Music, physics, mathematics and psychoacoustics

How to apply our knowledge of science in music education?

MUSICIAN QUOTES

“Music is the arithmetic of sounds as optics is the geometry of light” - *Claude Debussy*

“I like to think of music as an emotional science” - *George Gershwin*

“Music is a science which should have definite rules; these rules should be drawn from an evident principle; and this principle cannot really be known to us without the aid of mathematics.” - *Jean Philippe Rameau*

“Music in an experience, not a science” - *Ennio Morricone*

“Music is not math. It's science. You keep mixing the stuff up until it blows up on you, or it becomes this incredible potion.” - *Bruno Mars*

SCIENTIST QUOTES

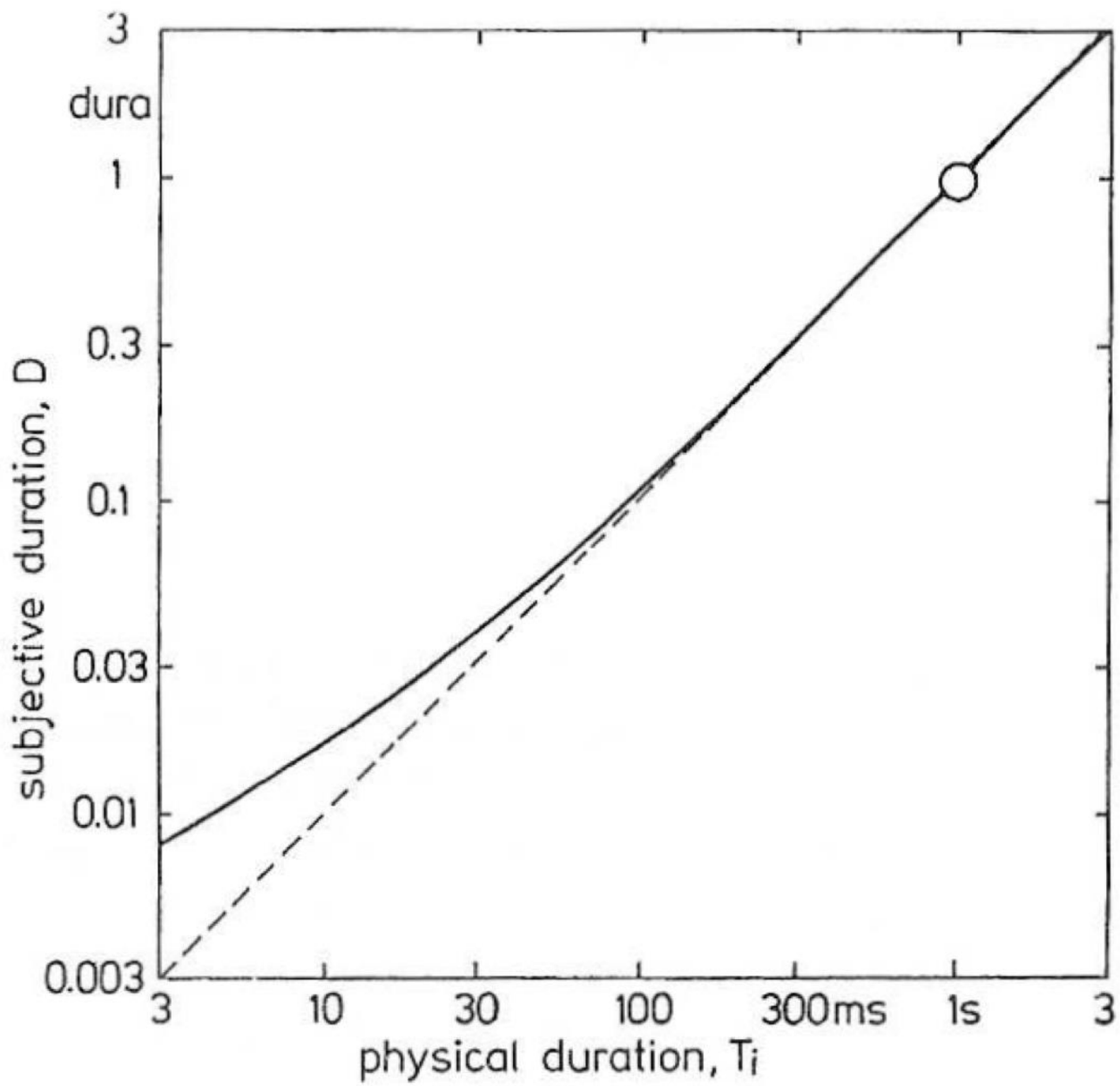
“Science cannot tell us a word about why music delights us, of why and how an old song can move us to tears.” - *Erwin Schrodinger*

“Mathematics is the poetry of logic and the music of reason.” - *Albert Einstein*

Articulation

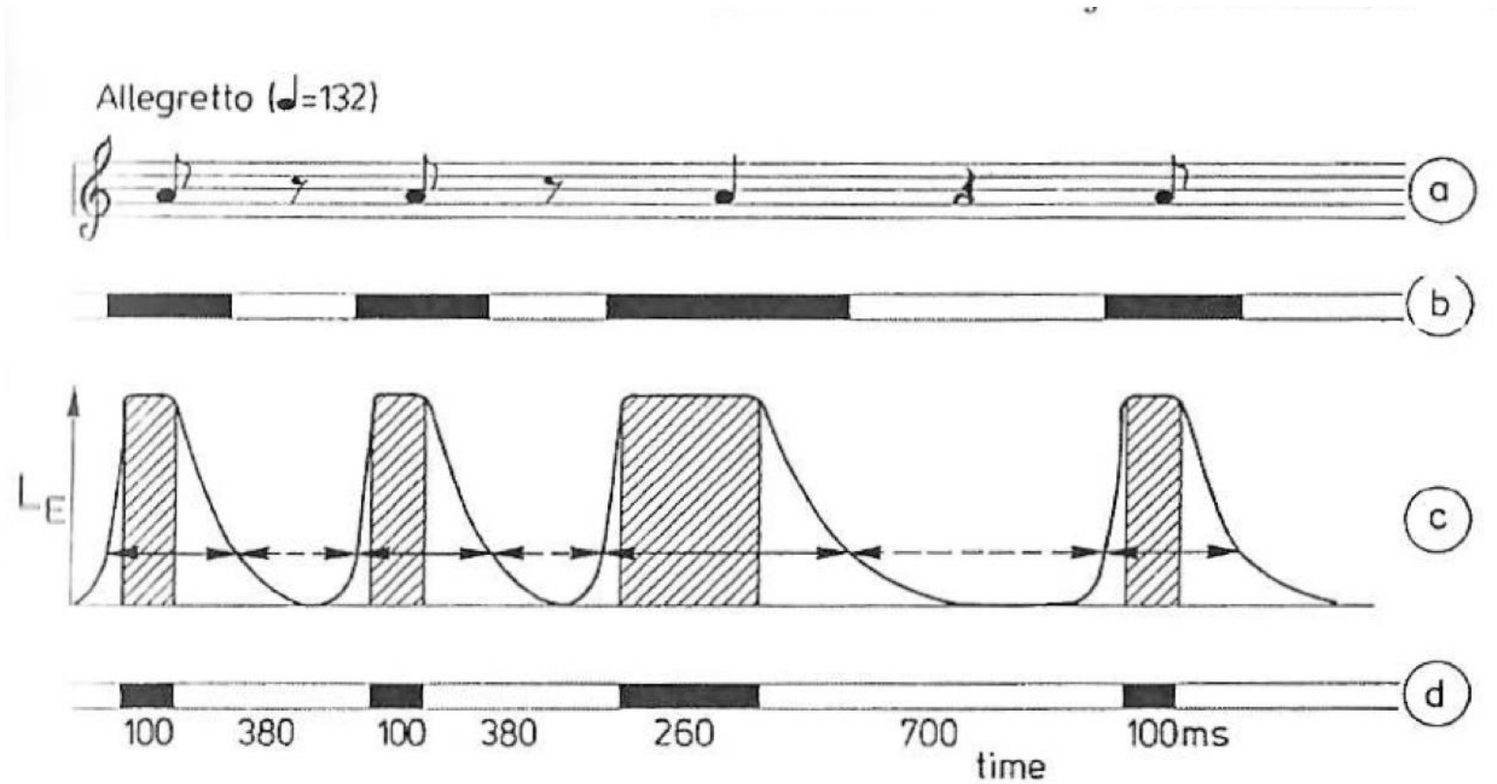
subjective duration vs physical duration

Subjective duration as a function of physical duration of 1-kHz tones at 60dB



Source: Fastl H., Zwicker E.: ***Psychoacoustics, Facts and Models (2007)***

Interpretation of the rhythmic notation



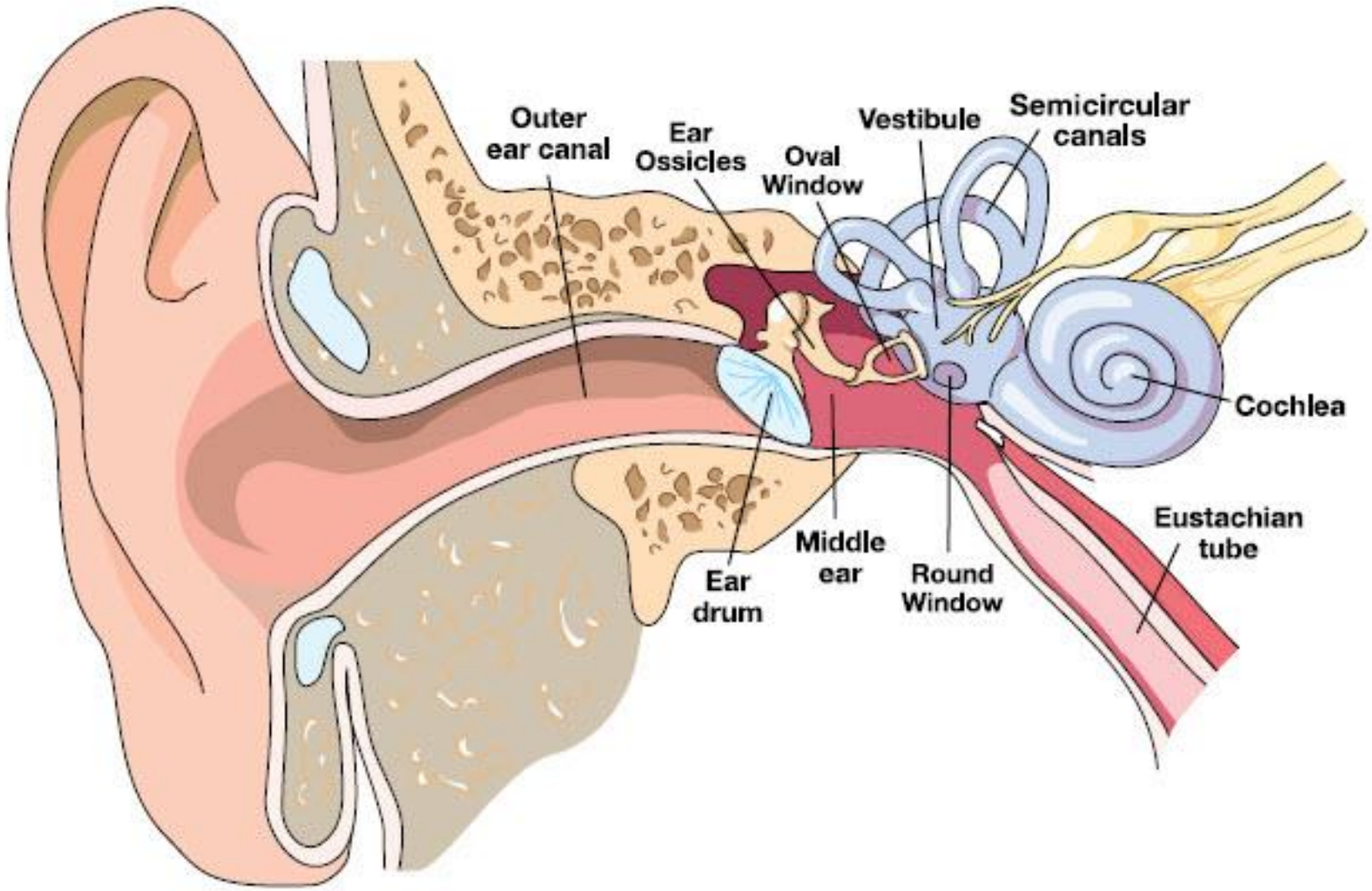
a - musical notation for a sequence of tones
b - corresponding expected sequence of durations
d - the actually played sequences of tone bursts and pauses
c - corresponding excitation level versus time

Source: Fastl H., Zwicker E.: ***Psychoacoustics, Facts and Models (2007)***

Dynamics

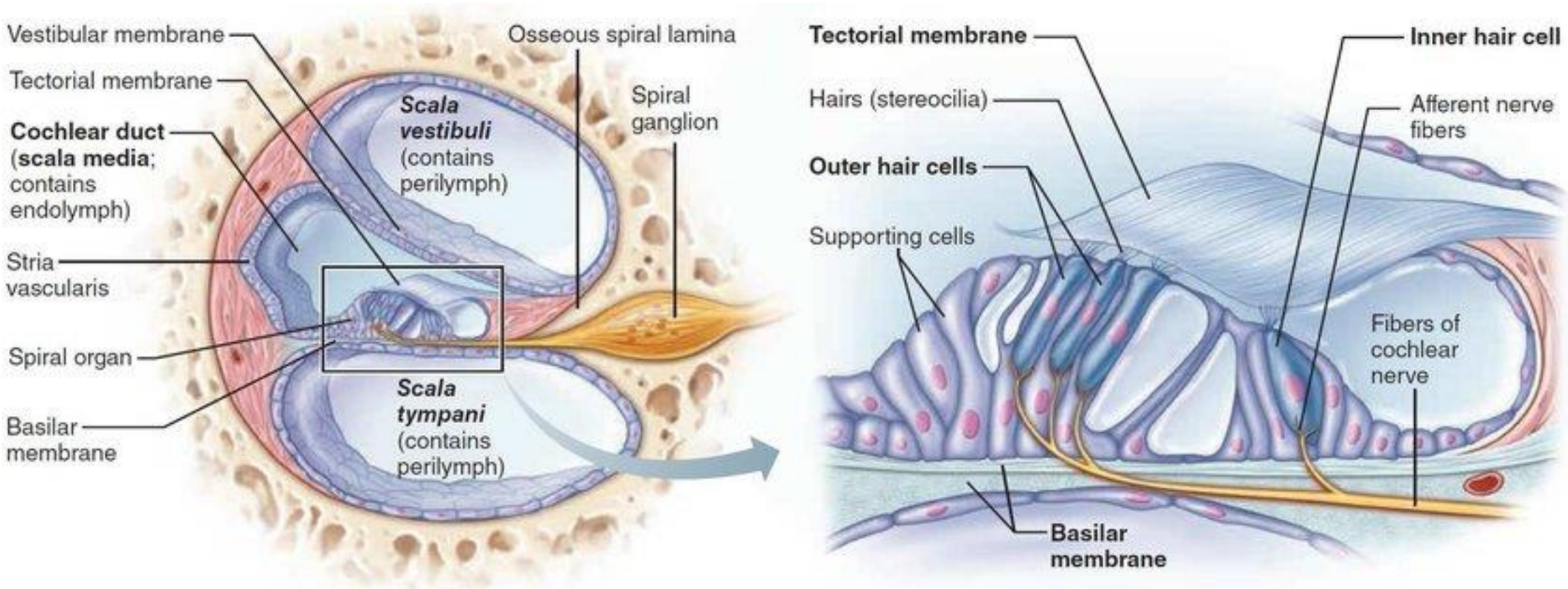
How does our perception of sound change at higher dynamic levels?

Anatomy of a human ear



source: https://world.dan.org/health/ears/anatomy-of-the-ear

Organ of Corti



Source: Russo M., Stella M., Sikora M., Pekić V.: ***Robust Cochlear-Model-Based Speech Recognition (2019)***

$$L = k\, I^{0.3}$$

L - subjective loudness
I - sound intensity
k - coefficient

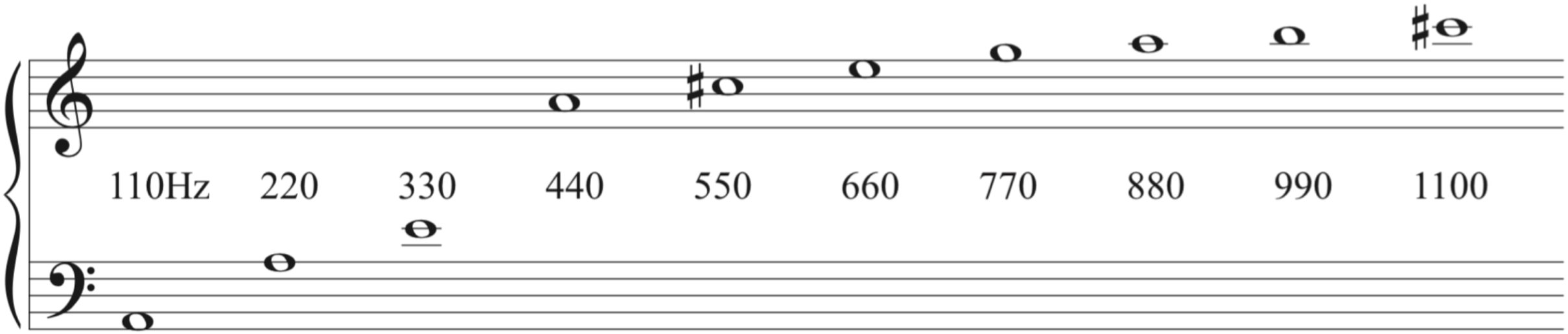
Ten violin players sound twice as loud as one violin player:

$$10^{0.3} \approx 2$$

Music harmony and mathematics

Harmonic series

fundamental: A_2 = 110Hz

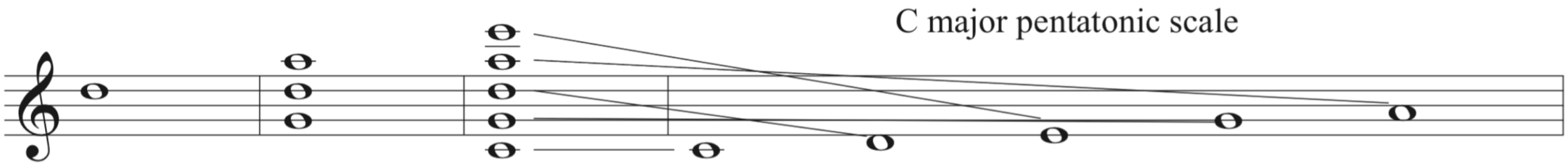


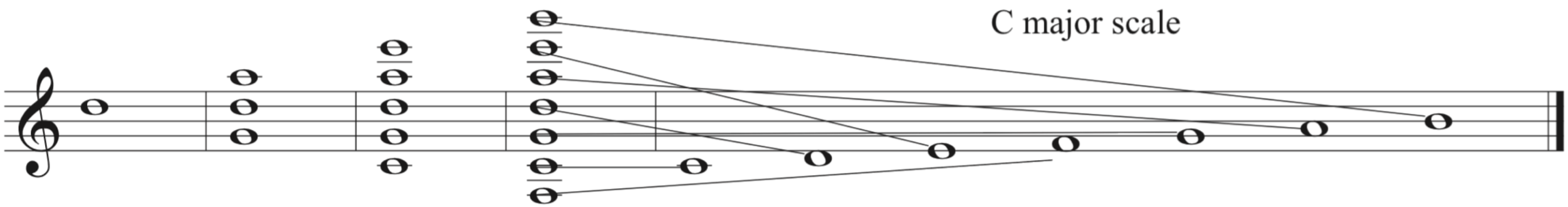
Intervals and the corresponding frequency ratios

(according to the just intonation tuning)

INTERVAL	FREQUENCY RATIO
octave	2/1
perfect fifth	3/2
perfect fourth	4/3
major third	5/4
minor third	6/5
major sixth	5/3
minor sixth	8/5
octave + perfect fifth	3/1
two octaves	4/1
root position major triad	6/5/4
root position minor triad	15/12/10

Perfect fifth as the most consonant interval other than octave



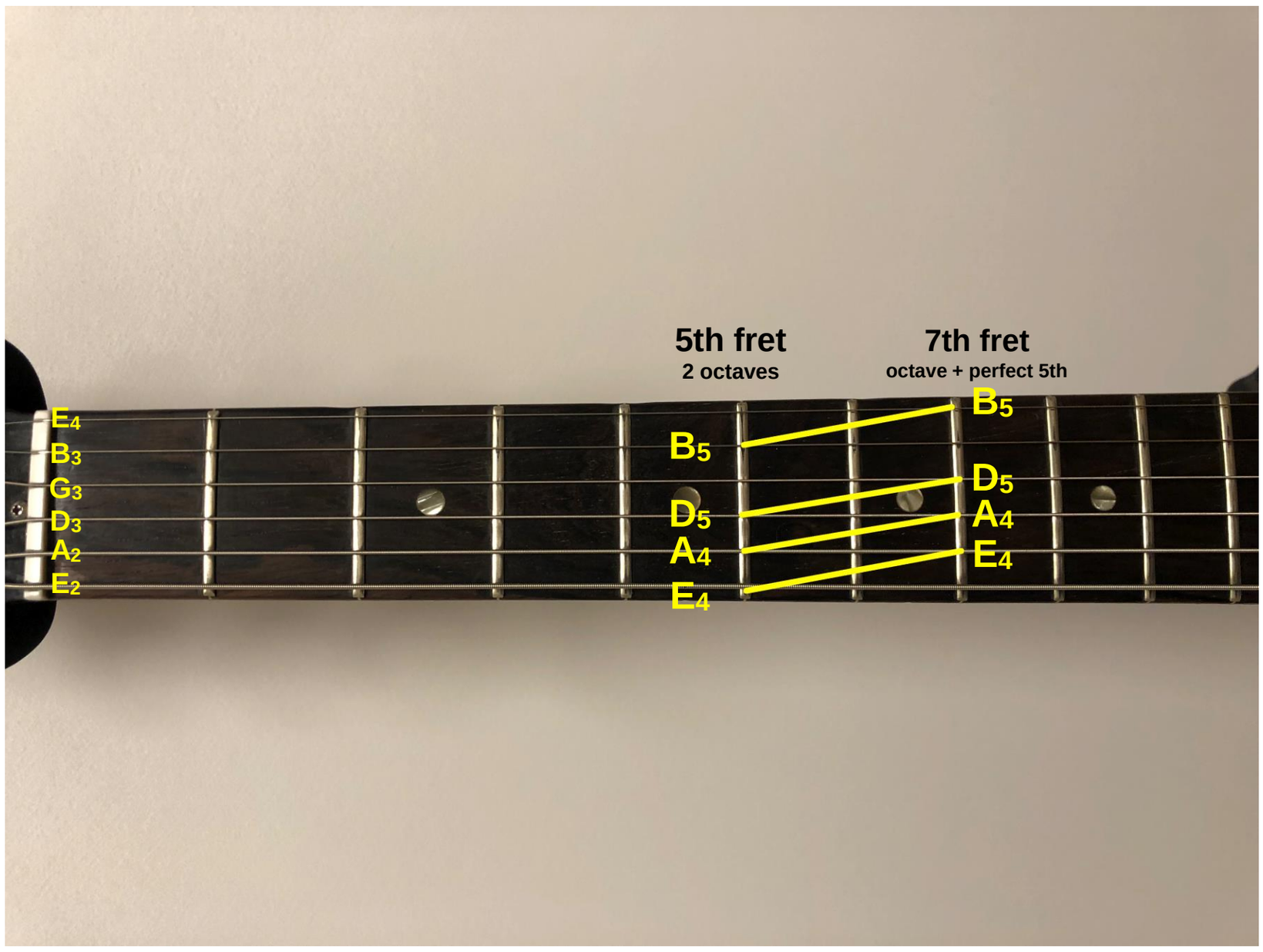


Equally tempered system of tuning

frequency ratio = $2^{(n/12)}$ **n - number of half steps**

INTERVAL	FREQUENCY RATIO IN JUST INTONATION	FREQUENCY RATIO EQUALLY TEMPERED
UNISON	1/1 = 1	$2^{(0/12)} = 1$
MINOR SECOND	16/15 = 1.067	$2^{(1/12)} = 1.059$
MAJOR SECOND	9/8 = 1.125	$2^{(2/12)} = 1.122$
MINOR THIRD	6/5 = 1.2	$2^{(3/12)} = 1.189$
MAJOR THIRD	5/4 = 1.25	$2^{(4/12)} = 1.260$
PERFECT FOURTH	4/3 = 1.333	$2^{(5/12)} = 1.335$
AUGMENTED FOURTH	45/32 = 1.406	$2^{(6/12)} = 1.414$
PERFECT FIFTH	3/2 = 1.5	$2^{(7/12)} = 1.498$
MINOR SIXTH	8/5 = 1.6	$2^{(8/12)} = 1.587$
MAJOR SIXTH	5/3 = 1.667	$2^{(9/12)} = 1.682$
MINOR SEVENTH	16/9 = 1.778	$2^{(10/12)} = 1.782$
MAJOR SEVENTH	15/8 = 1.875	$2^{(11/12)} = 1.888$
OCTAVE	2/1 = 2	$2^{(12/12)} = 2$

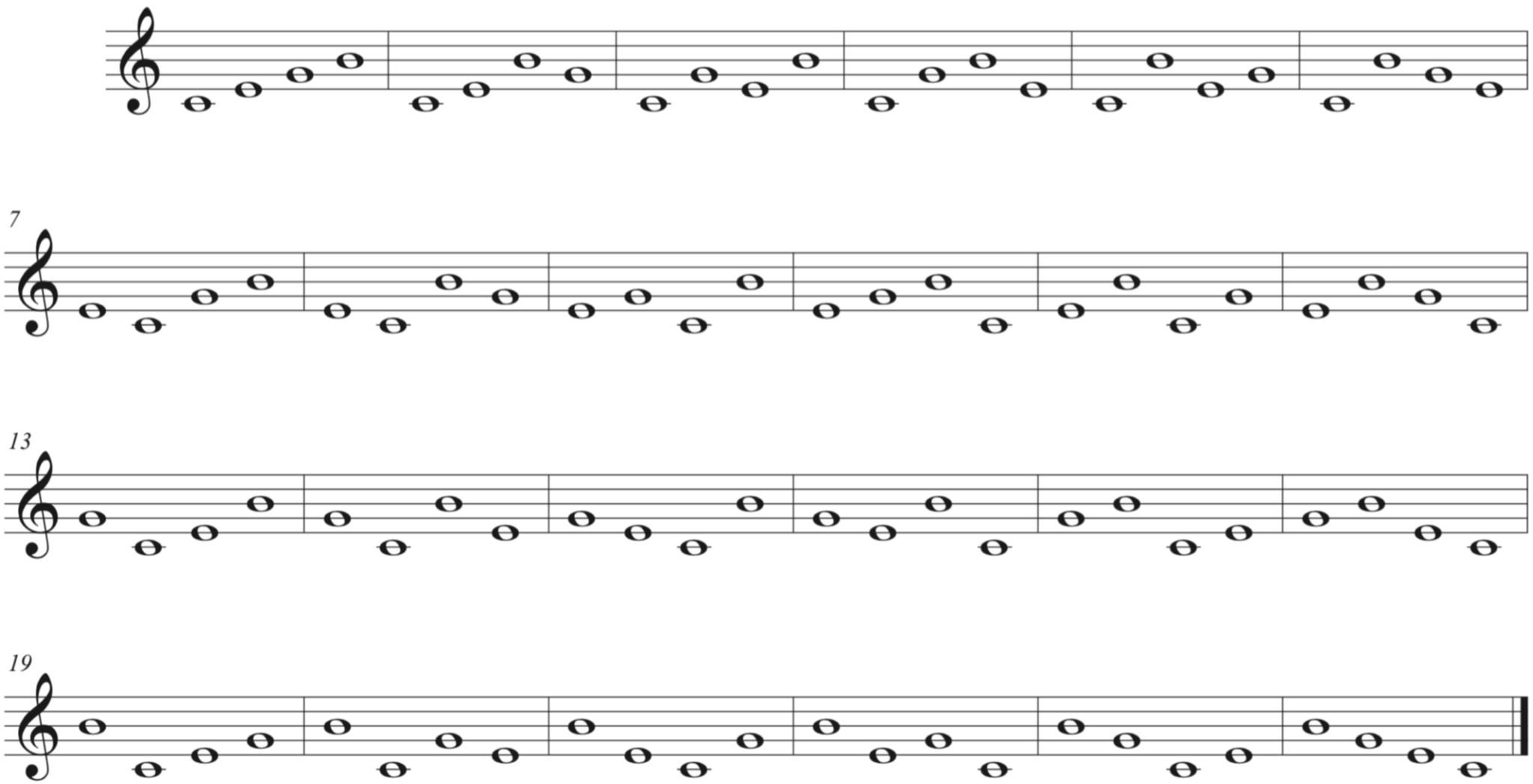
Tuning string instruments using harmonics - popular mistakes



Note permutations and melodic shapes

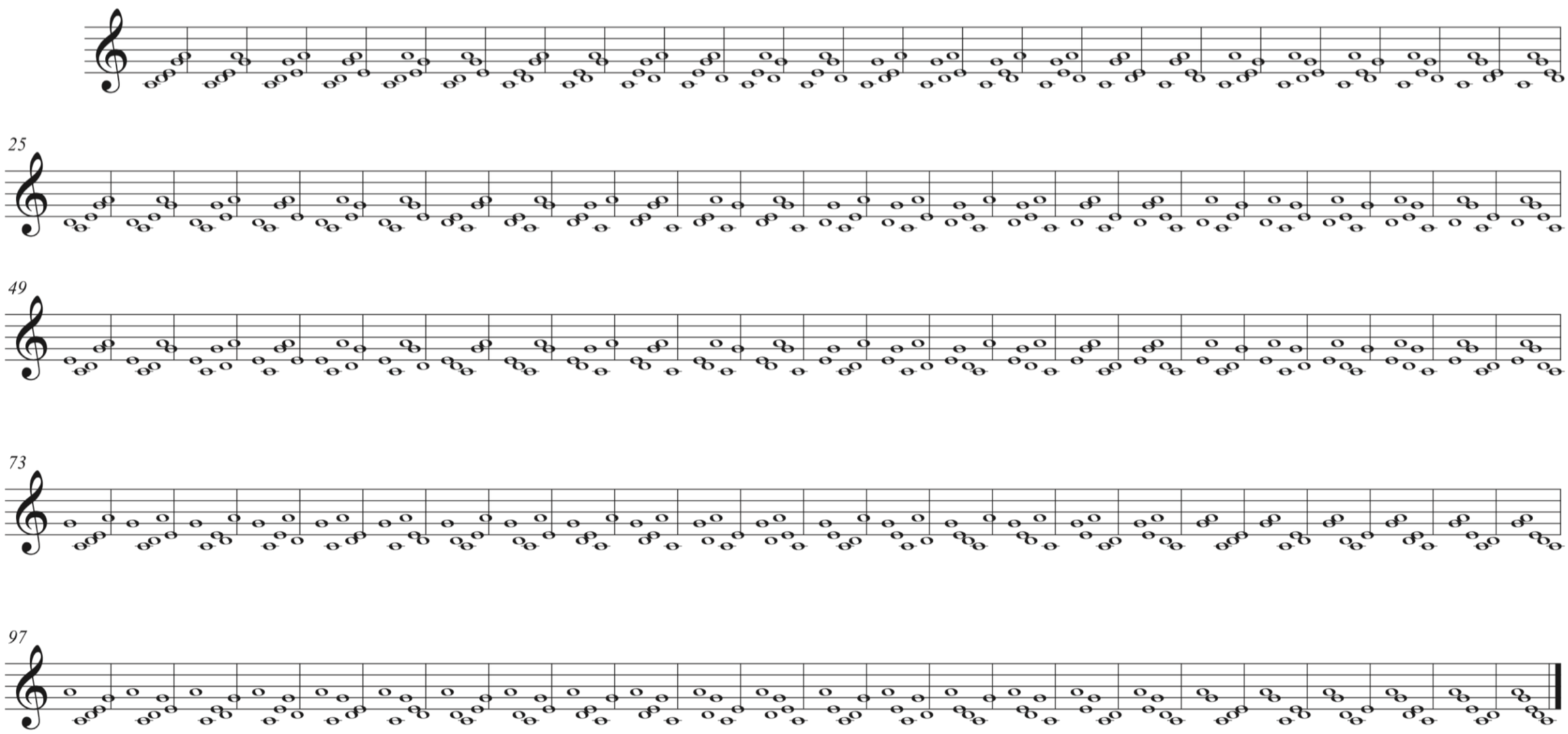
Seventh chord chord tone permutations

4! = 24



Pentatonic scale permutations

5! = 120



Other music related topics where knowledge of science could be useful:

- room acoustics
- sound engineering
- twelve tone music
- symmetrical scales