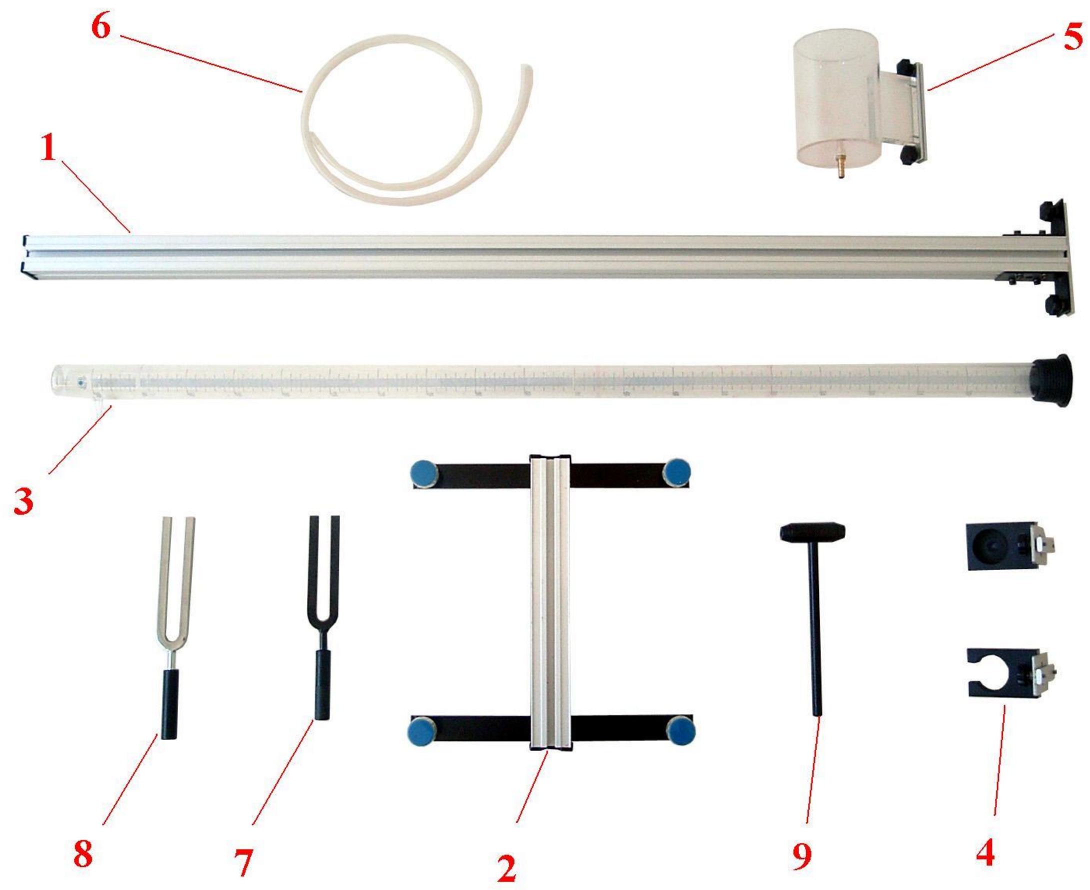
A01-745E-Y01

Resonance Experiment (Water-column)

Purpose

Observe the resonance phenomenon of a standing wave in a water column. Calculate the frequency of tuning forks by the propagation velocity of sound in the air.

Instrument



No.	Accessory	Qty	No.	Accessory	Qty
1	Support rod	1	2	Experiment base	1
3	Resonance tube	1	4	Support base and holder for resonance tube	1
5	Water supply device	1	6	Rubber pipe	1
7	Tuning fork (known frequency)	1	8	Tuning fork (unknown frequency	1
9	Tuning fork hammer	1			

Theory

In a medium, when a wave travels to the reflective surface, the incident wave will interfere with the reflected wave and can possibly form a standing wave. If the frequency of a standing wave is identical to the frequency of a tuning fork, the standing wave resonates with the tuning fork. The pitch which causes resonance is the fundamental frequency of the acoustic resonator. If the pitch is high, it is an overtone. If the frequency of a pitch is an integer multiple of the fundamental frequency, it is a harmonic. When the column presents a standing wave, the open end is an antinode and the close end is a node, as shown in **Figure 1 (a)(b)(c)**. The overtone generated in the column is an odd multiple harmonic of the fundamental frequency. The result will be different if both ends are opened.

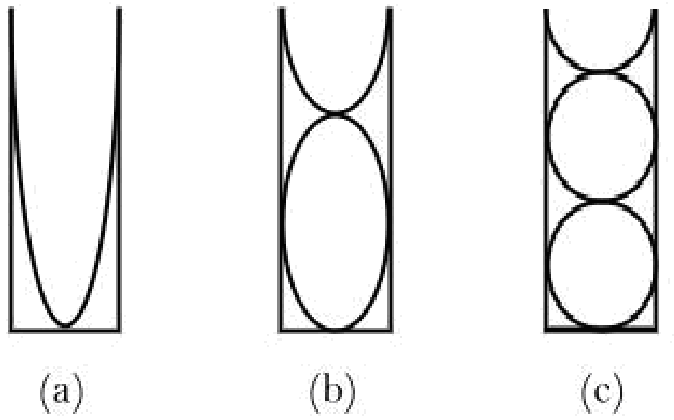


Figure 1

Thus, when the frequency is fixed, a standing wave can be formed in a tube as long as the length of the tube is appropriate. If the frequency is f and the wave length is λ, the length of the tube has at least to be $\lambda/4$. As shown in above figures, resonance can be generated if the length of the tube is an odd multiple of $\lambda/4$. Suppose the length of tube is ℓ, the length of wave is λ and n is the resonance position, the equation can be written as

$$\ell_n = \frac{(2n-1)\lambda}{4}$$

$$\ell_1 = \frac{1}{4}\lambda$$

So
$$\ell_2 = \frac{3}{4}\lambda$$

$$\ell_3 = \frac{5}{4}\lambda$$

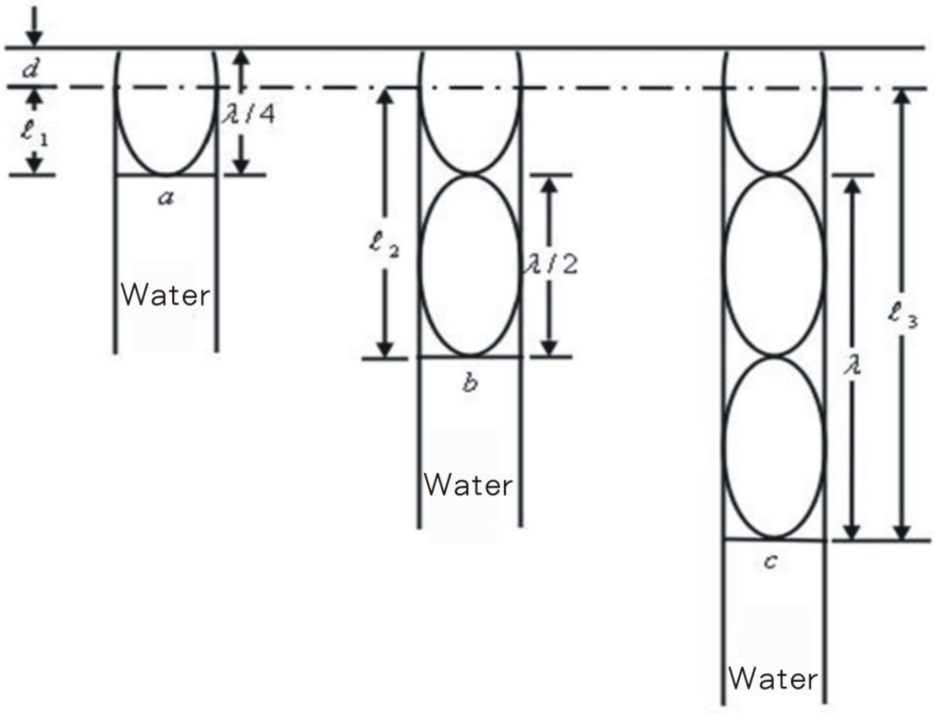


Figure 2

The equation is based on the fact that one end of the tube is an antinode. However, the actual position of antinode is outside the tube, as shown in **Figure 2**. Suppose the distance between the position of antinode and the tube is d, the equation can be written as

$$\ell_1 + d = \frac{\lambda}{4}$$

$$\ell_2 + d = \frac{3}{4}\lambda$$

$$\ell_3 + d = \frac{5}{4}\lambda$$

So
$$\ell_2 - \ell_1 = \ell_3 - \ell_2 = \frac{\lambda}{2}, \quad \ell_3 - \ell_1 = \lambda$$

Suppose the frequency of the tuning fork is f so the propagation velocity at temperature T ℃ can be written as

$$\because V = f\lambda$$

$$\therefore V = 2f(\ell_2 - \ell_1) = 2f(\ell_3 - \ell_2) = f(\ell_3 - \ell_1) \qquad (1)$$

If we already know f and the measured value (ℓ_1, ℓ_2, ℓ_3), we can then calculate the propagation velocity of sound in the air.

The propagation velocity of sound in the air is relevant to the material of medium. If the temperature rises, the density of air decreases. Hence, the propagation velocity of sound is related to the change of temperature.

$$V_t = 331.4 + 0.6T \ \text{(m/sec)} \qquad (2)$$

In the equation, V_t is the velocity of sound in T ℃ so the velocity of sound at 0℃ is V_0 =331.4 m/sec.

Procedure

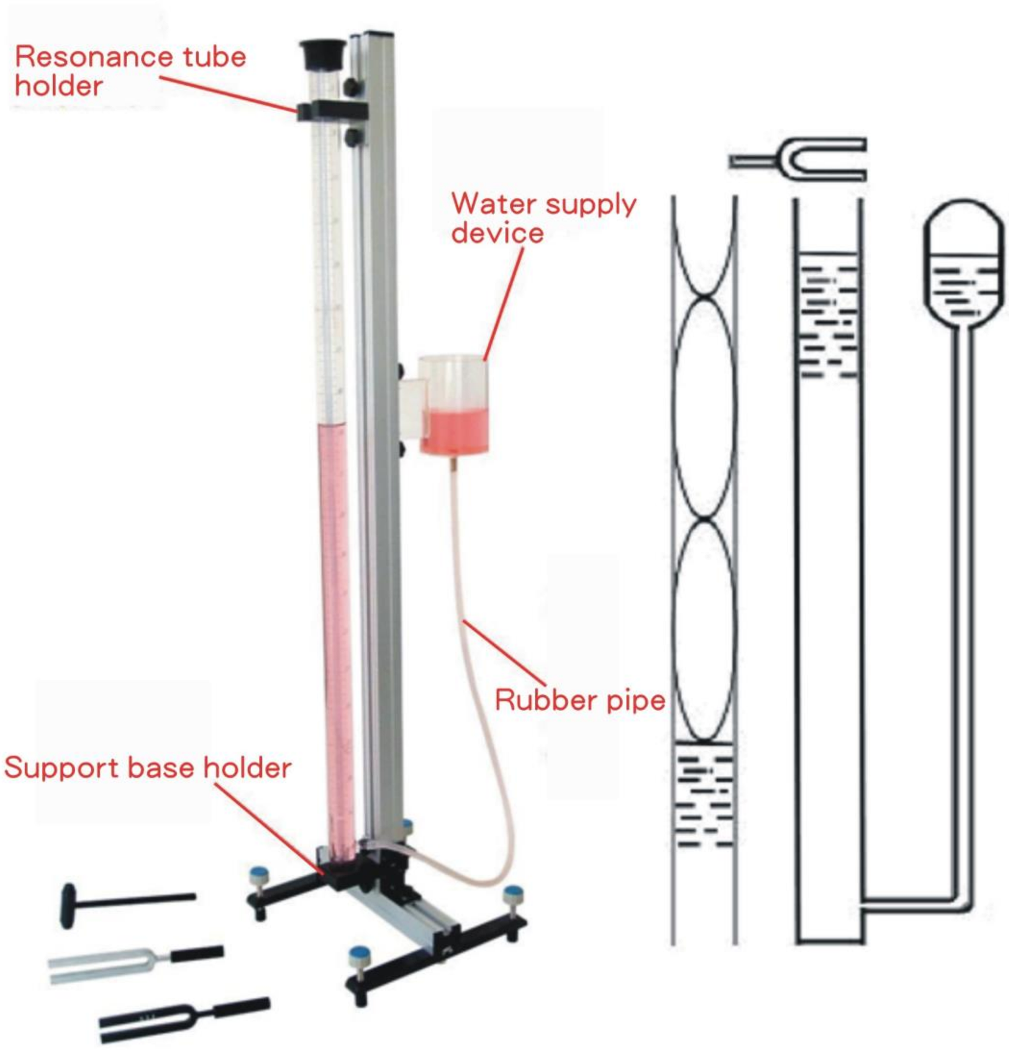


Figure 3

Part I: The propagation velocity of sound in the air

1. The experimental setup is shown in **Figure 3**.

2. Adjust the position of cup to 10cm.

3. Pour water to the resonance tube. Keep the water surface below the nozzle at 10cm so the rubber pipe is filled with water and there is no water in the cup.

4. Strike the tuning fork with known frequency. Place it vertically above the tube end, as shown in **Figure 3**.

※Do not strike the tuning fork directly at the tube end because the tube will be easily broken. Strike the tuning fork in distance and then move it close to the tube end.

5. Listen if resonance occurs. Raise the water level one cm every time and repeat above procedures.

6. Record positions (ℓ_1, ℓ_2 and ℓ_3) that have obvious resonance. Use the tuning fork with known frequency and equation 1 to calculate the experimental value of sound velocity. Measure the room temperature and use equation 2 to calculate the theoretical value of the sound velocity. Compare two values.

Part II: Tuning fork with unknown frequency

1. The experimental setup is shown in **Figure 3**.

2. Adjust the position of cup to 10cm.

3. Pour water to the resonance tube. Keep the water surface below the nozzle at 10cm so the rubber pipe is filled with water and there is no water in the cup.

4. Strike the tuning fork with known frequency. Place it vertically above the tube end, as shown in **Figure 3**.

※Do not strike the tuning fork directly at the tube end because the tube will be easily broken. Strike the tuning fork in distance and then move it close to the tube end.

5. Listen if there is resonance. Raise the water level 2 cm every time and repeat above procedures. Locate the position where it has the most obvious resonance. Repeat the procedure at 1cm above and below the position. Compare the three positions and find out where it has the most obvious resonance. This method allows us to locate the accurate resonance position.

6. Record positions (ℓ_1, ℓ_2 and ℓ_3) that have the most obvious resonance. Use the known theoretical value to calculate the frequency of the tuning fork.

Experiment result：

①Measure the sound velocity from a tuning fork with known frequency

Room temperature T (℃)		
Frequency of the tuning fork f (Hz)		512
Length of air column when resonance occurs (cm)	ℓ_1	
	ℓ_2	
	ℓ_3	
Wave length λ (m)	$2(\ell_2 - \ell_1)$	
	$2(\ell_3 - \ell_2)$	
	$\ell_3 - \ell_1$	
Average of wave length λ (m)		
Experimental value of sound velocity V_{expt} (m/sec)		
Theoretical value of sound velocity V_{theo} (m/sec)		
Errors (%)		

Experimental value of sound velocity $V_{\mathrm{expt}} =$ Frequency $f \times$ Wave length λ

Theoretical value of sound velocity $V_{theo} = 331 + 0.6T$

$$\text{Errors} = \frac{V_{\mathrm{expt}} - V_{theo}}{V_{theo}} \times 100\%$$

② Measure the frequency of tuning fork from the known sound velocity

Room temperature T (℃)		
Sound velocity V (m/sec)		
Length of air column when resonance occurs (cm)	ℓ_1	
	ℓ_2	
	ℓ_3	
Wave length λ (m)	$2(\ell_2 - \ell_1)$	
	$2(\ell_3 - \ell_2)$	
	$\ell_3 - \ell_1$	
Average of wave length λ (m)		
Theoretical value of frequency $f_{\mathrm{exp}t}$ (m/sec)		
Value of frequency f_{theo} (m/sec)		390
Errors (%)		

Experimental value of frequency $f_{\mathrm{exp}t} = \dfrac{\text{Velocity of sound } V}{\text{Wave length } \lambda}$

$$\text{Errors} = \frac{f_{\mathrm{exp}t} - f_{theo}}{f_{theo}} \times 100\%$$

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