorter events such as lightning, rain, or time taken to cover a distance.

Period	Method of measuring time in ancient times
Day	Time between two consecutive sunrises
Month	Time between two consecutive new or full moons
Year	Time taken by the Earth to complete one revolution around the sun

Take a rubber ball and drop it from a height on to a hard surface. The ball will bounce repeatedly and stop after some time. Which device would you require to measure the time taken by the ball to stop?

We require some convenient units that can be used for measuring short as well as long intervals of time.

- The internationally accepted unit of time is **second**. Its symbolic representation is **s**. However, this unit is used for representing shorter durations of time only. Minutes (min) and hours (h) are used for representing longer durations of time.

- We use different units of time depending on the requirement and convenience. For example, it is easy to express the pulse rate using minutes as units of time. However, while expressing the time taken to travel from Delhi to Jaipur, we use hours as the unit of time.

Modern Technology

Scientists use modern technology for scientific research to determine shorter intervals of time such as millisecond (ms), microsecond (μs), and nanosecond (ns); and larger intervals of time such as million years (MY), billion years (BY), etc.

Discuss with your teacher how the larger units of time are used in astronomy.

The given table shows the respective amount of time taken by all the participants to cross the finish line in a cycling race. The time displayed at the start of the race was 10:45:00

Who took the least amount of time to finish the race?

Participant	Display on digital clock
Ram	10:46:45
Shyam	10:46:35
Ajit	10:46:57
Aditya	10:46:13

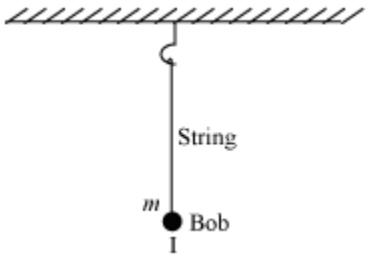
	Jay	10:47:01
	Ramesh	10:46:41

Till now, we were discussing the different types of clocks that are used by people today to measure time. **Now, the question that arises is – how is a clock able to measure time?**

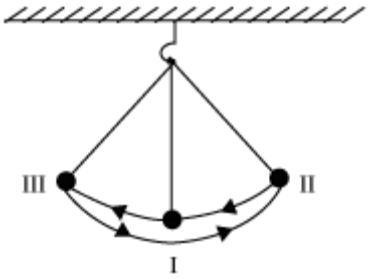
The answer lies in the fact that a clock uses some kind of periodic motion in its working. One such object that exhibits periodic motions is a **simple pendulum.** In this section, we will discuss some common characteristics of a simple pendulum.

Characteristics of a simple pendulum

- A simple pendulum consists of a mass *m* that is suspended by a piece of string. The mass is known asthe **bob** of the pendulum. A simple pendulum is shown in the given figure. Here, point **I** represents the **mean position** of the bob.



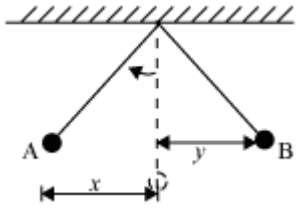
- The bob begins to move to and fro when it is released from the extreme position **II** i.e., it will go up to another extreme position **III** via mean position **I**, and then go up to position **II** again via mean position **I**. It will continue to move in the same way. This back and forth motion of the bob via mean position **I** is called the **periodic or the oscillatory motion of the bob.**



- The bob completes one **oscillation** when it moves from extreme position **II** to extreme position **III** via mean position **I** and then returns to extreme position **II**, following the same path.

- The time taken to complete one oscillation is termed as the **time period** of the pendulum. If a simple pendulum completes 15 oscillations in 5 seconds, then the time period of the pendulum is 1/3 seconds to complete one oscillation.
- Consider *T* is the time period of a simple pendulum which means that in *T* seconds the pendulum completes 1 oscillation. This implies that in 1 second, the number of oscillations will be 1/*T* which is equal to the frequency of the pendulum i.e. *f*.

$$f=1T \text{ or } T=1ff=1T \text{ or } T=1f$$

Take a stone and attach it to the ceiling by a thread. Now, move it to one side up to a distance *x* (point A) and release it. It will go up to point B on the other side. Measure the horizontal distance *y* with the help of a ruler. Is *y* = *x*?	

You will find that the distance $y < x$. This is because air particles present in the medium oppose the motion of the pendulum. Hence, its distance decreases continuously until the bob comes to rest.

What will happen to the motion of the pendulum if it is allowed to oscillate in space?

Suspend a bob in a vertical stand and allow it to oscillate. Measure the time required by it to complete 10 oscillations. Wait until the bob comes to rest at the mean position. Now, move the bob to a distance greater than the first distance and release it. Measure the time taken by the bob to complete 10 oscillations again. Repeat the same steps for different distances and record the time period in the following table. **Is the time period dependent on displacement *x*?** Discuss this with your teacher.

S. No	Value of x (in cm)	Time taken to complete 10 oscillations	Time period
1.	-	-	-
2.	-	-	-
3.	-	-	-
4.	-	-	-

After performing this activity, you will find that the time periods for all distances are nearly equal to each other. This activity shows that the time period of a pendulum does not depend on the distance through which it is displaced.

Repeat the same activity by changing the mass of the bob and find out whether the **time period of a pendulum depends on the mass of the bob**.

Modern quartz clocks and watches lose or gain one second once in 2 to 10 years!

Galileo and the swinging lamp Galileo was one of the greatest scientists of his time. He was a physicist, astronomer, and mathematician. Once when he was sitting in a cathedral, he noticed that the lamp, suspended by a long chain from the ceiling, swung back and forth because of wind currents. He measured the time taken by the lamp to complete one oscillation using his pulse rate. He was surprised to find that each oscillation took an equal amount of time. He set up his own pendulum and obtained the same result as that obtained with the swinging lamp. He concluded from his findings that a pendulum takes equal time to complete each oscillation.	

Measurement of Time

- Atomic standard of time → Periodic vibrations produced in a cesium atom
- 1 second → time required for 9, 192, 631, 770 vibrations of the radiation of cesium 133 atom
- In our country, the National Physical Laboratory (NPL) has the responsibility of maintaining Indian standard time.

- **Now try to determine the distance covered by the car at 3.5 minutes.**
- Now it is the time to learn about choosing an appropriate scale for a graph.
- **Choosing the Scale**
- It is not easy to choose a suitable scale according to the given data and dimensions of your graph paper. Suppose you have a graph sheet of dimensions 50 cm × 25 cm and the data of the motion of a car is given as

Time (in min)	0	10	20	30	40
Distance (in km)	0	20	40	60	80

- In this case, the total time is equal to 40 minutes. Hence, you cannot choose the scale on the time axis as 1 min = 1 cm because the reading will exceed the *x*-axis after marking up to 25 cm. Similarly, since the total distance covered by the car is 80 km, you cannot choose the scale as 1 km = 1 cm.
- It is very important to choose a suitable scale for both the axes. These scales may or may not be equal. Follow the given steps when choosing the scales.
- **I.**Take the difference between the first and last readings of each quantity.
- Time: 40 – 0 = 40 min
- Distance: 80 – 0 = 80 km
- **II.**Divide each dimension by the total number of readings. It is clear from the given table that the total number of readings is 5.
- Time: $\frac{25}{5} = 5$ cm
- Distance: $\frac{50}{5} = 10$ cm
- **III.**Finally, divide each difference by the quantities obtained in step **II** i.e., for
  Time: $\frac{40 \text{ min}}{5 \text{ cm}} = 8 \text{ min/cm}$
- Distance: $\frac{80 \text{ km}}{10 \text{ cm}} = 8 \text{ km/cm}$
- You have obtained 8 min/cm for time i.e., you can choose the scales on the time axis as 8 min = 1 cm, 2 cm, 3 cm, 4 cm, or 5 cm.
- Similarly, on the distance axis, you can choose the scales as 8 km = 1 cm, 2 cm, 3 cm, 4 cm …, or 10 cm, as you have obtained 8 km/cm.
- **IV.**You have to choose a scale that will utilize the maximum part of the graph sheet. Hence, you must choose the scales as
- Time: 8 min = 5 cm
- Distance: 8 km = 10 cm
- **Draw a line graph for the motion of the car using this scale.**