BIOL/PHYS 438

Zoological Physics

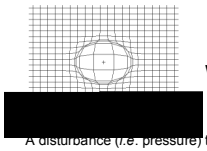
- Logistics
- How Animals Make Sounds
  - Broad-spectrum Generators
  - Tuneable Resonators
  - Coupling to Medium
- How Humans Make Speech

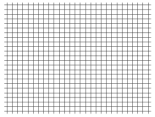
Logistics

Assignment 1: Solutions now online!
Assignment 2: Solutions now online!
Assignment 3: Solutions now online!
Assignment 4: Solutions online soon!
Assignment 5: Solutions online soon!
Assignment 6: Solutions online soon!

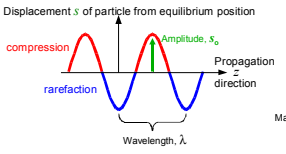
Poster Sessions: **see schedule at**
http://musr.physics.ubc.ca/p438/projects/projects.php
and **add your title!**

Sound Waves





A disturbance (*i.e.* pressure) that propagates energy by compressing and rarefacting the supporting medium like a spring.



Phase velocity:
$c = f\lambda$

Angular velocity:
$\omega = 2\pi f$

Max. particle velocity ⊥ to propagation:
$u_o = 2\pi f s_o$

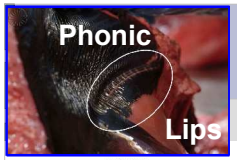
Broad-spectrum Generators

- Torsional Flutter
  - Tacoma Narrows Bridge & Blade of Grass
- Interrupted Airflow
  - Phonic Lips & Trumpets
  - Kazoos, Bagpipes, Oboes & Bassoons
- Interrupted motion
  - Combs, Washboards & Crickets
- Vortex Shedding

Tacoma Narrows Bridge collapse

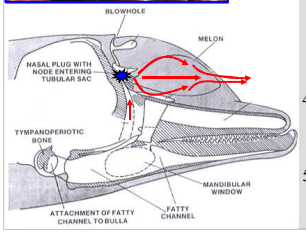
"Not resonance, but positive feedback."

Is the "blade of grass" noisemaker different??

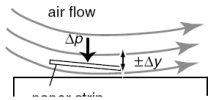


Interrupted Airflow

1. Δp generated
2. Pressurized air passes phonic lips
3. Vibrations coupled to local fat bodies
4. Sound is reflected off bones and air spaces (impedance mismatching)
5. Sound focused anteriorly by the fatty MELON



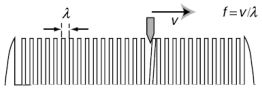
Interrupted Airflow: REEDS



Musical examples: noisemakers, kazoos, bagpipes, reed instruments (clarinet, saxophone), split-reed instruments (oboe, bassoon).

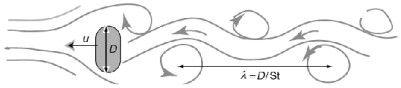
Animal examples: ??

Interrupted motion



Result: a sequence of evenly-spaced **pulses**, i.e. the fundamental frequency $f = v/\lambda$ and all of its harmonics! Like a **guitar** string plucked near the bridge or a bowed **violin** (catch/release sequence).

Vortex Shedding



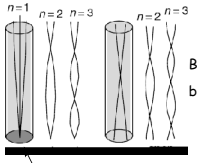
Strouhal number: St ~ 0.2 giving a dominant frequency of $f = \mathrm{St} \times u/D$ (higher frequency for faster motion of smaller objects). Definitely broad-spectrum!

Example: **bullroarer**

Tuneable Resonators

- **Pipes:** both ends closed or both ends open: $f_n = nc/2L$; one end closed and one end open: $f_n = (2n-1)c/4L$
  - Organ, Pan Pipes, Flute, Whistle, Horn
- **Stretched Strings:** $f_n = \frac{n}{\cdot}\sqrt{\frac{T}{}}$
  - Bass, Guitar, Violin
- **Vibrating Rod:**
  - Marimba
- **Helmholtz Resonator:**
  - Baleen Whales, Mole Crickets

Pipes

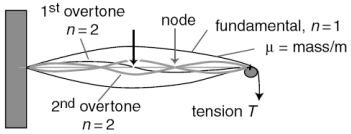


Both ends closed or both ends open: $f_n = nc/2L$

One end closed and one end open: $f_n = (2n-1)c/4L$

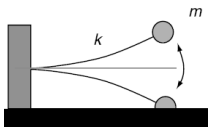
See Human "formants"

Stretched Strings



$$f_n = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$$

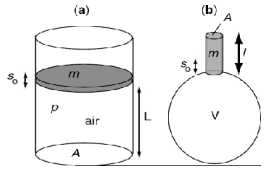
Vibrating Rod



Harmonica

Human vocal chords

Helmholtz Resonator



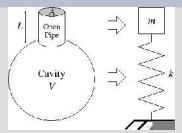
Effective spring constant

$k_{air} = \gamma_{air} pA/L$

$\gamma_{air} = 7/5 = 1.4$

$f_o = \frac{1}{2\pi}\sqrt{\frac{\gamma pA}{mL}} = \frac{c}{2\pi}\sqrt{\frac{\rho A}{mL}}$

How do baleen whales make sound?

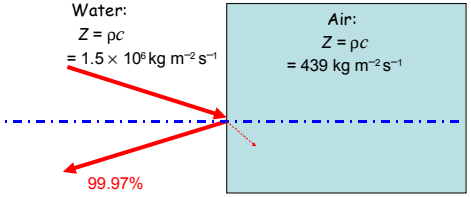


$f = (c/2\pi)\sqrt{(A/LV)}$

$f = (1500/2\pi)\sqrt{(0.13m^2/0.5m \times 1m^3)}$

$f = 46$ Hz

Impedance mismatching



The same phenomenon applies when sound tries to go from air to water (e.g. hearing in terrestrial animals)

Coupling to Medium

- Impedance Matching with Water:
  - Couple to pressure.
  - No problem unless the resonator is air-filled.
- Impedance Matching with Air:
  - Couple to displacement.
  - Usually requires a tympanum ("drum head").
- Impedance Matching with Sand or Soil:
  - (See Water.)

The Namib Desert golden mole (*Eremitalpa granti namibensis*)

- Functionally blind
- Nocturnal Insectivore
- Massive malleus, confers low-frequency sensitivity, via the cochlea, to substrate vibrations.

Human Voice

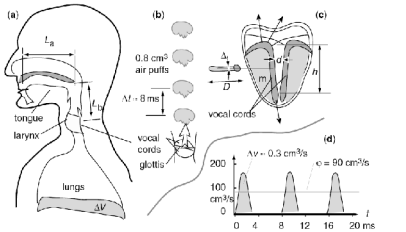
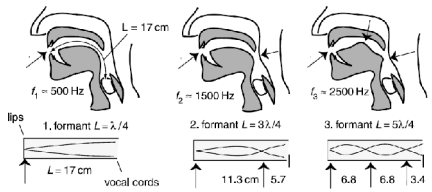


Fig. 9.21. (a) Cross section of human head. (b) Air puffs generated by the glottis. (c) Cross section of larynx with glottis opening area $A_{gl} = d \cdot h$. (d) Time sequence of volume flow φ.

Formants



Formant Filters

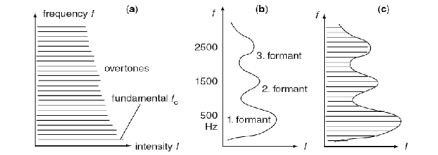
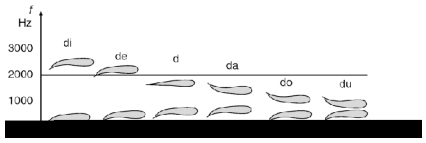


Fig. 9.22. (a) Frequencies produced by the vocal cords with overtones. (b) Formant filter function. (c) Resulting acoustical output.

"D" Sounds



Language Spectra