EXPERIMENT 15

AIM

(i) To study the relation between frequency and length of a given wire under constant tension using a sonometer.

(ii) To study the relation between the length of a given wire and tension for constant frequency using a sonometer.

APPARATUS AND MATERIAL REQUIRED

Sonometer, six tuning forks of known frequencies, metre scale, rubber pad, paper rider, hanger with half-kilogram weights, wooden bridges.

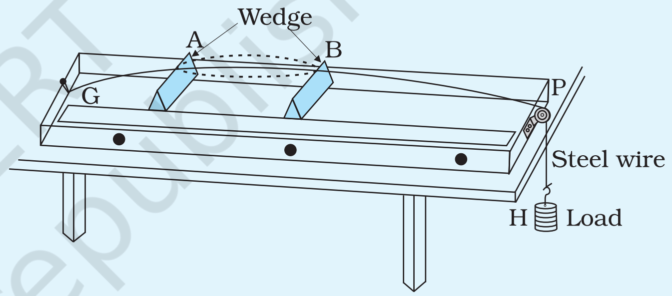

Fig. E 15.1: *A Sonometer*

SONOMETER

It consists of a long sounding board or a hollow wooden box W with a peg G at one end and a pulley at the other end as shown in Fig E 15.1. One end of a metal wire S is attached to the peg and the other end passes over the pulley P. A hanger H is suspended from the free end of the wire. By placing slotted weights on the hanger tension is applied to the wire. By placing two bridges A and B under the wire, the length of the vibrating wire can be fixed. Position of one of the bridges, say bridge A is kept fixed so that by varying the position of other bridge, say bridge B, the vibrating length can be altered.

PRINCIPLE

The frequency n of the fundamental mode of vibration of a string is given by

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} \quad \text{(E 15.1)}$$

where m = mass per unit length of the string

l = length of the string between the wedges

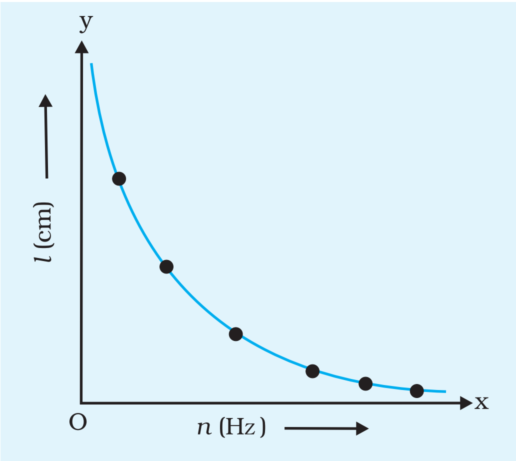

Fig. E 15.2: *Variation of resonant length with frequency of tuning fork*

T = Tension in the string (including the weight of the hanger) = Mg

M = mass suspended, including the mass of the hanger

(a) For a given m and fixed T,

$$n \propto \frac{1}{l} \quad \text{or} \quad n\,l = \text{constant.}$$

(b) If frequency n is constant, for a given wire (m is constant),

$$\frac{\sqrt{T}}{l} \text{ is constant. That is } l^2 \propto T.$$

(i) Variation of frequency with length

PROCEDURE

1. Set up the sonometer on the table and clean the groove on the pully to ensure that it has minimum friction. Stretch the wire by placing a suitable load on the hanger.
2. Set a tuning fork of frequency n_1 into vibrations by striking it against the rubber pad and hold it near one of your ears. Pluck the sonometer wire and compare the two sounds, one produced by the tuning fork and the other by the plucked wire. Make a note of difference between the two sounds.
3. Adjust the vibrating length of the wire by sliding the bridge B till the two sounds appear alike.
4. For final adjustment, place a small paper rider R in the middle of wire AB. Sound the tuning fork and place its shank stem on the bridge A or on the sonometer box. Slowly adjust the position of bridge B till the paper rider is agitated violently, which indicates resonance.

   The length of the wire between A and B is the resonant length such that its frequency of vibration of the fundamental mode equals the frequency of the tuning fork. Measure this length with the help of a metre scale.
5. Repeat the above procedures for other five tuning forks keeping the load on the hanger unchanged. Plot a graph between n and l (Fig. E 15.2)
6. After calculating frequency, n of each tuning fork, plot a graph between n and $1/l$ where l is the resonating length as shown in Fig. E 15.3.

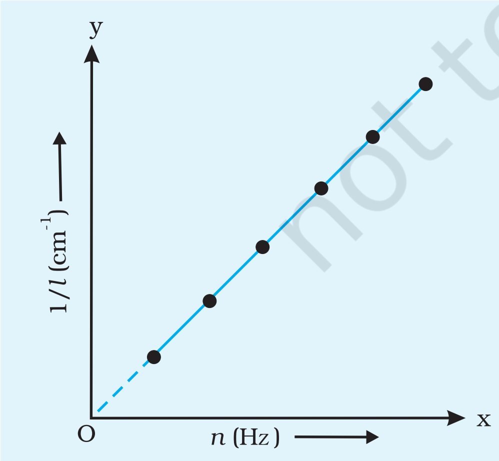

Fig. E 15.3: *Variation of* $1/l$ *with* n

OBSERVATIONS (A)

Tension (constant) on the wire (weight suspended from the hanger including its own weight) $T = \ldots N$

Table E 15.1: Variation of frequency with length

Frequency n of tuning fork (Hz)	n_1	n_2	n_3	n_4	n_5	n_6
Resonating length l (cm)						
$\frac{1}{l}$ (cm^{-1})						
nl (Hz cm)						

CALCULATIONS AND GRAPH

Calculate the product nl for each fork. and, calculate the reciprocals, $\frac{1}{l}$ of the resonating lengths l. Plot $\frac{1}{l}$ *vs* n, taking n along x axis and $\frac{1}{l}$ along y axis, starting from zero on both axes. See whether a straight line can be drawn from the origin to lie evenly between the plotted points.

RESULT

Check if the product $n\,l$ is found to be constant and the graph of $\frac{1}{l}$ *vs* n is also a straight line. Therefore, for a given tension, the resonant length of a given stretched string varies as reciprocal of the frequency.

DISCUSSION

1. Error may occur in measurement of length l. There is always an uncertainty in setting the bridge in the final adjustment.
2. Some friction might be present at the pulley and hence the tension may be less than that actually applied.
3. The wire may not be of uniform cross section.

(ii) Variation of resonant length with tension for constant frequency

1. Select a tuning fork of a certain frequency (say 256 *Hz*) and hang a load of 1kg from the hanger. Find the resonant length as before.

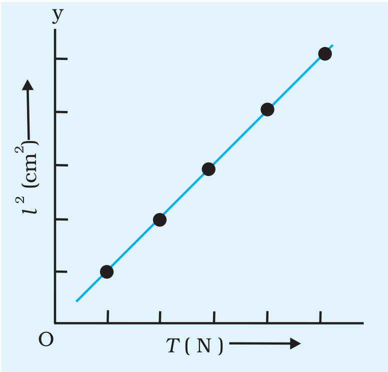

Fig. E 15.4: *Graph between l^2 and T*

2. Increase the load on the hanger in steps of 0.5 kg and each time find the resonating length with the same tuning fork. Do it for at least four loads.
3. Record your observations.
4. Plot graph between l^2 and T as shown in Fig. E 15.4.

OBSERVATIONS (B)

Frequency of the tuning fork = ... Hz

Table E 15.2: Variation of resonant length with tension

Tension applied *T* (including weight of the hanger) (N)					
Resonating length *l* of the wire					
l^2 (cm^2)					
T/l^2 (N cm^{-2})					

CALCULATIONS AND GRAPH

Calculate the value of T/l^2 for the tension applied in each case. Alternatively, plot a graph of l^2 *vs* T taking l^2 along *y*-axis and T along the *x*-axis.

RESULT

It is found that value of T/l^2 is constant within experimental error. The graph of l^2 *vs* T is found to be a straight line. This shows that

$l^2 \propto T$ or $l \propto \sqrt{T}$.

Thus, the resonating length varies as square root of tension for a given frequency of vibration of a stretched string.

PRECAUTIONS

1. Pulley should be frictionless ideally. In practice friction at the pulley should be minimised by applying grease or oil on it.
2. Wire should be free from kinks and of uniform cross section, ideally. If there are kinks, they should be removed by stretching as far as possible.

3. Bridges should be perpendicular to the wire, its height should be adjustes so that a node is formed at the bridge.
4. Tuning fork should be vibrated by striking its prongs against a soft rubber pad.
5. Load should be removed after the experiment.

SOURCES OF ERROR

1. Pulley may not be frictionless.
2. Wire may not be rigid and of uniform cross section.
3. Bridges may not be sharp.

DISCUSSION

1. Error may occur in measurement of length *l*. There is always an uncertainty in setting the bridge in the final adjustment.
2. Some friction might be present at the pulley and hence the tension may be less than that actually applied.
3. The wire may not be of uniform cross section.
4. Care should be taken to hold the tuning fork by the shank only.

SELF ASSESSMENT

1. What is the principle of superposition of waves?
2. What are stationary waves?
3. Under what circumstances are stationary waves formed?
4. Identify the nodes and antinodes in the string of your sonometer.
5. What is the ratio of the first three harmonics produced in a stretched string fixed at two ends?
6. Keeping material of wire and tension fixed, how will the resonant length change if the diameter of the wire is increased?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Take wires of the same material but of three different diameters and find the value of l for each of these for a given frequency, n and tension, T.
2. Plot a graph between the value of m and $\frac{1}{l^2}$ obtained, in 1 above, with m along X axis.
3. Pluck the string of an stringed musical instrument like a sitar, voilin or guitar with different lengths of string for same tension or same length of string with different tension. Observe how the frequency of the sound changes.