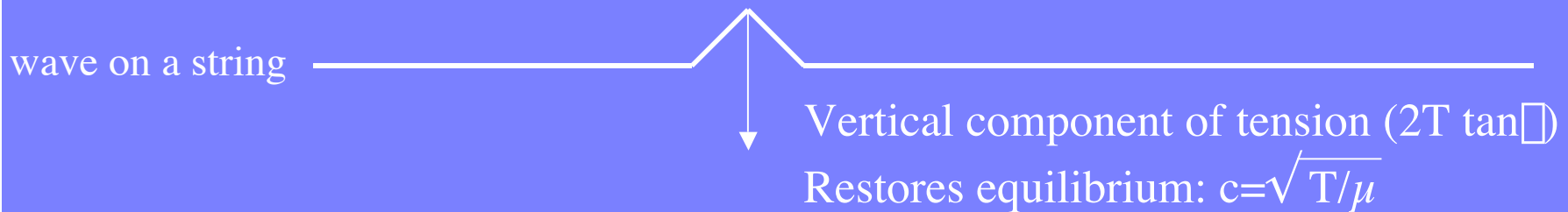
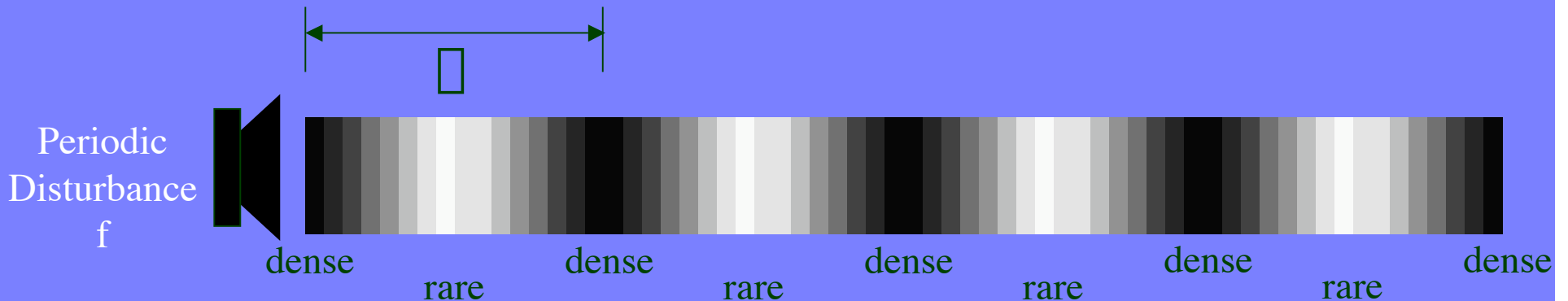


# Lecture 19: Properties of Sound

- Sound is a COMPRESSION “wave”
  - wave: propagating disturbance from equilibrium

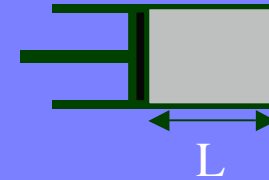


Tuning a violin string:  $f = (\sqrt{T/\mu})/L$



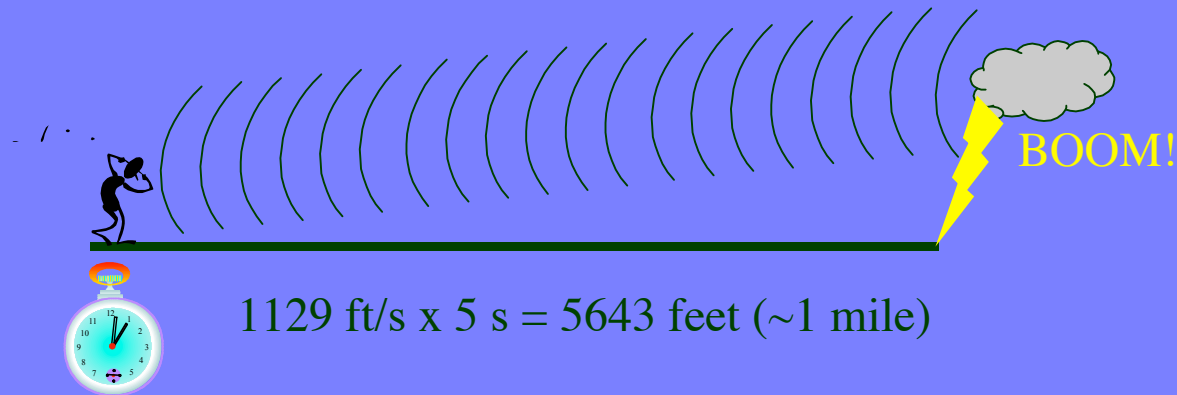
# Properties of Sound

– Elastic medium     $\text{Stress} = Y * \text{Strain}$   
 $dP/dV = -Y/V$



Ideal Gas     $Y = nRT/V$

$$c = 1.3 \sqrt{Y/\rho} = 1.3 \sqrt{RT/M} \quad \text{Mol. wgt. (kg/mole)}$$
$$= 344 \text{ m/s (Air)}$$



# Properties of Sound

amplitude      frequency      phase

↓                      ↓                      ↓

$$P = P_0 \cos(\omega t + \phi)$$
$$A = A_0 \cos(\omega t + \phi)$$

$\omega = 2\pi f$

$$c = \omega f$$

$$c = 1.3\sqrt{RT/M}$$

# Sound Intensity

$$I = 1/2 \rho c A_0^2 \omega^2 = 1/2 \rho A_0^2 \omega^2 = 1/2 P_0^2 / Z$$

$Z = \rho Y$ : Acoustic Impedance

dB (decibels) Measures I

$$L = 10 \log_{10} (I/I_0)$$

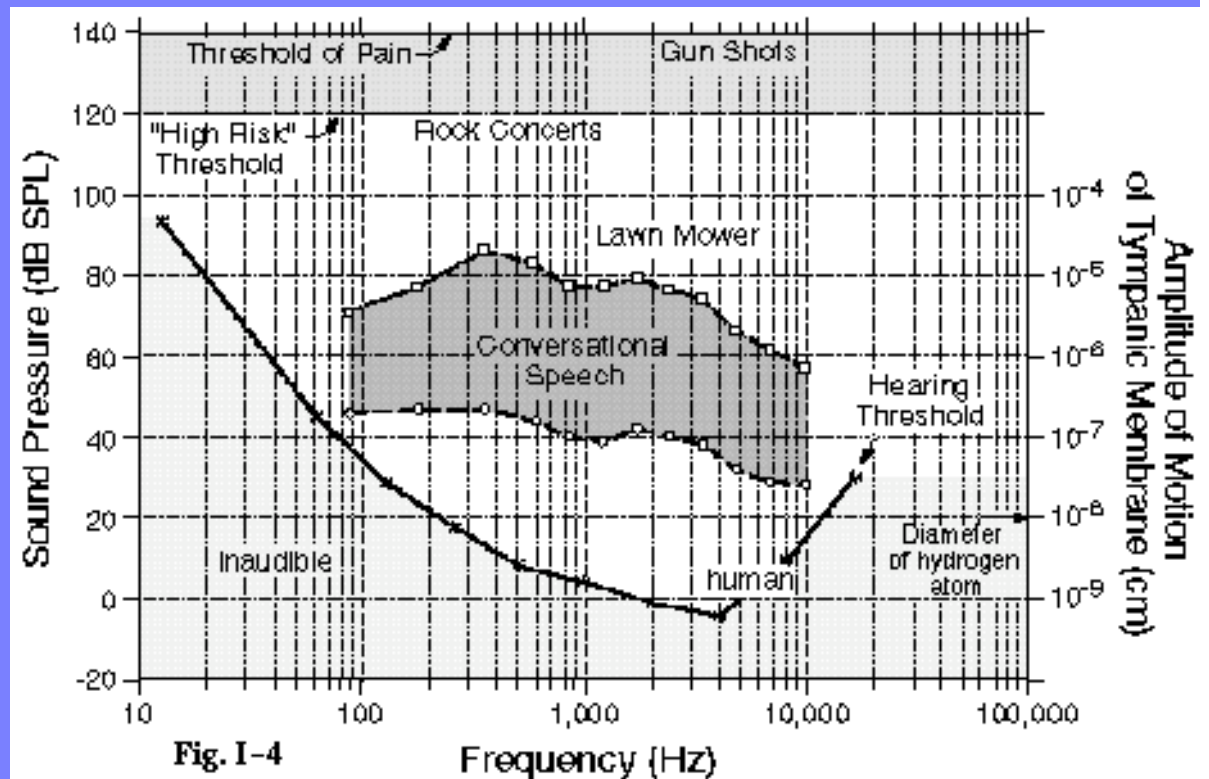
$$I_0 = 10^{-12} \text{ w/m}^2$$

|       |                        |
|-------|------------------------|
| 0 dB  | Threshold of Hearing   |
| 20 dB | Whisper                |
| 30 dB | Average home           |
| 60 dB | Talking (1 meter away) |
| 70 dB | Busy Street            |
| 85 dB | OSHA limits            |

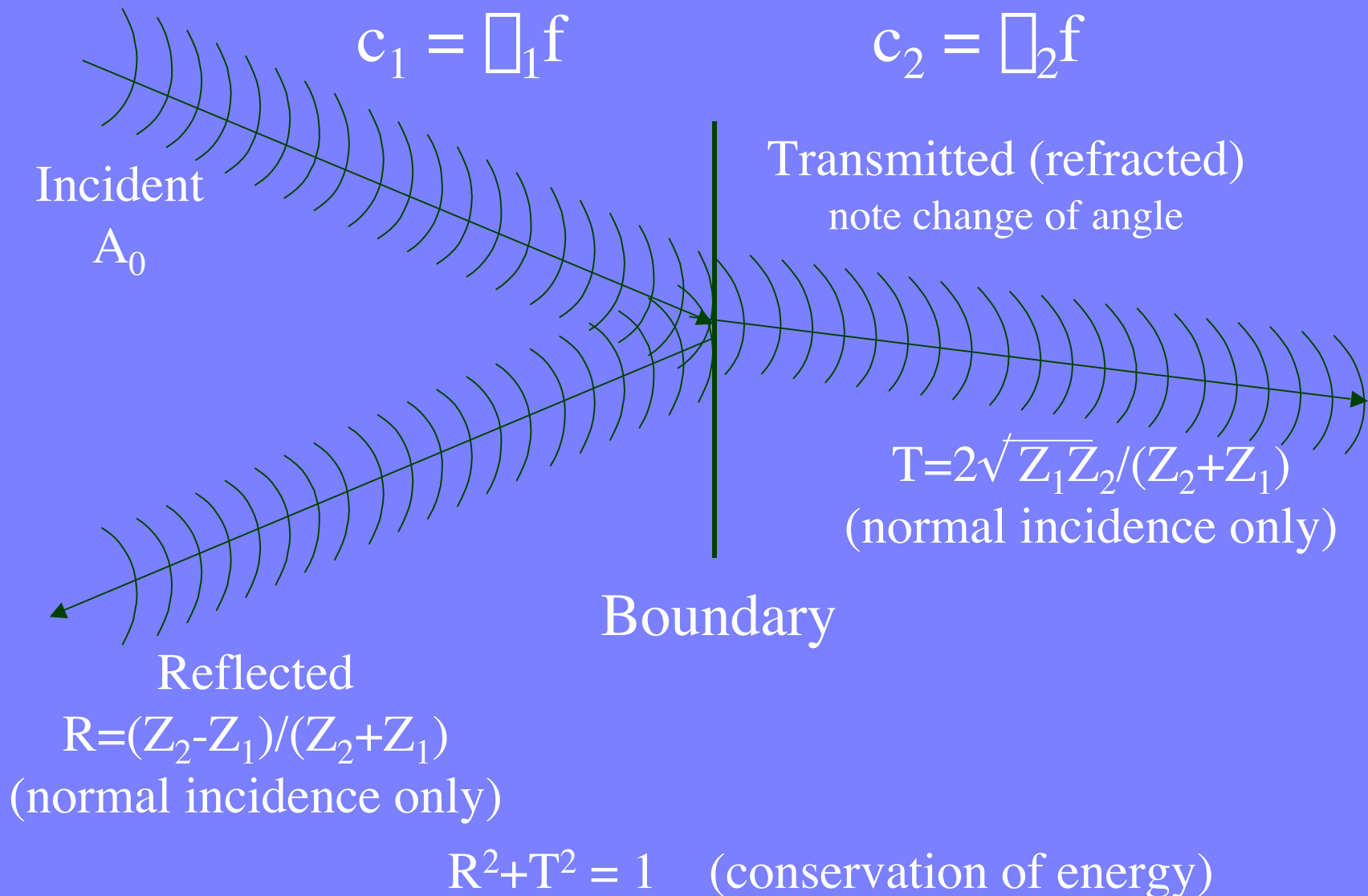
## SOUND PRESSURE LEVEL OF COMMON ENVIRONMENTAL SOUNDS (dB)

|                                 |     |                              |
|---------------------------------|-----|------------------------------|
| Pain threshold                  | 140 |                              |
| Jet aircraft                    | 130 |                              |
| Loud organ                      | 110 |                              |
| Rock concert                    | 100 | Wood workshop                |
|                                 | 90  | World series - Humphrey dome |
| Concerthall seat                | 80  |                              |
| Heavy traffic                   | 70  |                              |
|                                 | 60  | Ordinary conversation        |
|                                 | 50  | Softbackground music         |
| Quiet conversation              | 40  | Average residence            |
| Whisper                         | 30  |                              |
|                                 | 20  |                              |
|                                 | 10  |                              |
| Hearing threshold (young males) | 0   |                              |

# Audiogram



# Wave Properties: Reflection, Transmission, Refraction



# Acoustic Impedance

$$Z = \rho c$$

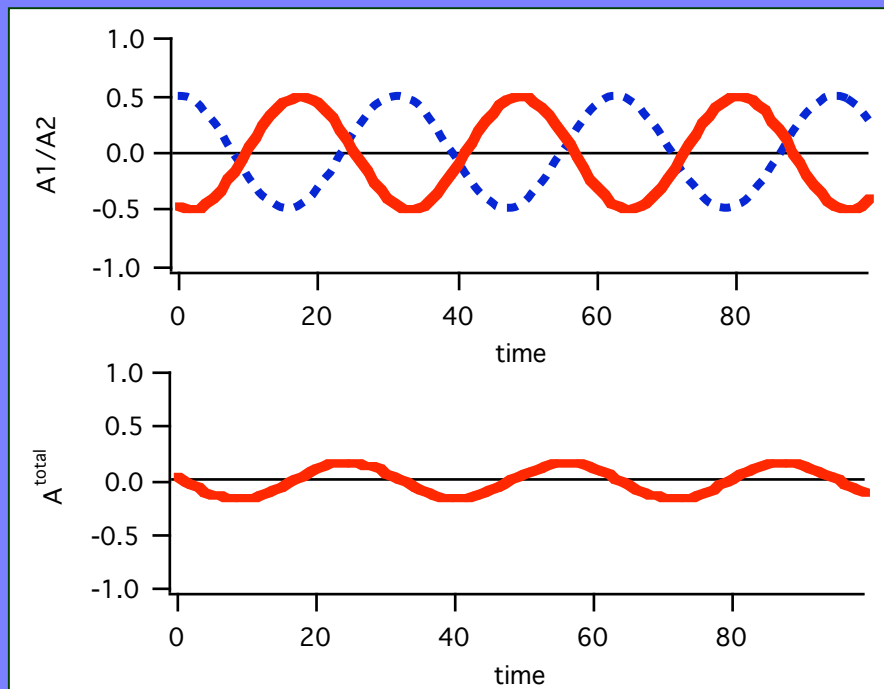
|            | c (m/s) | Z 10 <sup>6</sup> kg/m <sup>2</sup> /s |
|------------|---------|--|
| Air        | 344     | 0.0004                                 |
| Water      | 1484    | 1.48                                   |
| Blood      | 1550    | 1.61                                   |
| Myocardium | 1550    | 1.62 (perpendicular to fibers)         |
| Muscle     | 1580    | 1.64                                   |
| Liver      | 1570    | 1.65                                   |
| Kidney     | 1560    | 1.62                                   |
| Fat        | 1450    | 1.38                                   |
| Skull Bone | 3360    | 5.69 (compressive)                     |

( $\rho = 1.78 \text{ gm/cm}^3$ ,  $Y = 1.8 \times 10^8 \text{ N/m}^2$ )

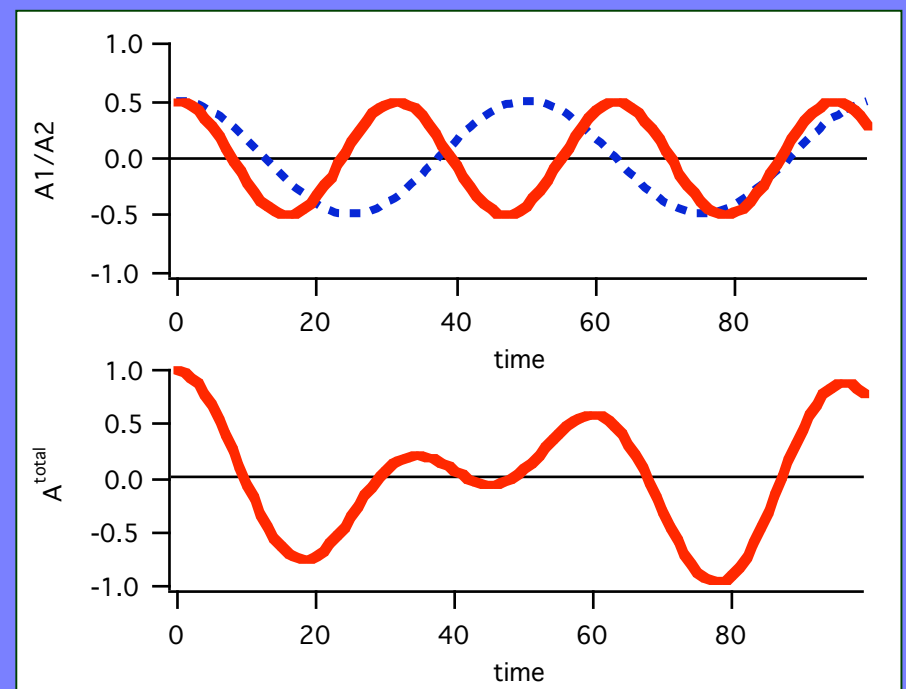
# More Wave Properties: Interference and Diffraction Combining Waves Together

$$A^1 = A^1_0 \cos(\omega_1 t + \phi_1) \quad A^2 = A^2_0 \cos(\omega_2 t + \phi_2)$$
$$A^{\text{total}} = A^1 + A^2$$

Different Phases

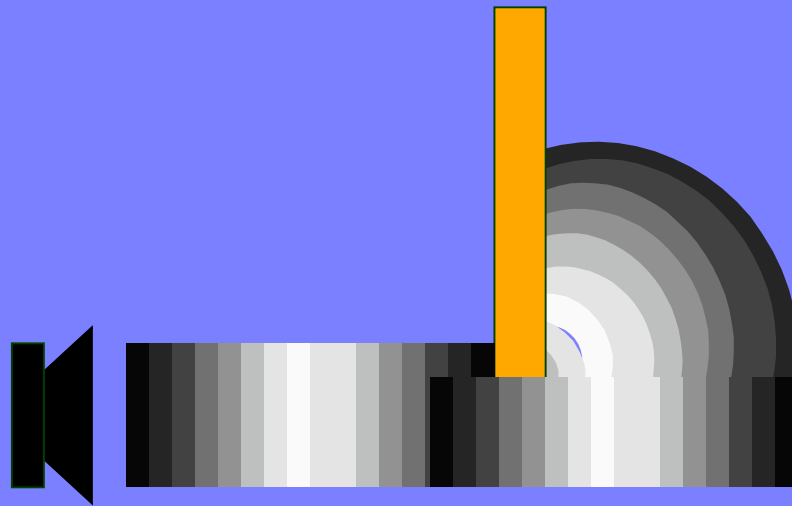


Different Frequencies

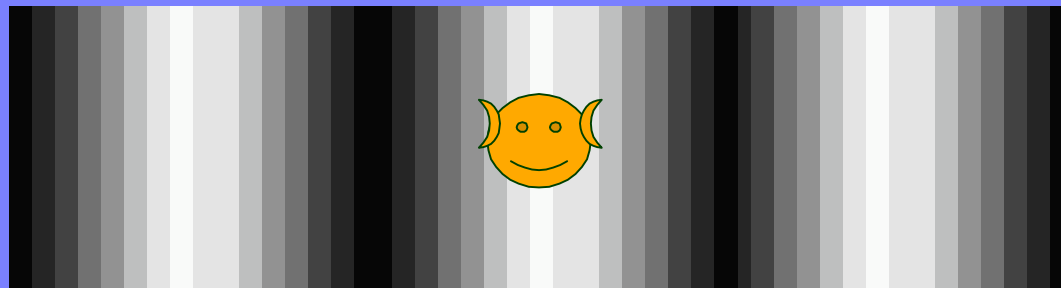




# Diffraction: Waves Move Around Corners



If  $\lambda \gg D$ , Not Much Shadow

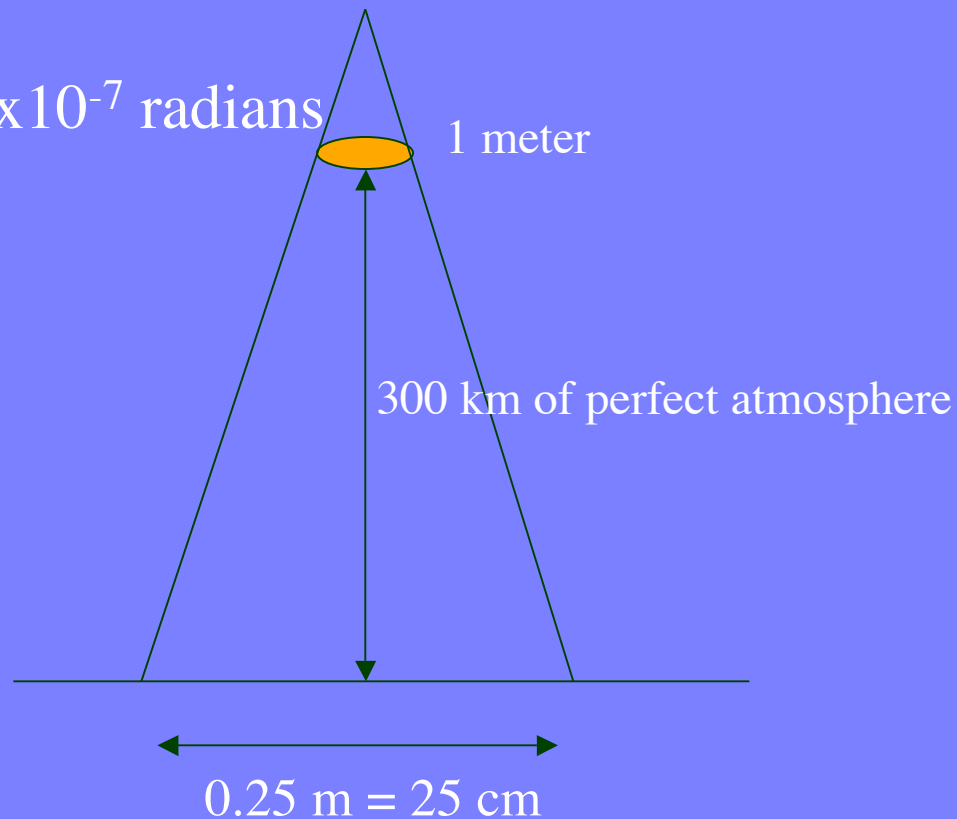


# Diffraction

Diffraction limits angle resolution

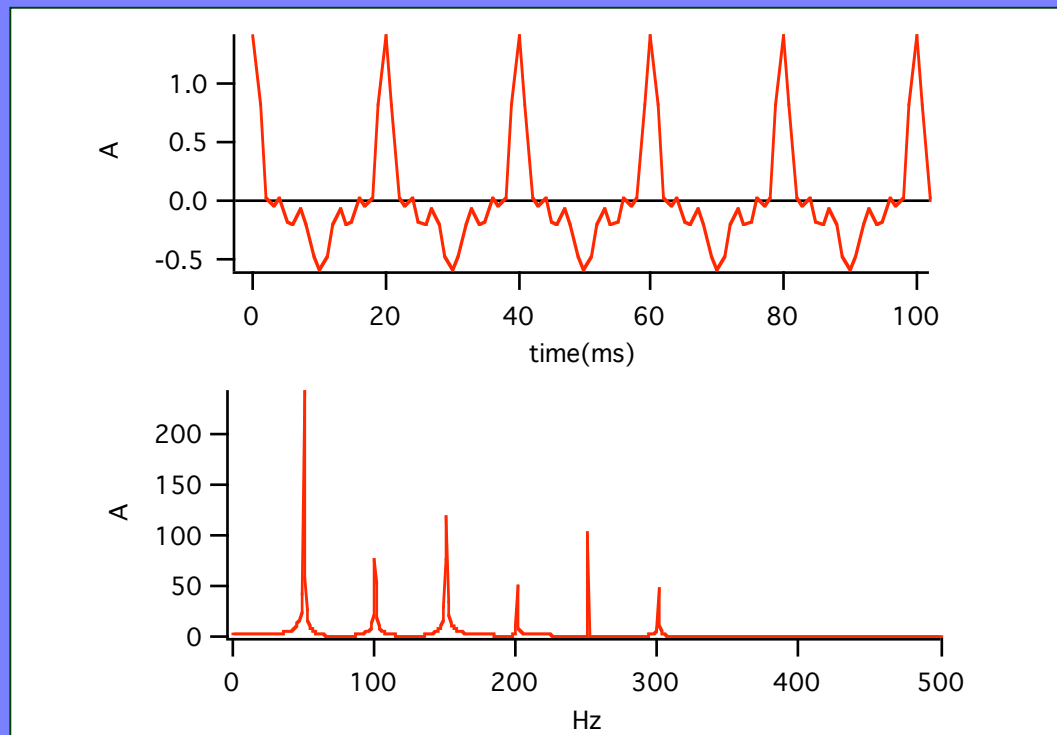
$$\theta = 1.22 \lambda / d$$

$$2\theta = 2 \times 1.22 \lambda / d = 8 \times 10^{-7} \text{ radians}$$

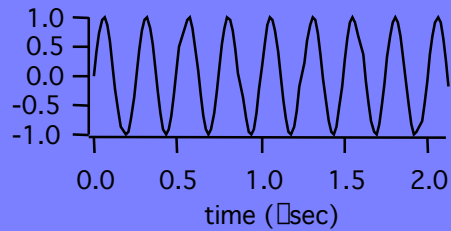
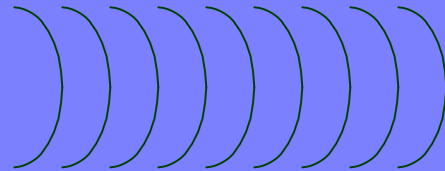


# Sound Spectrum

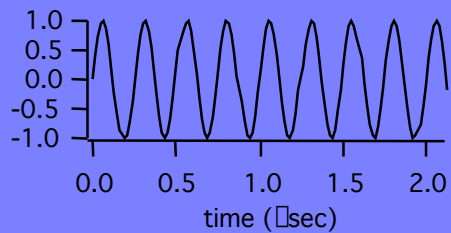
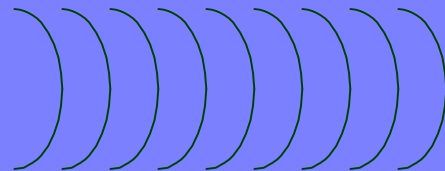
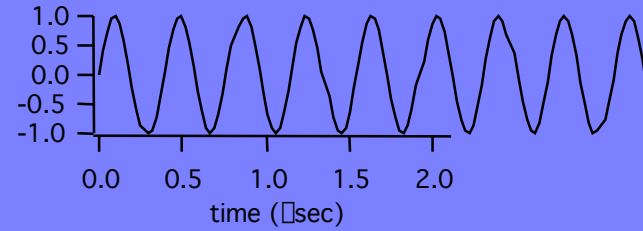
Sound is not (naturally) single frequency



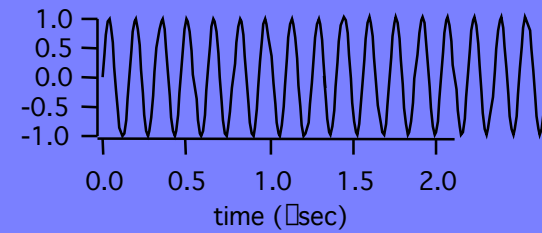
# Doppler Shift



moving listener hears



moving listener hears



$$\Delta f = v/c * f$$