# A LABORATORY MANUAL OF PHYSICS

FOR ADVANCED LEVEL CERTIFICATE,
SCHOLARSHIP AND INTERMEDIATE SCIENCE STUDENTS

BY

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## Sound

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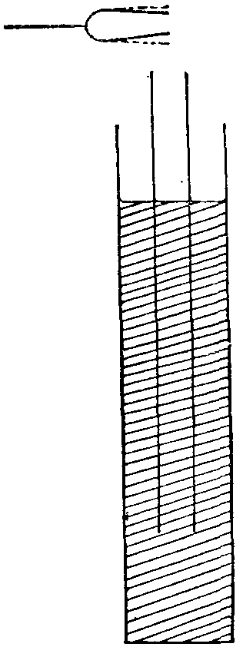
LIST OF ADDITIONAL EXPERIMENTS DESCRIBED IN THE TEXT

## Sound

# *SOUND*

EXPERIMENT 48

## DETERMINATION OF THE VELOCITY OF SOUND USING A RESONANCE TUBE



### Apparatus

Glass resonance tube about 100 cm. long and 3 cm. in diameter. This is held by a clamp inside a deep cylindrical container (e.g. a length of wider tubing closed with a rubber bung at the bottom end) which is almost completely full of water. Also required are: set of tuning forks of frequency range 256–512, and a metre rule.

### Method

The resonance tube is placed well down in the water and gradually raised. As this is done a vibrating fork is held over the mouth of the tube, and when resonance occurs (i.e. when the note of the fork swells out to its loudest volume), the length $l_1$ of the tube above the water level is measured. Three or four values of $l_1$ are found, and the mean taken. The tube is now further raised out of the water, and a second position of resonance is found, a mean value of the length $l_2$ of the air column being obtained. The experiment is repeated with each of the forks in turn, and from the results a mean value for the velocity of sound at the temperature of the experiment is determined.

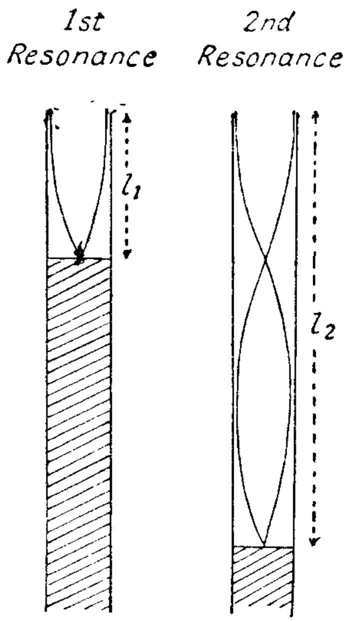
### Results

| Frequency $n$ | Readings of $l_1$ | Mean $l_1$ | Readings of $l_2$ | Mean $l_2$ | $V$ |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | Average = |

$\therefore$ velocity of sound in air at      °C. = ________________ cm./sec.

### Theory

Waves propagated down the tube are reflected at the closed end and stationary vibrations are produced by the interference of the incident and reflected wave trains. The air is at rest at the closed end, which is therefore a node, and for resonance the open end must be an antinode. Actually the antinodes are situated a short distance $e$ (known as the end correction) beyond the open end of the tube. The diagrams indicate the conditions of vibration for the first two positions of resonance, from which we have—




$$l_1 + e = \frac{\lambda}{4} \qquad (1)$$

$$l_2 + e = \frac{3\lambda}{4} \qquad (2)$$

where $\lambda$ is the wavelength of the note.

Hence by subtraction—

$$(l_2 - l_1) = \frac{\lambda}{2} \qquad (3)$$

Now if $V$ is the velocity of sound, and $n$ the frequency of the note, we have

$$V = n\lambda \qquad (4)$$

Hence from (3) and (4)—

$$V = 2n(l_2 - l_1) \qquad (5)$$

### Notes

(1) The value of $V$ obtained in the experiment should be compared with the result calculated from the formula

$$V = 331\left(1 + \frac{t^\circ C}{273}\right)^{\frac{1}{2}} \text{ metres/sec.}$$

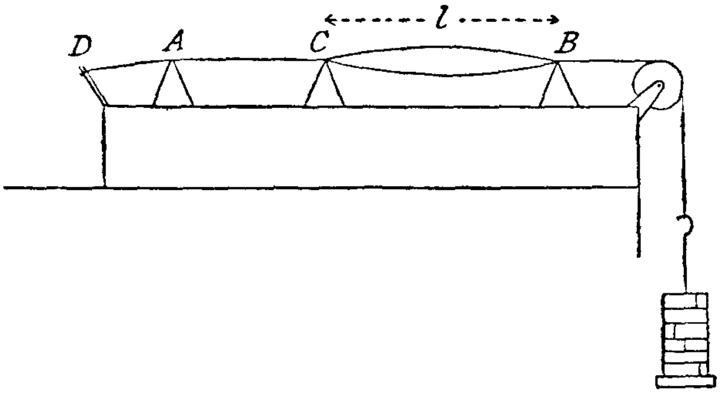
(2) Using the calculated value of $V$ at the temperature of the experiment, the frequency $n$ of a given tuning-fork can be found from equation (5).

(3) The value of the end correction for the tube can be calculated from equations (1) and (2) above which give

$$\frac{l_2 + e}{l_1 + e} = 3 \qquad \text{or} \qquad e = \tfrac{1}{2}(l_2 - 3l_1).$$

(4) Alternatively both the velocity of sound in air and the end correction for the tube can be obtained by a graphical method using forks of different frequencies. The first resonance position is found for each fork; the relation between the resonance length ($l$) and the frequency ($n$) being given by $l + e = \frac{V}{4n}$ (from equations (1) and (4) above). Thus by plotting $l$ as ordinates against $\frac{1}{n}$ as abscissae, a straight-line graph results which on extrapolation enables the value of $e$ to be obtained as the intercept on the $l$ axis. The value of the velocity of sound is obtained from the slope of the graph $\left(= \frac{V}{4}\right)$.

# DETERMINATION OF THE FREQUENCY OF A TUNING-FORK USING A SONOMETER




### Apparatus

Sonometer, length of steel wire of diameter about $\frac{1}{2}$ mm., supporting hook and set of slotted $\frac{1}{2}$-kgm. weights, tuning-fork, screw gauge.

### Method

The wire is tied to the peg $D$, passed over the two fixed bridges $A$ and $B$, and fastened to the hook. A movable bridge is placed under the wire at $C$ (initially approximately mid-way between $A$ and $B$), and the wire is loaded until the length $BC$, when gently plucked between thumb and finger at its midpoint, emits a note of approximately the same frequency as the fork. The sonometer is now tuned to have the same frequency as the fork by slight adjustments to the position of $C$. If the tuning is close, " beats " will be heard on simultaneously sounding the fork and plucking the wire. The position of $C$ should then be adjusted so that the beats get slower until finally they can no longer be distinguished. The two notes are then in unison. The length $BC$ is then measured, and the total load attached to the wire noted. Finally, the radius of the wire is taken by a screw gauge. The experiment is repeated by varying the load and finding the corresponding resonance length ($l$) in each case.

### Results

Readings of screw gauge:
, , , , , cm.

$\therefore$ mean diameter = cm.

Zero error = $\pm$ cm.

$\therefore$ true mean diameter = cm.

i.e. radius ($r$) = cm.

Density of wire ($\rho$)
(from tables) = gm./c.c.

| Load $W$ gm. | $l$ | $n$ |
|---|---|---|
| | | |
| | Average = | |

## Theory

The velocity of propagation of transverse waves along a stretched string or wire is

$$V = \sqrt{\frac{T}{m}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $T$ is the tension in the wire in dynes, and $m$ is the mass per centimetre length of the wire. Now if $n$ is the frequency of the note emitted, and $\lambda$ is wavelength, we have—

$$V = n\lambda \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence from (1) and (2)

$$n = \frac{1}{\lambda}\sqrt{\frac{T}{m}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If the vibrating length $BC$ of the wire is sounding its fundamental note, there will be one antinode mid-way between the two nodes $B$ and $C$. Thus $\lambda = 2l$ for the fundamental note,

i.e.

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{2l}\sqrt{\frac{Wg}{\pi r^2 \rho}} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $W$ is the attached load in gm., and $\rho$ is the density of the material in gm. per c.c.

## Notes

(1) The laws of vibration of a stretched string can be verified using the sonometer as follows :

(*a*) Load the wire to produce a suitable tension, and find the vibrating lengths ($l$) for a set of forks of standard frequencies ($n$). Then, graphically or otherwise, show—

$$n \propto \frac{1}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (i)$$

(*b*) Use a fixed length of wire, and vary the load ($W$) so as to produce unison in the wire for a set of standard forks. Then, graphically or otherwise, show—

$$n \propto \sqrt{W} \qquad \text{i.e.} \quad n \propto \sqrt{T} \quad . \quad . \quad . \quad . \quad . \quad (ii)$$

(*c*) Use two or more wires of different materials (e.g. brass, steel, etc.), but having the same diameters. Load the wires to be under the same tension, and find the vibrating lengths ($l$) in each case for a fork of given frequency. Then, since the frequency of a wire under constant tension is inversely proportional to its length, it will be sufficient to show that $l\rho^{\frac{1}{2}}$ is constant for each wire under the conditions of test to conclude that

$$n \propto \frac{1}{\rho^{\frac{1}{2}}} \qquad \text{or} \qquad n \propto \frac{1}{m^{\frac{1}{2}}} \quad . \quad . \quad . \quad . \quad . \quad (iii)$$

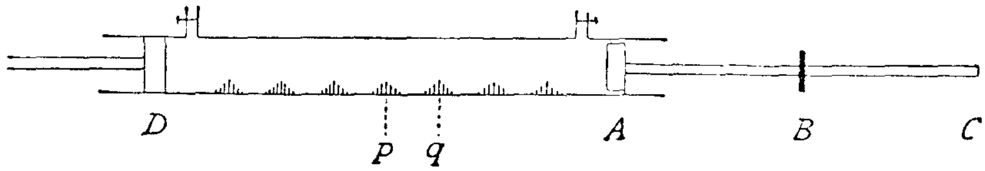
(2) The density of a suitable heavy weight $W$ (about 10 kilogrammes) can be found by attaching it to the end of the sonometer wire and finding the resonance length $l$ using a fork of given frequency ($n = 256$ will be suitable). The weight is now completely immersed in water, the upthrust of which reduces the effective mass of the weight to $W'$ (say), and using the same fork, the new resonance length $l'$ is found. Hence using equation (4) above we have

$$n = \frac{1}{2l}\sqrt{\frac{Wg}{\pi r^2 \rho}} = \frac{1}{2l'}\sqrt{\frac{W'g}{\pi r^2 \rho}},$$

and thus the density of the weight

$$= \frac{W}{W - W'} = \frac{l^2}{l^2 - l'^2}.$$

# DETERMINATION OF THE VELOCITY OF SOUND IN AIR USING KUNDT'S TUBE




## Apparatus

Glass tube about 100 cm. long and of diameter 3–4 cm. The tube is fitted with a tightly fitting piston $D$ at one end, and closed at the other by a loosely fitting piston head of cork attached to the end of a long brass rod $AC$ clamped firmly at its midpoint $B$. Also required are; lycopodium powder, resined cloth, metre rule.

## Method

The glass tube is first dried by gently warming over a bunsen flame and blowing a current of air through it. It is then lightly dusted inside with lycopodium powder and placed in a horizontal position as shown in the diagram. The brass rod is then set in longitudinal vibration by stroking it with the resined cloth, and the piston $D$ adjusted until the air column $AD$ resounds to the note of the rod. The lycopodium powder is then agitated and settles down in small heaps at the nodes of the standing vibration of the air column. When sharp resonance has been obtained the distance between several of these heaps is measured to obtain the average distance $pq$ between the nodes. The length $AC$ of the rod is also measured.

## Results

| | | |
|---|---|---|
| Young's modulus of brass ($E$)—from tables | = | dynes/cm.$^2$ |
| Density of brass ($\rho$)—from tables | = | gm./cm.$^3$ |
| Length of rod ($AC$) | = | cm. |
| Average inter-node distance ($pq$) | = | cm. |

$\therefore\ v =$ ______________ cm./sec. at °C.

### Theory

Let $V$, $v$ be the velocity of sound in the rod and air respectively, and let $\lambda_r$ and $\lambda_a$ be the wavelengths of the note of frequently $n$ in the rod and in the air. Now the rod vibrates with a node at $B$ and antinodes at $A$ and $C$, hence $\lambda_r = 2AC$: and if the distance between the heaps of lycopodium powder in the tube (i.e. distance between the nodes) is $pq$, then $\lambda_a = 2pq$. Thus, since frequency = velocity $\div$ wavelength, we have

$$n = \frac{V}{2AC} = \frac{v}{2pq}$$

from which

$$v = V\frac{pq}{AC} \quad \ldots \ldots \quad (1)$$

Now if $E$ is Young's Modulus of the rod, and $\rho$ its density,

$$V = \sqrt{\frac{E}{\rho}} \quad \ldots \ldots \quad (2)$$

Hence from (1) and (2)

$$v = \sqrt{\frac{E}{\rho}} \cdot \frac{pq}{AC}.$$

### Notes

(1) If the velocity of sound in air is calculated from the formula $v = 331\left(1 + \frac{t° C.}{273}\right)^{\frac{1}{2}}$ metres per sec., the value of the velocity ($V$) of sound in the rod can be found from equation (1) above. Hence the value of Young's Modulus of the rod can be obtained from equation (2) knowing the density ($\rho$) of the material.

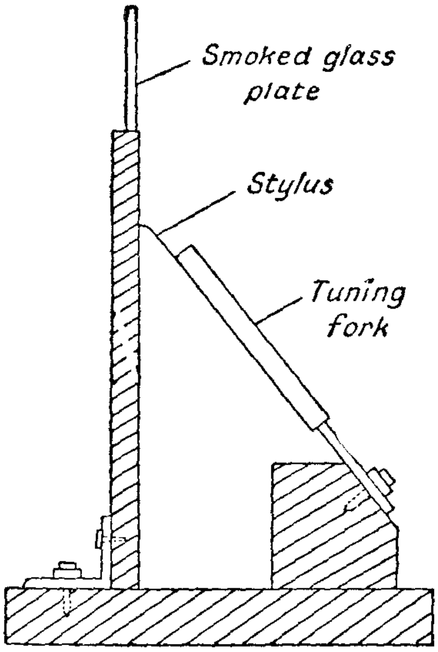
(2) With another gas introduced in the tube giving an inter-node distance of $p'q'$ we have

$$\frac{v_g}{v_a} = \frac{p'q'}{pq}$$ (where $v_g$ is the velocity of sound in the gas and $v_a$ is the velocity of sound in the air)

using the value of $v_a$ calculated from the formula above, $v_g$ can be found.

Now the velocity of propagation of sound in a gas is given by $v_g = \sqrt{\frac{\gamma p}{\rho}}$, where $p$ is the pressure of the gas, $\rho$ its density, and $\gamma$ the ratio of the specific heat at constant pressure to that at constant volume. Hence knowing $p$ and the value of $\rho$ for the gas at the temperature of the experiment, the value of $\gamma$ can be found. (see also Expt. 65).

# DETERMINATION OF THE FREQUENCY OF A TUNING-FORK BY THE FALLING-PLATE METHOD




## Apparatus

The apparatus consists of a wooden stand, adjustable in position by a clamping screw at the back, and grooved to take a smoked-glass plate. A tuning-fork with stylus attached is firmly screwed to a block of wood so that the stylus is just in contact with the glass plate as it falls. A travelling microscope, and a violin bow are also required.

## Method

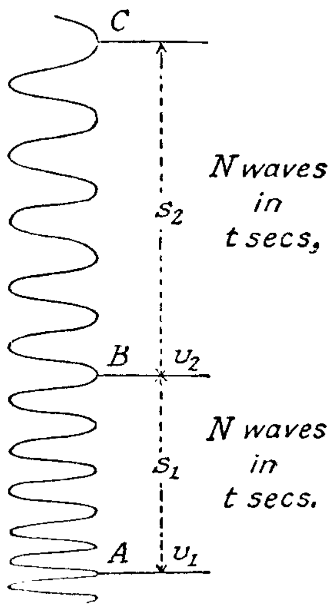
A light stylus, e.g. a short length of copper wire, is attached to the end of the fork by means of wax. The fork is then screwed in position. The glass plate is smoked on one side by holding it over a turpentine or benzene flame. It is then held at the top of the grooved wooden stand which has been adjusted to the correct position by the clamping screw. The fork is now gently stroked by the violin bow and the plate released—the stylus producing a wavy trace on its smoked surface as it falls. The distances covered by succeeding sets of 10 (say) waves are measured by the travelling microscope, and the frequency of the fork calculated as indicated.

## Results

| | | |
|---|---|---|
| Distance $AB$ $(s_1)$ | = | cm. |
| ,, $BC$ $(s_2)$ | = | cm. |
| Number of waves in each set $(N)$ | = | |
| $\therefore$ time for $N$ waves | = | sec. |
| Hence frequency of fork | = | ________________ |

### Theory

The type of wave trace obtained is indicated in the attached figure. Three well-defined crests ($A$, $B$, and $C$) are selected with the same number ($N$) of complete waves between them. Let the distances between $A$ and $B$, and $B$ and $C$, be $s_1$ and $s_2$ respectively, and




let the velocity of the plate at $A$ be $v_1$, and at $B$ be $v_2$. If $t$ is the time taken to trace $N$ waves, then assuming the plate to fall freely under gravity,

$$s_1 = v_1 t + \tfrac{1}{2}gt^2 \qquad (1)$$

and

$$\begin{aligned} s_2 &= v_2 t + \tfrac{1}{2}gt^2 \\ &= v_1 t + gt^2 + \tfrac{1}{2}gt^2 \qquad (2) \end{aligned}$$

since $v_2 = v_1 + gt$.

Subtracting (1) from (2),

$$s_2 - s_1 = gt^2$$

hence

$$t = \sqrt{\frac{s_2 - s_1}{g}}$$

and therefore the vibration frequency $n = \dfrac{N}{t} = N\sqrt{\dfrac{g}{s_2 - s_1}}$.

### Note

The frequency $n$ obtained as above is that of the fork loaded by the stylus and wax, and is thus lower than its true frequency. To obtain the corrected value, a second fork of the same frequency as the fork under investigation when unloaded, is obtained, and the number of beats counted when this fork and the loaded fork are sounded together. Then the number of these beats per second, if added to the frequency as calculated above, will give the corrected frequency.

# CALIBRATION OF A NARROW-NECKED RESONATOR

## Apparatus

Narrow-necked flask or bottle, graduated cylinder, set of tuning-forks of frequency range 256–512, beaker, pipette.

## Method

The flask is first filled with water up to the base of the neck, and the volume ($V$) of this water is found by pouring the contents of the flask into the graduated cylinder. Starting with the fork of lowest frequency, the vibrating fork is held over the mouth of the empty flask and water is gradually added until the flask resonates to the fork frequency ($n$). The flask is carefully tuned to this frequency by gradually adding (or withdrawing) small quantities of water by means of the pipette. When the most satisfactory resonance has been obtained, the water in the flask is poured into the measuring cylinder, and its volume ($v'$) is found. Hence by subtracting this volume from the volume of the flask, the volume ($v$) of air in the flask at resonance can be found. The experiment is repeated with each of the forks in turn up to the fork of highest frequency. A graph is then drawn with values of $v$ as ordinates and values of $\frac{1}{n^2}$ as abscissae.

## Results

Volume of flask ($V$) = c.c.

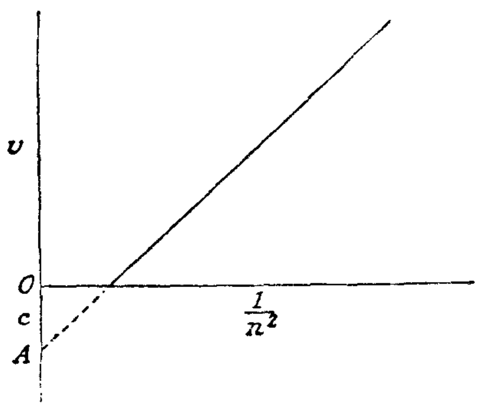
| Frequency $n$ | Vol. of water in flask $v'$ | Vol. of air at resonance $v = V - v'$ |
|---|---|---|
| | | |

### Theory

A resonator consists of a vessel of any shape with an opening to the atmosphere in the form of a narrow neck or small orifice. When a note is sounded in the vicinity of such a vessel, the air inside it is set into forced vibrations of frequency equal to the note frequency. If, however, the natural frequency of the vessel is the same as that of the external note, resonance occurs, and there is a maximum reinforcement of the sound. Dynamical considerations show that the relation between the resonance frequency ($n$) and the volume of air in the resonator is given by the following law—

$$n^2 v = \text{const.} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

On plotting the graph of the results, however, it will be found that the straight line obtained between $v$ and $\frac{1}{n^2}$ does not pass through the origin, but cuts the axis of $v$ on the




negative side of it. Thus equation (1) must be modified as follows—

$$n^2(v + c) = \text{const.}$$

where $c$ represents the " residual " volume $OA$ which may be considered as a neck correction.

### Note

Using a bottle or flask with a short, narrow neck, and proceeding as above to find the volume $v$ of air in the flask at resonance, the student can establish empirically the relation between the resonant frequency $n$ and the volume of air producing resonance. Thus, ignoring the small neck correction, and assuming the relation between $n$ and $v$ to be of the form $n^p v = \text{const.}$, the values of $p$ and the const. can be obtained from a graph of $\log v$ ($y$ axis) against $\log n$ ($x$ axis) in a manner similar to that described on p. 23.