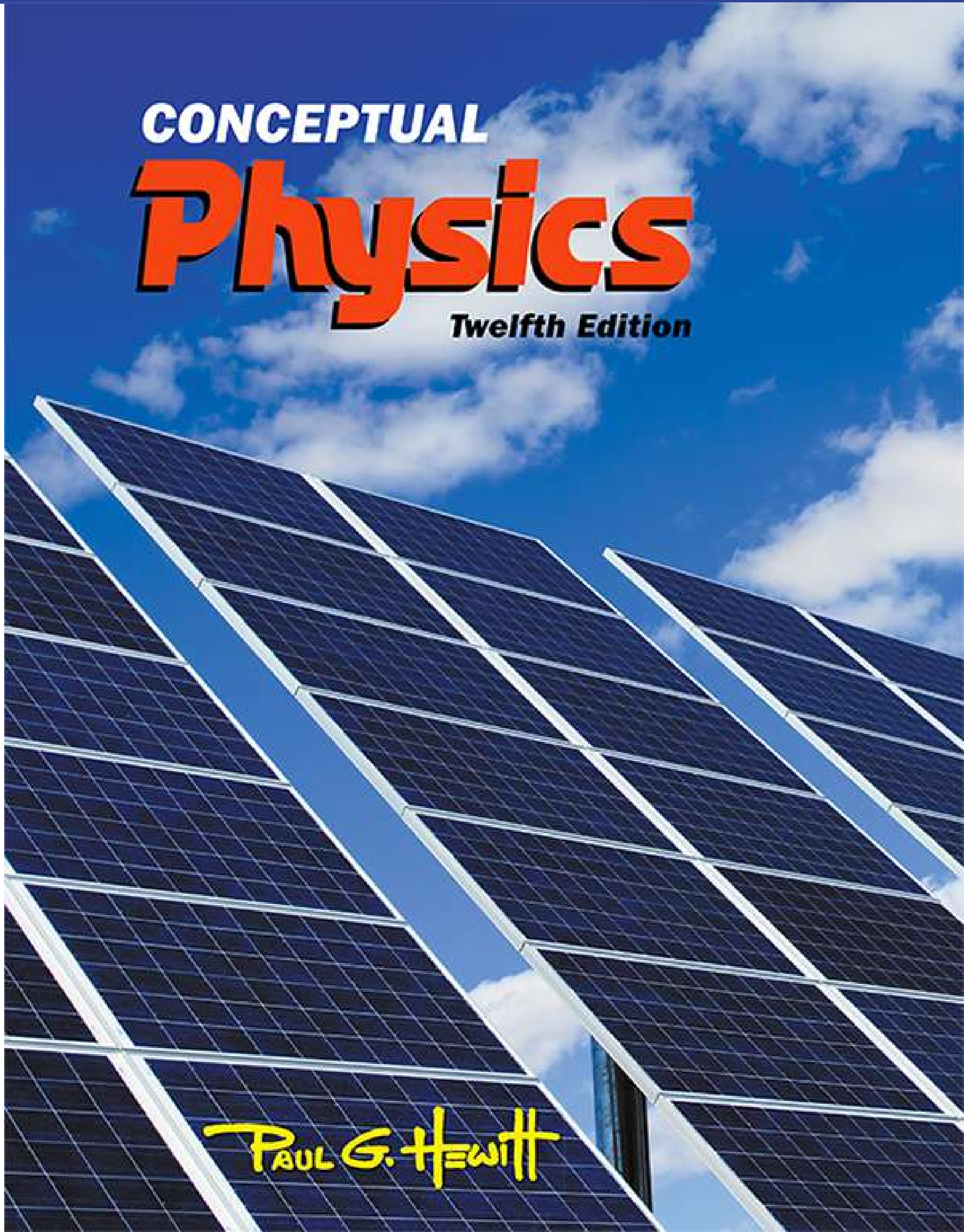
Chapter 21: Musical Sounds

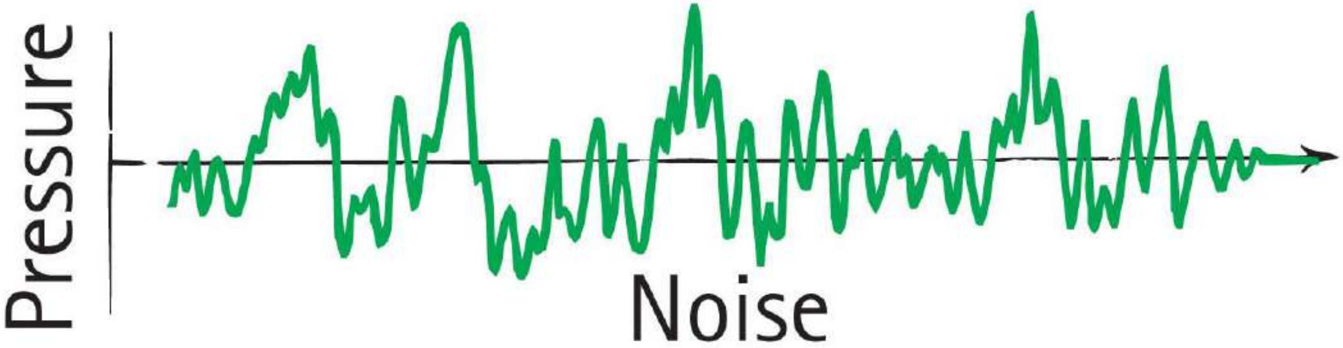


This lecture will help you understand:

- Noise and Music
- Musical Sounds
- Pitch
- Sound Intensity and Loudness
- Quality
- Musical Instruments
- Fourier Analysis
- Digital Versatile Discs (DVDs)

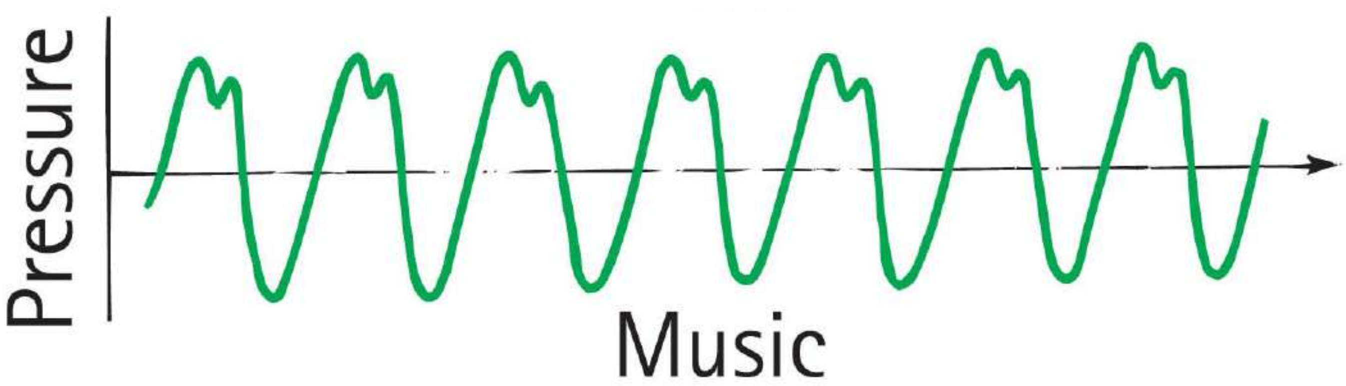
Noise and Music

- Noise corresponds to an irregular vibration of the eardrum produced by some irregular vibration in our surroundings, a jumble of wavelengths and amplitudes.
  - *White noise is a mixture of a variety of frequencies of* sound.



Noise and Music, Continued

- Music is the art of sound and has a different character.
- Musical sounds have periodic tones–or musical *notes*.
- The line that separates music and noise can be thin and subjective.



Musical Sounds

- Musical tone
  - Three characteristics:
    - Pitch
      - determined by frequency of sound waves as received by the ear
      - determined by fundamental frequency, lowest frequency
    - Intensity
      - determines the perceived loudness of sound

Musical Sounds, Continued

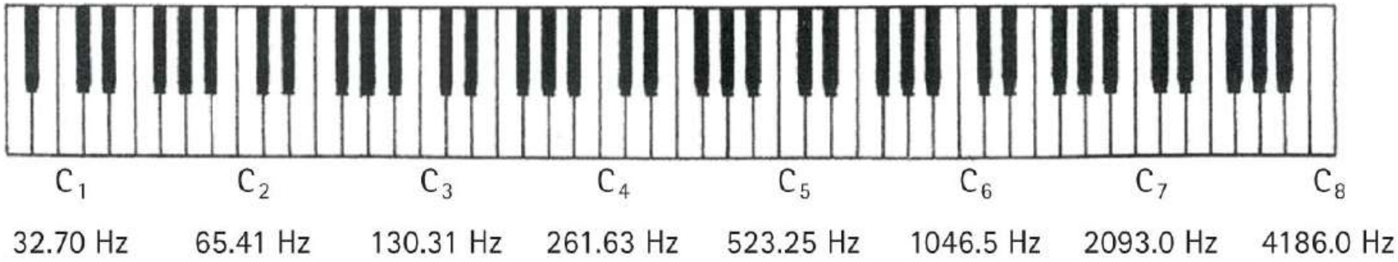
- Musical tone
  - Three characteristics (continued):
    - Quality
      - determined by prominence of the harmonics
      - determined by presence and relative intensity of the various partials

Pitch

- Music is organized on many different levels. Most noticeable are musical notes.
- Each note has its own **pitch**. We can describe pitch by frequency.
  - Rapid vibrations of the sound source (high frequency) produce sound of a high pitch.
  - Slow vibrations (low frequency) produce a low pitch.

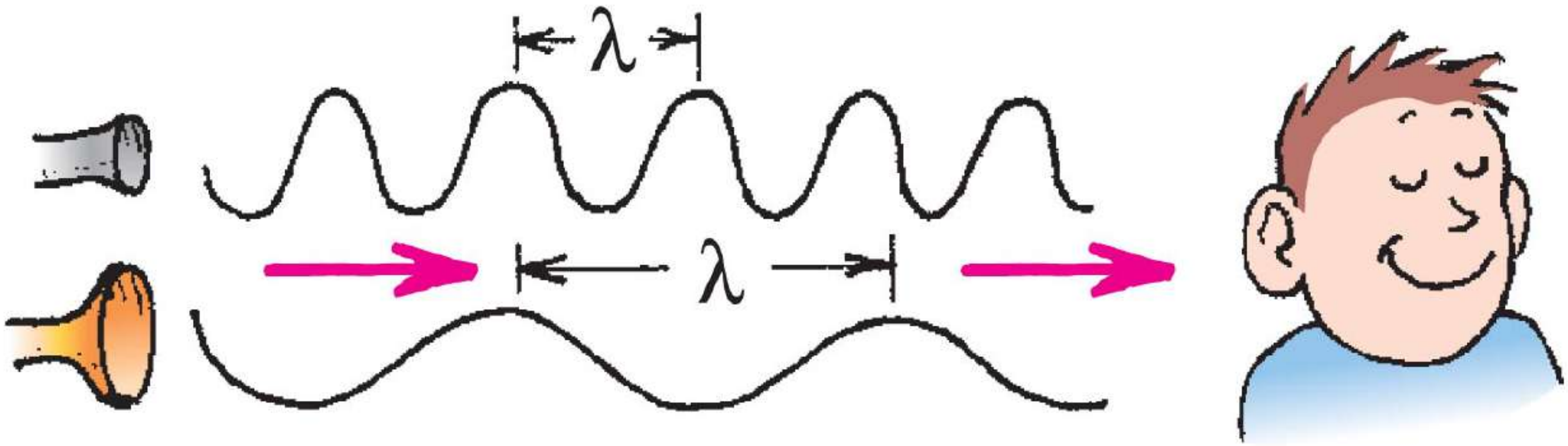
Pitch, Continued

- Musicians give different pitches different letter names: A, B, C, D, E, F, G.
  - Notes A through G are all notes within one octave.
  - Multiply the frequency on any note by 2, and you have the same note at a higher pitch in the next octave.
  - A piano keyboard covers a little more than seven octaves.



Pitch, Continued-1

- Different musical notes are obtained by changing the frequency of the vibrating sound source.
- This is usually done by altering the size, the tightness, or the mass of the vibrating object.



Pitch, Continued-2

- High-pitched sounds used in music are most often less than 4000 Hz, but the average human ear can hear sounds with frequencies up to 18,000 Hz.
  - Some people and most dogs can hear tones of higher pitch than this.
  - The upper limit of hearing in people gets lower as they grow older.
  - A high-pitched sound is often inaudible to an older person and yet may be clearly heard by a younger one.

Sound Intensity and Loudness

- The **intensity of sound depends on the amplitude of pressure variations** within the sound wave.
- The human ear responds to intensities covering the enormous range from 10^{-12} W/m^2 (the threshold of hearing) to more than 1 W/m^2 (the threshold of pain).

Sound Intensity and Loudness, Continued

- Because the range is so great, intensities are scaled by factors of 10, with the barely audible 10^{-12} W/m^2 as a reference intensity called 0 *bel* (a unit named after Alexander Bell).
- A sound 10 times more intense has an intensity of 1 bel (W/m^2) or 10 *decibels* (*dB*)

TABLE 21. COMMON SOURCES AND SOUND INTENSITIES

Source of Sound	Intensity $(\mathrm{W/m^2})$	Sound Level (dB)
Jet airplane 30 m away	10^2	140
Air-raid siren, nearby	1	120
Disco music, amplified	10^{-1}	110
Riveter	10^{-3}	90
Busy street traffic	10^{-5}	70
Conversation in home	10^{-6}	60
Quiet radio in home	10^{-8}	40
Whisper	10^{-10}	20
Rustle of leaves	10^{-11}	10
Threshold of hearing	10^{-12}	0

Sound Intensity and Loudness, Continued-1

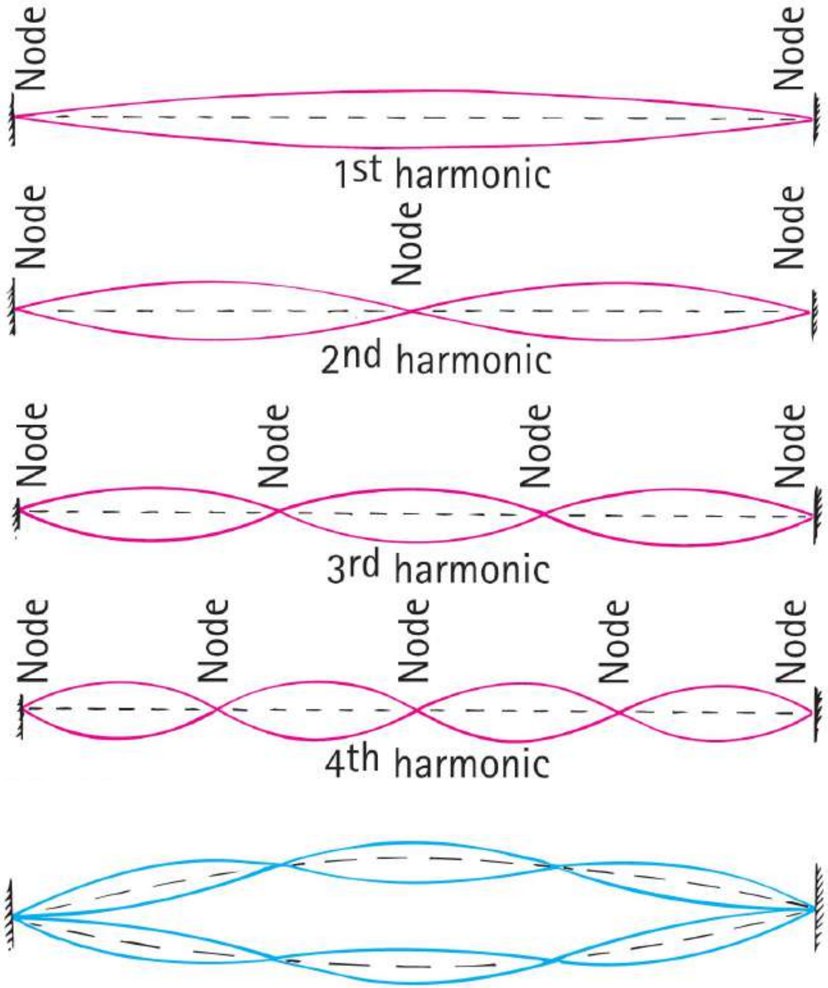
- Sound intensity is a purely objective and physical attribute of a sound wave, and it can be measured by various acoustical instruments.
- Loudness is a physiological sensation.
  - The ear senses some frequencies much better than others.
  - A 3500-Hz sound at 80 decibels sounds about twice as loud to most people as a 125-Hz sound at 80 decibels.
  - Humans are more sensitive to the 3500-Hz range of frequencies.

Quality

- We have no trouble distinguishing between the tone from a piano and a tone of the same pitch from a clarinet.
- Each of these tones has a characteristic sound that differs in **quality, the "color" of a tone—*timbre***.
- Timbre describes all of the aspects of a musical sound other than pitch, loudness, or length of tone.

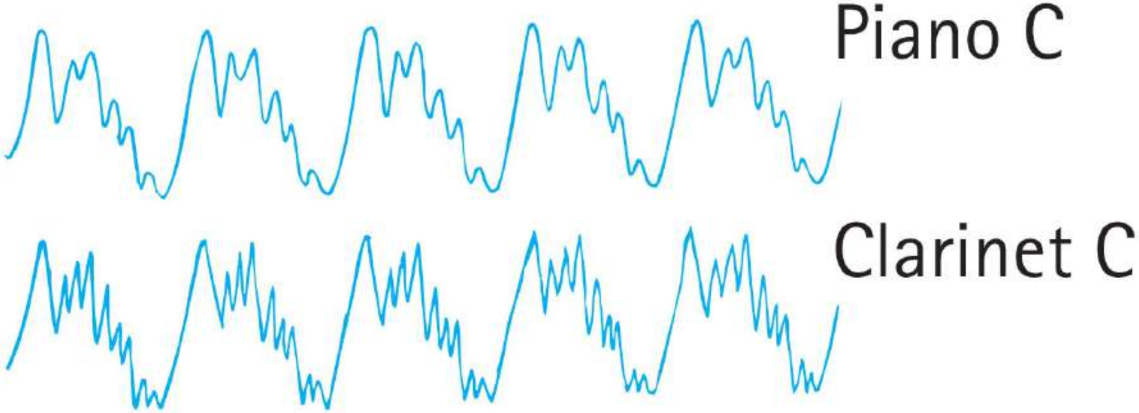
Quality, Continued

- Most musical sounds are composed of a superposition of many tones differing in frequency.
- The various tones are called **partial tones, or simply *partials*.** ***The lowest frequency***, called the **fundamental frequency, determines the pitch of the note.**
- **A partial** tone whose frequency is a whole-number multiple of the fundamental frequency is called a **harmonic.**
- A composite vibration of the fundamental mode and the third harmonic is shown in the figure.



Quality, Continued-1

- The quality of a tone is determined by the presence and relative intensity of the various partials.
- The sound produced by a certain tone from the piano and a clarinet of the same pitch have different qualities that the ear can recognize because their partials are different.
- A pair of tones of the same pitch with different qualities have either different partials or a difference in the relative intensity of the partials.



Musical Instruments

- Vibrating strings
  - Vibration of stringed instruments is transferred to a sounding board and then to the air.
- Vibrating air columns
  - Brass instruments.
  - Woodwinds—stream of air produced by musician sets a reed vibrating.
  - Fifes, flutes, piccolos—musician blows air against the edge of a hole to produce a fluttering stream.

Musical Instruments, Continued

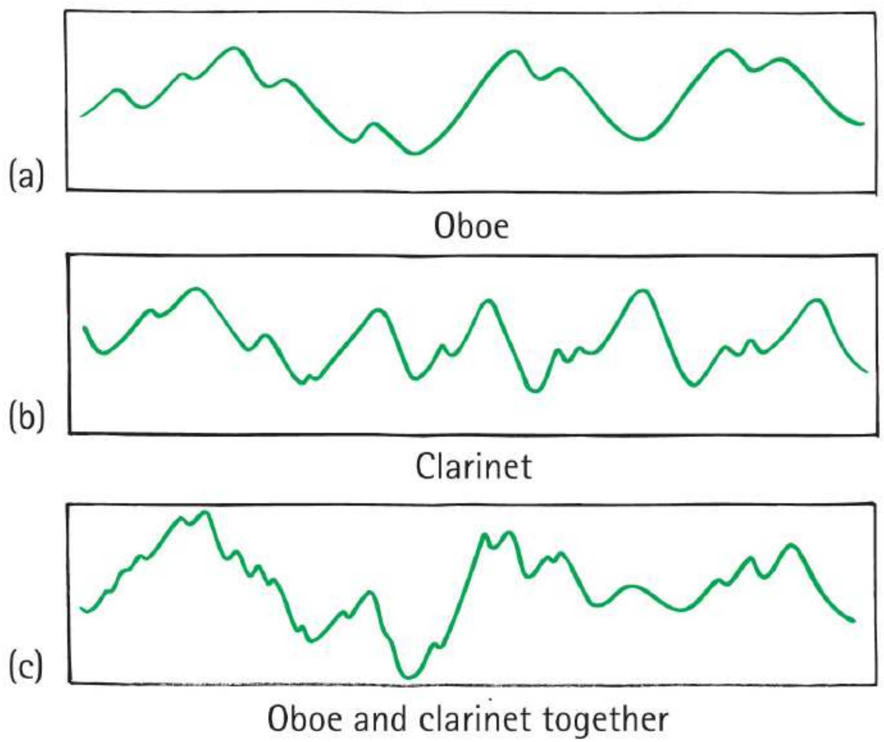
- Percussion
  - Striking a 2-dimensional membrane.
  - Tone produced depends on geometry, elasticity, and tension in the vibrating surface.
  - Pitch produced by changes in tension.

Musical Instruments, Continued-1

- Electronic musical instrument
  - differs from conventional musical instruments
  - uses electrons to generate the signals that make up musical sounds
  - modifies sound from an acoustic instrument
  - demands the composer and player demonstrate an expertise beyond the knowledge of musicology

Fourier Analysis

- The sound of an oboe displayed on the screen of an oscilloscope looks like this.
- The sound of an clarinet displayed on the screen of an oscilloscope looks like this.
- The two together look like this.

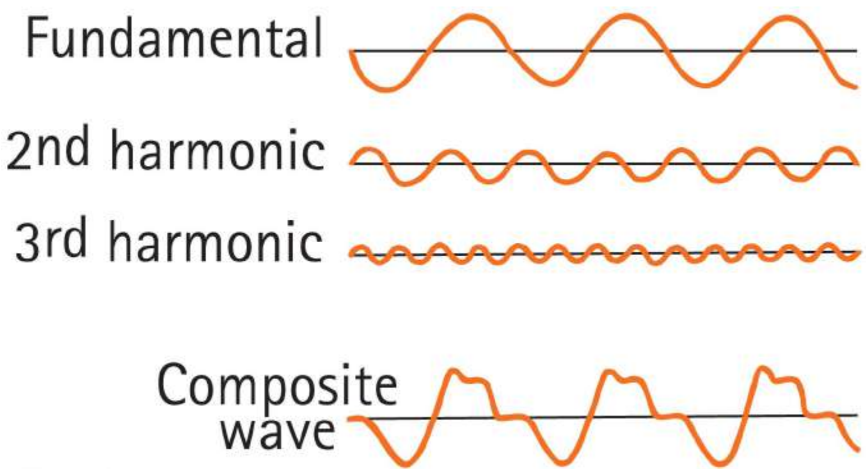


Fourier Analysis, Continued

- Fourier discovered a mathematical regularity to the component parts of periodic wave motion.
- He found that even the most complex periodic wave motion can be disassembled into simple sine waves that add together.
- Fourier found that all periodic waves may be broken down into constituent sine waves of different amplitudes and frequencies.
- The mathematical operation for performing this is called **Fourier analysis.**

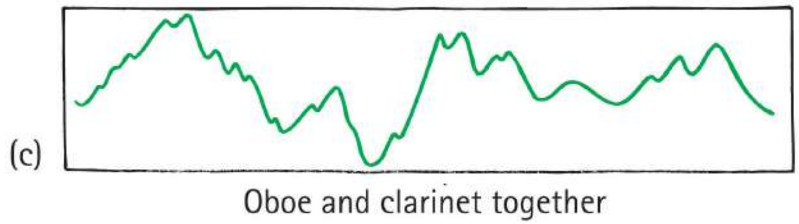
Fourier Analysis, Continued-1

- When these pure tones are sounded together, they combine to give the tone of the violin.
- The lowest-frequency sine wave is the fundamental and determines the pitch.
- The higher-frequency sine waves are the partials that determine the quality.
- Thus, the waveform of any musical sound is no more than a sum of simple sine waves.

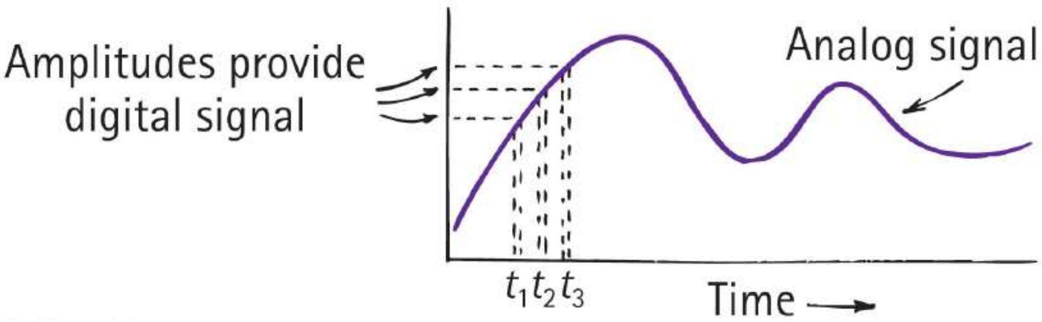


Digital Versatile Discs (DVDs)

- The output of phonograph records was signals like those shown below.



- This type of continuous waveform is called an *analog signal.*



- *The analog signal* can be changed to a *digital signal by measuring the numerical value of its amplitude* during each split second.

Digital Versatile Discs (DVDs), Continued

- Microscopic pits about one-thirtieth the diameter of a strand of human hair are imbedded in the CD or DVD
  - The short pits corresponding to 0.
  - The long pits corresponding to 1.
- When the beam falls on a short pit, it is reflected directly into the player's optical system and registers a 0.
- When the beam is incident upon a passing longer pit, the optical sensor registers a 1.
- Hence the beam reads the 1 and 0 digits of the binary code.