GOOD VIBRATIONS

The Physics of Music

Barry Parker

The Johns Hopkins University Press Baltimore

© 2009 The Johns Hopkins University Press
All rights reserved. Published 2009
Printed in the United States of America on acid-free paper
2 4 6 8 9 7 5 3 1
The Johns Hopkins University Press
2715 North Charles Street
Baltimore, Maryland 21218-4363
www.press.jhu.edu
Library of Congress Cataloging-in-Publication Data
Parker, Barry R.
Good vibrations : the physics of music / Barry Parker.
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-0-8018-9264-6 (hardcover : alk. paper)
ISBN-10: 0-8018-9264-3 (hardcover : alk. paper)
1. Vibration. 2. Sound-waves. 3. Sound.
4. Wave-motion, Theory of. I. Title.
QC231.P37 2009
781.2—dc22 2008054589

A catalog record for this book is available from the British Library.

Special discounts are available for bulk purchases of this book.
For more information, please contact Special Sales at 410-516-6936
or specialsales@press.jhu.edu.

The Johns Hopkins University Press uses environmentally friendly book materials, including recycled text paper that is composed of at least 30 percent post-consumer waste, whenever possible. All of our book papers are acid-free, and our jackets and covers are printed on paper with recycled content.

CONTENTS

ACKNOWLEDGMENTS

I am grateful to Trevor Lipscombe for his many suggestions and help in preparing this volum I would like to thank Carolyn Moser for careful editing of the manuscript and the staff of the Johns Hopkins University Press for their assistance in bringing this project to completion. Thanks, too, to my artist, Lori Beer, for doing an excellent job on the drawings. Finally, I appreciate the assistance I received from Mike's Music of Pocatello in obtaining the photographs.

For more information on the physics of music and information on other books by the author, visit the web page www.BarryParkerbooks.com.

Introduction

Physics and music may seem light years apart to many people. But surprisingly, they are closely related. Of course, music is sound, and sound is a branch of physics, but they are als connected in another way. Both are highly creative endeavors. The major advances in physic had their origin in somebody's mind. Einstein gave us relativity theory; Heisenberg and Schrödinger gave us quantum theory. In the same way, Beethoven gave us several magnificent symphonies, and Chopin gave us an array of beautiful piano pieces. So physics and music are both products of the mind. Physics may conjure up an image of difficult and complicated mathematics for some people, but to many it is a delightful and enjoyable endeavor. And certainly, most people love music. So I guess we can say that both have devoted fans.

This brings us to the question of whom this book is written for. I believe it will be of interes to musicians who are interested in learning more about the science behind music and to students and fans of physics, most of whom are also music lovers. (I know: I'm one of them. But in writing this book, I had to consider one issue: there is a big range of tastes in music. Some people love classical music and hate rock; others love rock and hate classical. Becaus of this I've tried to steer a middle road. I talk about all types of music; in fact, I have a chapte that surveys all the music types. And I'm afraid that's about all I can do. I hope it satisfies most people.

A Short Definition of Music

Okay, let's begin by considering the question, What is music? It may seem like an odd question; after all, everyone knows what music is. But there is actually more to it than you may think; besides, it's useful to consider the question in that it may help you understand the relationship between music and physics more thoroughly.

We'll start with descriptions of music given in the dictionary: music is "the art of combining sounds with a view to beauty of form and the expression of emotion" and "the art of organizing tones to produce a coherent sequence of sounds intended to elicit an aesthetic response in a listener." Both of these descriptions give us a pretty good idea of what music is but neither really goes to the heart of the question. Music is, in fact, very difficult to complete and satisfactorily describe. We know it is an art and that it is something that initiates an emotional response from almost anyone who listens to it. Beautiful passages can give you goose bumps, and terrible ones can illicit disgust or even rage. Regardless of your age, in fact, music elicits a response of some type in almost everyone. Even babies respond to music: a crying baby will quickly calm down when its mother begins to sing to it. Furthermore it seems that the human brain is programmed to respond to music. Study after study has shown that there is a correlation between music (particularly music making) and the deepest workings of the brain. We now know that it is the right side of the brain that gives us our appreciation of music, but research has shown that music actually engages many areas of th brain. We know, for example, that music is important in relation to language development, ar interestingly, it also appears to enhance mathematical ability. So besides its sheer entertainment value it may have other dividends.

You might ask, What characterizes music? As it turns out there are four major things. Firs of all, music is made up of tones, and these tones have a specific frequency, or pitch; in othe words, some notes are high and some are low. Secondly, music has rhythm, which is relatec to the length of each tone. Basically, rhythm is the beat of the music, and this beat is usually regular (it’s what you tap your feet to). Third, music varies in intensity; it can be loud or quiet or somewhere in between, but in almost all cases it varies to some degree. Finally, music ha a quality that we discuss in some detail later in the book. It is called timbre; in a sense it’s the thing that makes music interesting, but the easiest way to describe it is as follows: timbre is the property that allows us to distinguish various musical instruments even when somebody i playing the same tune on them. It’s also what makes one voice different from another.

Another interesting question is, Where did music begin? Music is so basic that there’s little doubt that even the earliest humans had some sort of music, or at least recognized rhythms. They may have banged on crude drums, or chanted, but this was a form of music. The earliest piece of written music was discovered in Mesopotamia (today’s Iraq) and is dated about 1500 BC.

Pythagoras and Musical Scales

For music as we know it, we need a sequence of tones that are “linked”—in other words, tones that have a pleasing relationship with one another. We refer to a linked sequence of tones as a scale. From a simple point of view, we can say that a scale is a special set of notes that seem to belong together.

The first scale was developed in Croton in southern Italy. About 539 BC the Greek philosopher Pythagoras founded a school in Croton. Most people know Pythagoras for his famous formula relating the sides of a triangle, but he actually accomplished many other things. He had an intense interest in musical tones, but his major interest was not their beauty: it was how they related to numbers, and mathematics. According to a story that has been told many times, he was passing a blacksmith’s shop one day when he heard the ringir of the blacksmith’s hammer as it struck the anvil. He stopped to listen and soon began to wonder if the tone would change if the blacksmith applied more force. He therefore stepped into the shop and asked the blacksmith if he would hit the anvil with different forces. To his surprise, the force of the blow didn't change the tone; the only thing that had an effect was the weight of the hammer. Confused, he went home and looked into the issue further. He bu himself a device we now refer to as a monochord (fig. 1). It was a hollow box with a string stretched across it; the string was supported by two wedges near the ends. Pythagoras presumably attached masses of different weight to the ends of the strings, but for simplicity we'll assume that the string was fixed at one end and had a screw at the other end that coul be used to tighten it. When he plucked the string a certain tone sounded, and when he tightened the string, the tone changed. We know that when a string is tightened, the tone increases in pitch, but Pythagoras knew nothing about pitch. Nevertheless, he also discovere that a shorter string at the same tension would also change in pitch (the pitch would increase

Fig. 1. Pythagoras's monochord.

He then proceeded to do several experiments. His main concern was ratio of the tones, s he began comparing various tones. You can do this by sounding two tones together or one immediately after the other. His first experiment consisted of producing a tone from the entir unstopped string and comparing it to a tone produced when a stop was placed halfway along the string, as shown in figure 2. He found that the combination of tones was pleasing. The ratio was 2/1 (the original length divided by the length of half of the string). The interval between the two tones in this case is an octave, and as we'll see later, the octave is a basic unit of music. The notes (or tones) on the piano, for example, are arranged in octaves so tha a given note in one octave is the same as a particular note in the octave above it (but at a different pitch).

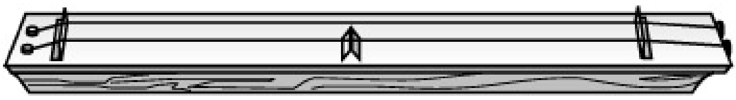


Fig. 2. The monochord with a stop halfway along the string. The full, unstopped string is also shown.

In his second experiment Pythagoras stopped the string one-third of the way from one en (fig. 3), and compared the tones from it to one from the entire string (he plucked the section that was 2/3 of the length of the entire string). Again, he found that the two tones were pleasing when sounded together. We know that they are a perfect fifth apart; this is like striking middle C on the piano, then striking the G above it immediately after (or playing them together). When he plucked the shorter section (1/3 of the original length), it also produced a pleasing tone with both the original length and 2/3 of it. It is G an octave above the lower G on the piano. As we will see, the perfect fifth plays an extremely important role in music.

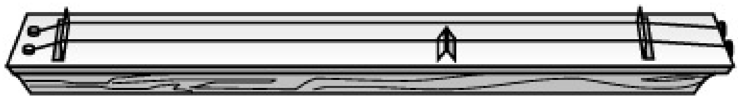


Fig. 3. The monochord with a stop one-third the way along the string.

In his next experiment Pythagoras compared the notes given by the 2/3 L string (L being the length of the original string) to the one from the 1/2 L string and noticed that they were also harmonious when sounded together. We know this as a perfect fourth. On the piano it is the interval between middle C and the F above it. What Pythagoras deduced from all this was that the integers 1, 2, 3, and 4 played an important role in making harmonious tones. He may have also noticed that the interval from C to E, which has a ratio of 5/4, was also harmonious so we can extend this to the integers from 1 to 5.

Let's look more closely at the ratios he discovered, beginning with 1, and writing them as 1/1, 5/4, 4/3, 3/2, 2/1. Their decimal equivalent are 1.000, 1.250, 1.333, 1.500, 2.000. They represent four important musical intervals: a major third, a perfect fourth, a perfect fifth, and an octave. From them Pythagoras was able to devise a musical scale called the pentatonic scale. In chapter 6 we will look at how scales are set up in much more detail; in particular, we'll see how the pentatonic scale can be used to devise the eight-note scale we use today.

A Map of This Book

We turn now to a brief summary of what the book is about. Music is, of course, sound, and sound, in turn, is a wave, so the early part of the book is concerned with sound and its relation to waves. In chapter 1 we will see how sound is related to wave motion and how wave motion, in turn, is related to another phenomenon called simple harmonic motion. We will see that there are two basic types of waves and how sound is produced by one of them. Also, as I mentioned earlier, one of the major properties of sound is loudness or intensity, and I introduce a table of loudness called the decibel scale.

In chapter 2 we look at how we hear music. The parts of the ear are introduced, and there is a discussion of how we recognize pitch and distinguish loudness. The chapter ends with a discussion of hearing loss.

Chapter 3 discusses waves in more detail. In particular, we consider what happens when waves strike various types of boundaries. Two of the phenomena that occur are reflection and refraction; we will see how they are important in relation to sound. Another phenomenon of importance is interference, and we will also examine it. Finally, we will look at a type of wave that plays a central role in music, the standing wave.

In chapter 4 we get to music itself. In this chapter we apply what we have learned in the first few chapters to music. In particular, we talk about overtones and the timbre of music. Various vibrational modes will be considered, and we will look at what is called harmonic analysis.

In this introduction I have already introduced the scale, which is, of course, central to music. We return to this subject in chapter 5, where I discuss several scales in detail—the Pythagorean scale, the diatonic scale, the tempered scale, and major and minor scales, as well as two scales of particular interest to musicians today, the pentatonic and the blues scales.

Closely related to scales are chords and chord sequences, introduced in chapter 6. Here, discuss in detail the many different kinds of chords and show you how to fill in a melody using chords, an important part of any musician's skills. We also look at other topics, such as chord sequences and the circle of fifths.

In chapter 7 we turn to rhythm and a survey of most of the types of music, ranging from rock and roll to the blues, jazz, new age, pop, and classical music. I think this chapter will giv you a good idea of the large range of musical types.

Musical instruments are, of course, central to music, and in chapter 8 we begin a survey o them and the physics on which each is based. In this chapter we discuss the piano, tracing it from its beginnings; in particular, we look at the important contributions of Christophori. We also consider the construction of a piano, the role that the various strings play, and finally ho a piano is tuned.

Another important stringed instrument is the violin. In chapter 9 we talk about both the violin and the guitar, along with some of the other stringed instruments. The art of violin making is important, and I discuss it along with the most famous of violins: the Stradivarius. We also look at the basic physics of violins and at some of the violin virtuosos. The chapter ends with a discussion of the guitar, which (as you no doubt know) is probably the most popular instrument in America today.

Chapters 10 and 11 cover the brass instruments—in particular, the trumpet and the trombone—and the woodwinds (particularly the clarinet and the saxophone). We look at the basic physics of each, how each instrument works, and as an aside, some of the outstanding instrumentalists.

One of the most important musical instruments is one we usually do not consider to be an instrument—the human voice. It is central to most types of music. In chapter 12 I begin with history of singing, then go on to look at the parts of our anatomy that produce the singing voice, namely, the lungs and the vocal cords. Other topics considered in this chapter are phonetics, resonators, and the singing formant (a region of resonance). Finally, I also talk about some of the more famous singers of the last few decades.

Within the last few years (or perhaps I should say decades) music has changed significantly, and the major reason is the introduction of electronic instruments, particularly synthesizers. In chapter 13 we discuss electronic music. We look at the synthesizer and talk about the introduction of digital technology in music; this technology has, as you probably know, caused a revolution. I also introduce MIDI (Musical Instrument Digital Interface), which enables different electronic instruments to communicate with one another and has also changed music significantly. The chapter ends with a discussion of the microphone and loudspeakers, both of which are central to modern music.

MIDI plays such an important role in music today that it's worth looking at in detail, and we do this in chapter 14. It centers on the use of sequencers to record music. I will concentrate on the software approach, which is widely used today. The electronic recording industry has exploded in the last few years, particularly with the introduction of samplers, samples, and virtual instruments; they have, in fact, changed music recording significantly and are now used by literally everyone in the industry. I also discuss mixing, central to sequencing and recording, and the various sound effects such as reverberation.

In chapter 15 we turn to acoustics, both of concert halls and smaller studios. As we will see, Wallace Sabine of Harvard almost single-handedly developed the science around the turn of the century. Central to the acoustics of a concert hall is what is called the reverberation time (the time to inaudibility). We will look at the significance of reverberation in relation to concert halls, and I will show you how to calculate it. Also in this chapter we will consider what are usually referred to as "home studios," the smaller studios set up by amateurs or professionals that are playing an increasing role in the music industry.

In the epilogue I discuss iPods briefly because they are now playing a large role in the music industry.

Musical Notation

Throughout the book I use musical notation. Since not everyone may be familiar with it, the following is a brief survey of it. If you're already familiar with it you can, of course, skip this section.

In chapter 5, I discuss the musical scale in detail. Here, I give only a brief overview. In doing so, it is convenient to refer to the piano, but of course, everything I say also applies to other instruments. On the piano we have the notes as shown in figure 4. The low C here is usually referred to as middle C because it is roughly in the middle of the piano keyboard. The black keys are sharps and flats. For a given note—say G—the black key to the left of it is G-flat (written as G♭), and the black key to its right is G-sharp (written as G#). (More generally, a sharp is a half tone up from a given note, and a flat, a half tone down, so that in actuality any key on the piano—black or white—can be the sharp or flat of an adjacent key.)

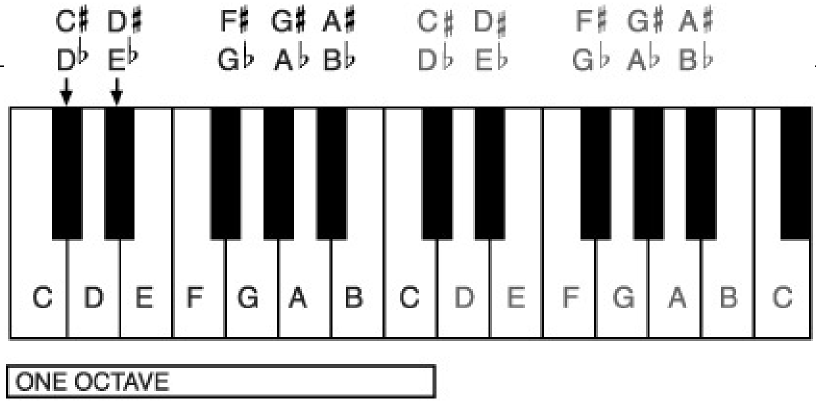
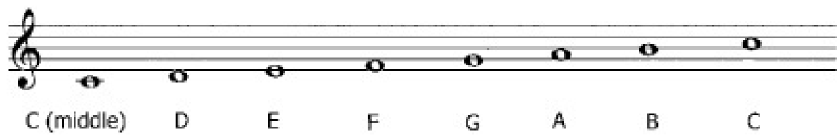


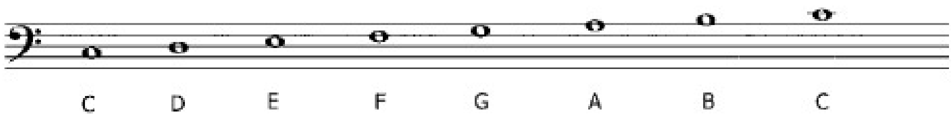
Fig. 4. The piano keyboard, showing the notes up from middle C. Two octaves are shown.

To designate these notes we have what is called a score, namely, the written music. The score is composed of sets of five horizontal lines, each of which is called a stave. Each of the lines on a stave, and the blank spaces between them, refer to notes on the piano (or any instrument). There are, in fact, two staves, one for the right hand (treble) and one for the left (bass). For the treble we have (where the sign 𝄞 is a treble clef)

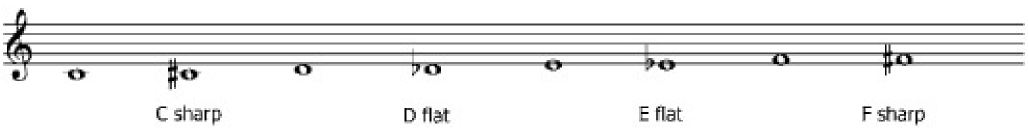


This example shows what is called a whole note, but in practice many different types of notes appear. (I will discuss them below.)

For the left hand, or bass, we have (where 𝄢 is called the bass clef)

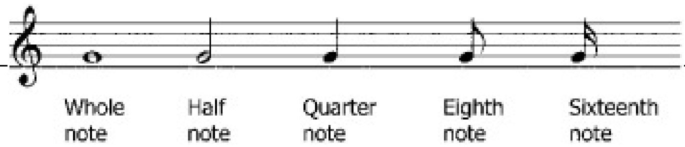


We represent the piano's black keys (sharps and flats) on our score as follows (for the treble):

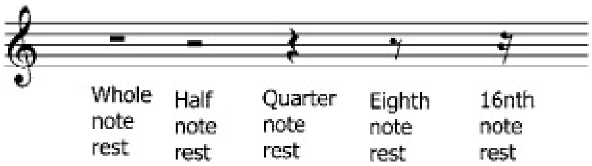


This is basically the same for the bass.

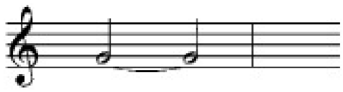
I mentioned that there are several types of notes besides the whole notes I have written above. The different types of notes designate the timing of music. Music is written in various units of time: 4/4 or 4 beats to the bar (as in the fox trot), 3/4 or 3 beats to the bar (waltz), and so on. The whole note stands for 4 beats, the half note for 2 beats, and so on. The time for other types of notes are shown below.



One of the other things you see are rests. Rests indicate places where no notes are played. Rests are designated in the following way.



Also you will see a tie between notes. A tie between two notes means that the note is to be held (not replayed) and is designated by



Finally, throughout the book I will be referring to various octaves within the keyboard, where an octave is the interval from one note to the equivalent, or same, note above it (e.g., from middle C to the C twelve notes above it), and it is important to distinguish between these octaves. We do this by calling the lowest octave (e.g., from the lowest C on the piano to the above it) C_1 to B_1. The next octave up is C_2 to B_2, and so on. In this scheme middle C is C_4.

There is, of course, considerably more to music than this, but these comments should be of help in understanding the music sections in the following chapters.

I

1

Making Music
How Sound Is Made

Music is sound, but it’s a very special kind of sound. I think everyone would agree with that. I this chapter we’ll be talking about how sound is produced and what properties it has to have t be music. Let’s begin by defining sound. Sound is a wave that is created by a vibrating objec this object can take many forms, such as a tuning fork, the human voice, a siren, or a musica instrument. Once created, the sound propagates through a medium, usually air, from its source to another location where it is picked up by a receiver. The most common receiver is, of course, our ears.

Given that we’re mainly interested in the form of sound that we call music, we have to distinguish it from the other sounds we hear. What is it that makes music different? There ar many ways we can define it; a simple one is, Music is sound that is organized. We can also say that music differs from ordinary noise in that the vibrations associated with it are more uniform; in short, there are no sudden changes. Finally, musical sounds are, for the most part, pleasant and pleasing to the ear.

According to the first of our definitions, music is sound that is organized, so let’s look at how it is organized. We see that it consists of notes, rhythms, phrases, and measures and has an overall form. All of these things help to organize it. Another important aspect of music is melody, in other words, the tune we whistle or hum after we’ve heard the music a few times. This melody is usually repeated several times throughout a musical piece and is something else that helps keep it organized.

The simplest form of music is the pure tone; it is the type of tone you get from a tuning fork. Pure tones are basic to music, but as we will see, they are not heard very often. Music composed only of pure tones would not be interesting.

So music is organized noise that has a melody and consists of structured rhythms and various types of pure tones. This is, of course, a very mechanical definition and doesn’t convey what music really is and what it really does. As everyone knows, its most important role is to convey emotion, and it does this well. There’s no doubt that it affects us all; it can convey joy, it can give us goose bumps, and it can even make us cry. Why does it have such a powerful force on people? This is one of the questions we will look at in this book.

The Motion of Waves

One of the first things we learn about sound is that it is a wave. This means that our study of sound will center on the study of waves. What exactly is a wave? Waves are, of course, all around us; we encounter waves of many different types every day. Besides sound waves, we have radio and TV waves, water waves, waves in our microwave ovens, and earthquake waves. In each case they are caused by some sort of vibratory motion.

One of the most familiar waves is a water wave, so let’s begin by looking briefly at one. Assume you are sitting on the bank of a pond and throw a stone into the water. What do you see? When the stone hits the water, you will see a series of concentric rings that appear to move outward from the point where the stone hit, as illustrated in figure 5. Looking at these rings closely, you see that they consist of crests and depressions, or troughs. The tops of the crests are higher than the level of the water when there were no crests, and the bottoms of the trough are lower (fig. 6). The waves move out with a certain speed from where the stone struck the water, and it appears as if the water is actually moving. There is, indeed, some motion in the neighborhood of a particular crest or trough, but this consists only of a small amount of circular motion. The water as a whole does not move. The wave passes through the water.

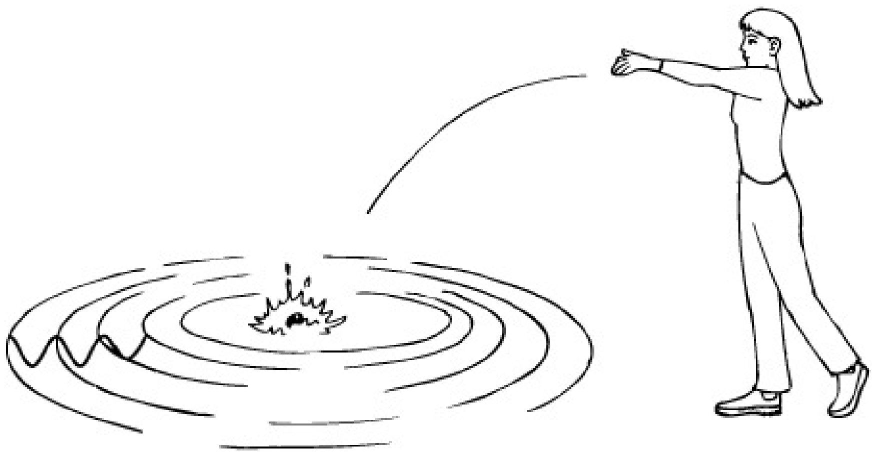


Fig. 5. Girl throwing rock into pond, creating waves.

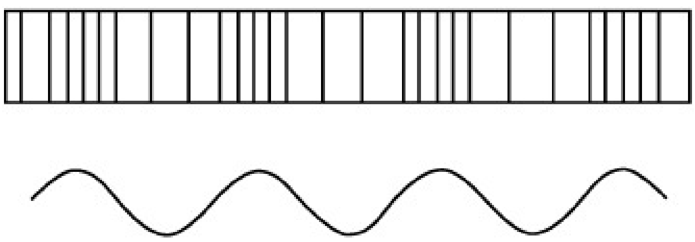


Fig. 6. A cross section of the waves in figure 5 showing a series of crests and troughs.

If you could take a cross section of the wave—in other words, cut it in a direction outward from the source—you would get a wiggly line that consisted of a series of crests and troughs. The curve of this line is known as a sine curve, since it is identical to the curve we get when we plot the trigonometrical function sine.

To understand this type of wave a little better, let's generate one and look closely at its properties. The best way to do this is to attach a rope to a doorknob or other projection and pull it tight, then give it a sudden upward jerk. A pulse that is similar to single wave (a crest and a trough) will travel down it from our hands to the knob (fig. 7). What we really want, though, is a series of these pulses. For this we have to keep jerking our hands up and down, and if we want the pulses to be equally spaced, we have to do it uniformly, or regularly. This will create an array of equally spaced pulses moving down the rope that will look exactly like the cross section we took of the water wave.

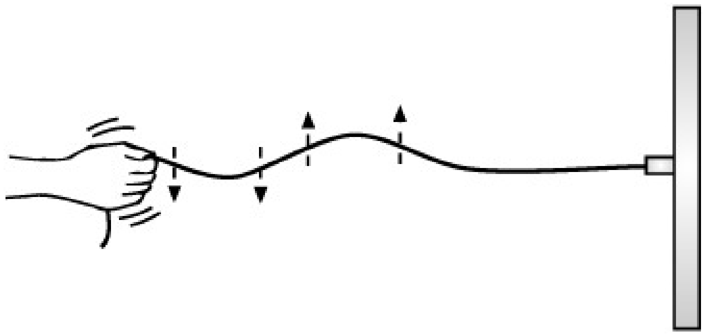


Fig. 7. Jiggling a string to create a wave.

The obvious conclusion from this is that vibratory motion is needed to create waves. As it turns out, though, a particular type of motion is critical in the case of music: simple harmonic motion (SHM). Simple harmonic motion is motion where the force on the object undergoing the motion is proportional to the displacement from its equilibrium position. It is said to obey Hooke's law.

A good example of something that undergoes simple harmonic motion is a taut string, like the string of a guitar, that is pulled to the side and released. It's easy to see that the farther we pull the string back, the greater the force pulling it back to its equilibrium position will be. So it obviously obeys Hooke's law. If we pull the string to the right and release it, as in figure 8, the restoring force will accelerate it back toward its equilibrium position, so that it moves faster and faster in this direction. You're no doubt familiar with acceleration in relation to your car. You have to accelerate to get up to speed; in other words, you have to increase, or change, your speed, so acceleration is change in speed.

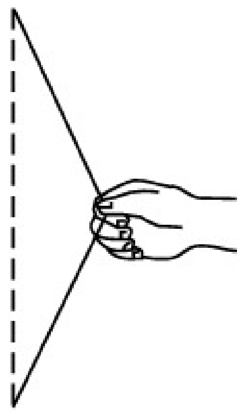


Fig. 8. When a string is pulled to the side and then released, it undergoes simple harmonic motion.

As the string approaches its equilibrium position (straight up and down in the diagram) its displacement from equilibrium decreases, and as a result, the restoring force also decreases But it is the restoring force that is causing the acceleration; this is, in fact, known as Newton's second law of motion (acceleration is proportional to force). So the string moves faster and faster as it approaches the equilibrium position, but at the same time the acceleration itself is decreasing because the force is decreasing. Finally, at the equilibrium position, the restoring force is zero, and since the acceleration is proportional to the force, it is also zero. With no force acting on the string, it might seem that the string would stop moving, but it doesn't; in fact, it has its maximum velocity as it passes through the equilibrium position. Why doesn't it stop? Because of inertia. Inertia is something you experience every time you're in a car and i accelerates. Simply put, it is resistance to change in motion; an object will stay at rest or in motion until it is forced to do otherwise. A force will cause an object to move and accelerate, but to do this the force must overcome the object's inertia. Similarly, an object in uniform motion will not change its motion unless it is forced to do so. And in the case of our string, as it passes the equilibrium position there is no force on it. As it moves past equilibrium, however, the restoring force comes back into play, but now it's acting in the opposite direction. Since this force is proportional to the displacement of the string from equilibrium, it grows as the string continues to move. And, of course, associated with this force is an acceleration, but it is now in the opposite direction, so it's now a deceleration.

As the string continues to move to the left, the restoring force continues to increase, and because of the resulting deceleration, its velocity continues to decrease until finally it is zero. The string is now the same distance to the left of the equilibrium position as it was to the righ when it started. At this point the restoring force again changes direction and is directed back to the equilibrium position. The string therefore begins accelerating in this direction, and as before, it passes through the equilibrium position with its maximum velocity and moves back to the position on the right from where it began. This process would continue indefinitely if there were no air resistance or friction at the ends of the string. But in practice there is alway some friction, and as a result, the vibrations are damped and eventually die out.

It's obvious that simple harmonic motion is relatively complicated. The reason is that the velocity of the object undergoing the motion is continually changing, and so is its acceleration The changes are always smooth, though, so there are no abrupt motions.

Stretched strings are not the only things that undergo simple harmonic motion when they are pulled aside. Pendulums also have this property (fig. 9). Galileo was sitting in a cathedral one day in 1583 when he noticed the chandeliers swinging back and forth. They were all of the same length, but they were not all swaying the same distance from their equilibrium positions (straight up and down). We refer to the distance from the equilibrium position as the amplitude. Galileo noticed that, regardless of their amplitude, the chandeliers appeared to move back and forth in the same length of time (we refer to this as their period). He used his pulse to time them, and sure enough, their period was the same.

The observation fascinated Galileo, and when he returned to his home he decided to look into the motion of pendulums further. He attached a bob to the end of a string and began experimenting with it. The first thing he noticed was that the period of the swing did not depend on the weight of the bob, but it did depend on the length of the pendulum. In fact, it varied as the square root of the length. This meant that if a pendulum was one foot long and had a period of one second, a pendulum two feet long would have a period of $\sqrt{2}$ seconds, and a pendulum four feet long would have a period of $\sqrt{4} = 2$ seconds.

Now, let's look at the motion as we did in the case of the stretched string. In this case when the bob is pulled to the side, a restoring force also acts on it, but this case is different because the bob moves in an arc of a circle when it returns to equilibrium. At its extreme it is raised to a higher level as compared with its equilibrium position. Because of this, when it is released, gravity acts on it, pulling it downward in an arcing curve. But it is obvious that gravity is not the only force involved. There is a force on the string—an upward pull. The gravitational pull that causes the restoring force is therefore only the part that is not balanced by the upward pull of the string.

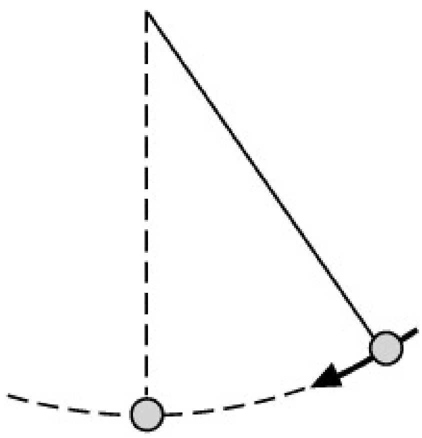


Fig. 9. A simple pendulum.

Because the gravitational force is largest when the bob is first released, the acceleration is also the greatest at this point. As the bob drops, however, the gravitational force decreases and so does the acceleration. But because of the acceleration, the velocity of the bob increases and is at a maximum when the string is vertical. At this position, there is no unbalanced force, but because of inertia, the bob swings through this position and past it. On the other side of this position the force acts back toward it, and the bob therefore slows down. Eventually it stops at roughly the same distance on the opposite side of the vertical. At this position the gravitational force has built up again, and the bob starts back down toward the equilibrium position (the vertical). It performs this motion over and over again, and if it were not for friction it would continue to do so indefinitely.

It’s easy to see that this motion is very similar to the plucking of a string. Both, in fact, are simple harmonic motion.

Types of Waves

Simple harmonic motion is basic to wave motion. One way to see this is to go back to our rope tied to a doorknob. We saw that we could create a series of equally spaced pulses that moved down the rope and that they were similar to the cross section of the waves we saw or water. Looking at this wave closely, we see that it consists of equally spaced crests and troughs. The crests are the places where the rope is displaced above its usual equilibrium position (when it is pulled tight), and the troughs are the valleys created below the equilibrium position. There are, of course, places along the rope where it is not displaced from its equilibrium position; they are referred to as nodes. This type of wave is called a transverse wave. It is the type of wave that is set up on a violin string, or a string in a piano. The motion of the rope is perpendicular to the motion of the wave in this type of wave; it is, in fact, a bas property of a transverse wave.

There is another type of wave that is also important in nature. To see how this type of wav is generated it is helpful to use a Slinky. I’m sure you are familiar with this toy; you probably played with one when you were young. It is a continuous metal coil that can easily be stretched out. If you attach a Slinky to a doorknob, pull it out straight (or at least as close to straight as you can), and then hit or pound the end of the Slinky, you will, as in the case of ou rope example, see a pulse move along it to the doorknob. But this pulse is different from the one with the rope (fig. 10). It’s a disturbance caused by the back-and-forth movement of the coils in the Slinky. The first coil is disturbed by the blow you gave it; it pushes the second coil and displaces it from its equilibrium position. This causes a push or pull on the third coil, whic is displaced from its equilibrium position, and so on. The result is a disturbance that moves down the Slinky. The disturbance in this case is in the direction the wave is traveling, so in th respect it is different from a transverse wave. In several respects, however, this wave is similar to the transverse wave we talked about above. It is referred to as a longitudinal wave, and as we will see, it is also of importance in music.

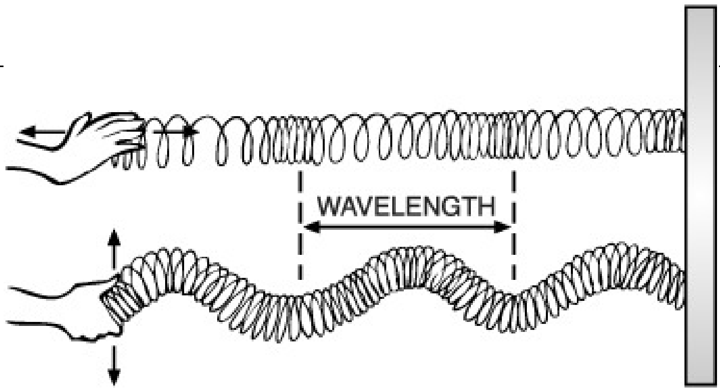


Fig. 10. Using a Slinky to illustrate waves. Both transverse and longitudinal waves are shown

Let’s look at both of these waves in more detail, beginning with the transverse wave. We saw that it has crests and troughs and has a regular repetitive shape down its length. And since it has the same shape as the trigonometrical sine function we call it a sine wave. In the sine wave a small section of it is repeated over and over. The distance of repetition (from one point to a similar point farther on) is known as the wavelength of the wave, which is usually designated by a lowercase Greek lambda, λ The wavelength can be measured from the maximum of one crest to the next, or from a minimum of a trough to the next, or any other two equivalent points. Similarly, the distance from the equilibrium position to the maximum of a crest is called the amplitude of the wave. Wavelengths and amplitude are shown in figure 11. Another important property of the transverse, or sine, wave is the number of crests (or troughs) that pass a given point per second; this number is referred to as the frequency of the wave and is usually designated by f.

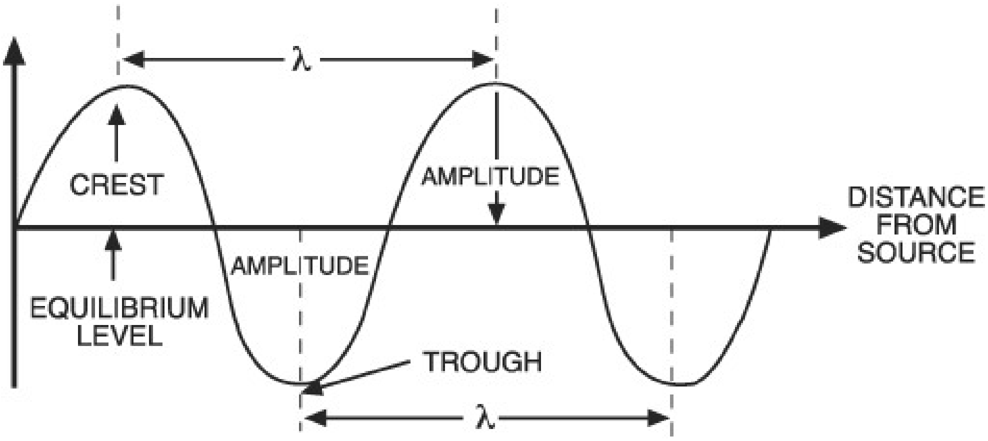


Fig. 11. An illustration of amplitude and wavelength (λ).

If we have two waves traveling down two ropes that are side by side and the crests and troughs from one line up with the other, we say that the two waves are in phase. If the crests and troughs do not line up the two waves are out of phase. Furthermore, we can specify how far they are out of phase; if, for example, a crest lines up with a tough on the other wave, we say they are out of phase by half a wavelength.

Let’s turn now to the longitudinal waves we saw on the Slinky. As we look down the wave we see regions where the coils of the Slinky are closer together than usual; they are referred to as compressions. We also see regions where the coils are farther apart than usual; these regions are referred to as rarefactions. Compressions and rarefactions are analogous to crests and troughs in transverse waves. In the same way, therefore, we have a wavelength for a longitudinal wave; it is the distance between two rarefactions or two compressions (or other equivalent points). In addition, the points that remain at equilibrium correspond to nodes, and the number of compressions (or rarefactions) that pass a given point per second is the frequency of the wave.

Sound

As we saw earlier, sound is a wave created by a vibrating object that propagates through a medium from one location to another. The medium that transmits it is usually air, but many other media such as water and steel also transmit sound waves. But we now know there are two types of waves: transverse or longitudinal. Which type is sound? If you think about a sound wave moving through air, it’s easy to see that it has to be a longitudinal wave. A sound wave moves through air as a result of the motion of the air molecules. When you talk or sing your vocal cords exert a force on the air molecules next to them. As a result, these molecules are displaced from their equilibrium position. They, in turn, exert a push or a pull on their neighbors, causing them to be displaced from their equilibrium position. These push and pull motions, continuing all the way to the receiver, are like the waves that traveled down the Slinky.

Sound waves need a medium such as air to propagate them, and as a result they are referred to as mechanical waves. There are also nonmechanical waves that do not need a medium to transport them. They are called electromagnetic waves, and as we will see, they also play an important role in music. A radio wave is an example.

Properties of Sound Waves

A tuning fork is a familiar device that creates a sound wave of a single frequency. As the tines, or prongs, of the tuning fork vibrate back and forth they push on the air molecules around them. The forward motion of the tine pushes molecules together creating a compression; then, as the tine moves back it creates a rarefaction. If we place an open tube next to the tuning fork, compressions and rarefactions will be set up in it, as is shown in figure 12. This wave has the same properties as the longitudinal wave we talked about earlier. The distance between successive compressions (or rarefactions) in the tube is the wavelength of the sound wave. Tuning forks are made to vibrate at a particular frequency. Thus, if a tuning fork is designed to sound middle C, it will vibrate at 256 vibrations/sec. The frequency of the longitudinal waves passing down the tube would therefore also be 256 vibrations/sec.

sample content of Good Vibrations: The Physics of Music

- download Inner Tube: A Novel
- download online Traces Of A Stream: Literacy and Social Change Among African American Women (Pitt Comp Literacy Culture) for free
- download Bob Miller's Calc for the Cluless: Calc II book
- **Imperialism and Global Political Economy pdf**

- http://bestarthritiscare.com/library/My-Hour.pdf
- http://anvilpr.com/library/A-Dictionary-of-Earth-Sciences.pdf
- http://paulczajak.com/?library/Bob-Miller-s-Calc-for-the-Cluless--Calc-II.pdf
- http://fortune-touko.com/library/Fantasy-City--Pleasure-and-Profit-in-the-Postmodern-Metropolis.pdf