A Brief Introduction to Musical Acoustics

EELE 477

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Harmonic and Inharmonic Sounds

- Musical instruments with simple oscillators usually produce periodic waveforms
- Periodic waveforms have a fundamental frequency, f_0, and a *harmonic* spectrum: spectral energy just at frequencies that are integer multiples of f_0.
- These harmonic components are called *harmonics*, *overtones*, or *partials* .
- Some musical instruments produce inharmonic sounds: bells, drums, etc.

Pitch

- Musical sounds often have a *pitch* that is related to the sound's spectral content
- The pitch of a harmonic sound is usually close to the fundamental frequency of that sound
- Inharmonic sounds may have a perceived pitch, but it is not merely the fundamental of some harmonic series

Organization of Western Music

- Two harmonic sounds with different fundamental frequencies can lead to interesting frequency coincidences among their partials
- When the fundamentals have a low integer ratio relationship, this is a *consonant* interval

Consonant Intervals

Unison	3rd	4th	5th	Octave
1/1	5/4	4/3	3/2	2/1
100	125	133.33	150	**200**
200	250	266.67	**300**	**400**
300	375	**400**	450	**600**
400	**500**	533.33	**600**	**800**
500	625	666.67	750	**1000**
600	750	**800**	**900**	**1200**
700	875	933.33	1050	**1400**
800	**1000**	1066.67	**1200**	**1600**
900	1125	**1200**	1350	**1800**
1000	1250	1333.33	**1500**	**2000**
1100	1375	1466.67	1650	**2200**
1200	**1500**	**1600**	**1800**	**2400**
1300	1625	1733.33	1950	**2600**
1400	1750	1866.67	**2100**	**2800**
1500	1875	**2000**	2250	**3000**
1600	**2000**	2133.33	**2400**	**3200**

Musical Scales and Temperament

- European music is based on the notion of a diatonic pitch *scale*. The scale specifies the allowable musical pitches: 8 scale steps out of 12.
- Problem: if integer frequency ratios are used (*Just* intonation), chords only sound in tune if based on fundamental (*tonic*) pitch. Changing musical “key” is not possible.

Equal Tempered Scale

- To solve the musical “key” problem, keyboard instruments now use *equal-tempered* tuning.
- Note frequencies are distributed uniformly in a logarithmic span:

$$f_n = f_0 \times 2^{n/12}$$

- Just vs. equal tempered tuning:

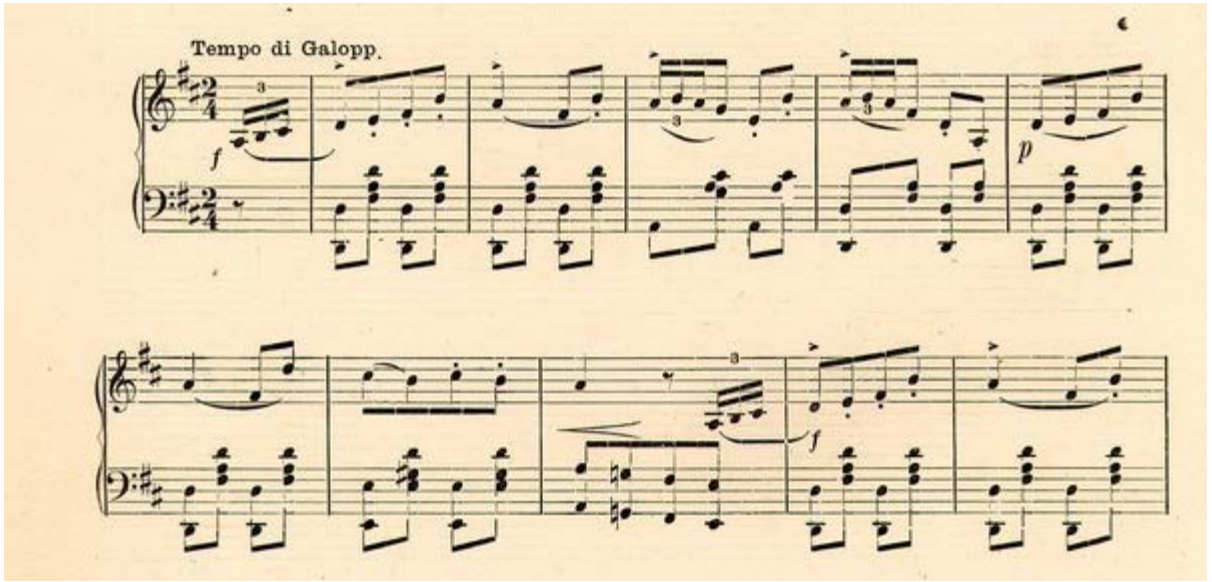
Unison	3rd	4th	5th	Octave
100	125.0000	133.3333	150.0000	200.0000
100	125.9921	133.4840	149.8307	200.0000

Rhythm

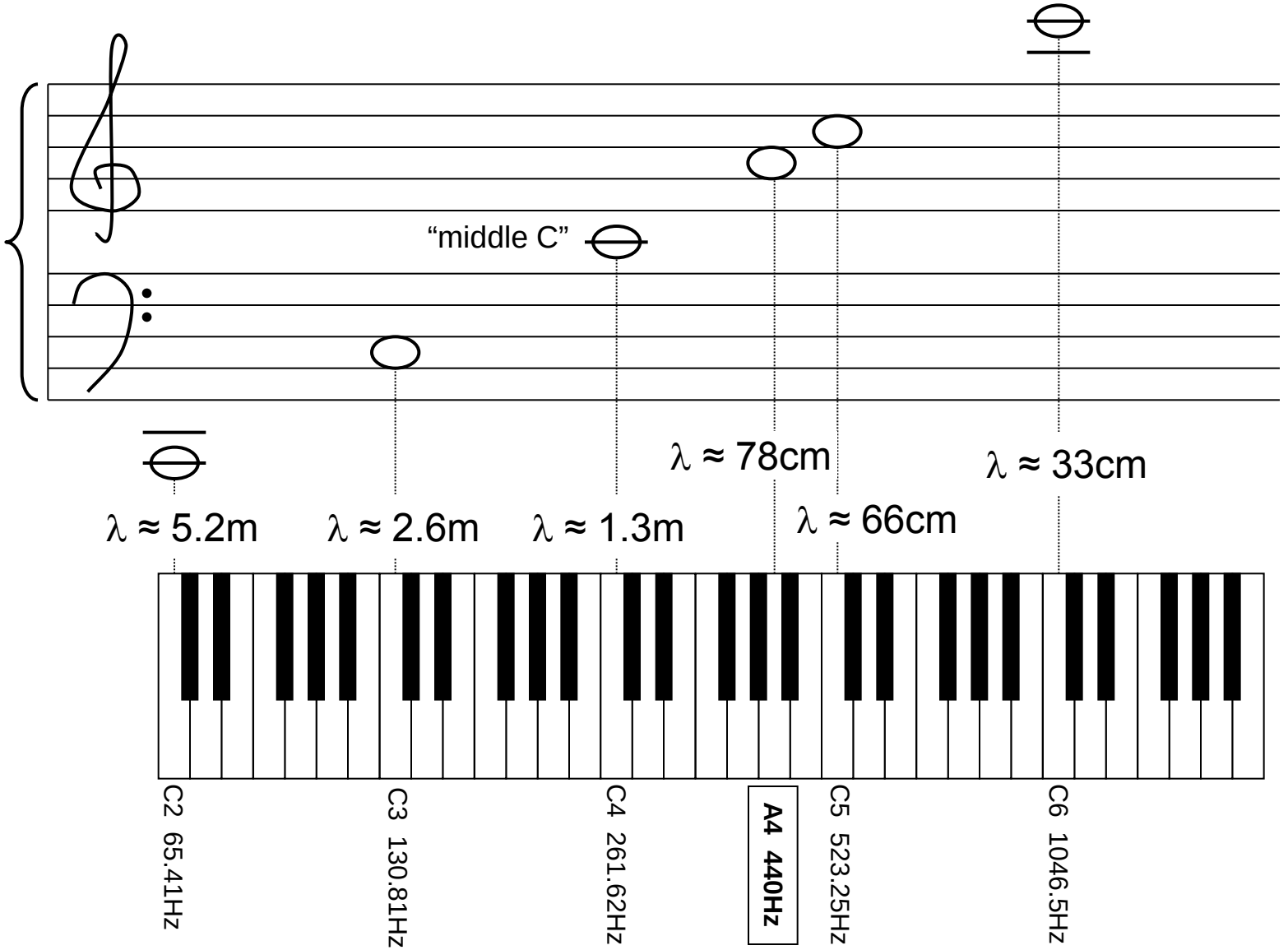
- Beats per minute
- Beats per measure (time signature)
- Duration of musical notes specified in fractions:
  whole, half, quarter, eighth, sixteenth, 32^{nd}

Musical Notation

- Notation specifies pitches, durations, and time evolution
- Representation is like a spectrogram: frequency vs. time



Standard Tuning Frequencies



Musical Timbre

- The relative spectral energy at different frequencies is perceived as a distinct *tone color*, or timbre (pronounced as either *tam--burr* or *tim-burr*)
- Timbre: The combination of qualities of a sound that distinguishes it from other sounds of the same pitch and volume

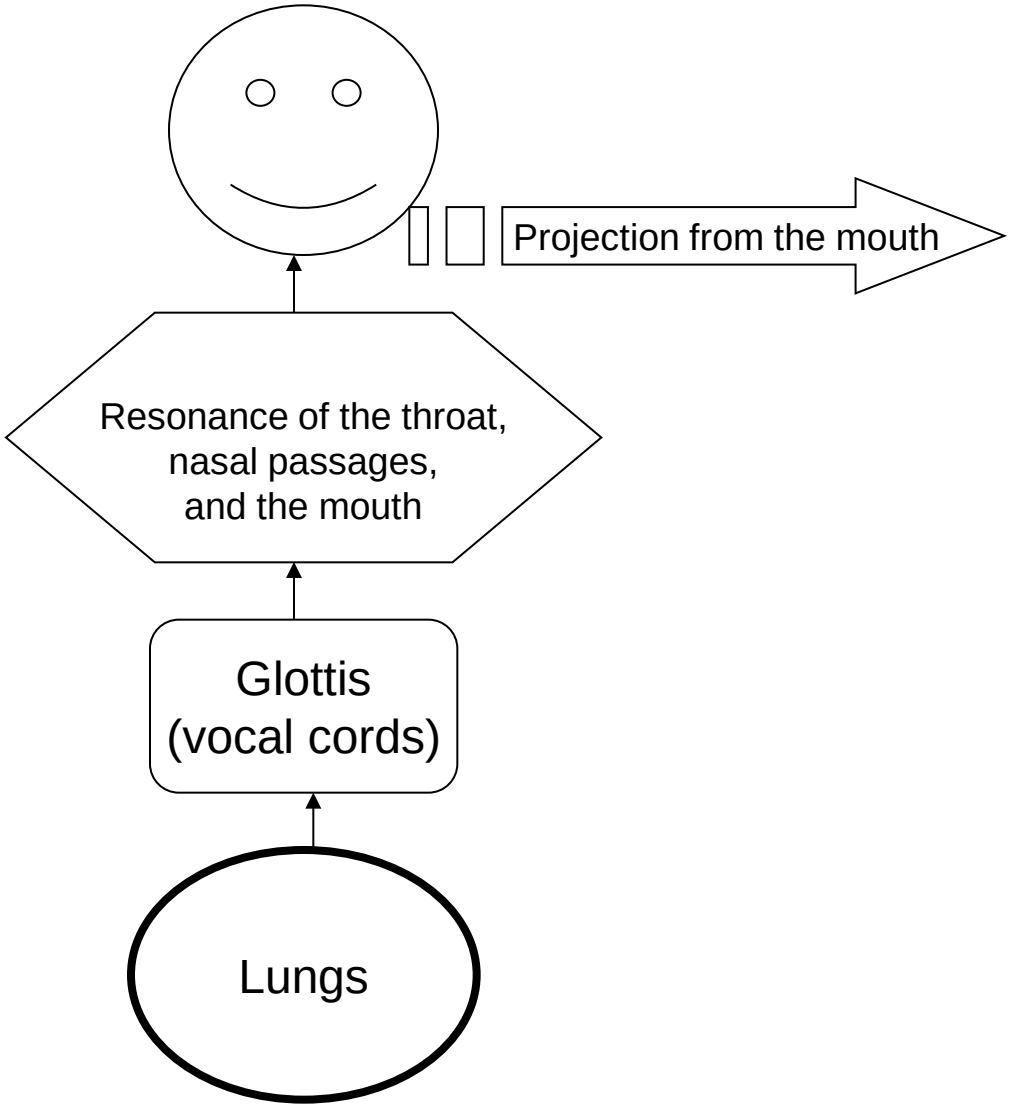
Musical Instruments

- Almost any object can be considered a musical instrument
- Most *conventional* musical instruments have
  - an *excitation source*
  - a *vibrating element*
  - a *resonant body*
  - a means of *coupling* the vibrations so that they radiate into the air as sound waves

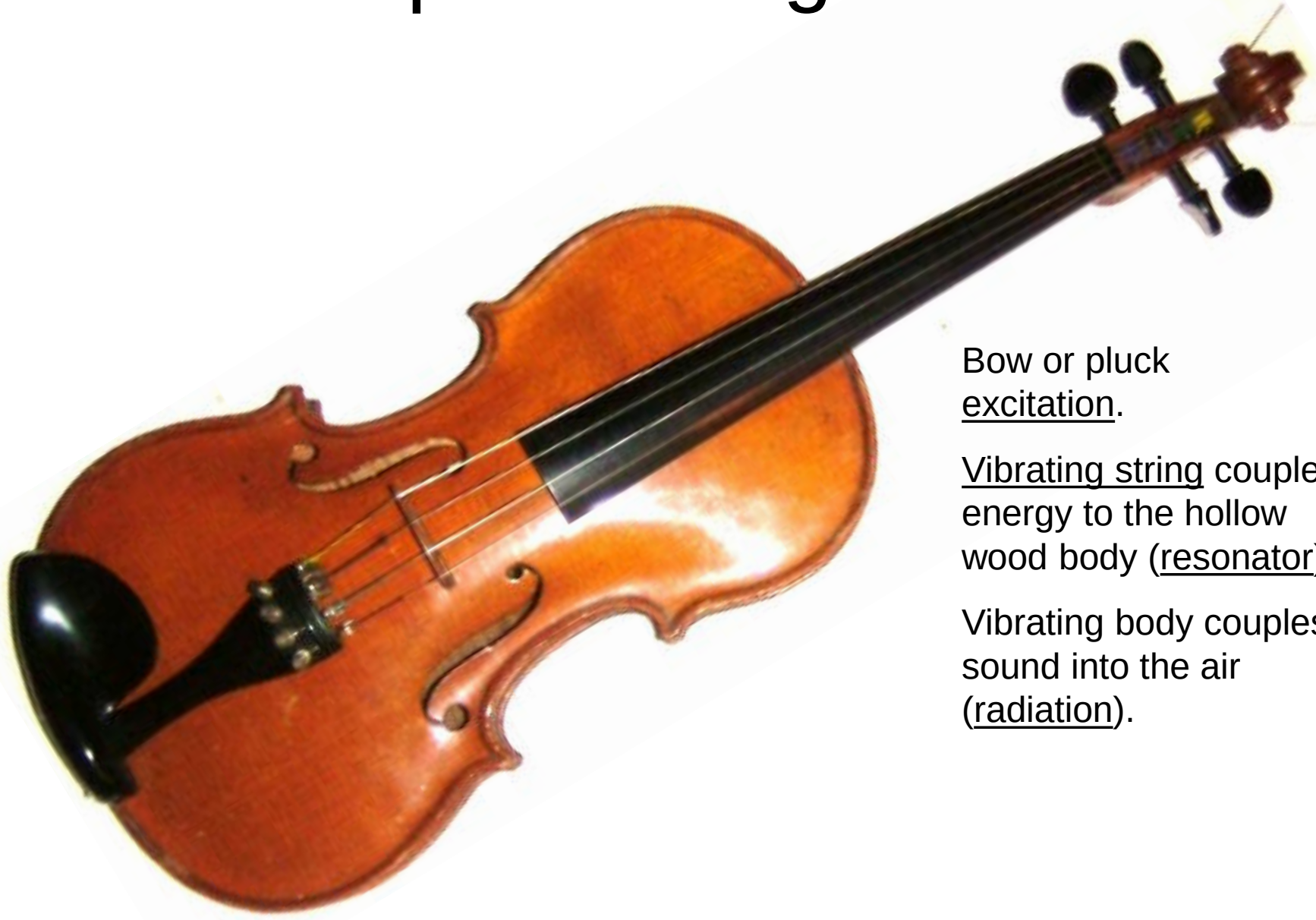
Musical Instruments (cont.)

- The excitation is a motive force
- The vibrating element usually creates many harmonics
- The resonant body emphasizes some frequencies and deemphasizes others
- The coupling means takes energy from the vibrating element and “loses” it (radiates) into an acoustical wave through the air

Example: Singing Voice



Example: String Instrument



Bow or pluck excitation.

Vibrating string couples energy to the hollow wood body (resonator).

Vibrating body couples sound into the air (radiation).