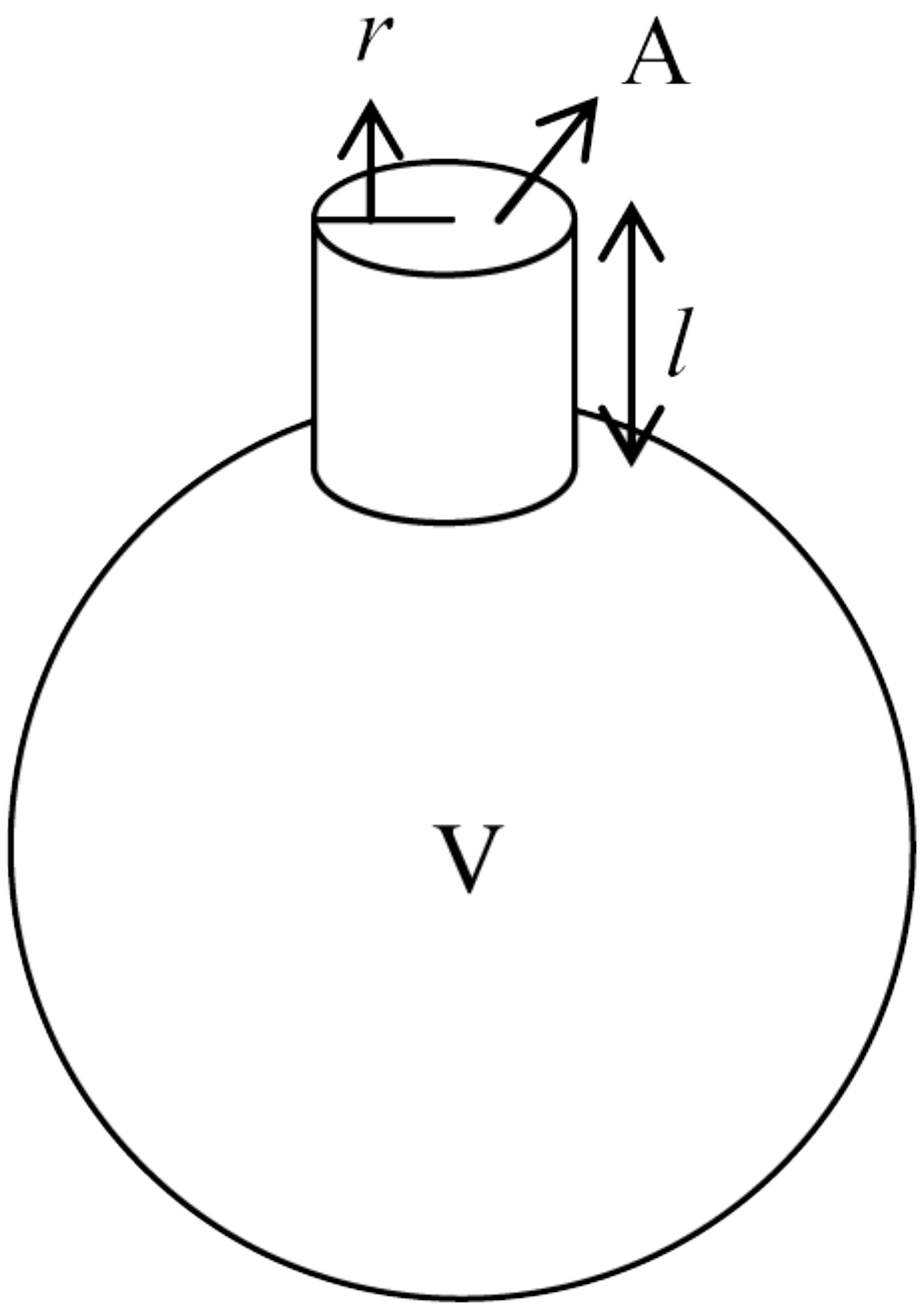
Helmholtz resonator



$$f = \frac{v}{2\pi}\sqrt{\frac{A}{l_{\text{eff}}V}}$$

- Example:

$r = 1\ \text{cm}\,,\ l = 2.7\ \text{cm}\,,\ V = 425\ \text{mL}\,,\ v = 346\ \text{m/s}$

$A = \pi r^2,\ 1\ \text{mL} = 10^{-6}\ \text{m}^3 \quad \Rightarrow \quad f = 239\ \text{Hz}$

4. Fourier analysis & synthesis

Fourier's theorem

- **standing wave vibrations** are the **"building blocks"** for any complex vibration
- any complex periodic wave can be written as a **sum of harmonics**:

$$y(t) = A_1 \sin(2\pi f_1 t + \phi_1) + A_2 \sin(2\pi f_2 t + \phi_2) + \cdots$$

$$f_N = N f_1, \qquad N = 1,2,\cdots$$

- **Ohm's law of hearing**: Phases have little effect on the timbre of the sound
- **Fourier analysis**: decomposing a complex periodic wave into its contributing harmonics
- **Fourier synthesis**: constructing a complex periodic wave by combining harmonics

5. String instruments

Plucked versus bowed strings

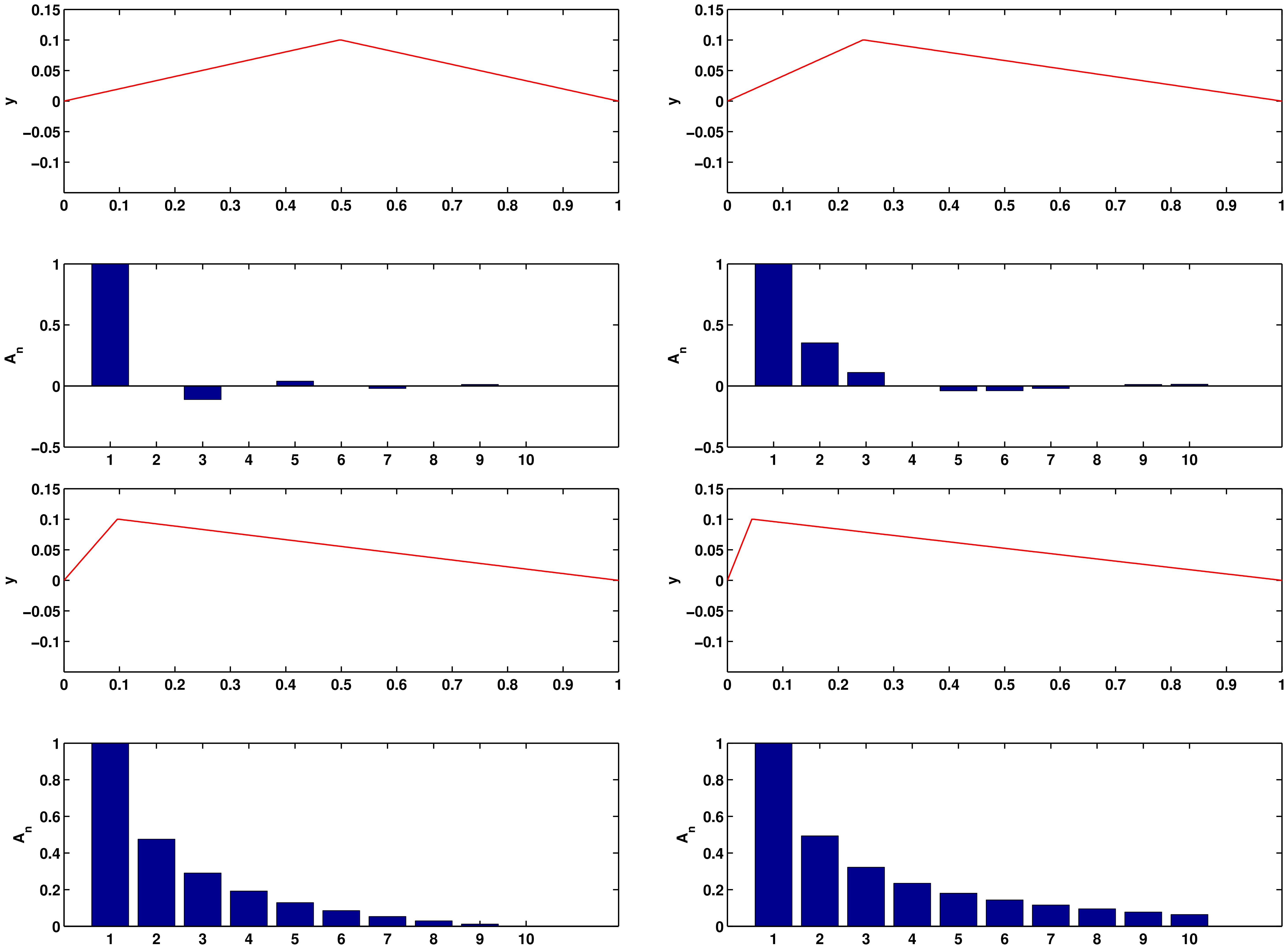
- Plucked string: https://www.youtube.com/watch?v=_X72on6CSL0
- Bowed string: https://www.youtube.com/watch?v=6JeyiM0YNo4
- iPhone guitar video: https://www.youtube.com/watch?v=TKF6nFzpHBU

- NOTE: the iPhone guitar video does not show the wave pulses on the strings as they really are. Rather one sees multiple images of the same pulse shape on the string due to the "rolling shutter" effect of the iPhone camera. The actual pulses on a guitar string behave as shown in the first video.

Fourier coefficients of a plucked string

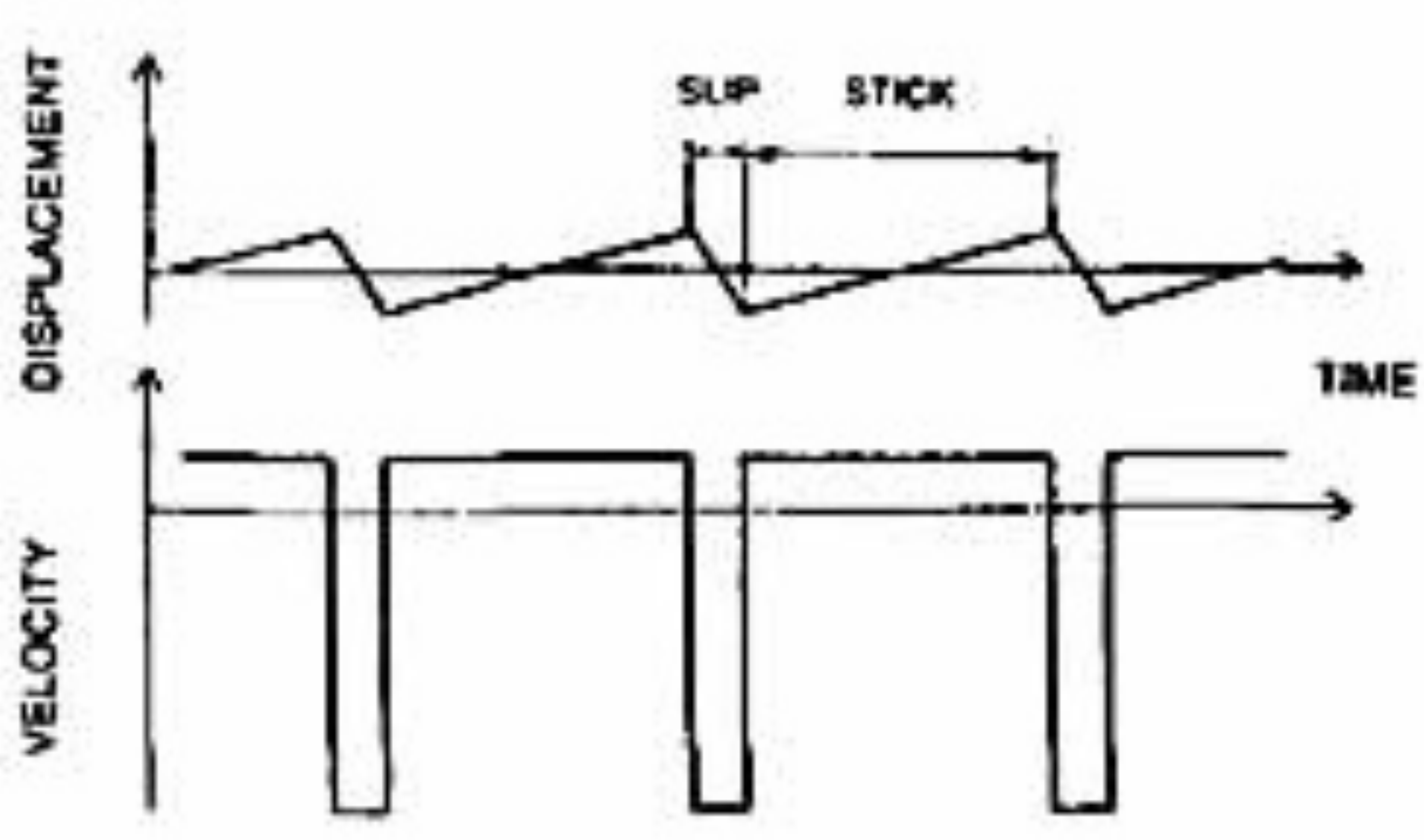
- Sounds are **richer** when the string is plucked **closer to the bridge**

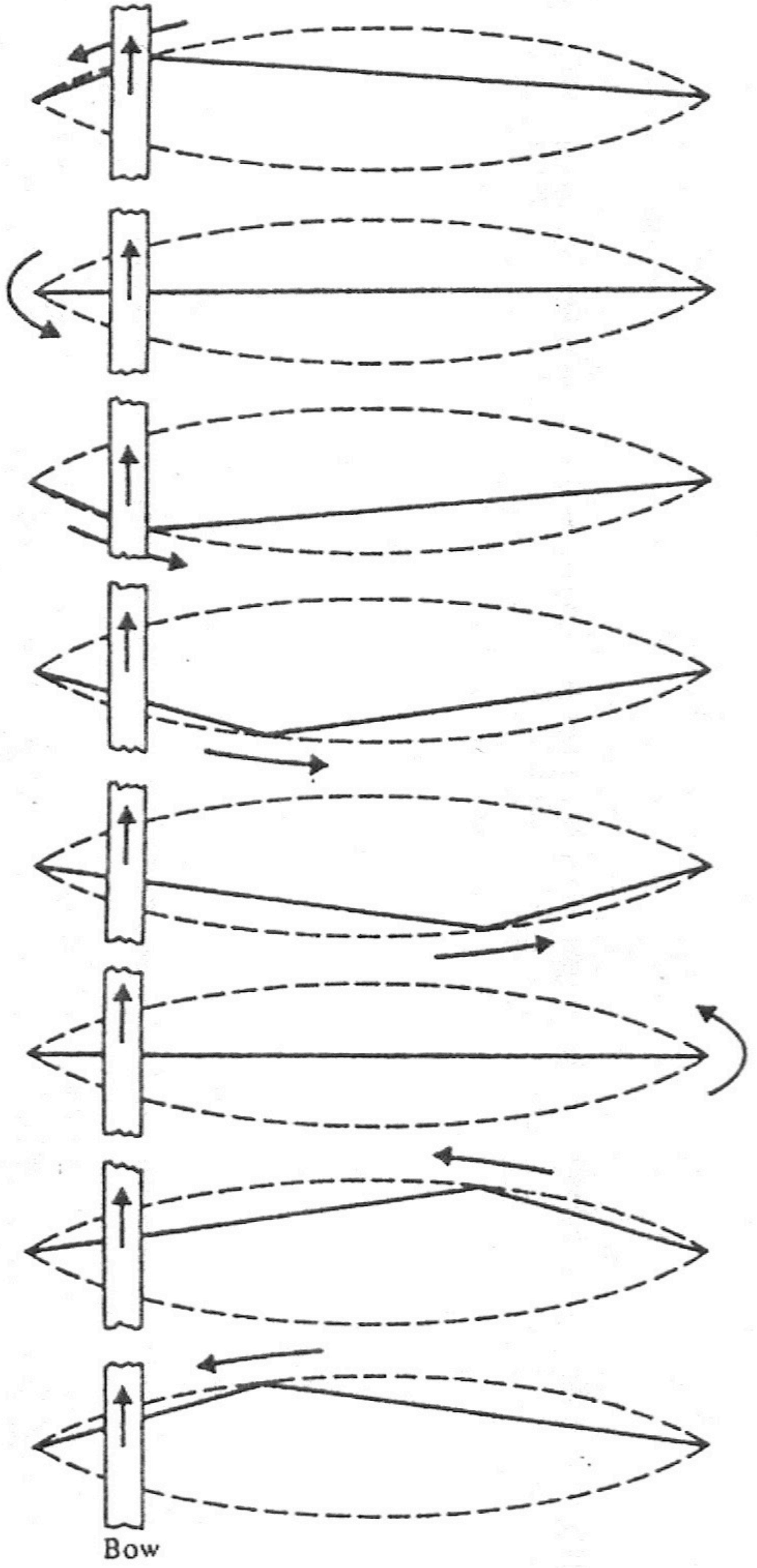
- If the string is plucked in the **middle**, there at **no even harmonics**



Stick-slip motion of a bowed string

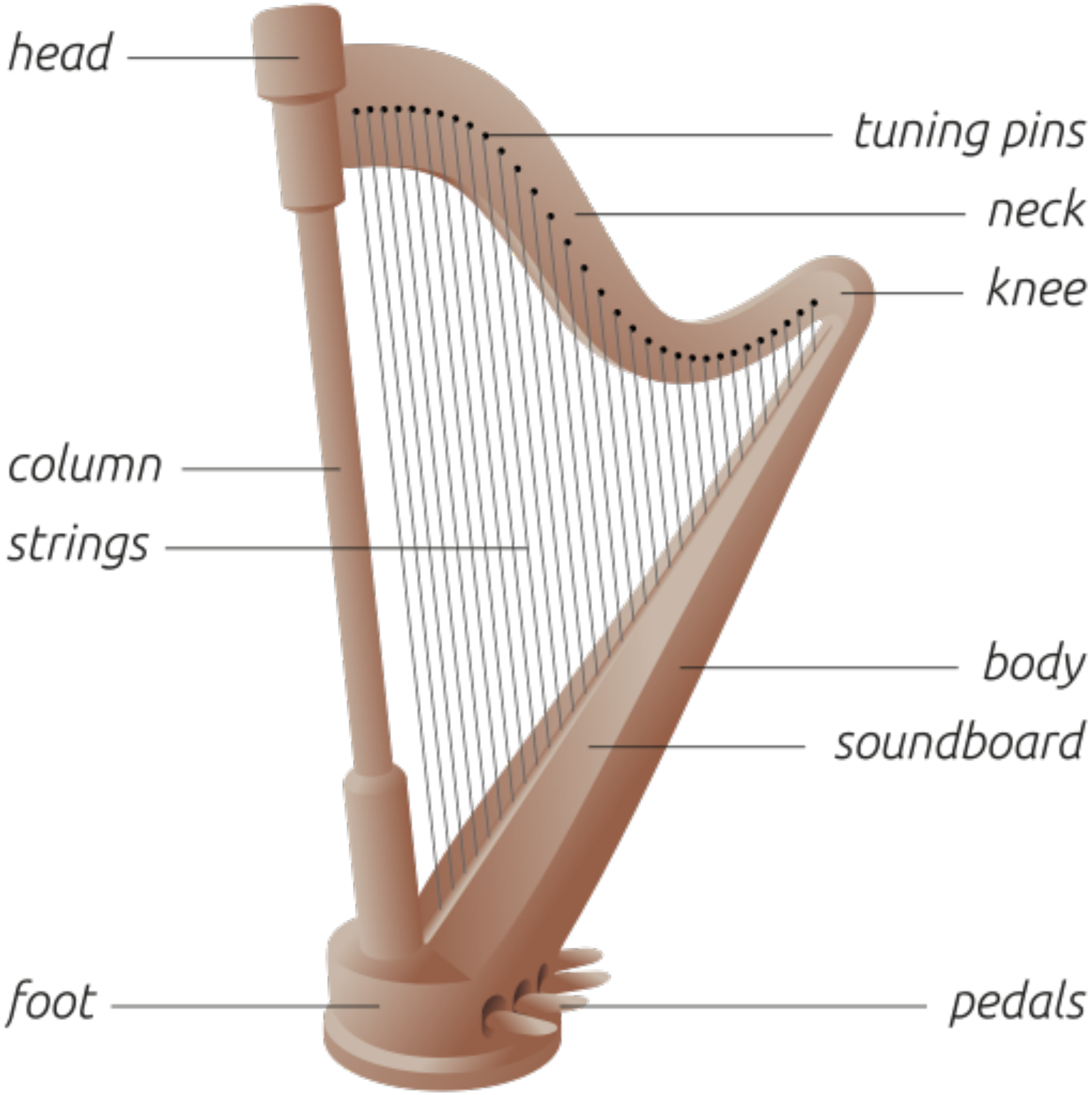
- The violin string alternately “sticks” and then “slips” against the bow hundreds of times per second





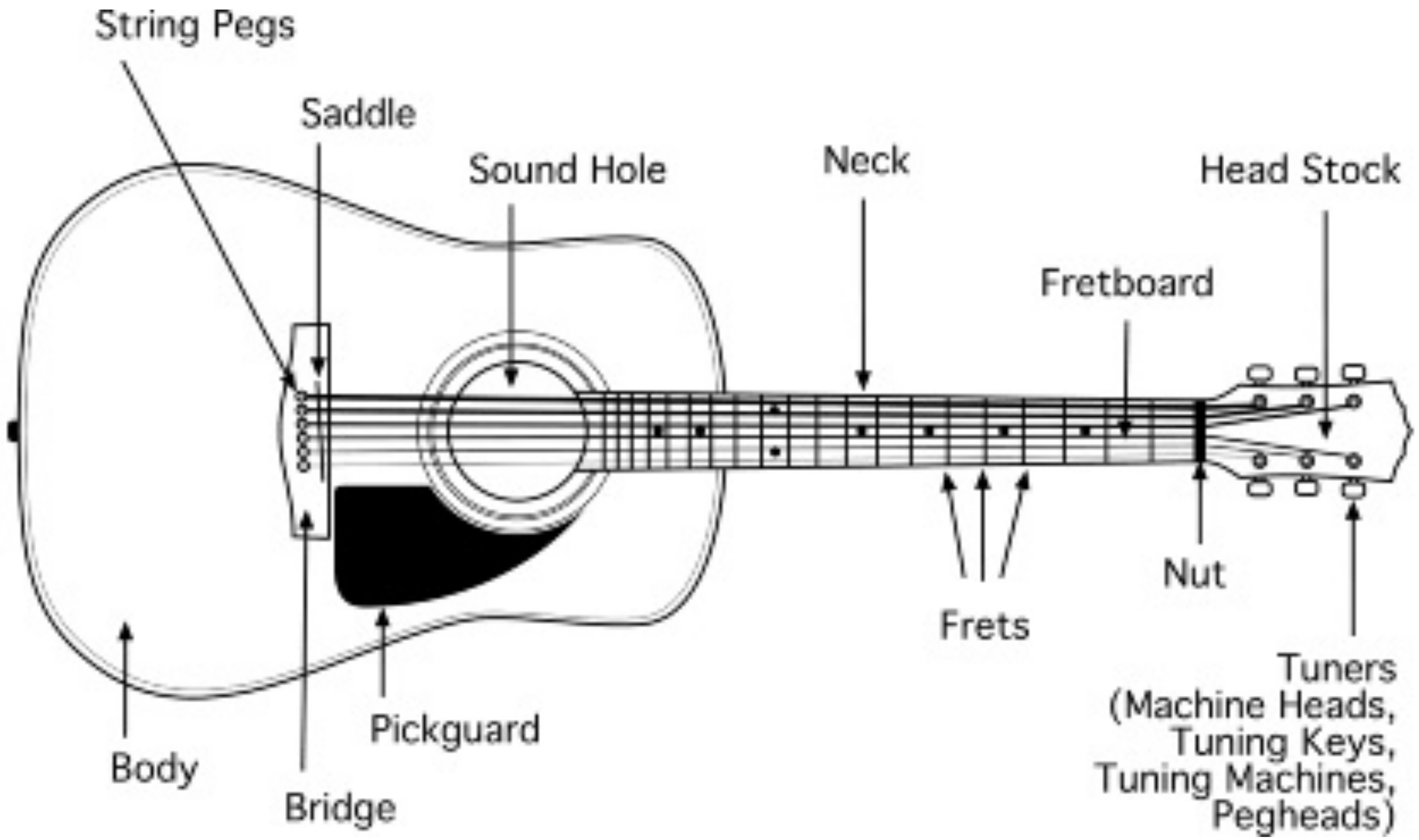
Harp

- the strings have **different fixed lengths** and are plucked
- only **one note** per string -> need lots of strings
- foot pedal can change the note but only by **only a semitone**



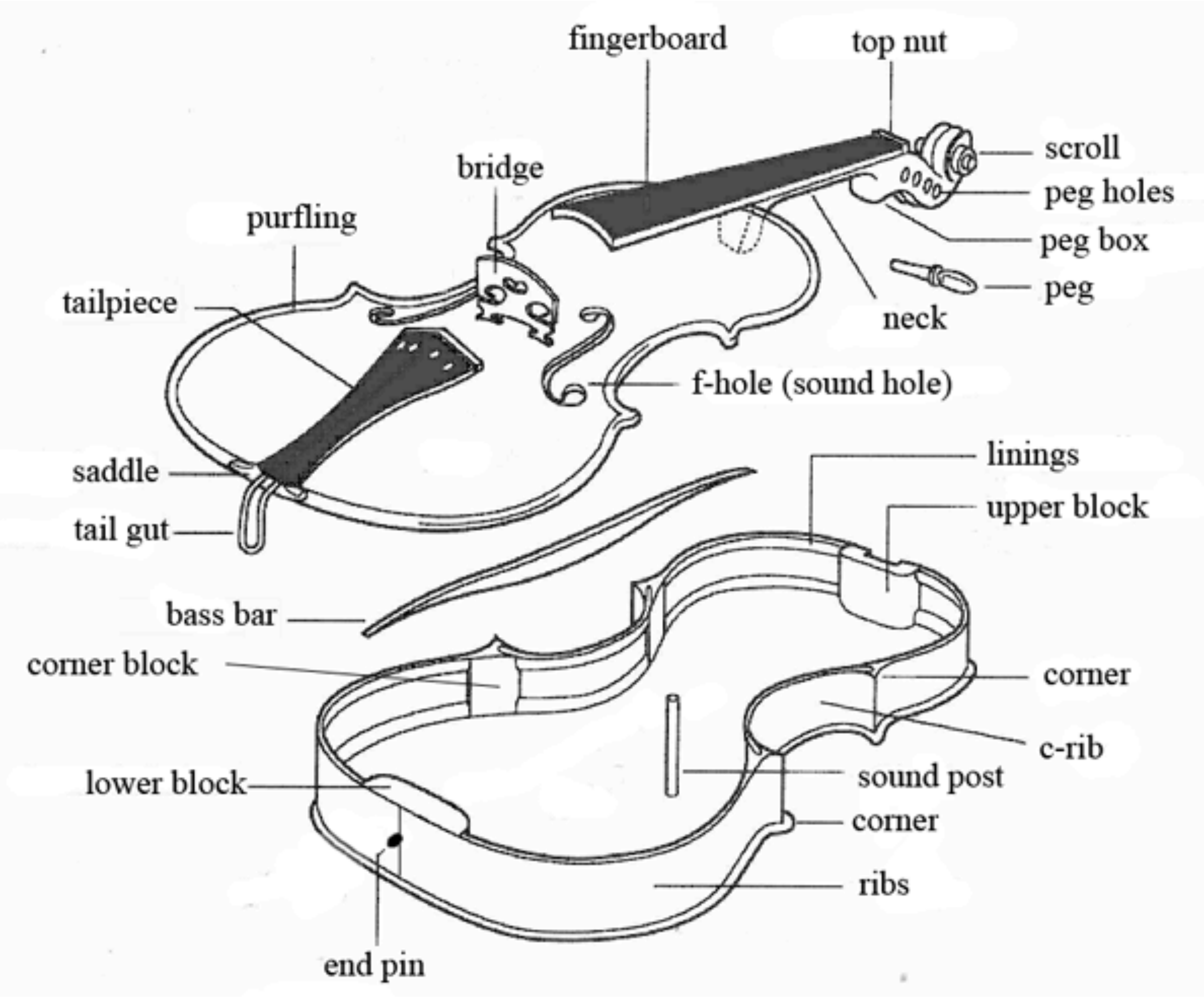
Guitar

- strings are all the **same length**, but are made of different materials and are under different tensions
- get **multiple notes** per string by pressing against a fret
- frets -> **fixed notes** (like a piano keyboard)



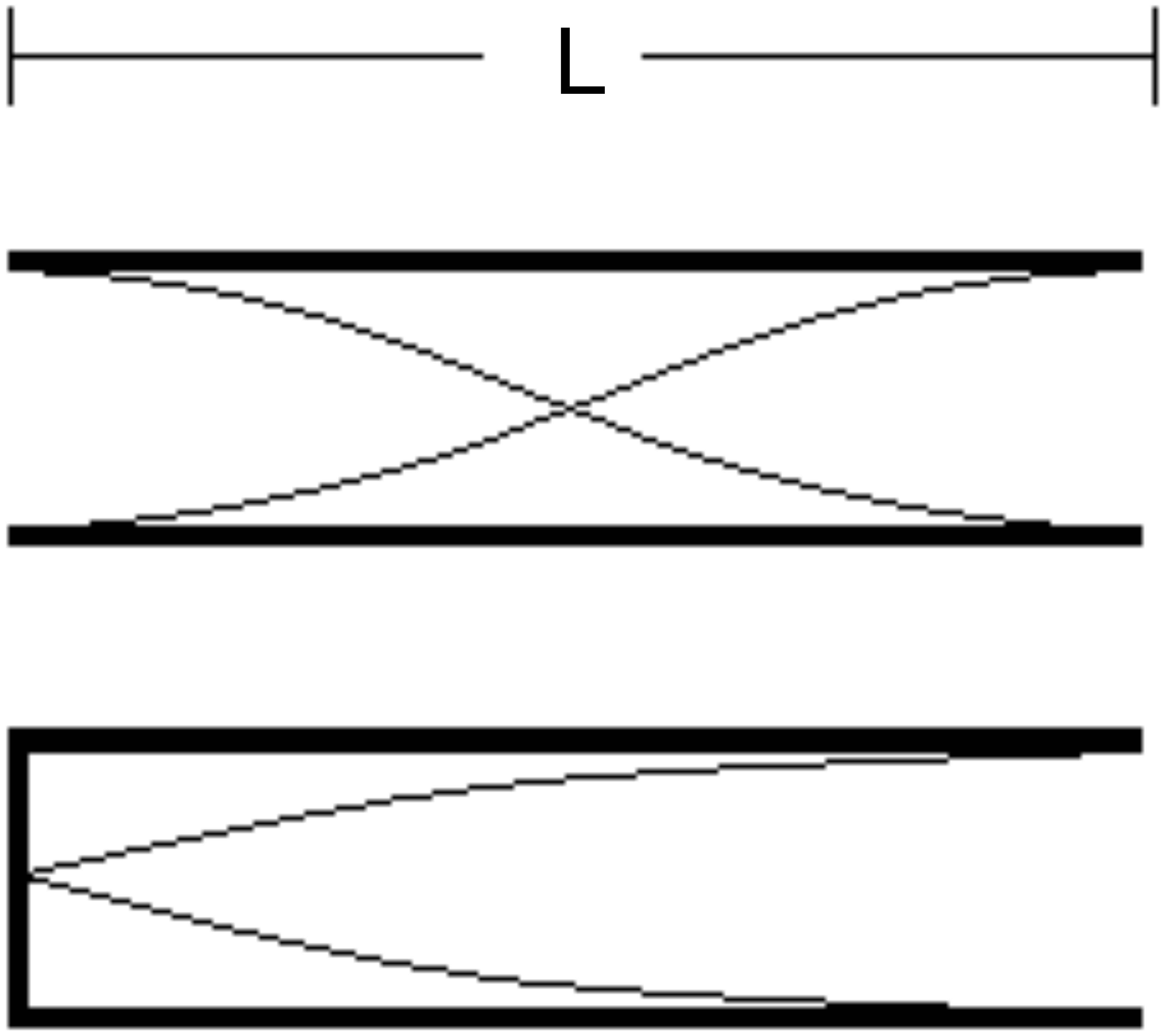
Violin

- strings are all the **same length**, but are made of different materials and are under different tensions
- get **multiple notes** per string by pressing against the neck
- no frets -> **no fixed notes**
- string vibrations are **quickly damped** if strings are plucked -> bowed instead
- can **vary tone quality** by adjusting the intensity of bowing



6. Wind instruments

Open and closed tubes (recall previous discussion)



$$\lambda_N = \frac{2L}{N} \qquad f_N = N f_1 \qquad f_1 = \frac{v}{2L} \qquad N = 1,2,\cdots$$

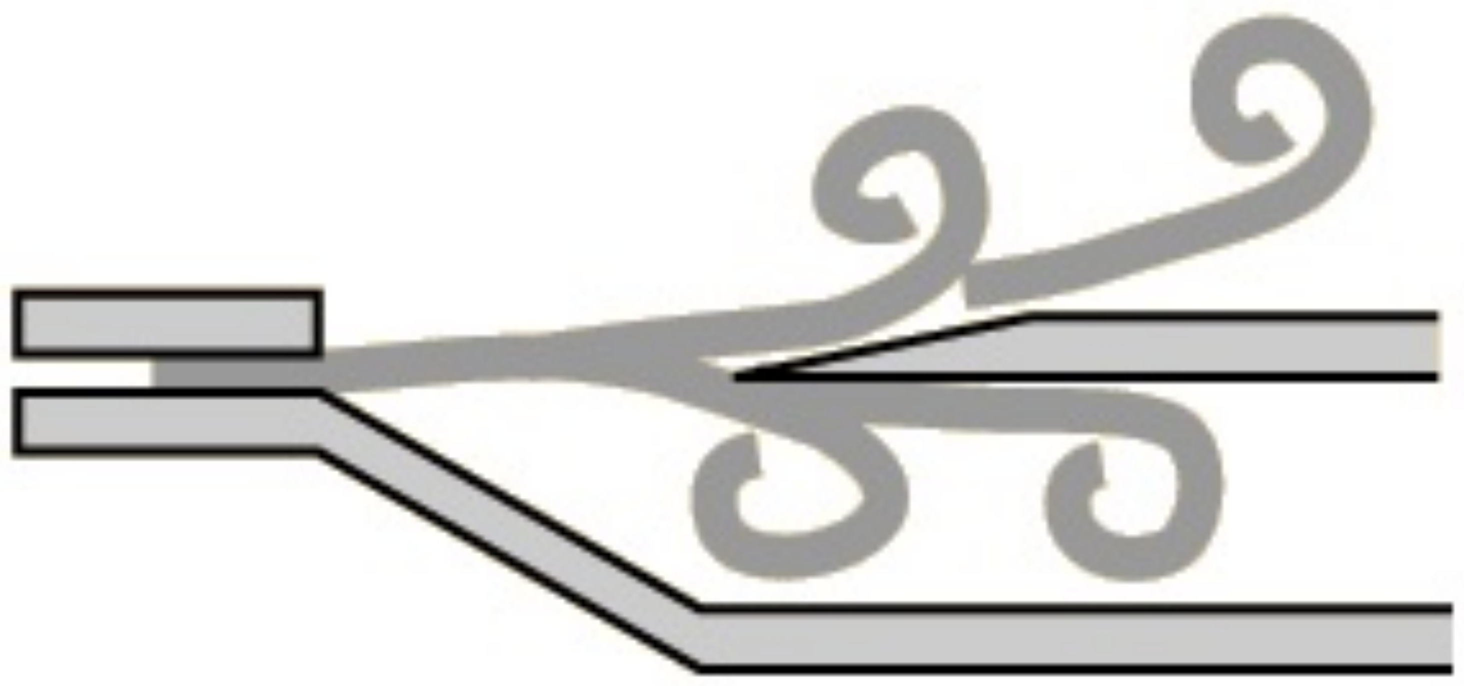
(both even and odd harmonics)

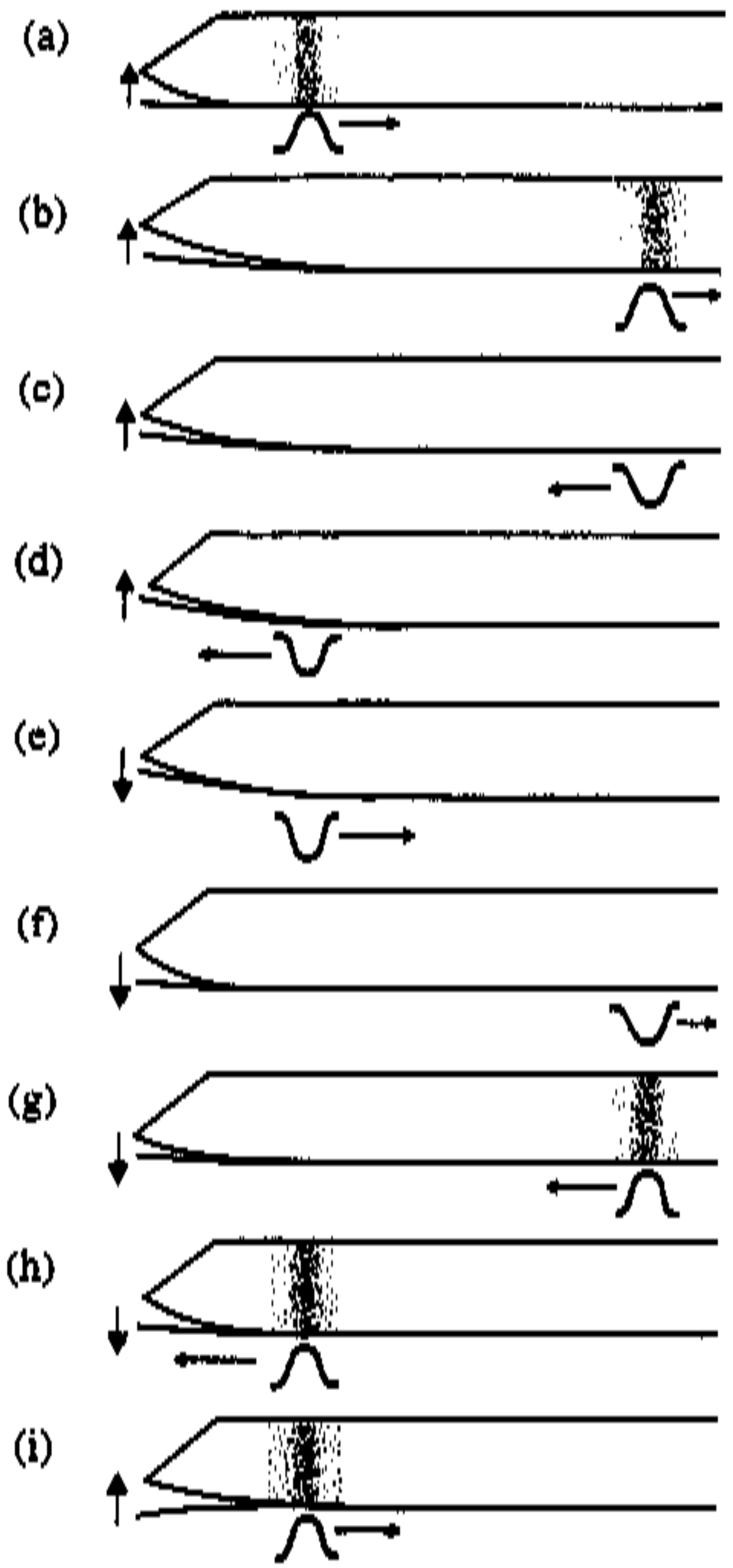
$$\lambda_N = \frac{4L}{N} \qquad f_N = N f_1 \qquad f_1 = \frac{v}{4L} \qquad N = 1,3,5,\cdots$$

(only odd harmonics)

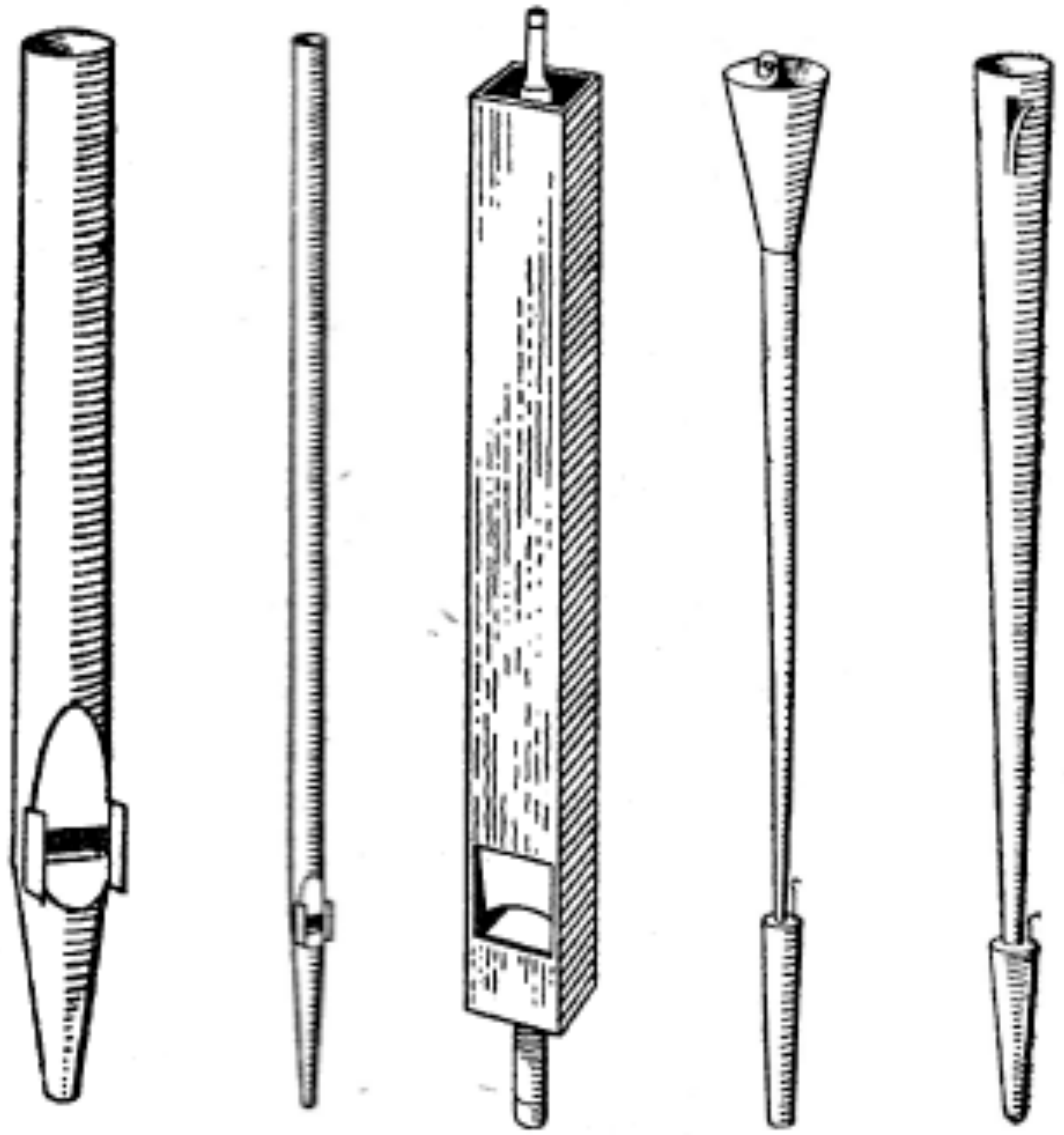
(air molecule displacements)

Excitations produced by an oscillating air stream or a vibrating reed





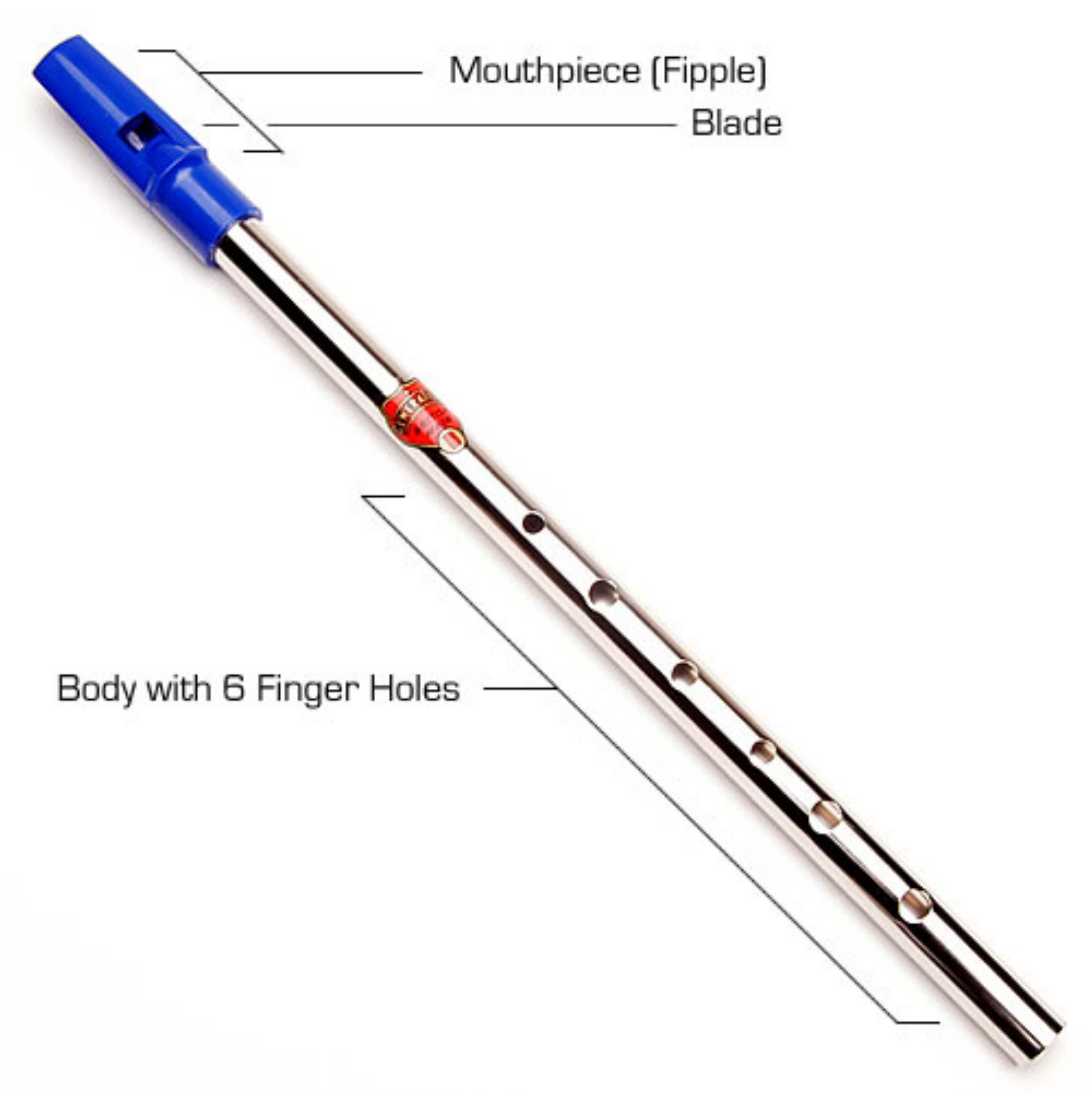
Flue-organ pipe



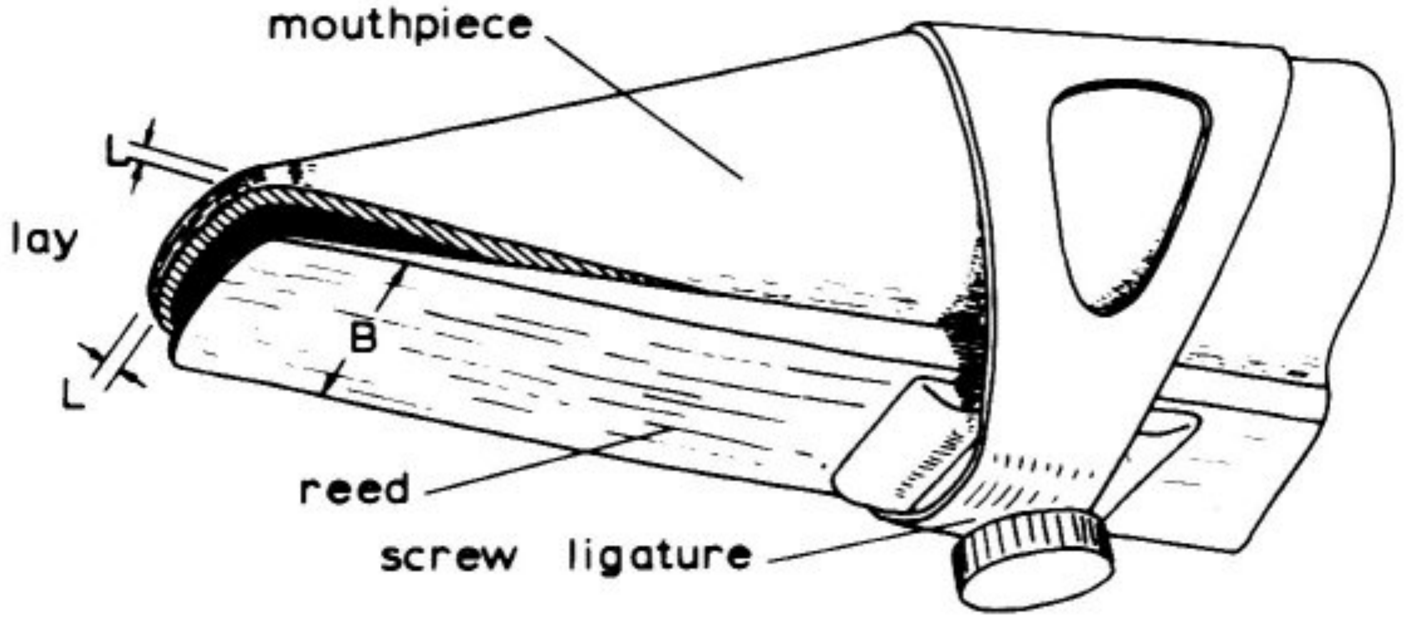
Different types of pipe

1. *Open Diapason*
2. *Dulciana*
3. *Stopped Diapason*
4. *Oboe (reed pipe)*
5. *Trumpet (reed pipe)*

Penny whistle



Clarinet


mouthpiece
lay
L
L
B
reed
screw
ligature

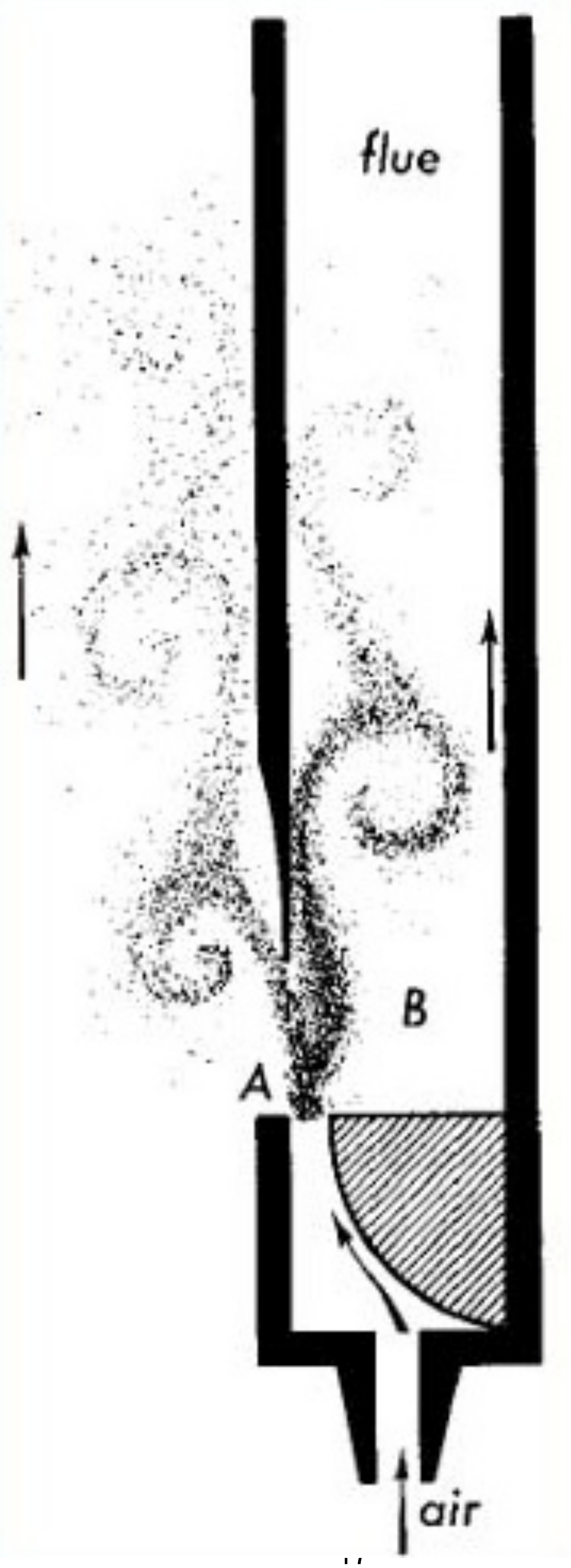

MouthPiece
Barrel Joint
Upper Joint
Ligature
Lower Joint
Bell

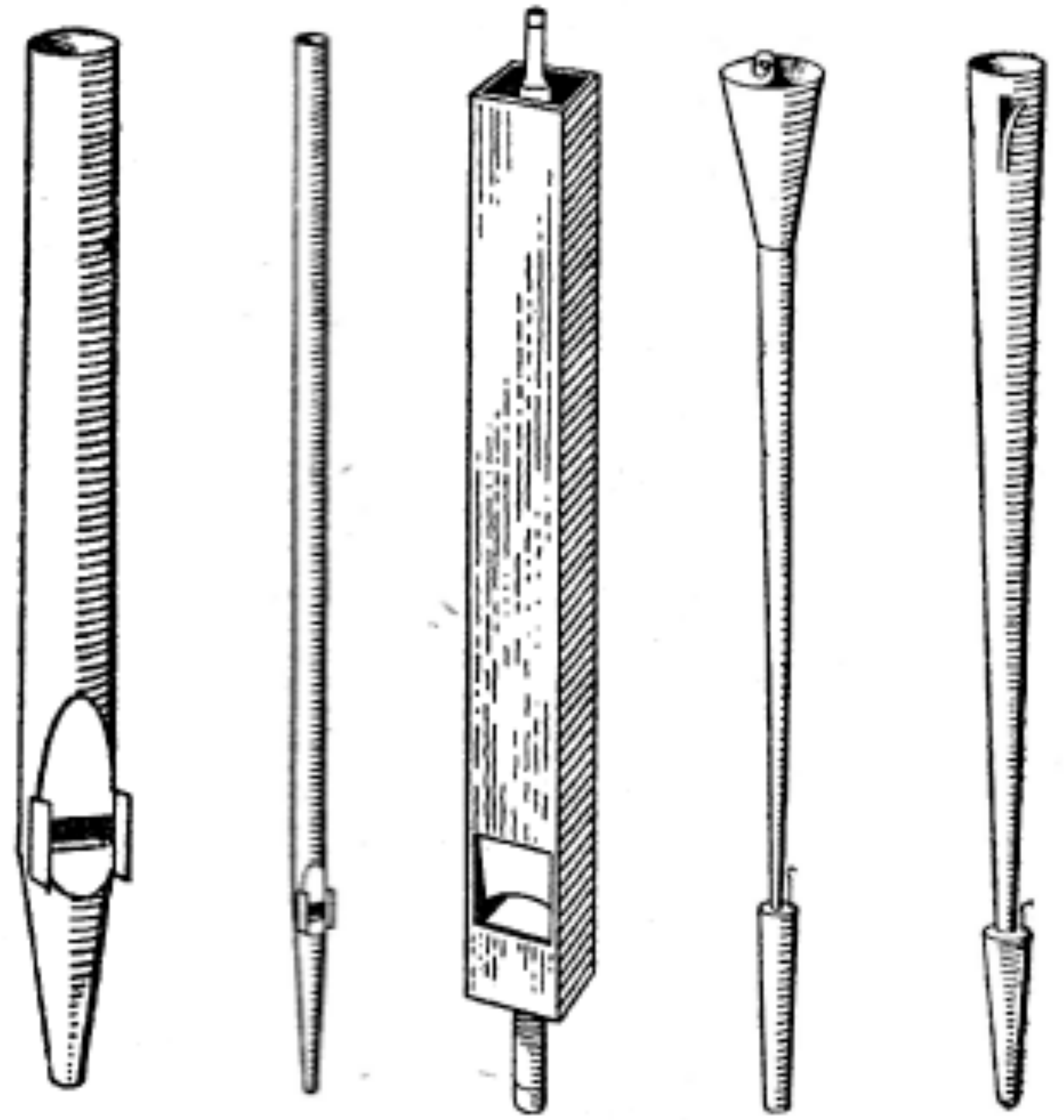
Flue-organ pipe

- Excitation can be either an oscillating air stream or a vibrating reed

- Pipe has fixed length

- One note per pipe -> need lots of pipes

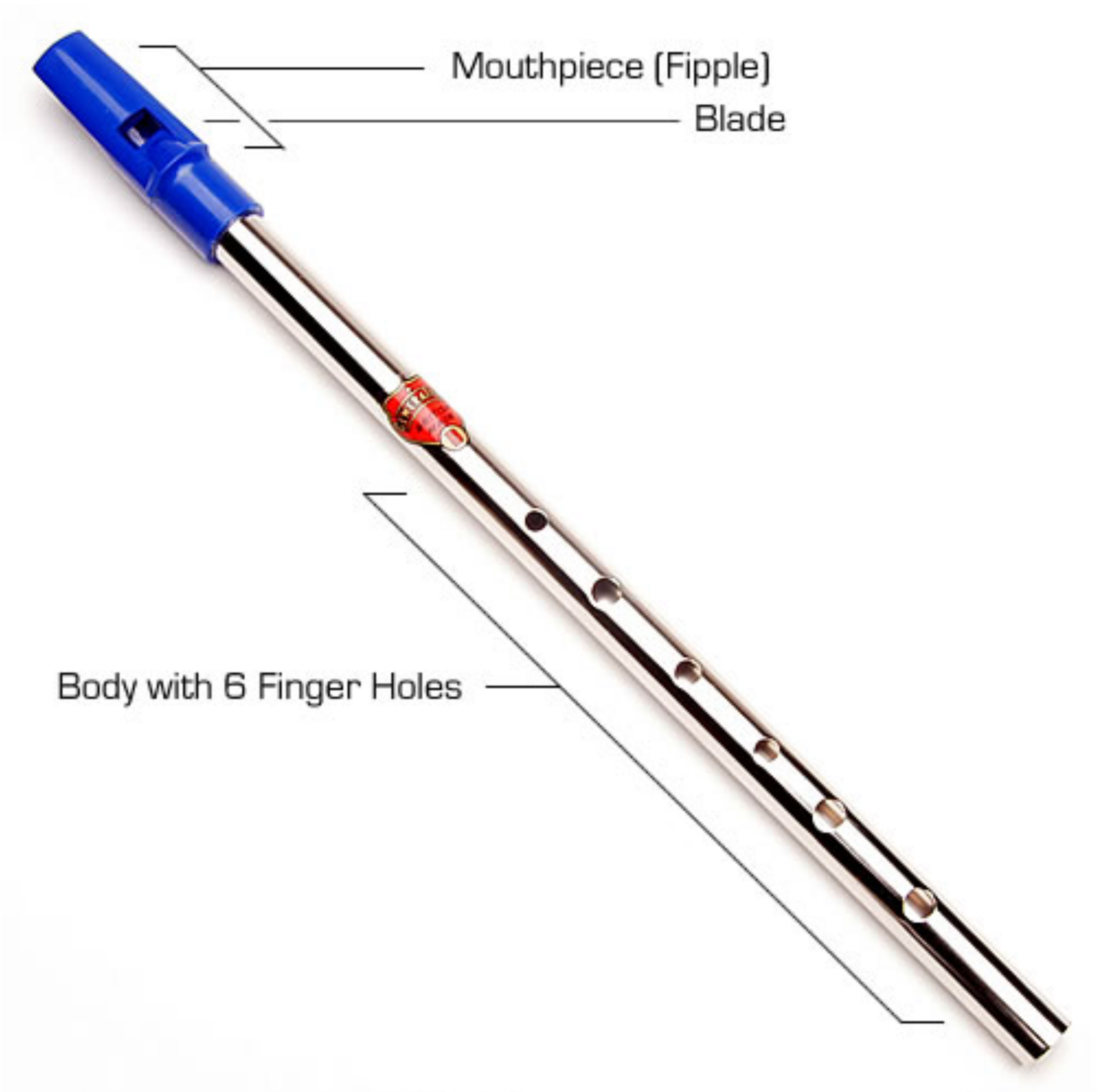




Different types of pipe
1. *Open Diapason*
2. *Dulciana*
3. *Stopped Diapason*
4. *Oboe (reed pipe)*
5. *Trumpet (reed pipe)*

Penny whistle

- Oscillating air stream -> open at both ends
- Finger holes allow playing multiple notes



Clarinet

- Vibrating reed -> closed at one end
- Finger holes and keys -> multiple notes
- Bell at end creates contribution from even harmonics