
 EXPERIMENT NO.25 — INTERFERENCE OF ACOUSTIC WAVES

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Purpose:

Determination of the sound velocity in gases with the aid of the Quincke's "trombone". Determination of the ratio of specific heats of gases $\kappa = c_p/c_V$.

Introduction:

The acoustic waves are waves of the longitudinal type, which can be generated and transported in any medium: solid, liquid or gaseous. They manifest themselves as in periodic changes of the pressure and density of portions of the medium. By convention, as the acoustic waves are considered those that belong to the 20 - 20 000 Hz range, as this is the interval of frequencies audible to the human ear. However, other "sounds" (ultra- or infra-sounds), inaudible to humans, have exactly the same nature as "normal" acoustic waves.

A physical system performing harmonic oscillations generates harmonic (sinusoidal) waves. The deviation Δp of the momentary pressure $p(x, t)$ in any medium at point x and at time t from the equilibrium value p_0 , is given by

$$\Delta p = p - p_0 \equiv y = y_m \sin(kx - \omega t), \quad (25.22)$$

where $k = 2\pi/\lambda$ and $\omega = 2\pi/T$ are the wave number (wave vector magnitude) and angular frequency, respectively. As usually, T denotes the wave period and λ – wavelength. The amplitude of deviations is y_m . Actually, equation 25.1 represents a wave traveling in x -direction.



Figure 25-1: Interference scheme for acoustic waves reaching detector via two different routes; S – sound source, D – detector.

Two waves meeting in a point of the medium add up, or interfere. The last term corresponds to the situation when the frequencies of two waves are the same (it implies also the equality of wavelengths). Two waves coming from the same source and reaching a detector after having covered different distances x_1 and x_2 (cf. Fig.25-1) meet as a sum

$$y = y_1 + y_2 = y_{m1} \sin(kx_1 - \omega t) + y_{m2} \sin(kx_2 - \omega t) \equiv \mathcal{A} \sin(\omega t - \phi). \quad (25.23)$$

Both the phase shift ϕ and the resulting amplitude $\mathcal{A}$ can be calculated from simple trigonometric considerations. Particularly, the amplitude $\mathcal{A}$ is given by the expression

$$|y_{m1} - y_{m2}| \leq \mathcal{A} = \sqrt{y_{m1}^2 + y_{m2}^2 + 2y_{m1}y_{m2} \cos k(x_1 - x_2)} \leq |y_{m1} + y_{m2}|. \quad (25.24)$$

The amplitude reaches then the minimum for

$$\cos k(x_1 - x_2) = -1, \quad (25.25)$$

i.e. for $x_2 - x_1 = \lambda \left(n - \frac{1}{2} \right)$, $n = 1, 2, \dots$. The difference of the distances traveled by the two waves must be equal to an odd multiple of the half-wavelength: $x_2 - x_1 = \frac{1}{2}\lambda, \frac{3}{2}\lambda, \frac{5}{2}\lambda, \dots$. The two consecutive $\Delta x \equiv x_1 - x_2$ values differ then by λ . Measuring Δx (by observing two or more consecutive minima of recorded sound intensity) is equivalent to measuring the wavelength and, as the wave frequency $\nu = 2\pi\omega$ is known, the wave velocity c can be easily calculated as:

$$c = \nu\lambda. \quad (25.26)$$

On the other hand, the sound velocity in gases is given by the formula

$$c = \sqrt{\frac{\kappa RT}{\mu}}, \quad (25.27)$$

with T and μ being gas temperature and molecular mass, respectively; R is the universal gas constant $R = 8.313 \text{ J/K}$ and $\kappa \equiv c_p/c_v$ is the ratio of the molar specific heats for gas at constant pressure and volume, respectively. Thus, once the sound velocity is known (measured) this parameter can be easily calculated and confronted with its theoretical value (e.g., $\kappa = 7/5$ for a monoatomic gas, and $\kappa = 7/5$ for a diatomic one).

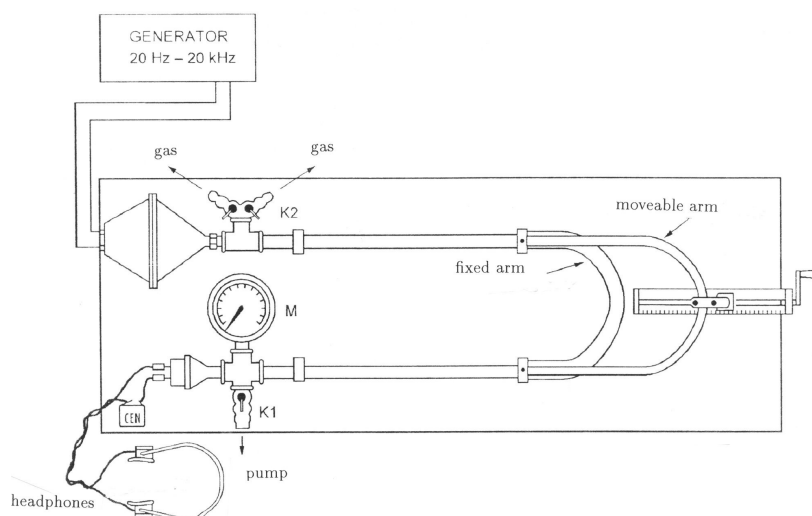


Figure 25-2: A Quincke's trombone.

Experimental Setup

The experimental setup, known as the Quincke's trombone, is shown in Fig.25-2. Waves from an acoustic membrane (activated by a frequency generator) travel through two separate U-shaped pipes. One of the pipes is of a constant length (x_1); the length of the other pipe (x_2) can be varied (as in a trombone). The detecting system is a pair of headphones; the goal is to find such values of (x_2) that correspond to the maximum damping of the acoustic signal and calculate the λ value.

Experimental procedure

1. Empty the two pipes by pumping out the gas contained in them and fill them with air by opening the valve.
2. For several (at least 10) acoustic frequencies find 2 - 5 positions of the moveable arm that correspond to the minimum of the acoustic signal; record them as $a_1, a_2, a_3, \dots$ values (Cf. table)
3. Read out the temperature of air.
4. Repeat the whole procedure for the system filled with a different gas; after emptying it (pumping out) you should fill it with the gas supplied by the tutor.

Report

1. Using the table as below record the measured values and calculate the wavelength and wave velocity for each recorded minimum of the sound signal. Calculate the mean (average) value $\bar{c}$, and its standard deviation $\sigma_{\bar{c}}$. Repeat the calculations of the mean rejecting the results that differ from the calculated mean $\bar{c}$ by more than $\pm 2\sigma_{\bar{c}}$. Confront the final $\bar{c}$ value with the value given in physical tables. Note: do not forget about the temperature dependence of c . The formula 25.27 should be used if the two confronted values correspond to different medium temperatures.
2. Calculate the c_p/c_V ratio using equation 25.27. The μ value for air should be calculated as a weighted mean; air can be treated as a mixture of gases: N₂ (78%), O₂ (21%), and Ar (1%).

ν [Hz]	Sound minimum [mm]					Inter-minimum distance [mm]				λ [m]	c [m/s]
	a_1	a_2	a_3	a_4	a_5	Δ_1	Δ_2	Δ_3	Δ_4		

Questions for discussion:

- What is wave? Define quantities: amplitude, phase, period, wavelength, velocity, frequency.
- Longitudinal waves and transverse waves.
- Sound and its velocity (if the sound wave propagates in a medium what medium properties influence the wave speed?)
- Interference – general ideas and the particular case (the one you will have to deal with when performing the experiment).