Janice VanCleave's

PHYSICS FOR EVERY KID

SECOND EDITION

Easy Activities That Make Learning Science Fun

Janice VanCleave

ILLUSTRATIONS BY Tina Cash Walsh

JB JOSSEY-BASS™
A Wiley Brand

Janice VanCleave's Physics for Every Kid

Second Edition

Janice VanCleave's Physics for Every Kid

Easy Activities That Make Learning Science Fun

Janice VanCleave

Second Edition

JOSSEY-BASS™
A Wiley Brand

Copyright © 2021 John Wiley & Sons. All rights reserved.

Illustrations by Tina Cash Walsh.

Jossey-Bass

A Wiley Imprint 111 River St, Hoboken, NJ 07030 www.josseybass.com

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, phone +1 978 750 8400, fax +1 978 750 4470, or on the web at www.copyright.com. Requests to the publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, phone + 1 201 748 6011, fax +1 201 748 6008, or online at www.wiley.com/go/permissions.

Limit of Liability/Disclaimer of Warranty: Although the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

Jossey-Bass books and products are available through most bookstores. To contact Jossey-Bass directly, call our Customer Care Department within the U.S. at 800–956–7739, outside the U.S. at +1 317 572 3986, or fax +1 317 572 4002.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at http://booksupport.wiley.com. For more information about Wiley products, visit www.wiley.com.

Library of Congress Cataloging-in-Publication Data is Available:

ISBN 9781119654285 (paperback)
ISBN 9781119654315 (ePDF)
ISBN 9781119654292 (ePub)

Cover illustrations by Tina Cash Walsh
Cover design by Paul McCarthy

SECOND EDITION

Table of Contents

Introduction ix
Foreword xiii

I Energy Introduction 1

1. Energy Conservation 5
2. Frequency 9
3. Coupled Pendulums 11
4. Sound Waves in Air 14
5. Pressure Waves 17
6. Pitch 20
7. Sound Transmission 23
8. The Effect of Mass on Sound 27
9. Natural Frequency 30
10. Neutral Atom 32
11. Electric Current 36
12. Conductors vs. Insulators 39
13. LED 43
14. Electrochemical Energy 46
15. Polarizing an Insulator 51

16. Polarizing a Conductor 56
17. Electroscope 59
18. Triboelectric Effect 63
19. Adhesion: Charging by Contact 66
20. Light Energy 70
21. Light Transmission 73
22. Light Waves 77
23. Interference in Thin Films 80
24. Concave Lens 84
25. Convex Lens 87
26. Plano-Convex Lens 90
27. Polarized Light 93
28. Filters 96
29. Optical Density 99
30. Refractive Index 103
31. Shadows 108

II Force and Motion Introduction 113

32. Inertia: Newton's First Law of Motion 115
33. Rotational Inertia 118
34. Acceleration 122
35. Impulse 126
36. Gravity 129
37. Friction 132
38. Air Resistance 135
39. Drag Force 137
40. Air Pressure 141
41. Torque 145
42. Resultant Force of Gravity 148
43. Center of Gravity 151
44. Balance 154

45. Shifting the Center of Gravity 157
46. Action/Reaction 161
47. Normal Force 165
48. Balloon Rocket 169
49. Bounce 173
50. Coandă Effect 177
51. Bernoulli's Principle 179
52. Pressure Differences 182
53. Balanced Forces 185
54. Unbalanced Forces 188
55. Lift Forces 191

III Simple Machines Introduction 195

56. First-Class Lever 199
57. Equal-Arm Balance 203
58. Second-Class Lever 206
59. Third-Class Lever 210
60. Just for Fun: Third-Class Lever 214
61. Inclined Plane 217
62. Screw 220
63. Wedge 223
64. Moveable Pulley 226
65. Fixed Pulley 229
66. Wheel and Axle 233

IV Magnets Introduction 237

67. Ferromagnetism 240
68. Magnetic Field 244
69. 3-D Magnetic Field 248
70. Mapping Magnetic Fields 251

71. Temporary vs. Permanent Magnets 254
72. Magnetic Permeability 257
73. Compass Rose 260
74. Floating Compass 262
75. Magnetic Declination 265
76. Electromagnet 269
77. Right-Hand Rule 274
78. Demagnetization 277
79. Dipping Needle 279
80. Magnetic Energy 283

Glossary 287
Index 311

Introduction

Throughout the writing of this book, I have daydreamed about the fun I have teaching hands-on physics. I've pictured children and educators enjoying these science activities, while reading instructions that are clear and easy to follow and simple explanations about what happened and why. Science safety was a primary concern when designing the activities in this book. It is my fervent hope that this physics book will ignite a profound curiosity for scientific discovery in readers of all ages. The bottom line is that I want to share my passion for physics and how exciting and relevant science is to our everyday lives.

One doesn't need a degree in science to benefit from learning more about why magnets stick to the fridge door and not to a wooden door. Wonder how a parachute works? Why does a magnifying glass make things look bigger? I imagine children of all ages stopping and questioning the physical world around us. Scientific investigations help develop patterns and higher-level thinking to solve real, everyday problems.

The order of presentation is designed to provide a physics foundation upon which to build new principles of science. The activities in each specific topic spiral in content.

Throughout the activities, certain words and phrases are in bold; the meanings of these are given in the Glossary at the end of the book. Working through the activities in order is suggested. However, any activity has educational value on its own merit. With the help of the Glossary, as well as introductions for various topics, you can pick and choose any investigation and be rewarded with a successful experiment. Of course, a good outcome depends upon following the procedure steps in order. Substituting equipment can affect the results for some activities, but science is meant to be fun so trust your judgment about changes.

This book was designed to give the reader a taste of physics:

Energy Learn about stored energy, energy of moving objects and the transfer between them, and the study of different forms of energy including mechanical, electrical, sound, and light. Energy is simply the ability to do work, which means to change or deform or move an object, and to create heat.

Force and Motion Learn about the effect of forces acting on an object, and study about the force of gravity and how it affects falling objects. A study of Sir Isaac Newton's Three Laws of Motion and how they apply to our everyday lives is covered.

Simple Machines Learn about simple machines which are mechanical devices that change the direction and/or magnitude (size) of a force. Levers, inclined planes, wedges, wheels and axles, pulleys, and screws are studied.

Magnets Learn about magnets and their effect, including an invisible field around magnets responsible for the most remarkable property of a magnet, which is a force that pulls on other magnetic materials, such as iron, and attracts or repels other magnets.

The Activities

This book is written to guide you through the steps necessary in successfully completing a science experiment and to present methods of solving problems and making discoveries.

Introduction: Background information provides knowledge about the topic of the investigation and generally describes cause and effect relationships that you can investigate.

See for Yourself: A list of common but necessary materials and step-by-step instructions on how to perform the experiment is provided.

What Happened? A statement of the predicted outcome is provided with a discussion of what should have happened during the activity. A scientific explanation of what was observed is provided using understandable language and technical, scientific vocabulary so that readers of any age can master the scientific principles involved and discuss their findings.

General Instructions

1. **Read first.** Read each experiment completely before starting.
2. **Collect needed supplies.** You will experience less frustration and more fun if all the necessary materials for the experiments are ready and set up for easy access.
3. **Experiment.** Follow each step very carefully, never skip steps, and do not add your own. Safety is of the utmost importance. By reading the experiment before starting, you will be able to note any safety warnings. Then, follow

instructions exactly so you can feel confident that your outcome will have the desired results.

4. **Observe.** If your results are not the same as described in the experiment, carefully reread the instructions, and start over from the beginning. Check to make sure your materials are as described and in good working order. Use the illustrations to see if the activity is set up properly. Consider factors, such as the ambient temperature, humidity, lighting, and so on, that might affect the results.

Measurements

Measuring quantities described in this book are given in imperial units followed by approximate metric equivalents in parentheses. Unless specifically noted, the quantities listed are not critical, and a variation of a very small amount more or less will not alter the results.

Foreword

Imagine a toddler gleefully dropping a bottle off the highchair tray. Their parent returns the bottle to its rightful place only to see it dropped again. And each time the bottle falls to the floor. This toddler and Sir Isaac Newton have something in common. They both find physics delightful! Janice VanCleave knows that this toddler is learning about the laws of physics! This book is written for every kid who wants to keep dropping things, rolling things, and, most of all, wants to keep learning about the physical world.

And who hasn't wondered about how something as large as an airplane can stay up in the sky? Janice VanCleave never wants that sense of wonder to end. Written for people of all ages with a curiosity about the world around us, this book will be a treasure for the homeschooling parent or classroom teacher that wants to add easy-to-do science that promises to have kids asking, "Is it time for science yet?"

Each activity starts out with a clear explanation of a scientific phenomenon. We have all played with magnets. But did you know that you can map an invisible magnetic force field with a compass? Soon, you find yourself eagerly gathering a few common household materials because the activity is so enticing you can't wait to try it! Each science activity, often deceptively simple, is followed by an explanation that uses everyday language to explain complex principles. It is simply astounding to experiment with something that you have seen a million times, but for the first time you really understand the science. Wow.

Janice VanCleave is a teacher at heart. Her true passion is explaining science in a way that anyone can understand it. This book is a treasure. It unlocks the mystery of physical laws that we see every moment of every day.

I can't help but think that one day the baby who dropped the bottle off the highchair tray will open this book. Then, a true adventure of science discovery and learning will take place. Once again, exploring physics will be delightful! Perhaps that kid will grow up to be the first person to walk on Mars. Anything is possible.

Mary Bowen

Energy Introduction

Energy is the capacity to do work. In **physics**, work is done when a force is applied to an object causing it to move. A **force** is a pushing or pulling action on an object. Forces are measured in pounds (lb) or **newtons** (N), where 1 lb = 4.5 N. **Work** occurs only when a force causes something to move. If you push on a tree and it doesn't move, then no work has been done even though the effort may have exhausted you. Study how work is calculated in this important equation: $W = F \times d$; where W is the work done; F is a specific force and d is the distance moved. Comparatively, when the equation is $W = F_{net} \times d$, the work being done considers all forces (F_{net}) that are acting on the object that is being moved, including frictional forces. **Weight** is a measure of Earth's gravitational force pulling an object down toward the center of Earth. Gravity is the force of **attraction** between two objects with mass. Yes, your body has a force of attraction on other objects, but it is such a minute force that it is basically ineffective. Whereas, the mass of Earth is great enough to produce a force that pulls things on or near Earth's surface down. Down means toward the center of Earth; thus, when you drop something, it falls perpendicular to Earth's surface. Forces do not always cause **linear motion**, which is motion in a straight line. **Torque** is a turning force that causes motion around a center point, such as the turning of a lid or the spinning of a merry-go-round.

Movement is the change of an object's physical position. Linear movement is measured in feet (ft) or centimeters (cm), where 1 ft = 30 cm. Not all movement is linear or rotational but rather some objects **vibrate**, meaning they move back and forth. **Frequency** is a measure of the number of times something happens in a specific amount of time. Frequency can be measured in **hertz** (**Hz**), where 1 Hz = 1 cycle per second or one back and forth vibration.

Potential energy is the energy an object has because of its position relative to some zero position. It is energy that has the potential to do 'work.' Two types of potential energy investigated in this book are **gravitational potential energy** and **elastic potential energy.**

> **Gravitational potential energy** is the stored energy an object has because of its position above a specific ground zero. This type of potential energy is due to the force of gravity acting on the object. To obtain this energy, work had to be done on an object to raise it to a higher level above ground zero, such as placing a book on a top shelf with the floor below being ground zero. Gravitational potential energy is directly related to the mass of the object as well as its height above ground zero. When the book is dropped from a specific height, its gravitational potential energy is converted to kinetic energy as the book falls.

> **Elastic potential energy** is the energy stored in an object that can be stretched or compressed. A force is needed to compress or stretch an elastic object. Consider a trampoline, which has the greatest elastic potential energy

when it is stretched the most, as does a rubber band. A coiled spring stores elastic potential energy when a force compresses it as well as when a force stretches it. In both cases, when the spring is released, the spring's elastic potential energy results in the wound coils moving back to their normal position. Thus, the elastic potential energy is converted to kinetic energy.

Kinetic energy (**KE**) is the energy of objects that are moving. Remember, kinetic energy does not cause an object to move, instead objects have kinetic energy because they are moving. A ball at the top of a ramp has gravitational potential energy. As the ball rolls down the ramp, its gravitational potential energy is converted to kinetic energy. There are three types of kinetic energy: vibrational, rotational, and translational. **Vibrational KE** is the energy caused by a back and forth movement; **rotational KE** is the result of turning about an axis, and **translational KE** is the result of linear movement from one place to another.

Mechanical energy is the sum of an object's potential energy and kinetic energy. Objects have mechanical energy if they are moving or have positional potential energy. Remember that an object doesn't have to be a machine to have mechanical energy. For example, both rivers and wind have mechanical energy.

In addition to mechanical energy activities, other types of energy will be investigated: sound energy, electrical energy, and light energy.

Sound is the sensation perceived by an organism's sense of hearing produced by the stimulation of hearing organs by sound **waves**. **Sound energy** is a type of energy produced by vibrating objects, such as when a guitar string is plucked. The movement of the string moves the air around it, producing a pattern of disturbances in the air called sound waves. Sound energy is transferred through mediums, such as solids, liquids, and gases. This type of energy can be heard by humans and other animals.

Electricity is a type of energy that we often take for granted until it is not available. All electric appliances, including computers and TVs do not work if the electric power line bringing electrical energy to your home is broken during a storm. You will discover more about **current electricity** as well as how to perform magic tricks using **static electricity** in the activities included in this book. You will also learn how the chemical energy stored in batteries produces the current electricity necessary for cell phones and tablets. Other electrical terms such as **free electrons**, **conductors**, **insulators**, **polarization**, and **closed** and **open circuits** will be investigated in the activities related to electrical energy.

Light energy is radiation. **Radiation** is a type of wave energy that does not need a medium to move through, such as radiation from the Sun that moves through space to Earth. The term radiation can sound dangerous and frightening, but did you know that common visible light and heat waves, called infrared light, are all forms of radiation? We can't imagine homes without our useful microwave oven. There are seven types of radiation: gamma rays, X-rays, ultraviolet light, visible light, infrared light, microwaves, and radiowaves.

1. Energy Conservation

The Law of Conservation of Energy states that energy is neither created nor destroyed. Instead, energy can be converted, or changed, into another form of energy. In this activity, the mechanical energy of a pendulum will be investigated. **Mechanical energy** is the summation of an object's **potential energy** (stored energy) and **kinetic energy** (energy of moving objects). A **pendulum** is a weight, called a **bob**, hung from a fixed point so that it can freely move backward and forward. Each swing of the bob, from one side to the other forms an arc, as shown in Figure 1. Work is done on the pendulum when it is raised to position A. This means that energy is being transferred to the pendulum. When raised, the pendulum gains **gravitational potential energy**, which is stored energy due to an object's height. When released, gravity pulls the pendulum down and its gravitational potential energy is converted into kinetic energy.

Gravity is the force of attraction between any two objects with mass in the Universe. The greater the mass, the greater is an object's gravitational force. Earth is very massive; thus, it attracts objects near or on its surface in a direction toward its center. At position A, the pendulum has maximum gravitational potential energy, which is changed to kinetic energy as the pendulum swings down to position B. From position B to C, the pendulum is moving against the downward force of gravity; thus, it slows. During this upward part of the swing, the pendulum's kinetic energy changes into gravitational potential energy again.

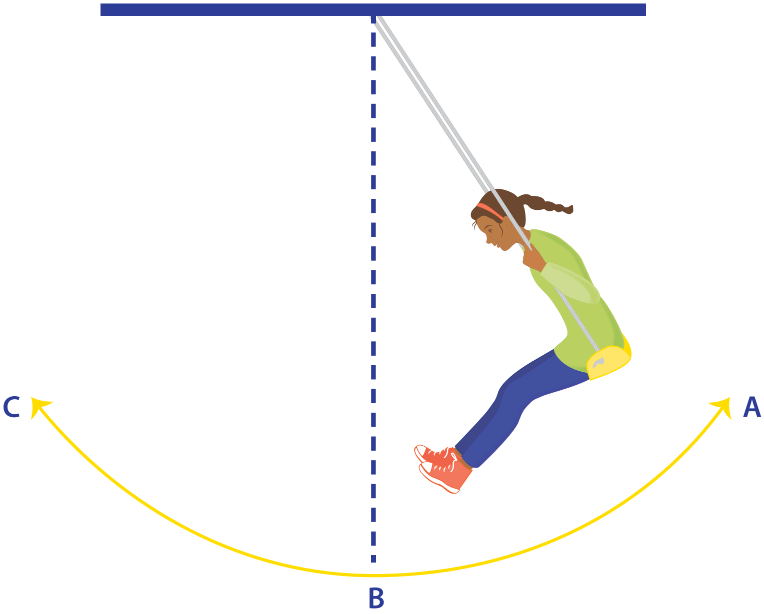


FIG 1

The mechanical energy of a pendulum involves the transfer of kinetic energy into potential energy and back to kinetic energy, and so on. It is important to note that the amount of potential energy at position C is less than it was when the pendulum was first lifted to position A (Figure 1). This means the pendulum loses mechanical energy with each swing and each swing is lower and lower until it finally stops. This lost energy was changed into another form of energy, such as heat or sound (air vibration).

See for Yourself

Materials

string, 8 inch (20 cm)
tape
washer with a hole or any comparable weight

What to Do

1. Tie one end of the string to the washer.
2. Tape the free end of the string to the edge of a table (Figure 2).

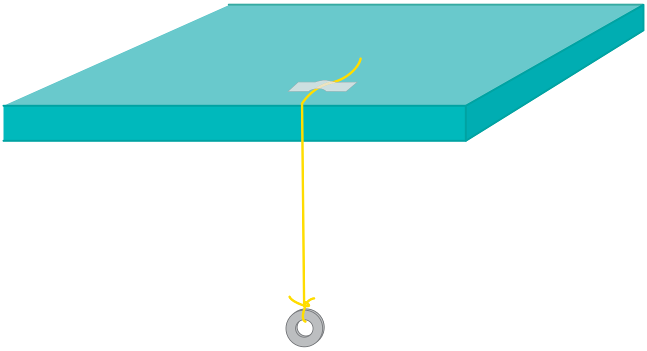


FIG 2

3. Pull the pendulum to the side a short distance and release. It should swing back and forth. Observe the movement of the pendulum. Make note of the pendulum's height during each swing.

What Happened?

In Figure 1 the pendulum is first held stationary at position A, which is higher than position C. This means work has been done on the pendulum by lifting it, giving the pendulum gravitational potential energy. When the pendulum is released, the force of gravity acts on the pendulum pulling it downward. When moving, the pendulum has kinetic energy. Halfway between A and B, half of the mechanical energy is divided between potential energy and kinetic energy. At position B, the potential energy of the pendulum is zero and the kinetic energy is at its maximum. This kinetic energy decreases as the pendulum moves toward position C. Halfway between B and C, mechanical energy is again divided between potential energy and kinetic energy. Finally, the pendulum rises slightly below position C. In this position, its potential energy is less than at the start of the swing. This reduction of mechanical energy decreases incrementally until the pendulum stops moving and hangs vertically at a standstill at position B.

2. Frequency

Frequency is how many times an event occurs in a specific amount of time, such as the back and forth swing of a pendulum. A pendulum is an apparatus with a hanging weight from a fixed point that can move freely back and forth. A string with a washer attached to the end is one example of a pendulum. The weight on a pendulum is called the bob. Each forward and back swing of the bob on a pendulum is counted as one cycle.

The frequency of a pendulum is determined by counting the number of cycles, the back and forth movements, the pendulum bob makes in a one-second interval. The length of the cable or string attached to the bob determines the pendulum's frequency. The longer the string, the lower the pendulum's frequency.

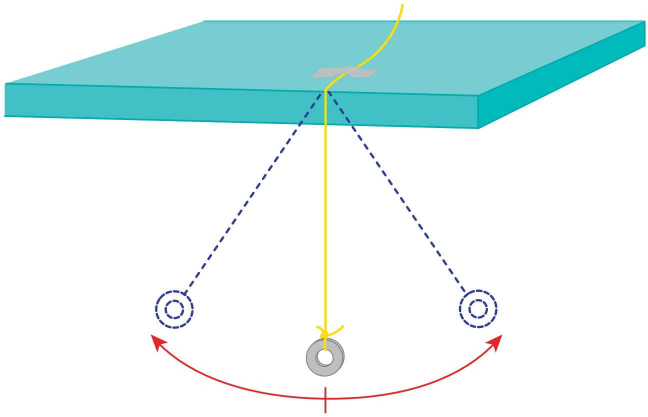
See for Yourself

Materials

string, 18 inches (45 cm)
washer with a hole, or any comparable weight
tape

What to Do

1. Tie one end of the string to the washer.
2. Tape the free end of the string to the edge of a table. Leave part of the end of the string free. This end of the string will be pulled to shorten the string.
3. Pull the washer to one side and release it. The washer should freely swing without touching anything (Figure 1).



Pendulum

FIG 1

4. As the washer swings, slowly pull the end of the string to shorten it. As you shorten the string, observe the change in the frequency of the pendulum.

What Happened?

As the length of the string is shortened, the distance the bob swings gets shorter. Thus, it takes less time for the bob to swing back and forth. This means that, given the same interval of time, a shorter pendulum will swing back and forth more times than a longer pendulum. So, there is a relationship. The frequency of a shorter pendulum is higher than the frequency of a longer pendulum.

3. Coupled Pendulums

Coupled pendulums can be formed by two pendulums suspended from a common support. In this setup, energy from one swinging pendulum can be transferred through the medium connecting the two pendulums. As a result, one swinging pendulum will transfer energy to the second pendulum, starting it swinging. As the energy is transferred back and forth, one pendulum stops and the other swings, reversing the energy transfer. Through careful observation, a prediction can be made when one pendulum will stop and the other one will start. It looks a bit magical but it's not. It's all about the transfer of mechanical energy.

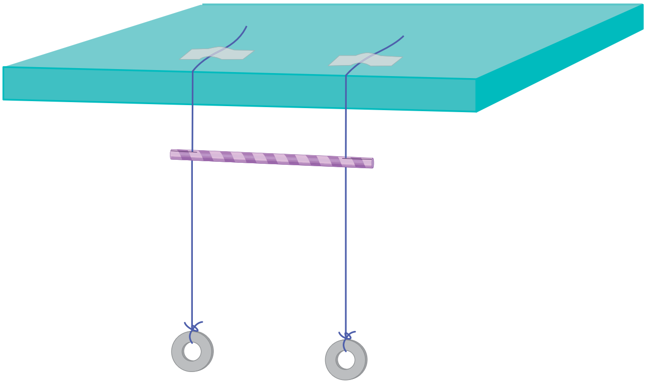


FIG 1

See for Yourself

Materials

string, 2 × 8 inch (20 cm) pieces
tape
ruler
scissors
straw
2 washers with holes, or any comparable weight

What to Do

1. Tie one end of each string to a washer.
2. Tape the free end of each string to the edge of a table. The strings need to be about 6 inches (15 cm) apart. The string lengths for both pendulums need to be the same.
3. Cut 6 inches (15 cm) from the straw, and then cut short slits in both ends of the straw.
4. At about 2 inches (5 cm) from the tops of the string, attach the straw. The string should slide into the slits on the ends of each straw. Make sure that the straw is parallel with the table edge and the lengths of the pendulums below the straw are equal.
5. Pull one of the pendulums toward you a short distance and release; it should swing under the table. Observe movement in both pendulums.

What Happened?

Pendulums of the same length have the same natural frequency, which is the number cycles or the back and forth movements the pendulums would make in 1 second.

When only one pendulum is pulled and released, the end of the attached straw also moves back and forth with the same frequency. With each swing, the straw is giving the second pendulum small tugs. With each tug, the second pendulum moves a little higher. This happens at the expense of energy being transferred from the first pendulum. Thus, one pendulum slows down as the other pendulum swings higher. At this point there is a reverse of energy transfer. One might wonder why this back and forth transfer doesn’t continue forever. The swinging pendulums are at the same time losing energy to other forms of energy, including heat and sound (air vibrations). Eventually, both pendulums will come to a standstill.

4. Sound Waves in Air

Sound waves travel through air in the form of waves called **longitudinal waves**. Sound waves transport energy as they travel through a medium. Sound waves are produced when an object, such as a plucked guitar string, vibrates. On one side of the string, the air molecules are compressed, or squeezed together, creating a high-pressure area. Areas of high pressure are called **compression**. At the same time on the opposite side of the string, a low-pressure area is produced allowing the air molecules to spread out, which is called **rarefaction**. Figure 1 models the compression and rarefaction of air surrounding a vibrating string that is represented by the red line. It is important to note that the air molecules around the string are moving back and forth but they never move far. Instead, each time the air molecules are compressed, they hit against other air molecules pushing them farther away from the string. The sound wave continues to move away from the source of the sound, the vibrating string, in all directions. Sound waves continue to move and bounce off surfaces until there is no more energy.

Sound Wave

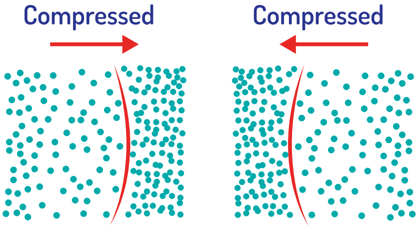


FIG 1