CENTRAL
SCIEN-
TIFIC
COMPANY

OPERATING INSTRUCTIONS

Resonance Apparatus
No. 84930-02

1. Introduction

You can use the Central Scientific Resonance Apparatus to study resonance columns and determine experimentally the velocity of sound in air. A tuning fork of known frequency is sounded at the mouth of a vertical column of air in a clear tube that is partially filled with water. The length of the air column is adjusted by regulating the water level in the clear tube until the column of air resonates at the same frequency as the vibrating tuning fork. By locating several resonance positions and determining their average distance, it is possible to compute the wavelength of sound in air and its velocity.

2. Description

The Resonance Apparatus consists of a clear resonance tube and a water reservoir mounted on a metal base.

The resonance tube has a 110cm scale mounted along its length marked off in 1mm increments. It is terminated by a metal collar that fits into the tripod base. A fitting on the metal collar connects the resonance tube to the water reservoir through the rubber tubing.

The water reservoir sits in a ring clamp and can be moved up and down along the support rod. The rubber hose from the resonance tube connects to a fitting on the bottom of the reservoir can.

Also supplied is the length of rubber tubing, a ring clamp and collar for supporting the upper end of the resonance tube, and a small clamp for holding a tuning fork. (The tuning fork is not supplied.)

3. Assembly

Some minor assembly is required before the Resonance Apparatus can be used.

Screw the aluminum support rod into the centered hole in the tripod base. Attach the two ring clamps and the one right-angle clamp to the support rod. The right-angle clamp, which holds the tuning fork, should be the highest. It is followed by the small ring clamp that supports the resonance tube and the large ring clamp that holds the reservoir can.

Place the water reservoir into the larger ring clamp. Mount the resonance tube to the tripod base by fitting the small guide pin under the metal collar into the small guide hole in one of the legs of the tripod base. Slip the smaller ring clamp around the resonance tube a few centimeters from the top and put the plastic support collar down the clear tube and rest it on the ring clamp. Connect the length of rubber hose between the metal collar and the water reservoir.

Before filling the reservoir can with water, move it to a height just below the top of the resonance tube. Fill the reservoir can until the water level stabilizes at about 1/2 inch above the bottom of the can. The water level in the clear tube should be about 20cm from the top of the tube. This level lets the can travel the full length of the scale without overflowing.

4. Theory

A wave can be defined as a disturbance propagated through a medium by the oscillation of the particles composing the medium. (Although this definition is satisfactory for material waves such as sound and water waves, it is inadequate for light, which is a non-material vibration.) A single wave traveling alone is a rare occurrence; what usually is observed is a continuous train of waves. An investigation of the medium shows that while all of the particles are executing identical vibrations, the motion of each successive particle is delayed slightly behind its predecessor. This delay is called a *phase difference* and is due to the fact that an impulse sent out from the source travels at a finite velocity and arrives at the successive particles at increasingly later times. Thus, the velocity of propagation of the wave determines the progressive difference in phase.

The situation is represented in Figure 1. The particles are represented as oscillating up and down along the arrows when a train of waves passes through the medium from left to right. At any given instant the successive particles will be in different stages of motion, the result being a deformation of the medium as indicated by the curved line. At a slightly later instant all of the particles will have advanced by the same amount in their respective orbits and, although the configuration will have the same form, it will have shifted to the right.

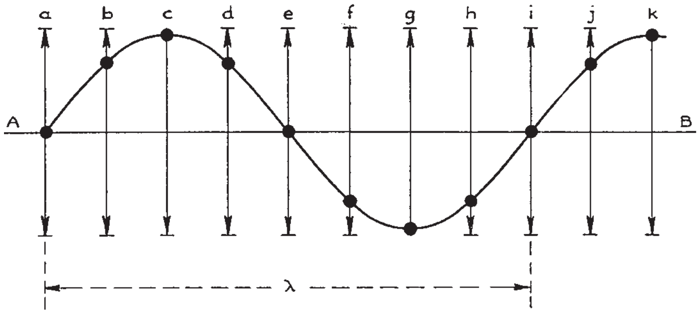

Figure 1 Oscillation of the particles in a transverse wave.

Starting with any given particle, as the phase difference increases along the direction of propagation, a particle is eventually reached that is one whole vibration behind the first and in the same phase of motion. This situation occurs at regular intervals throughout the medium. The distance between successive particles in the same phase of motion is called a *wavelength*. In Figure 1 the distance from **a** to **i** or from **c** to **k** is one wavelength. Such particles as **a** and **e** or **c** and **g** differ in phase by half a vibration and are opposite in phase.

A wave like the one in Figure 1, in which the particles oscillate back and forth in straight lines at right angles to the direction in which the wave is traveling, is called a *transverse* wave. This is the type of wave involved in vibrating strings. If the linear vibration of the particles is parallel to the direction of propagation, the wave is said to be a *longitudinal* wave. Sound waves belong to the latter class; the particles of air (or other medium) rush forward producing a packing, or *compression*, and then spring back leaving a *rarefaction*. Such a situation is represented schematically by Figure 2 in which the regions of crowded dots represent the compressions **C** and the regions of scattered dots represent the rarefactions **R**, all particles being thought of as oscillating back and forth in horizontal paths. This figure does not represent the situation for a longitudinal wave as satisfactorily as Figure 1 does for a transverse wave, because it does not indicate the displacements of the individual particles. It is often convenient to represent a longitudinal wave graphically by means of a curved line similar to that of Figure 1 in which vertical distances from the line **AB** represent longitudinal displacements of the particles. In Figure 2 the meaning of a wavelength is the same as in Figure 1; it may be measured from one compression to the next, or between any two successive particles in the same phase.

Figure 2 Schematic representation of a longitudinal wave.

The *amplitude* of a wave is the maximum displacement of a particle from its equilibrium position. In Figure 1 the amplitude is one-half the length of the arrows. The amplitude depends upon the amount of energy that is supplied to the wave; in the case of sound waves, it is the factor that determines the intensity of the sound.

The *frequency* of a wave is the number of waves generated per second and is equal to the number of oscillations per second of the source producing it. In the case of sound waves the frequency determines the pitch of the sound. The frequency **n**, the wavelength λ, and the velocity **V** for any kind of wave are related by the simple equation

$$\mathbf{V} = \mathbf{n}\lambda \qquad (1)$$

The validity of this equation is apparent when it is considered that if, in one second, **n** waves of length λ are stretched out end to end, their combined length is $\mathbf{n}\lambda$ and the first wave must have traveled a distance $\mathbf{n}\lambda$ from the source. Equation (1) is a means of determining the velocity of sound by measuring the wavelength of the waves produced by a source of known frequency.

The experimental determination of λ involves the production of *standing waves*. When a train of waves from a source is reflected at a boundary, the disturbance in the medium between the source and the reflector has a complicated nature resulting from the interaction of the direct and reflected waves. The interaction of the two wave trains is such that at certain equally spaced positions the phase of the disturbance due to the reflected waves is opposite at all times to that due to the direct waves. The result is that the two effects mutually cancel each other and the disturbance is always zero. These positions of no disturbance are called *nodes*. Midway between the nodes the phase relations are such that the disturbance in the medium is a maximum. These regions are called *antinodes*. The amplitude of vibration increases gradually from zero at a node to maximum at an antinode. The succession of nodes and antinodes is called a standing wave. The nodes and antinodes in string waves are familiar to anyone who has ever generated waves in a rope by whipping it. The distance between nodes is equal to one-half of a wavelength. This relationship is important to the experimental study of waves of all kinds, particularly sound waves. Standing waves in a stretched string vibrating in two segments are represented in Figure 3.

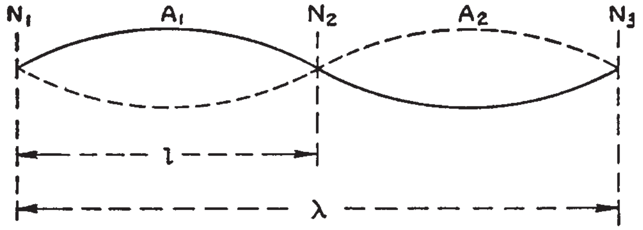

Figure 3 Standing wave in a string.

Although the physical situation is somewhat different in the case of sound waves in air, the same schematic method of representation can be used to indicate the positions of the nodes and antinodes.

Resonance is the intensification of the sound wave from a source by means of the sympathetic vibration of another body, called a resonator, tuned to respond to the same frequency. When an organ pipe is used as a resonance chamber, standing waves are set up in the air column in the pipe. The simplest resonance chamber consists of a tube open at one end and closed at the other, the open end being placed near the sounding body. If the tube is the proper length, standing waves are set up that reinforce the sound emitted by the source. In such a resonator there is a node at the closed end since no vibration can occur there, and an antinode at the open end because there the particles of air have the greatest freedom of motion. The shortest closed pipe that resonates with a source of a given frequency **n** (i.e., with a given wavelength λ) is one whose length is one-quarter wavelength. This situation is illustrated in Figure 4a in which the schematic representation of Figure 3 is used. A pipe three times as long as the minimum will also resonate with the same note as shown in Figure 4b. Any closed pipe whose length is an odd number of multiples of a quarter wavelength will produce resonance.

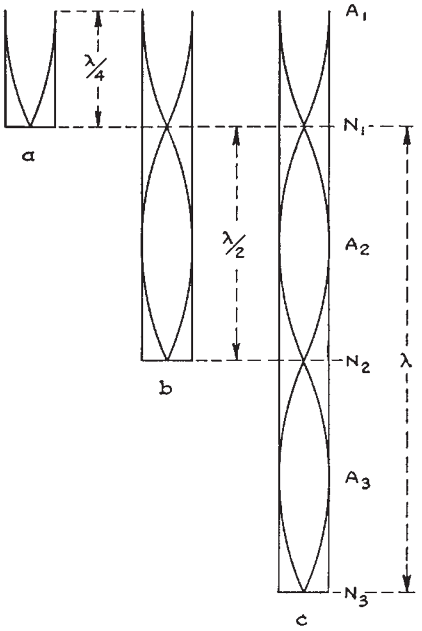

Figure 4 Standing waves in air columns.

Owing to the fact that the maximum disturbance does not occur exactly at the mouth of the pipe, the distance $\mathbf{a_1n_1}$ (Figure 4) is not exactly one-quarter wavelength. An end correction, equal approximately to 0.6 of the radius of the pipe, must be added to the measured length. The necessity for making this correction can be eliminated by using a long tube and measuring the successive internodal distances $\mathbf{N_1N_2}$, $\mathbf{N_2N_3}$, etc.

The velocity of sound in air (or any gas) is related to the physical properties of the medium by the equation

$$\mathbf{V = \sqrt{k\,(p/d)}} \qquad (2)$$

The pressure **p** and the density **d** are in absolute units and **k** is a constant, the numerical value being the ratio of the specific heat at constant pressure to the specific heat at constant volume. (For air **k = 1.403**.) When **p** is in dynes per cm^2 and **d** in gm per cm^3, equation (2) yields **V** in cm per sec.

Since the density of a gas decreases as the temperature increases, the velocity of sound is greater the higher the temperature. Application of the law of expansion of gases yields

$$\mathbf{V_t = V_0 \sqrt{1 + at}} \qquad (3)$$

where $\mathbf{V_t}$ is the velocity at temperature t° C, $\mathbf{V_0}$ the velocity at 0° C, and **a** the coefficient of expansion of the gas (about 0.6/C°).

5. Operation

In addition to the resonance apparatus, two tuning forks of different but known frequency (for example 512 and 480Hz), a rubber hammer, and a thermometer are needed to perform the resonance in air experiment. Use several rubber bands for marking water height if increased precision is desired.

Mount the tuning fork with the greater frequency firmly in its clamp so its prongs vibrate in a vertical plane over the end of the tube.

Set the fork in vibration by striking it with the rubber hammer.

Caution: Never strike a tuning fork with a metal object or let it strike against the resonance tube while vibrating.

Slowly lower the reservoir container and listen for an intensification of sound as the resonance chamber is lengthened. Locate the position of maximum intensity as closely as possible by raising and lowering the water level several times and mark the position with a rubber band. Again lower the reservoir and locate a second resonance point. Continue as far as the length of the resonance tube permits. Measure the internodal distances and compute an average value.

Repeat the experiment with the other fork.

6. Interpretation of Data

From the average value of the internodal distance determine the wavelength. Substitute this result into equation (3) and compute the velocity at 0° C. Compare it with the generally accepted value of 331.45 m/sec.

7. Maintenance

No special maintenance is required for the Resonance Apparatus, though the water should be drained out after each use prior to storage. If given reasonable care, it will provide years of satisfactory service. Should any difficulty occur that can not be corrected, contact Central Scientific Company. So we can serve you better, please do not return the apparatus or any of its parts without authorization.

8. Copyright Notice

The Resonance Apparatus operating instructions are copyrighted and all rights reserved. Permission is granted to all non-profit educational institutions to make as many copies of these instructions as they like as long as it is for the sole purpose of teaching students. Reproduction by anyone for any other reason is prohibited.

Written 12/91