Measurement of Time

Time

Like length and mass, time is also a fundamental physical quantity. Any event which repeats itself after an equal interval of time can be used for measurement of time. In nature, there are many such events which are repetitive. Examples are (i) motion of earth round the sun, (ii) motion of earth on its own axis, (iii) motion of wall clock or pendulum, and many more.
In fact, rotation of earth on its own axis has been taken to fix a unit of time, called second.

Second

It is basic unit of time. It is defined as l/86400th part of a mean solar day. A mean solar day is defined as the interval between two consecutive overhead passages of the sun at one place on the earth, as the earth rotates on its axis from west to east. The value of solar day varies over the year, hence its mean over one year is taken as mean solar day.
A second is also defined as the time interval in which 9,192,631,770 vibrations in an atom of cesium-133 take place during transition between the two hyper fine levels of ground state.

Time measuring devices

The various time measuring devices are :

1. **Clocks.** These are mechanical devices in which potential energy given to its spring during its binding, is converted into kinetic energy of its moving parts called hands. The ends of its two hands move along a circular path graduated to measure hours and minutes.
2. **Watches.** These are also mechanical devices much smaller in size but more fine in time measurement. Watches have three hands and measure hours, minutes and as well as seconds.
3. **Electric clocks.** These are run by a fixed frequency alternating current which passes through its synchronous motor. Currents from high frequency electronic oscillators work electronic watches.
4. **Quartz-crystal clocks.** A quartz crystal controls an electronic oscillator by its Own natural frequency. The current from quartz controlled oscillator works the quartz crystal clocks which have higher accuracy and precision.
5. **Atomic clocks.** Vibration of atoms has been utilised for making atomic clocks. These atomic vibrations are so steady that the clocks controlled by them hardly show a difference of a fraction of a second over thousands of years.

Measurment of time in laboratories

In laboratories, we have to measure time intervals ranging approximately from 10-2 seconds to 103 seconds. For the purpose of measuring time in this range, we use following time measuring devices :

1. Stopwatch

It is used for more accurate measurement of duration of an event or time interval between two events.

In appearance it also looks like an ordinary watch (Fig. 4.01).

It has an arrangement for the 'start' and 'stop' of the watch. There is a lever at the top of the body. When this lever is pressed for the first time, the watch starts when the same lever is pressed for the second time, the watch stops. A third press on the lever brings the watch to zero reading.

It has two hands, a short and a long hand.

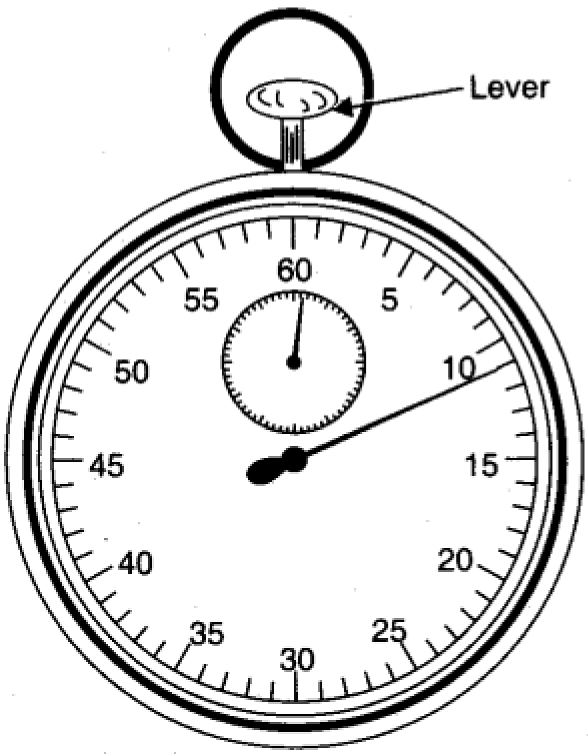


Fig. 4.01. Stopwatch.

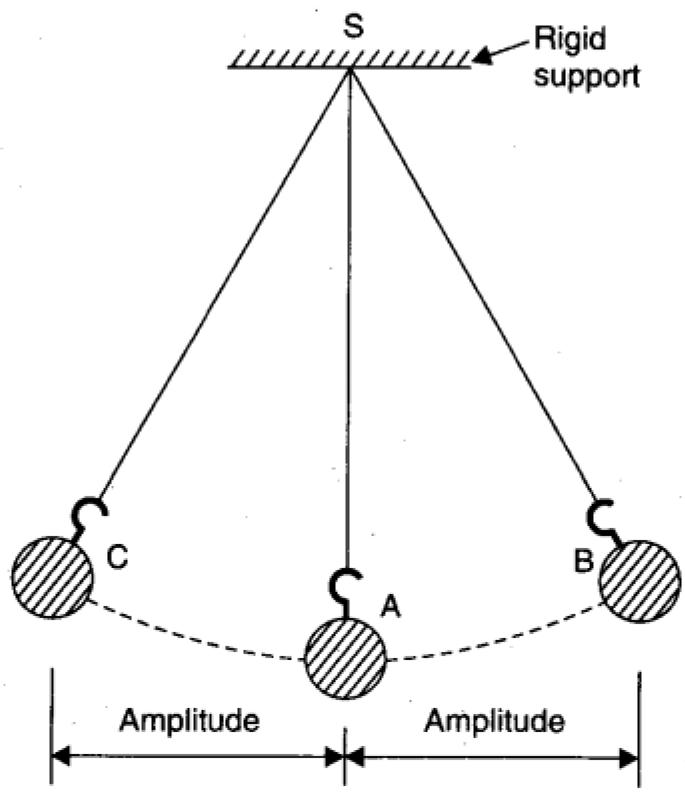
Hands start moving when the lever is pressed down. The tip of the long hand moves over a bigger circular scale covering the whole face of the watch. This tip moves one small division of circular scale in 0.1 sec or 0.2 sec and completes one complete-rotation in 30 sec or 1 minute. The tip of short hand moves over a small circular scale at the top of face of the watch. It moves one division on the small circular scale when long hand makes one full round on big scale.

Hence one division of small scale correspond to 30 sec or 1 minute. Moving hands are stopped by pressing the lever for the second time. When the lever is pressed for the third time, both hands fly back to. zero positions.

With both hands at zero positions, the watch is started when an event starts and stopped when the event ends. The position of the two hands gives the duration of the event in fraction of a second. The least count of such stop watches is 0.1 sec or 0.2 sec.

2. Simple pendulum

A simple pendulum is the simplest device for measuring time.



A—mean position, B, C—extreme positions.

Fig. 4.02. Simple pendulum.

(i) Construction. An ideal simple pendulum consists of a heavy point mass (called bob) tied to one end of a perfectly inextensible, flexible and weightless string. In practice, we make it by tying a metallic spherical bob to a fine cotton stitching thread (Fig. 4.02).
(ii) Working. The free end of the string is tied to a point of suspension S in a rigid support. When left free, the string becomes vertical and the bob stays in mean position A.
When displaced to one extreme position B (right extreme) and left free, the bob returns to mean position A, goes to extreme left position C and again returns to mean position A. This completes one vibration and the motion is repeated. The motion of the bob is a simple harmonic motion (S.H.M.). The time period, T of the simple pendulum depends upon its length l which is the distance between point of suspension S and C.G. of the

bob, which is also C.G. of the pendulum.

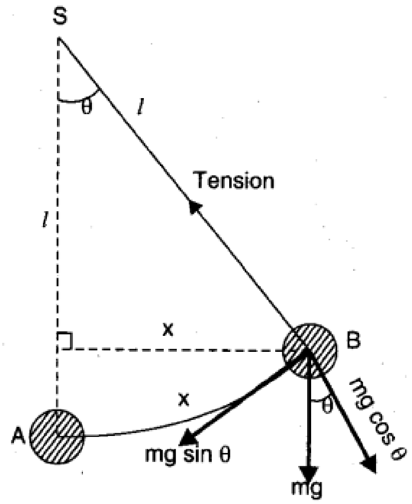


Fig. 4.03. Time period of a simple pendulum.

(iii) Theory. Let a simple pendulum of length l have a bob of mass m. Let the bob be displaced from its vertical mean position A to position B by an angle θ and distance (Fig. 4.03).

The component mg cos θ of its weight balances tension in string. Component mg sin θ acts on the bob as restoring force and produces acceleration in it.

Inward restoring force on bob,

$$F = -mg \sin \theta$$

Inward acceleration $= \dfrac{\text{Force}}{\text{Mass}}$

$$a = -\frac{mg \sin \theta}{m} = -g \sin \theta$$

$$a = -g\,\frac{x}{l} \qquad \left(\text{For small angle, } \sin \theta = \theta = \frac{x}{l}\right) \quad 0 < \theta \leq 18^\circ$$

Since, $\dfrac{g}{l} = \text{Constant}$

$$a \propto -x$$

Inward acceleration ∝ displacement.

It means that the motion of the bob, when released, will be simple harmonic motion (S.H.M.).

Time period T is given by

$$T = 2\pi\sqrt{\frac{\text{Displacement}}{\text{Acceleration}}} \quad \text{or} \quad T = 2\pi\sqrt{\frac{x}{a}}$$

or

$$T = 2\pi\sqrt{\frac{x}{\frac{gx}{l}}} \quad \text{or} \quad T = 2\pi\sqrt{\frac{l}{g}}.$$

This time period is independent of amplitude of the motion of the bob, provided it remains small (so that θ = sin θ).
Knowing l and g, T can be known.
Hence, a simple pendulum becomes a good time-indicator and as such can be used as a time measuring device.
(iv) Damping. Under ideal conditions of motion (vibration), the amplitude of vibration of the pendulum bob must remain constant. This will be the case when the point of suspension is free from friction and there is no air surrounding the bob. But actually both the factors are present.
The presence of air causes damping and the amplitude of vibration goes on decreasing continually as shown in Fig. 4.04. But even then the time period is not much effected. Amplitude decreases by a constant ratio.

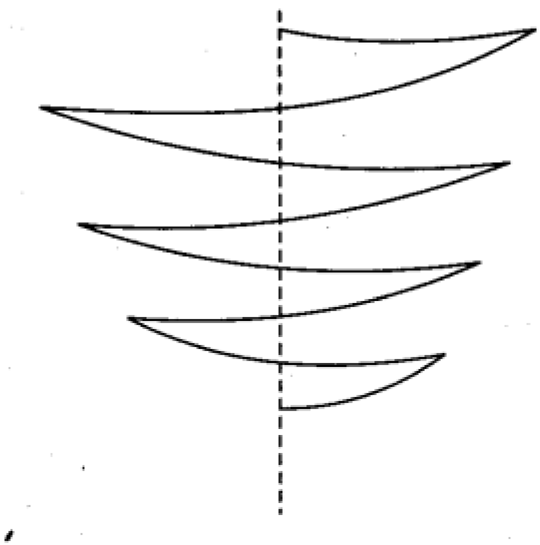


Fig. 4.04. Damped oscillations.

(v) Seconds pendulum. A simple pendulum, whose time period is two seconds (i.e. whose hob takes one second to move from one extreme to other extreme), is called seconds pendulum. Its length is 4-04. Damped oscillations. about 99.4 cm.

3. Ticker-Tape timer (Not in CBSE Syllabus)
It is another device used for measuring time in the laboratory. It can measure time intervals of the order of 1/50 th or 1/100 th of a second.

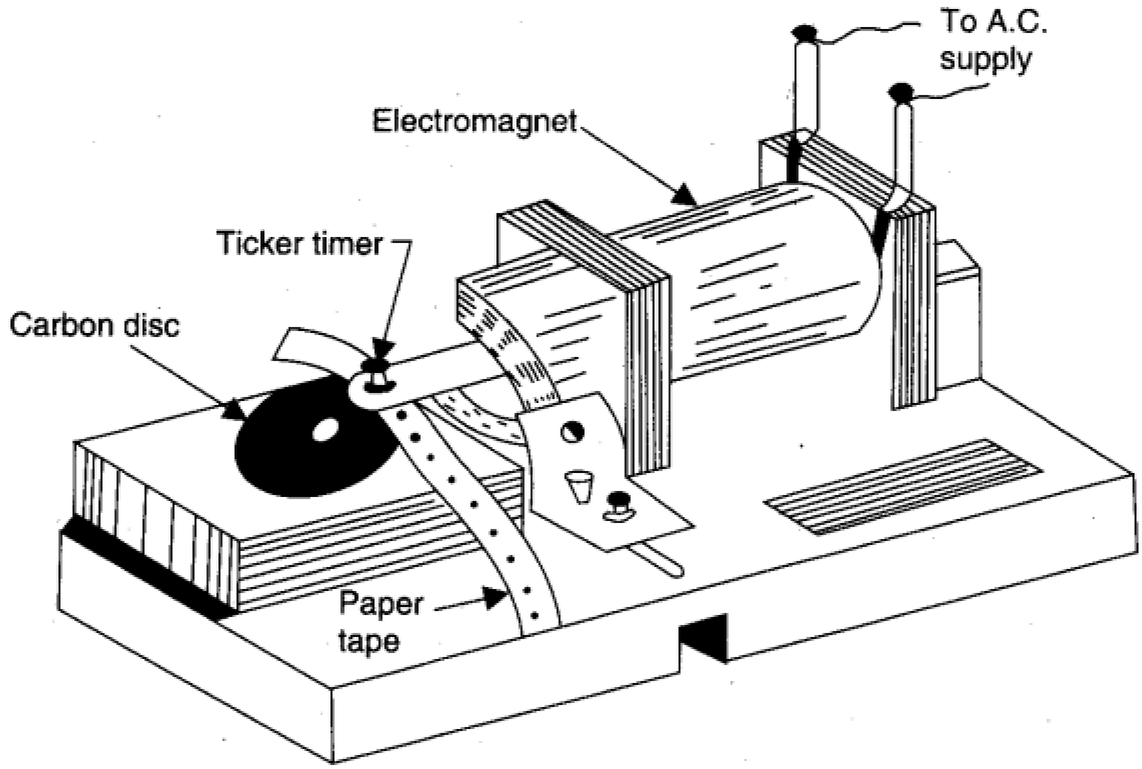


Fig. 4.05. Ticker-tape timer.

(i) Construction. Its simple type consists of an electromagnet whose coils are fed with alternating current of known steady frequency. A soft iron strip fixed at one end and free at the other end, runs through the core of the electromagnet. The free end of the strip has a small pointed hammer attached to it which strikes a disc made of carbon paper. A paper tape passes from under the disc.

(ii) Working. When alternating current is passed through the electromagnet, the soft iron strip gets magnetised and demagnetised twice during one cycle of current. It makes soft iron strip vibrate inside the core of the electromagnet with a frequency double of the frequency of the alternating current. As the strip vibrates, the pointed hammer strikes the carbon disc which leaves a dot on the paper tape below it.

As the paper tape is pulled from under the disc, dots are marked on it at a constant interval of time. This interval is half the time period of the alternating electromagnet current and can be known. With a 50 cycles per sec alternating current in laboratory, this time interval will be 1/100 sec. This time interval is called a tick and can be used as a standard unit of time.

Some important definitions connected with S.H.M.

1. Periodic Motion. A motion that repeats itself in equal intervals of time, is called a periodic motion.
2. Oscillatory Motion. The periodic motion in which a body moves to and fro (back and forth) over the same path, is called an oscillatory motion.

3. Simple Harmonic Motion (S.H.M.). An oscillatory motion which can be expressed in terms of single harmonic function (e.g., sine and cosine functions), is called a simple harmonic motion (S.H.M.).
4. Displacement. At any moment, the distance of the body (particle) from mean position, is called the displacement (it is a vector quantity). Its symbol is y.
5. Amplitude. Maximum displacement on either side of mean position is called amplitude. Its symbol is A.
6. Vibration. Motion from mean position to one extreme, then to other extreme and then back to mean position from same side, is called one vibration.
7. Time Period. The time taken by the body to complete one vibration, is called the time period of the body. Its symbol is T.
8. Frequency. The number of vibrations made by the body in one second, is called the frequency of the body. Its symbol is v.
   Hence, $v = 1/T$ or $vT=1$.

Viva Voce

Question. 1. Define a second.
Answer. It is a basic unit of time. It is defined as l/86400th part of a mean solar day. [Read Art. 4.02 for recent definition.]

Question. 2. Define a mean solar day.
Answer. A mean solar day is defined as the interval between two consecutive overhead passages of the sun at one place on the earth, as the earth rotates on its axis from west to east.

Question. 3. Is solar day constant ?
Answer. No, it varies in value over the year.

Question. 4. What is the difference between a clock and a watch ?
Answer. A clock has a big size. Its least count is 1 sec. A watch has a smaller size. Its least count is 0.1 sec or 0.2 sec.