5. Sea Shell

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Problem

When you put a sea-shell to your ear you can hear 'the sea'. Study the nature and the characteristics of the sound.

Overview

- Two Kinds of Sea Shells
- Experiments
  - Setup
  - Results
- Theory
  - Nature of the Noise
  - Shell as a Helmholtz Resonator
  - Shell Held Tightly at Ear
  - Shell Away from Ear
  - Overtones
- Experiment vs. Theory

Two Kinds of Sea Shells

(1) one (2) two

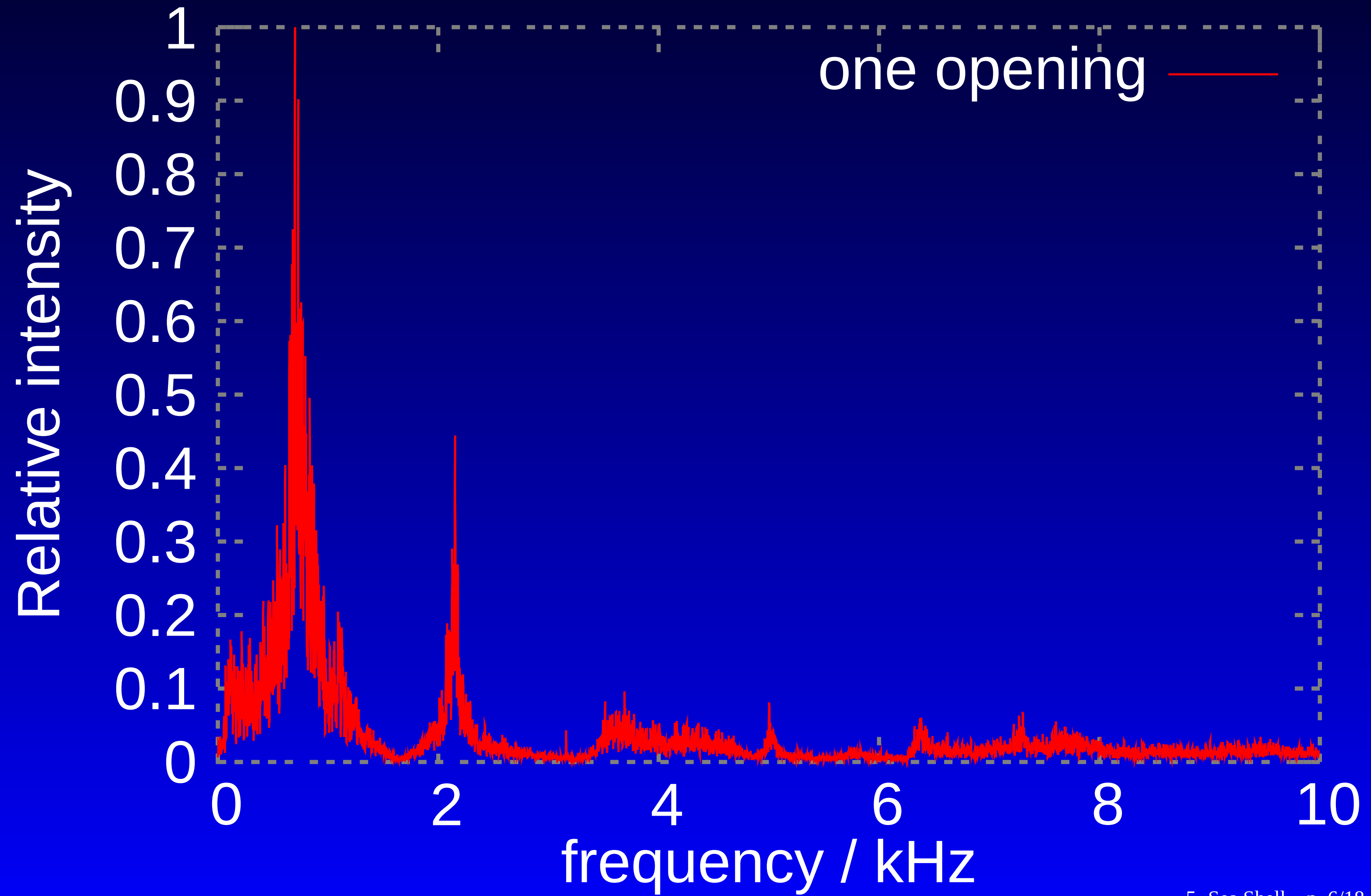
opening(s)

when held tightly to the ear

(3) shell held away from ear

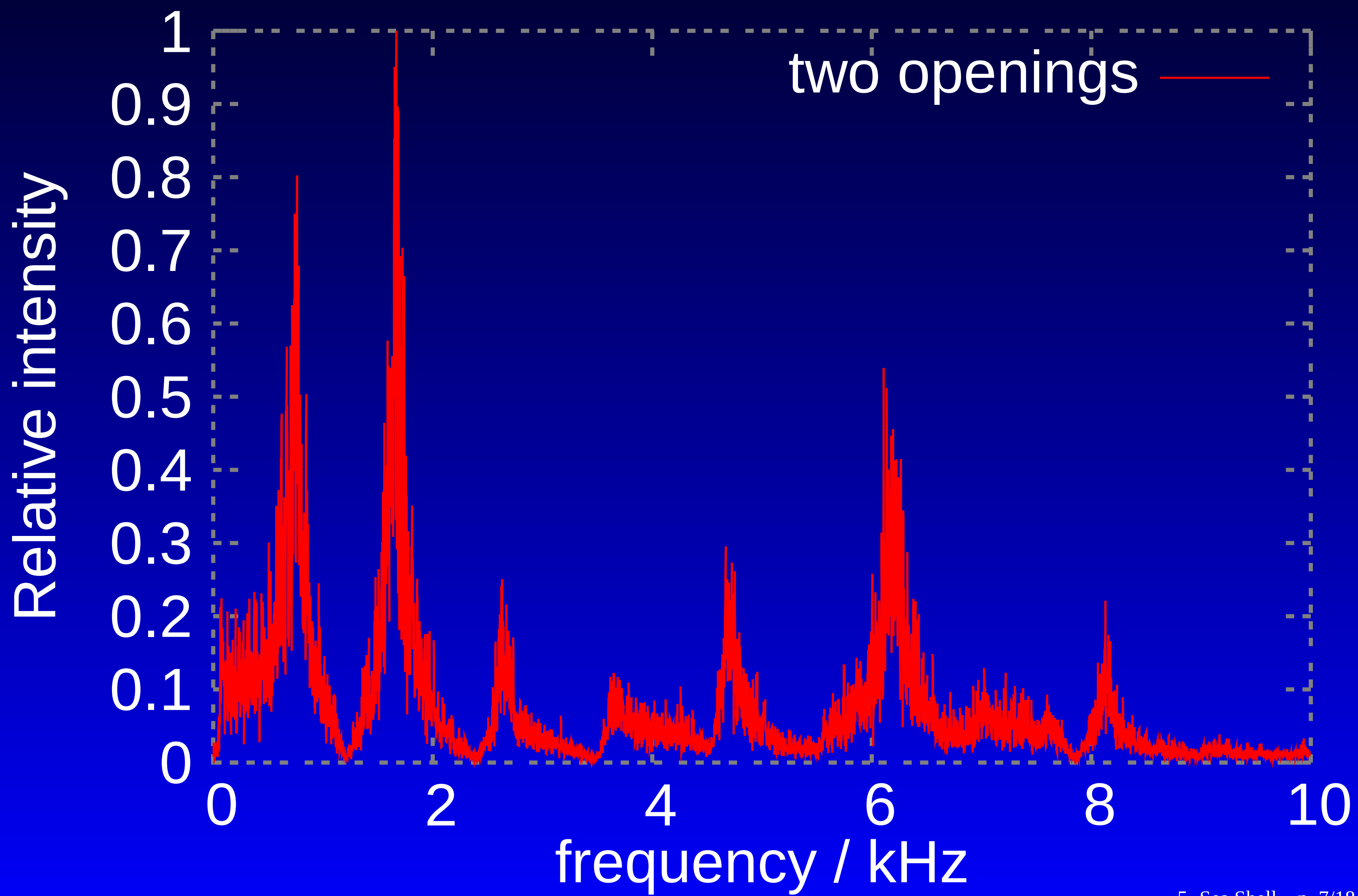
Experimental Setup

Results I



one opening
Relative intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
frequency / kHz

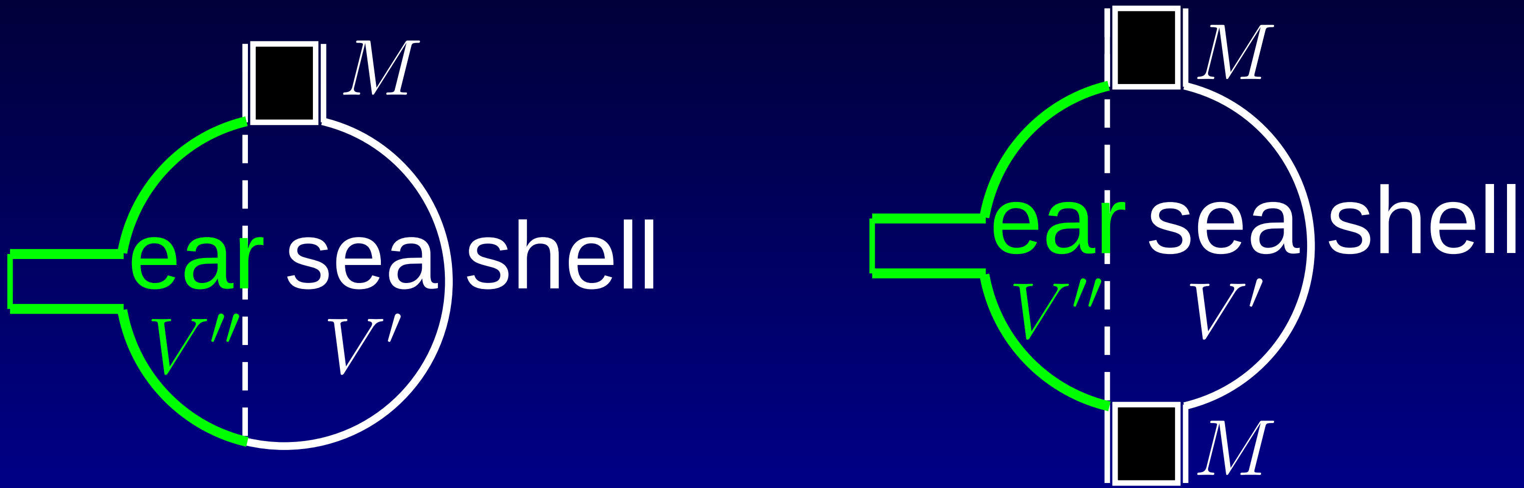
Results II


two openings
Relative intensity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
frequency / kHz

Nature of the Noise

- Not blood
- Ambient noise filtered by shell

Shell as Helmholtz Resonator



- Wave entering shell causes pressure-change
- Reacting force
- Intensities of resonance frequency and overtones magnified by shell

Reactive Force from Shell

- Pressure change in shell is adiabatic:

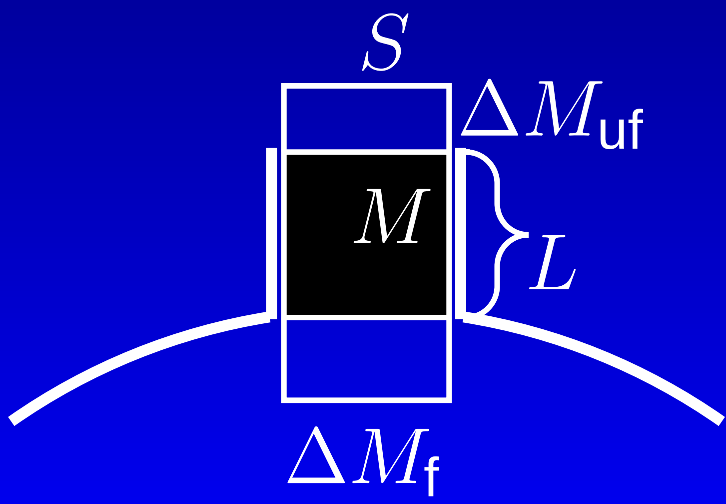
$$pV^{\gamma} = \mathrm{const.}$$

- Deriving:
$\mathrm{d}pV^{\gamma} + \gamma V^{\gamma-1} p \mathrm{d}V = 0 \quad \Rightarrow \quad \mathrm{d}p = -K \frac{\mathrm{d}V}{V}$
- $\gamma p = K = \rho_0 c^2 \qquad \mathrm{d}V = -S\,\mathrm{d}\xi$
- Reactive pressure force $\mathrm{d}F = -S\,\mathrm{d}p$:

$$F_p(t) = -\frac{\rho_0 c^2 S^2}{V} \xi(t) = -D \xi(t)$$

Effective Oscillating Mass

- Mass in neck: $M = \rho_0 \pi a^2 L$
- Additional mass loaded on interface layers, obtained by integration over all wavelets:
  $\Delta M_{\mathsf{f}} \approx \frac{8}{3}\rho_0 a^3 \qquad \Delta M_{\mathsf{uf}} \approx 2\rho_0 a^3$
- Effective mass
  $M_{\mathsf{eff}} = M + \Delta M_{\mathsf{uf}} + \Delta M_{\mathsf{f}} = \rho_0 a^3 \left(\frac{14}{3} + \frac{\pi L}{a}\right)$



Resonance Frequency

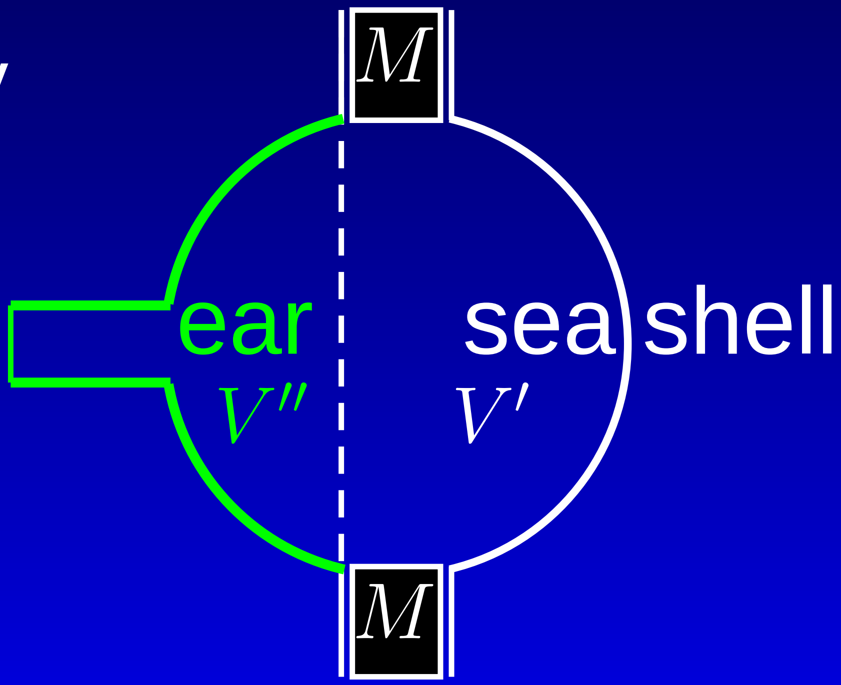
- Helmholtz-Resonator:
  - Air in Cavity $\longrightarrow$ spring
  - Air in Neck $\longrightarrow$ oscillating mass
- Resonance Frequency

$$\nu_0 = \frac{1}{2\pi}\sqrt{\frac{D}{M_{\text{eff}}}} = \frac{c}{2\pi}\sqrt{\frac{S}{L_{\text{eff}}V}}$$

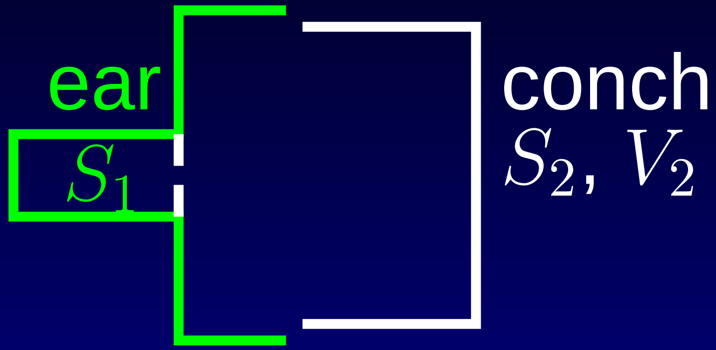
Two Openings

- At both exits two identical masses M_{eff} oscillate
- Two masses connected to a spring
- $D_{\text{eff}} = 2D$
- Resonance frequency

$$\nu_0 = \frac{c}{2\pi}\sqrt{\frac{2S}{L_{\text{eff}}V}}$$



Shell Held Away from Ear



- Tone pitch increases when pushing shell away from ear:

$$\nu_0' = \frac{c}{2\pi}\sqrt{\frac{S'}{L'_{\text{eff}}V'}}$$

- Intensity decreases with distance

Overtones

- Helmholtz-resonator: mass connected to a spring
- Modified view: wave propagates through cavity
- Nodal plane in cavity
- Position of nodal planes determines overtones

Exemplary Calculation

- Cross-sectional area S of neck not constant
- Difficulty to measure Length L accurately
- Reasonable (exemplary) Values:

$$S = 3\,\text{mm} \qquad L_{\text{eff}} = 1\,\text{cm} \qquad V = 50\,\text{ml}$$

$\Rightarrow$ Resonance frequency: 478.6 Hz

- Same order of magnitude as in experiments

Summary

- Shell works as a Helmholtz Resonator
  - Certain frequencies are amplified
- We hear the sea as
  - range around resonance frequency is amplified
    (no sharp resonance)
  - impure overtones
    $\longrightarrow$ no whole number multiples of resonance frequency
    $\longrightarrow$ overlapping of different tones

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