Musical Notes and Frequency

The notes that make up the music we listen to correspond to specific frequencies of sound. For example, the note known as "Middle C" on a piano corresponds to a frequency of about $256\ Hz$.

The most basic of the musical scales is called the **diatonic scale**. You may be familiar with the diatonic scale as "Do-Re-Mi-Fa-Sol-La-Ti-Do." A diatonic scale is one that consists of three major triads.

A **major triad** is a collection of three notes whose frequencies have an interesting mathematical relationship: they have frequencies in the ratio 4:5:6. A major triad is generally agreed to be "pleasant" sounding.

An **octave** consists of the range of frequencies between a given musical tone and the tone with double or half its frequency. So, for example, the C note one octave above Middle C is $512\ Hz$, (which may be symbolized as C'). The C note one octave below Middle C is $128\ Hz$.

The musical notes are lettered A through G. Within an octave, three major triads can be constructed, as shown below.

C	D	E	F	G	A	B	C′	D′
4	...	5	...	6				
			4	...	5	...	6	
				4	...	5	...	6

Example 1
Given that the frequency of Middle C is $256\ Hz$, determine the frequency of the D note.

Tonal Quality and Timbre

It is true that a C played on a piano and a C played on a guitar are both associated with the same frequency, but there is little chance of mistaking the sound produced by a piano for that of a guitar. This is because musical instruments produce blends of frequencies at the same time. There is typically one dominant frequency for any particular note, and it is this dominant frequency that we have been speaking of.

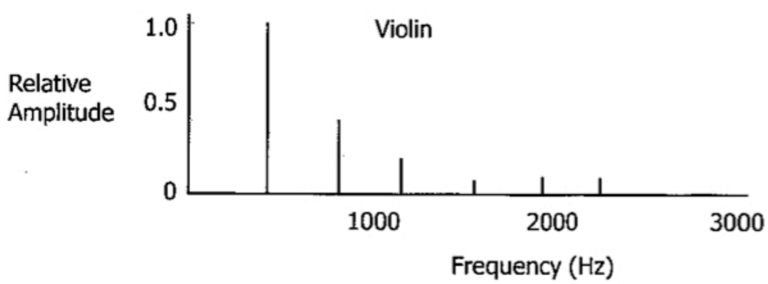
The blend of frequencies produced by a musical instrument is known as the **timbre** of the sound. While the same note played on two different instruments may be the same, they will differ in timbre.

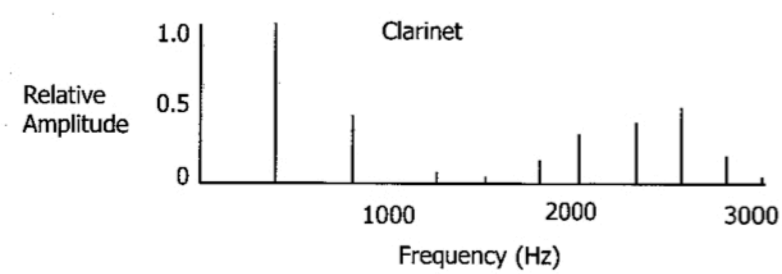
The sound wave produced by a musical instrument is called a **complex sound wave** because it consists of a mixture of the fundamental and harmonic frequencies. In general, complex sound waves are considered more "pleasing" than pure tones.

Pleasing Sounds

The tone quality of a sound is enhanced by complexity of a sound wave. This complexity is enhanced by the number and distribution of the harmonics of the fundamental frequency superimposed on the sound wave.

The diagrams below show the same note played on a violin and a clarinet. These diagrams are called sound spectra. The relative amplitudes of the harmonics are displayed.



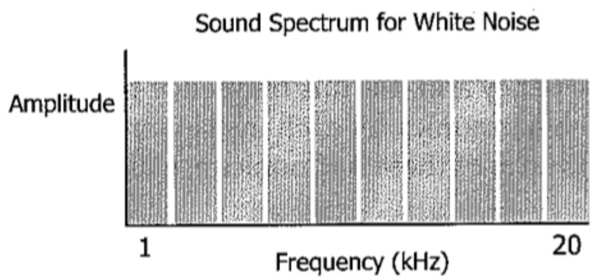


The frequency with the largest amplitude is the **fundamental frequency**, and it is this frequency that we hear as **pitch**. The number of the harmonics for each instrument are not necessarily the same, and the amplitudes of these harmonics are different.

Noise

If there is a random mixture of frequencies, then the sound is not easily identified based on any pitch. This is not a pleasing sound, and we call this **noise**. Noise is defined as a sound produced by irregular vibrations in a manner that is unpleasant to the listener.

If all frequencies of sound are present in equal amplitudes, the result is called **white noise**. This is the sound spectrum for white noise.



White noise has been found to have a relaxing effect and some dentists have used this to help patients relax.

Environmental Noise and Noise Control

There are many sources of noise in our environment: traffic, music played too loud, etc. Exposure to loud sounds has been shown to cause the ear to lose its sensitivity, especially to high frequencies. The longer the person is exposed to loud sounds, the greater the effect.

A person can recover from short-term exposure in a period of hours, but the effects of long-term exposure can last for days or weeks. Long exposure to $100\ dB$ or greater sound levels can produce permanent damage.

One major contributor to hearing loss is the playing of loud music from headphones. Headphones are placed next to the ear, in some cases right in the ear canal. The sound waves are funneled directly into the eardrum, which experiences the maximum sound intensity. When these devices are played at a "normal volume," they may be producing sound at the ear drum with an intensity of $120\ dB$. This efficient delivery system of the sound at maximum intensity over prolonged periods of time will result in physical damage to the ear and a loss of hearing.

There are various techniques to control the loudness of undesirable sounds. One of the more interesting ways of doing so is the use of **"noise-cancelling" headphones**. These look and function just like regular headphones, but they additionally have built in microphones and circuitry that detect external noise. The electronic signals from the microphones are processed by circuitry inside the headphones and reproduce a noise that is exactly **out of phase** compared to the original signal. This out of phase version is superimposed with the desired signal from the music being played, and played through the headphones. The external noise then literally cancels due to destructive interference when it combines with the original noise. The result is a dramatic reduction in the external noise heard by the person wearing the headphones (the music being played is unaffected).

Another very effective (and much less expensive) way to reduce sound is simply to wear ear plugs. Earplugs effectively reduce the decibel level of all external sounds.

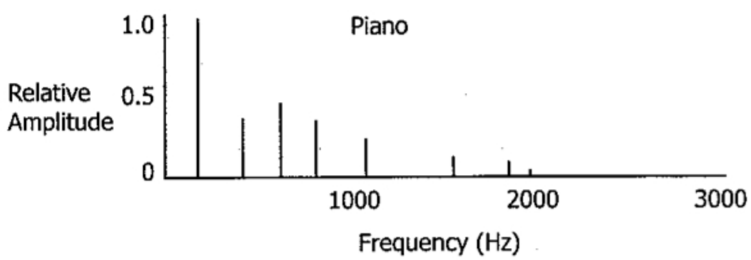
Waves Worksheet #11

1. If the frequency of a G note is $384\ Hz$, what must be the frequency of the B note? Use the major triad G, B, D′ to determine the frequency.

2. The tones produced by a typical orchestra are complex sound waves, and most have fundamental frequencies less than $5\ 000\ Hz$. However, a high-quality stereo system must be able to reproduce $20\ 000\ Hz$ frequencies accurately. Explain why.

3. The soprano voice has a frequency range of approximately $250\ Hz$ to $1\ 000\ Hz$. The bass voice has a frequency range of approximately $80\ Hz$ to $400\ Hz$. How would the sound spectrum be similar and different if both voices sand the same note at a fundamental frequency of $360\ Hz$?

4. The diagram below shows the sound spectrum of a piano playing the A_3 note.



   a) Which line would represent the fundamental frequency?
   b) How would the sound spectrum of a flute playing the same note be different than the one for the piano?
   c) How would the sound spectrum for white noise be different than the one shown above for the piano?

5. Three distinguishing features of sound are tone quality, pitch, and loudness. Briefly describe what these are and upon what physical properties of waves they depend.