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| Date: |  | January 26, 2019 |  |  | David Awad |
| Class/Period: |  | Physics M20C Lab. Thursday 1pm-4pm. |  |  |  |

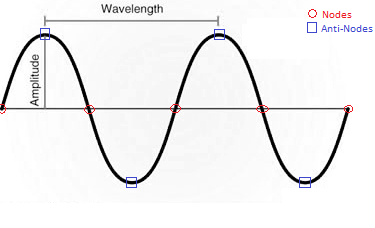
The Speed of Sound in Air

**Objective**

Determine the speed of sound in air through two procedures: first, measuring the points of resonance along a variable length air column when a fixed frequency sound-source is projected into the containing tube apparatus and, second, sending a sound pulse to a receiver placed at various distances from the source and measuring the send-receive time difference.

**Theory**

**Note: Theories, concepts, and proofs heavily quoted from “Physics M20C Lab Manual” by Clint D Harper, “Physics for Scientists and Engineers” 9th edition by Serway and Jewett, and Wikipedia.**



**Nodes and Anti-Nodes**

A node is a point along a standing wave where the wave has minimum amplitude. The opposite of a node is an anti-node, a point where the amplitude of the standing wave is a maximum. These occur midway between the nodes.

**Frequencies: Natural, Fundamental, and Harmonics**

Frequency is the number of occurrences of a repeating event per unit of time, generally seconds. Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving or damping force. The fundamental frequency, often referred to as the fundamental, is defined as the lowest frequency of a periodic waveform. A harmonic is a wave with a frequency that is a positive integer multiple of the fundamental frequency (1st harmonic). The following harmonics are known as higher harmonics.

**Resonance**

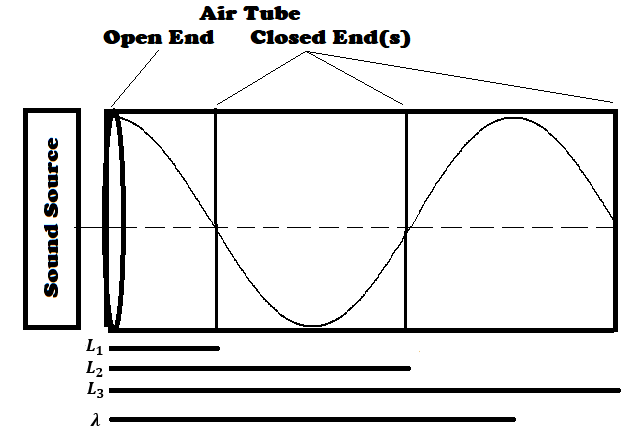
A phenomenon that occurs when the frequency at which a force is periodically applied is equal or nearly equal to one of the natural frequencies of the system on which it acts. This causes the system to oscillate with larger amplitude than when the force is applied at other frequencies.

**Theoretical Speed of Sound**

As a theoretical basis, a reliable formula for the speed of sound in dry air at one atmosphere pressure is:

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|  |  | **Equation 0.1**  **(T is air temperature in** °**C)** |

**Open Resonance Air Column Apparatus**

****A resonating air column in a tube with one end open and the other end closed will have a node at the closed end and an anti-node at the open end. If the air column is resonating in the fundamental mode it will have no other nodes or anti-nodes. On a sine wave, the distance from one of the maxima to the next point where it crosses zero is a quarter wavelength. Thus, for an air column in a tube with one open and one closed end, the length of the resonating column, L, and the wavelength λ, are related by:

|  |  |  |
| --- | --- | --- |
|  |  | **Equation 1.1A**  **(First Harmonic / Fundamental)** |

The second, third, and all following harmonics (N) can be found by increasing the distance between the open and closed ends of the tube by a factor of half a wavelength from the previous harmonic (N – 1). Thus, the wavelength at the second and third harmonic are defined as:

|  |  |  |
| --- | --- | --- |
|  |  | **Equation 1.1B**  **(Second Harmonic)** |
|  |  |  |
|  |  | **Equation 1.1C**  **(Third Harmonic)** |

For all types of waves, the relationship between frequency (f) and velocity (v) of the wave is:

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|  |  | **Equation 1.2** |

**Acoustic Delay Time**

The velocity (v) of a sound pulse sent between two points can be calculated by dividing the distance between the source and receiver, d, by the difference in time, t.

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|  |  | **Equation 2.1** |

**Procedure**

**Analysis / Discussion**

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| **Table 1.1**  **Open Resonance Air Column Apparatus at Variable Length** | | | |
| **Frequency (Hertz)** | **(1/4) (meters)** | **(3/4) (meters)** | **(5/4) (meters)** |
| 600 | 0.135 | 0.420 | 0.720 |
| 500 | 0.170 | 0.506 | 0.850 |
| (Note: ) | | | |

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| **Table 2.1**  **Acoustic Delay Time** | | |
| **Test Number** | **Distance ‘d’ (meters)** | **Time Difference ‘t’ (Seconds)** |
| 1 | 0.400 | 0.00119 |
| 2 | 0.270 | 0.00082 |
| 3 | 0.435 | 0.00124 |
| (Note: ) | | |

**Calculations**

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| **Calculation 0.1 -**  **Theoretical Speed of Sound in Dry Air** | | |
|  |  | Use **Equation 0.1** |
|  |  |  |
|  |  | Measured temperature at time of experiment was 23.3C. |

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| **Calculation 1.1 -**  **Speed of Sound from Average Wavelength and Frequency (600Hz)** | | |
|  |  | Use **Equation 1.1A**  1.1a |
|  |  | Use **Equation 1.1B**  1.1b |
|  |  | Use **Equation 1.1C**  1.1c |
|  |  |  |
|  |  | Average of 1.1a-1.1c |
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| **Calculation 1.2 -**  **Speed of Sound from Average Wavelength and Frequency (500Hz)** | | |
|  |  | Use **Equation 1.1A**  1.2a |
|  |  | Use **Equation 1.1B**  1.2b |
|  |  | Use **Equation 1.1C**  1.2c |
|  |  |  |
|  |  | Average of 1.2a-1.2c |
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| **Calculation 1.3 -**  **Error Propagation for Speed of Sound with Average Wavelength and Frequency** | | |
|  |  | **Use Equation 1.2** |
|  |  |  |
|  |  | Take partial derivatives in respect for wavelength and frequency. |
|  |  |  |
|  |  | Definition for absolute error. |
|  |  |  |
|  |  | Definition for relative error. |
|  |  |  |
|  |  | Substitute in partial derivatives and V. Simplify. Note: . |
|  |  |  |
|  |  | Use the smallest measured wavelength to estimate largest possible error. |

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| **Calculation 1.4 -**  **Percent Discrepancies for Speed of Sound with Average Wavelength and Frequency** | | |
|  |  | Definition of percent discrepancy. |
|  |  |  |
|  |  | Percent discrepancy for 600Hz test.  Use theoretical value from **Calculation 0.1**. |
|  |  |  |
|  |  | Percent discrepancy for 500Hz test.  Use theoretical value from **Calculation 0.1**. |

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| **Calculation 2.1 -**  **Speed of Sound from Acoustic Delay Time** | | |
|  |  | Use **Equation 2.1**  2.1a |
|  |  | Use **Equation 2.1**  2.1b |
|  |  | Use **Equation 2.1**  2.1c |
|  |  |  |
|  |  | Average of 2.1a-2.1c |

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| **Calculation 2.2 -**  **Error Propagation for Speed of Sound from Acoustic Delay Time** | | |
|  |  | Use **Equation 2.1** |
|  |  |  |
|  |  | Take partial derivatives in respect for distance and time. |
|  |  |  |
|  |  | Definition for absolute error. |
|  |  |  |
|  |  | Definition for relative error. |
|  |  |  |
|  |  | Substitute in partial derivatives and V. Simplify. Note: . |
|  |  |  |
|  |  | Use the smallest measured distance and time to estimate largest possible error. |

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| **Calculation 2.3 -**  **Percent Discrepancy for Speed of Sound from Acoustic Delay Time** | | |
|  |  | Definition of percent discrepancy. |
|  |  |  |
|  |  | Use theoretical value from **Calculation 0.1** and experimental average from **Calculation 2.1**. |

**Conclusion**