Pitch = human ear’s perception of frequency of a sound vibration

Low pitch ⇔ low frequency of vibration/oscillation
High pitch ⇔ high frequency of vibration/oscillation

Audible Frequency Range of Human Hearing:
15 – 20 Hz < f < 20 KHz  (≈ 3 orders of magnitude)

As we grow older, dynamic range of frequencies we can hear decreases (both high and low frequencies)

Frequency ranges of musical instruments typically ~ 100 Hz to ~ few KHz
  e.g. guitar  Low E = 82 Hz
                  High E = 330 Hz

Piano highest note is ~ 4200 Hz
Very little above ~ 10 KHz  (squeals & scrapes)

Human ear needs to be able to perceive a sound for a minimum length of time in order to determine pitch – this minimum time depends on frequency:

\[
\text{For } f \sim 100 \text{ Hz } (\tau \sim 10 \text{ m sec}): \quad t_{\text{min}} \approx 40 \text{ m sec} \quad (\sim 4 \text{ cycles})
\]
\[
\text{For } f \geq 1000 \text{ Hz } (\tau \leq 1 \text{ m sec}): \quad t_{\text{min}} \geq 13 \text{ m sec} \quad (\geq 13 \text{ cycles})
\]

Perceived pitch also depends to some extent on the **loudness** of the sound.
— Effect arises due to non-linearities in the response of the ear.
— Pitch appears to **decrease** slightly as loudness increases.
— This effect exists only for pure/simple tones (!!!)
— Complex tones show **no** perceived pitch changes with intensity! (why??)

Two ears of the same person may **NOT** perceive sound of a given frequency as having the same pitch!!! = DIPLACUSIS – happens only for diseased and/or injured ears.

For **normal** musical purposes, frequency and pitch are synonymous (usually) — Applies only to **periodic** sound vibrations.
Sound **pulses** are made up of a **continuum** of frequencies, i.e. sound pulses are **anharmonic** and hence have **no** characteristic frequency and/or pitch.

Human ear can discriminate changes in sound intensity levels of **JND ~1/2 dB**. This corresponds to a ~ 12% change in sound intensity. Thus, the ear is not very sensitive to accurately discriminating changes in loudness of sounds.

Typical human ear can discern changes in pitch/frequency at the $\Delta f \sim 3$ Hz level in the frequency range $30 \leq f \leq 1000$ Hz.

Note that: $\frac{\Delta f}{f} = \frac{3}{30} = 10\% \quad (\approx 2$ semitones$)$,

Whereas: $\frac{\Delta f}{f} = \frac{3}{1000} = 0.3\% \quad (\approx 0.1$ semitones$)$

A good musician can actually discern frequency/pitch changes that are **much** smaller than this. Above $f \geq 500$ Hz, $\approx 0.03$ semitone!!!

∴ The human ear/brain **is** capable of detecting small changes in frequency!!!

The human ear/brain is also capable of perceiving a fundamental even when **no** fundamental is actually present!!!

— This is the so-called **missing fundamental effect**.

— This effect is consequence of effect of the non-linear response in/inside the human ear itself, and/or a non-linear response in the human brain’s **processing** of frequency information – e.g. whenever a quadratic non-linear response exists (in any system), if two signals A and B with frequencies $f_A$ and $f_B$ are input to that system, sum and difference frequencies ($f_A + f_B$) and $|f_A - f_B|$ are produced! Thus a 2$^{nd}$ harmonic, $2f_i$ and a 3$^{rd}$ harmonic, $3f_i$ can produce a “missing” fundamental from the difference frequency, $|3f_i - 2f_i| = f_i$ !!! For further details on distortion, read e.g. Professor Errede’s UIUC P498POM lecture notes on “Theory of Distortion I & II” – available on the web at: [http://online.physics.uiuc.edu/courses/phys498pom/498pom_lectures.html](http://online.physics.uiuc.edu/courses/phys498pom/498pom_lectures.html)

— For some musical instruments – e.g. the trumpet, the oboe and/or the bassoon – the 2$^{nd}$ (even 3$^{rd}$) harmonics have a **larger** amplitude than that of the fundamental, however we perceive the “note” that is played on the trumpet (and/or oboe, bassoon) as that of the fundamental!!!
Note that the vertical axes are displayed on a logarithmic scale.

$f_{A5} = 880.0 \text{ Hz}, f_{Bb5} = 932.3 \text{ Hz}$
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