



Integrated Physics and Chemistry

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FIRST EDITION

Cambridge Physics Outlet
Peabody, Massachusetts 01960

CPO
science

Unit 1: Forces and Motion



Chapter 1: Science and Measurement 1

1.1 Time and Distance	3
1.2 Investigations and Experiments	7
1.3 Speed	13
Chapter 1 Review	17

Chapter 2: Mathematical Models 21

2.1 Using a Scientific Model to Predict Speed	23
2.2 Position and Time	29
2.3 Acceleration	33
Chapter 2 Review	39

Chapter 3: Forces and Motion 43

3.1 Force, Mass, and Acceleration ...	45
3.2 Weight, Gravity, and Friction	52
3.3 Equilibrium, Action and Reaction .	56
Chapter 3 Review	60

Unit 2: Work and Energy



Chapter 4: Machines and Mechanical Systems 63

4.1 Forces in Machines	65
4.2 The Lever	71
Chapter 4 Review	73

Chapter 5: Work, Energy and Power 77

5.1 Work	79
5.2 Energy Conservation	83
5.3 Energy Transformations	87
Chapter 5 Review	91

Unit 3: Electricity and Magnetism



Chapter 6: Electricity and Electric Circuits 95

6.1 What Is a Circuit?	97
6.2 Charge	101
Chapter 6 Review	105

Chapter 7: Measuring Electricity 107

7.1 Voltage	109
7.2 Current	113
7.3 Resistance	117
Chapter 7 Review	122

Chapter 8: Electrical Relationships 125

8.1 Ohm's Law	127
8.2 Work, Energy, and Power	133
Chapter 8 Review	137

Chapter 9: Circuits 139

9.1 More Electric Circuits	141
9.2 Series Circuits	143
9.3 Parallel Circuits	146
Chapter 9 Review	149

Chapter 10: Magnetism 153

10.1 Permanent Magnets	155
10.2 Electromagnets	160
Chapter 10 Review	166



CONTENTS

Table of Contents

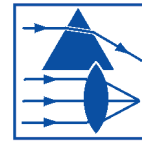


Unit 4: Sound and Waves



Chapter 11: Harmonic Motion	169
11.1 Harmonic Motion	171
11.2 Graphs of Harmonic Motion	176
11.3 Simple Mechanical Oscillators ...	180
Chapter 11 Review	181
Chapter 12: Waves	185
12.1 Waves	187
12.2 Waves in Motion	192
12.3 Natural Frequency and Resonance	195
Chapter 12 Review	199
Chapter 13: Sound and Music	203
13.1 Sound	205
13.2 Properties of Sound	207
13.3 Music	216
Chapter 13 Review	219

Unit 5: Light and Optics



Chapter 14: Light and Color	223
14.1 Introduction to Light	225
14.2 Color	234
Chapter 14 Review	241
Chapter 15: Optics	245
15.1 Seeing an Image	247
15.2 The Human Eye	256
15.3 Optical Technology	259
Chapter 15 Review	263

Unit 6: Properties of Matter



Chapter 16: What is Matter?	267
16.1 Classifying Matter	269
16.2 Measuring Matter	272
16.3 States of Matter	275
Chapter 16 Review	279
Chapter 17: Properties of Matter	281
17.1 Properties of Solids	283
17.2 Density of Fluids	287
17.3 Buoyancy of Fluids	289
17.4 Viscosity of Fluids	294
Chapter 17 Review	298
Chapter 18: Atoms and Elements	301
18.1 Atomic Structure	303
18.2 Comparing Atoms	307
18.3 The Periodic Table of Elements .	312
Chapter 18 Review	315

Unit 7: Changes in Matter



Chapter 19: Molecules and Compounds	317
19.1 Bonding and Molecules	319
19.2 Chemical Formulas	326
19.3 Comparing Molecules	333
Chapter 19 Review	339
Chapter 20: Chemical Reactions	343
20.1 Chemical Changes	345
20.2 Chemical Equations	349
20.3 Conservation of Mass	355
20.4 Using Equations as Recipes	357
Chapter 20 Review	361
Chapter 21: Types of Reactions	365
21.1 Classifying Reactions	367
21.2 Energy in Reactions	373
Chapter 21 Review	375
Chapter 22: Chemistry and the Environment	377
22.1 Nuclear Reactions	379
22.2 Carbon Reactions	386
Chapter 22 Review	390



CONTENTS

Table of Contents



Unit 8: Water and Solutions



Chapter 23: Solutions 393

23.1 What is a Solution?	395
23.2 Dissolving Rate	398
23.3 Solubility	401
Chapter 23 Review	408

Chapter 24: Water Quality 411

24.1 Water	413
24.2 The Water Cycle	417
Chapter 24 Review	424

Chapter 25: Acids and Bases 427

25.1 Acids, Bases, and pH	429
25.2 Acid Rain	436
Chapter 25 Review	438

Unit 9: Heating and Cooling



Chapter 26: Measuring Heat 441

26.1 Temperature Scales	443
26.2 Measuring Changes in Heat	447
26.3 Specific Heat	450
Chapter 26 Review	453

Chapter 27: Heat Transfer 457

27.1 Conduction	459
27.2 Convection	462
27.3 Radiation	466
Chapter 27 Review	469

Chapter 28: Heating, Cooling, and Systems 471

28.1 Weather	473
28.2 Living Systems	479
28.3 Mechanical Systems	483
Chapter 28 Review	488

Reference Section

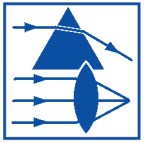
Glossary

Index

UNIT 5



Light and Optics



Chapter 15

Optics

Introduction to Chapter 15

Cameras, telescopes, and our eyes are all optic devices. Rays of light are everywhere and optic devices bend and bounce these rays to produce all the colors and images that you can see. This chapter will introduce you to the science of optics.

Investigations for Chapter 15

15.1 Seeing an Image

What does magnification really mean and how do you plot a reflected image?

We see images based on what happens to light. In this Investigation you will discover how light can be bent by a lens to magnify an image, or bounced by a mirror to produce a reflected image. Plotting the rays of light from an object will allow you to understand what a mirror or lens is doing.

15.2 The Human Eye

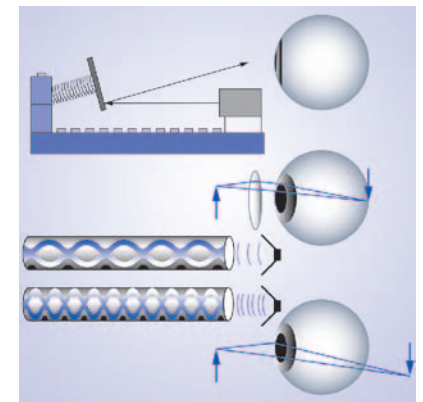
How does a lens form an image?

A lens can bend light to create amazing images. The actual bending of the light in our eye is caused by a clear lens that can change shape slightly. The shape-changing lens in the eye allows us to see close up or far away. In this Investigation, you will work with lenses to focus light and create images.

15.3 Optical Technology

How are optics used in everyday life?

Fiber optics are becoming one of the most important and versatile aspects of optical technology. Fiber optics work on a simple principle. If light is traveling in a material like glass or water, and enters into air, it can become trapped in the material. In this Investigation you will explore total internal reflection, the process that makes fiber optics possible.



Learning Goals

By the end of the lesson, you will be able to:

- ✓ Describe the function of the human eye.
- ✓ Describe the difference between objects and images.
- ✓ Describe and demonstrate the formation of an image.
- ✓ Draw a ray diagram for a lens.
- ✓ Calculate the magnification of a lens.
- ✓ Describe the index of refraction and explain how it is applied in the making of lenses.
- ✓ Identify the characteristics of reflection.
- ✓ Draw a reflected ray.
- ✓ Predict how light will bend when its speed changes.
- ✓ Understand internal reflection.
- ✓ Identify uses of fiber optics.

Vocabulary

angle of incidence	focal length	index of refraction	reflected ray
angle of refraction	focal point	lens	refraction
converging	focus	normal	total internal reflection
critical angle	image	ray diagrams	virtual image
diverging	incident ray	real image	



15.1 Seeing an Image

Try this quick experiment: Take a magnifying lens and look through it at your thumb. You can adjust the distance until the thumb is big. You are actually seeing a big thumb. You are bending the light that is coming from your thumb, so that you *see* a huge thumb. Imagine how big your hand would be if your thumb really was that big. It would be a giant hand!

Now imagine that a few cells of your thumb were under a microscope. You can see the individual cells of your skin. You can see parts of the cell and they look big. Now imagine how big your thumb would be if all the cells were actually that big. Wow! You have the hand of super giant! Of course, your hand is actually the same size it always was, though what you see is a super giant hand. One branch of optics is the study of how to manipulate light to create images that are different from the original object.



Figure 15.1: A magnifying glass makes your thumb look as big as if you were a giant!

What is optics?

Definition of optics The study of how light behaves is called **optics**. Optics deals with the collection and use of light to create **images**. The category of optics covers devices that direct light like lenses, mirrors, cameras, telescopes, and microscopes. It includes events of light like rainbows, sunsets, and eclipses. Ultimately, all of the light from these sources gets to your eye. We will see that the eye itself is an optical instrument.

Lenses, mirrors, and prisms Your eye contains a lens. A lens is one kind of optical device that is used to bend light. By bending the light so that it comes together (**converging**), you can magnify an image and by bending the light so that it spreads apart (**diverging**), you can get a smaller image.

A mirror is a familiar optic device; you probably used one this morning. Mirrors reflect light and allow us to see ourselves. Flat mirrors show a true-size image. Curved mirrors cause light to come together or spread apart. A fun house at the circus uses curved mirrors to make you look thin, wide, or upside down. Curved mirrors distort images. The curved side-view mirror on a car, for example, makes the cars behind you look farther away than they really are.

A prism is another optic device that can cause light to change directions. Traditionally, a prism is used to separate the colors of light and to demonstrate how light bends (**refracts**) as it travels through different media (figure 15.2).

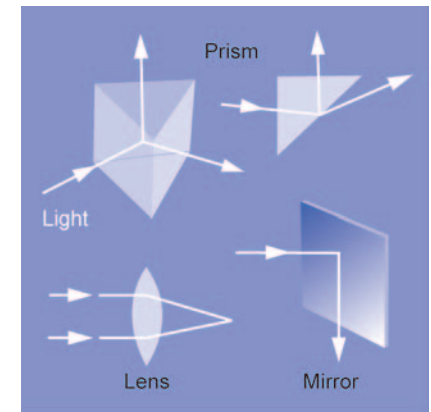
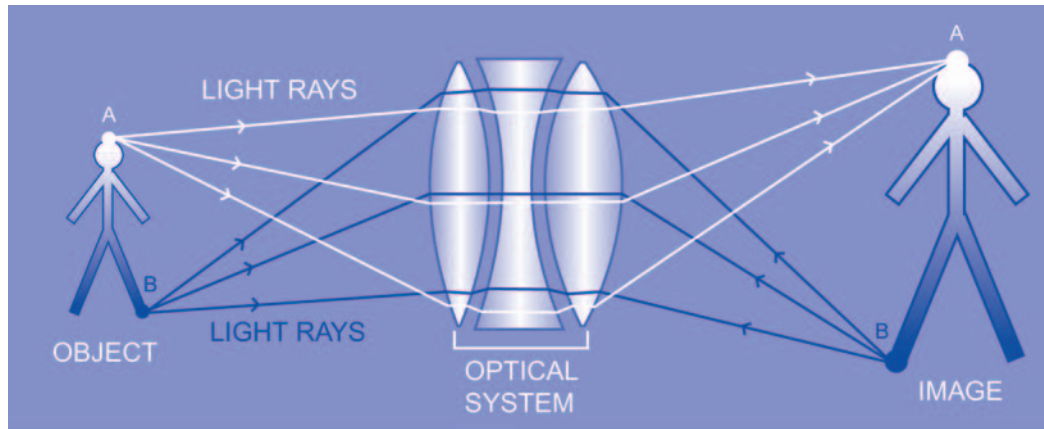


Figure 15.2: Lenses, mirrors, and prisms are part of the study of optics.

Light rays

What is a light ray?

It is convenient to think about light in terms of rays. A ray of light can be considered an imaginary arrow that follows a single beam of light. This simplification allows us to analyze where the light travels. We only need to follow the rays. Very often we will need to follow several rays of light to determine what will happen.



Drawing light rays in diagrams

Light waves are like the waves you see in the ocean as they move continually toward the beach. Rays are represented by lines that are **perpendicular** to the wave fronts. The lines have arrows that show you which way the light is moving. When you see a ray drawn on a diagram, you should know that technically, the ray isn't really one ray of light but a series of light waves. Figure 15.3 uses an arrow to represent which way the light waves are moving.

Rays come from objects

When we see an object, every point on the object reflects many rays of light. Let's consider an example to demonstrate what this means. Look at the clock in your classroom, and focus on the number seven. If you walk around the room, you will find that you can still see the number seven. This demonstrates how light from a single point (in this case, the number seven) can be seen from different angles. This is true because light is reflected to all angles in the room. Figure 15.4 is an illustration of how light rays are reflected off a vase.

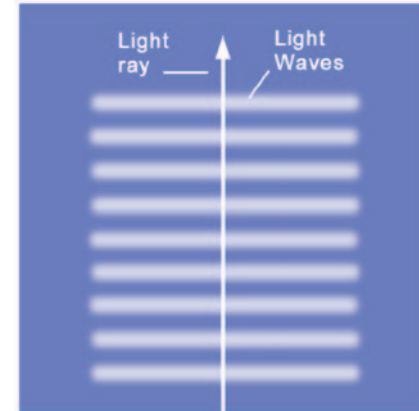


Figure 15.3: The relationship between rays and wave fronts. The ray is the path of the wave.

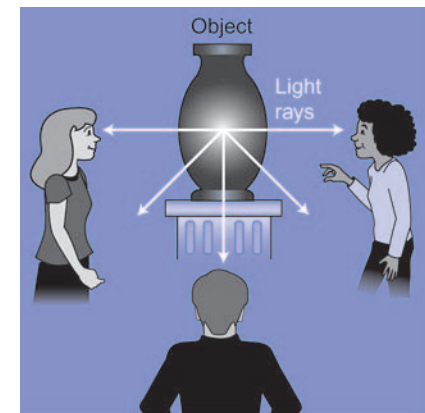


Figure 15.4: Every point on an object is the source of many light rays that come at all angles to the viewer.

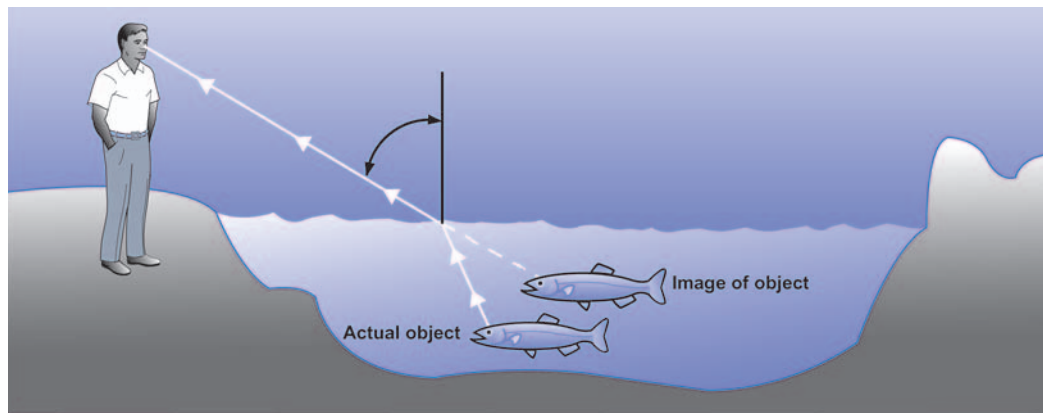


Images

Rays come together in an image Suppose you could collect all the rays from one point on an object, bringing them all together again. You would have created an image. An image is a place where many rays from the same point on an object meet together again in a point. A camera works by collecting the rays from an object and bending them so they form an image on the film.

Objects and images It is helpful to think about optics in terms of objects and images. Objects are any real physical things that give off or reflect light rays. Images are “pictures” of objects that are formed in places where light rays from the object meet. The **focus** is the place where all the light rays from the object meet to form the image.

Light travels in straight lines Normally, light travels in straight lines. Most of the time, when you see some object, it is because the light traveled in a straight line from the object to your eye. As long as nothing is in the way, you can be sure the object is precisely where you perceived it to be. This is because the light rays did not bend.



Light rays can be bent To make images, we often need to bend light rays. Light is sometimes bent *between* an object and your eye. This bending will usually make the image appear different from the object in size or location. A good example is seeing a fish under water. The light waves from the fish bend as they travel from the water to the air. Due to the bending rays, the *image* of the fish appears in a different place from where the fish is actually swimming.

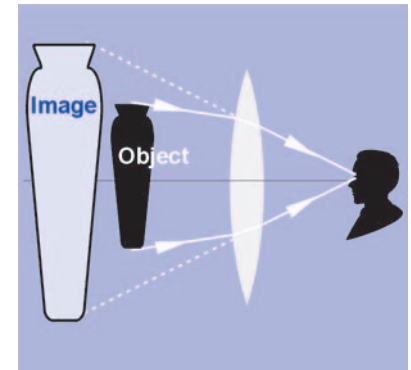


Figure 15.5: *The difference between objects and images.*

The light rays from the object are bent when they go through the lens. Our brain does not know the rays were bent. We “see” the rays as having traveled in straight lines.

The image appears larger because the lens has bent the light rays so they appear to come from a larger object. This is the principle of the magnifying glass.



Figure 15.6: *A magnifying glass makes a virtual image that appears larger than the object.*

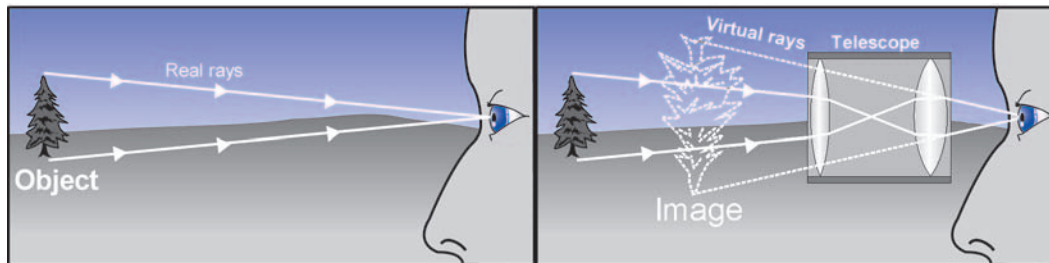
Optical systems

What is an optical system? An optical system collects light and uses refraction and reflection to form an image. When we use an optical system, we do not see the actual object. What we really see is an image. When light is bent through an optical system before it gets to our eyes, the image we see might not represent the actual object as it truly is.

Refraction Refraction is the bending of light that occurs when light crosses a boundary between two different substances. Usually one is air and the other is a clear material such as glass, plastic, or even water. A lens is a special shape of clear solid material that uses refraction to cause light to come together or spread apart. A magnifying glass on a sunny day can be used to illustrate how one type of lens works (figure 15.7).

Reflection A mirror reflects rays of light so that they change their path. Reflection happens when objects or waves can “bounce” off a surface. Whenever a wave strikes a surface, part of the energy is reflected. By changing the shape of a mirror you can also cause light to come to a focus, just like with a lens (figure 15.8).

The telescope A telescope is a collection of lenses that can magnify an image. When you look through a telescope, the rays of light are bent and appear as if they were coming from an image much closer than the actual object. A telescope is an optical system that makes objects appear larger than they are, and sometimes upside down!



Why we see magnified images The illusion created by a telescope happens because we perceive that light travels in a straight line. If the device bends light so that it appears to have come straight from a large object, then we see a magnified image.

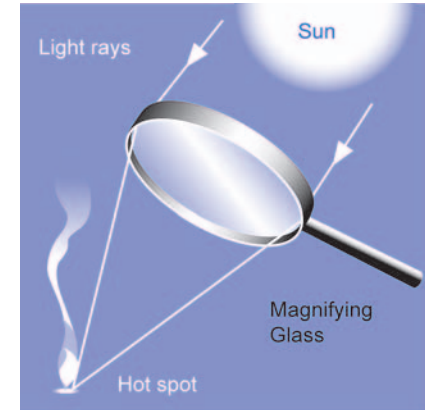


Figure 15.7: A magnifying glass can bend many rays to come together at a focus. On a sunny day the focus can be quite hot!

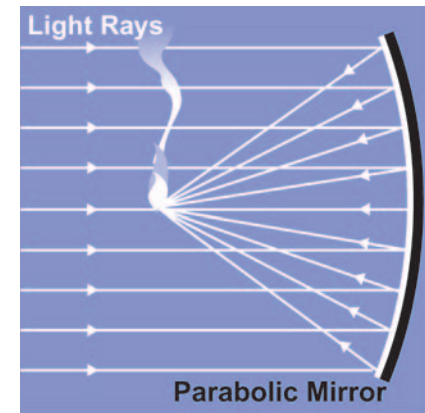
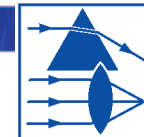


Figure 15.8: Mirrors also change the direction of light rays. A curved mirror can make light rays from the sun change direction and meet at a focus, just like a lens. This is how solar ovens work.



The functions of an optical system

Most optical devices have two important functions.

- 1 They collect light rays.
- 2 They bend the collected light rays to form an image.

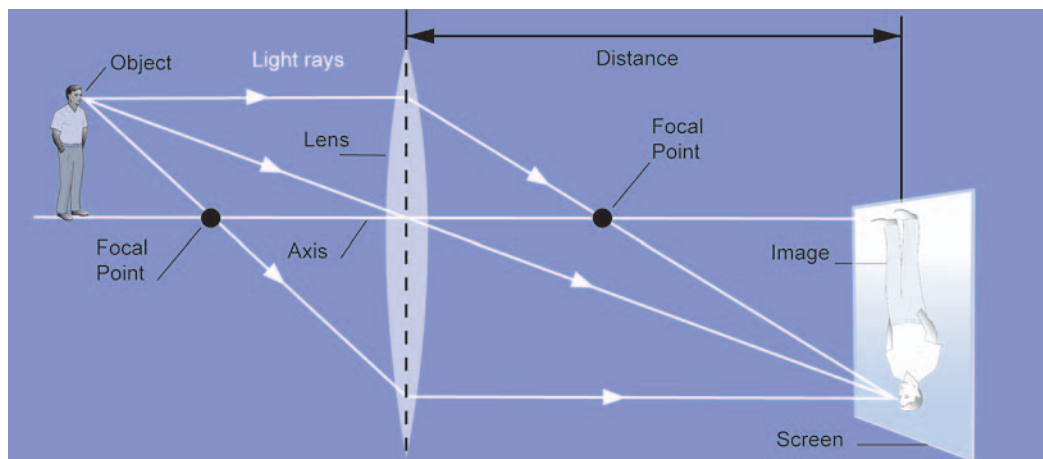
Both functions are important. If you are interested in astronomy, for example, most of the things in the night sky don't produce enough light for our eyes to see. Not only does a telescope make things appear larger, it also collects more light so we can see fainter objects.

The ray diagram

To figure out how an optical system works we often draw **ray diagrams**. Ray diagrams trace how several light rays behave as they go through the system. The rays come straight from an object and are bent or bounced as they encounter a lens or mirror. By tracing the rays through the system we are usually looking to find what kind of image will be produced.

Some typical questions that we use ray diagrams to answer are:

- 1 Where is the focus (or is there a focus)?
- 2 Will the image be magnified or reduced in size?
- 3 Will the image be upside down or right side up?
- 4 Will the image be inverted left to right?



A plastic bag lens

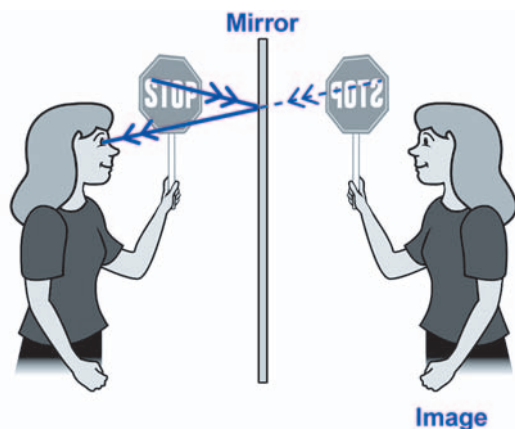


Water is capable of bending light. Take a clear plastic bag and fill it with water. Now look through it. What you see is called an image. The shape of the optic device determines the shape of the image. Squeeze the bag in different places and see how the image changes.

Reflection and mirrors

Mirrors create a virtual image

When you look in a mirror, you see an image. The image appears to be behind the mirror and is reversed from left to right. For example, if you hold a stop sign in front of a mirror, the letters appear backward. Why does this occur?



The light rays that travel from the “S” in the stop sign hit the mirror at an angle and are reflected back to your eye at an equal but opposite angle.

Your brain assumes that this reflected ray traveled to your eye in a straight line from an “object” behind the mirror. As a result, the image of the “S” appears to have come from the opposite direction as the actual letter on the stop sign.

Incident and reflected rays

To investigate mirrors further, we will talk about incident and reflected rays. The **incident ray** is the ray that comes from the object and hits the mirror. The **reflected ray** is the ray that bounces off the mirror (figure 15.9). There is a rule that tells us how to predict the direction of the reflected ray once we know the incident ray’s direction.

The law of reflection

The rule that determines the reflected ray is called the *law of reflection*. This law is very simple: Light rays bounce off a mirror at the same angle at which they arrive. The only tricky part is defining the angles. To keep things clear we always define angles relative to the **normal**. In optics, the normal is a line perpendicular to the mirror (figure 15.9).

If a light ray comes in at an angle of 30 degrees from the normal, it bounces off at the same angle, 30 degrees. If a ray comes in at zero degrees (straight on) it also bounces back at zero degrees. In other words, the light comes in and reflects out on the same normal.

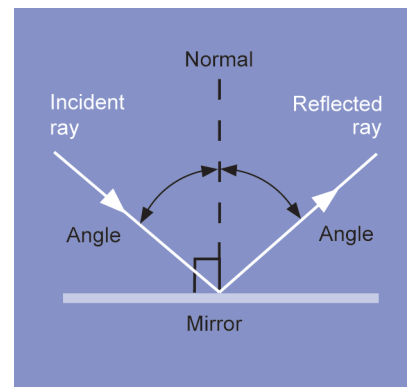


Figure 15.9: The normal is a line perpendicular to the mirror. The incident ray is the ray that comes in to the mirror. The reflected ray is the ray that bounces off the mirror.

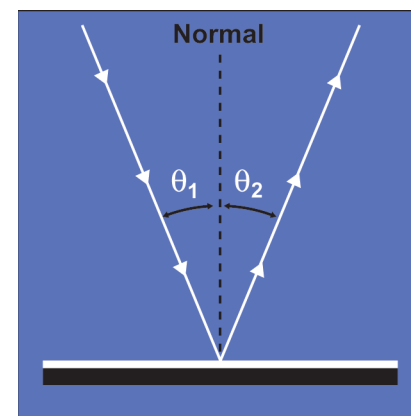


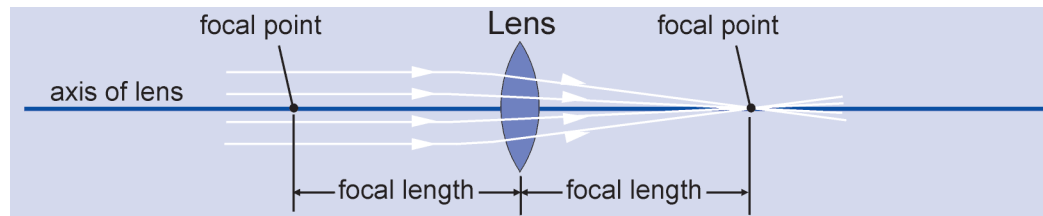
Figure 15.10: The law of reflection states that the angle of incidence (θ_1) is equal to the angle of reflection (θ_2). By throwing a ball against a wall, how could you demonstrate that $\theta_1 = \theta_2$?



Refraction and lenses

Refraction When light crosses the boundary between two different (transparent) materials the rays may bend. We call the bending **refraction**. Refraction happens because the wave fronts move more slowly in materials other than air (figure 15.11). As we already learned, if we change the shape of wave fronts we can turn a wave.

What is a lens? A **lens** is a shape of transparent material, like glass, that is used to bend the light rays. Figure 15.12 shows how the curved surface of a lens works. We choose the shape of the lens depending on how strongly we want to bend the light. Lenses come in many different shapes and strengths.



Focal point and focal length Almost all lenses are shaped to have a very useful property. Light rays that enter a lens **parallel** to its axis will bend to meet at a point called the **focal point**. The distance from the center of the lens to the focal point is called the **focal length**. The focal length of a lens determines how powerful the lens is and how it can be used to focus light.

Converging and diverging lenses There are two kinds of lenses we will examine. **Converging lenses** bend the parallel light rays passing through them inward toward the focal point. **Diverging lenses** bend the parallel light rays passing through them outward away from the focal point. A parallel beam coming into a diverging lens is bent away from the focal point.

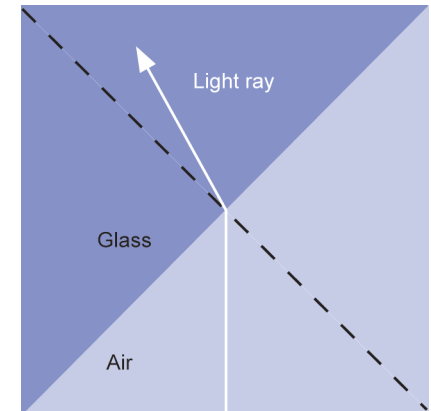
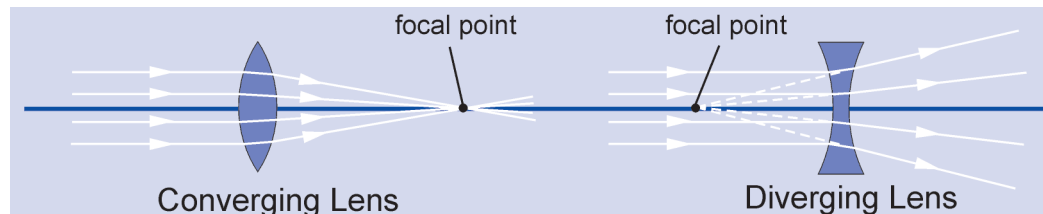


Figure 15.11: A ray of light is refracted (bent) when it crosses from one material into another.

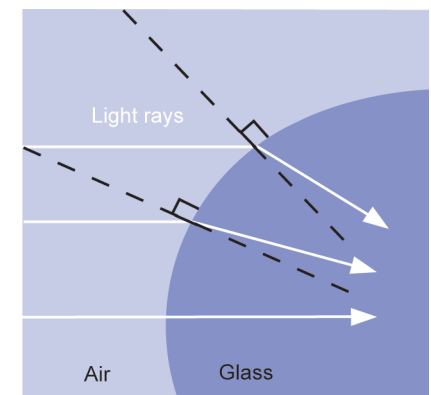


Figure 15.12: For a curved surface, the amount the ray bends depends on where it hits the surface. Rays farther out are bent the most. If the surface is curved just right, all the rays that hit the lens are bent so they meet at the focus.

Forming images with lenses

Why are lenses useful? Lenses are used in eyeglasses, microscopes, telescopes, and other devices to form images. An image, as you have learned, forms when light rays emitted or reflected from one point on an object meet at a point again. Ray diagrams can be used to show where the image will form, how large the image will appear, and whether it is upside down or right side up.

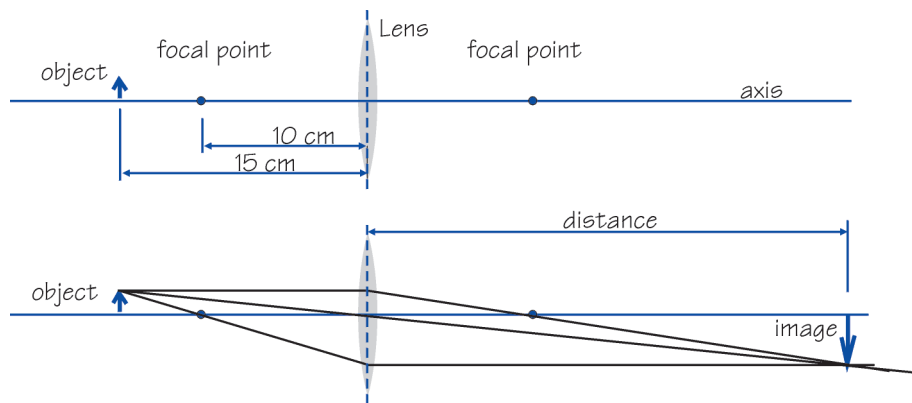
What kinds of images are formed? If an object is placed to the left of a converging lens at a distance greater than the focal length, an inverted image is formed on the right-hand side of the lens. We call this image a **real image**. Real images can be projected on a smooth surface, like photographic slides onto a wall. Since real images are inverted, slides must be loaded into the carousel upside down, so that the picture appears right side up!

Example: A lens has a focal length of 10 centimeters. An object is placed 15 centimeters to the left of the lens. Trace the rays and predict where the image will be. Is the image bigger, smaller, or inverted?

Step 1: Draw the axis and focal points.

Step 2: Draw three rays from the object's tip.

Step 3: The image of the object's tip is found where the three rays meet.

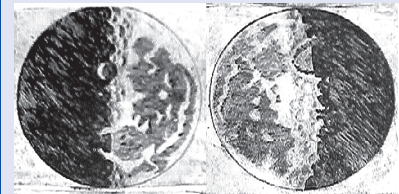


The image is formed 30 cm to the right of the lens. It is magnified and inverted.

If an object is placed to the left of a converging lens at a distance less than the focal length, the lens acts as a magnifying glass. The lens bends the rays so that they appear to be coming from an object larger and farther away than the real object. These rays appear to come from an image, but don't actually meet, so the images are called **virtual images**. Mirrors create virtual images.

Galileo and the telescope

Lenses were being made as early as the 13th century to help people see. Galileo did not invent the telescope, but he learned of it around 1608. He was the first to use it as a tool for astronomy, and by 1609 he had created an improved telescope of far better magnification than any in existence.



One of the first things Galileo saw was that the line between dark and light on the Moon was not smooth, but jagged. Galileo correctly recognized that the jagged line was due to tall mountains on the moon casting shadows onto the lighter side. His 400-year-old sketches show incredible detail including craters and the lunar maria (seas).

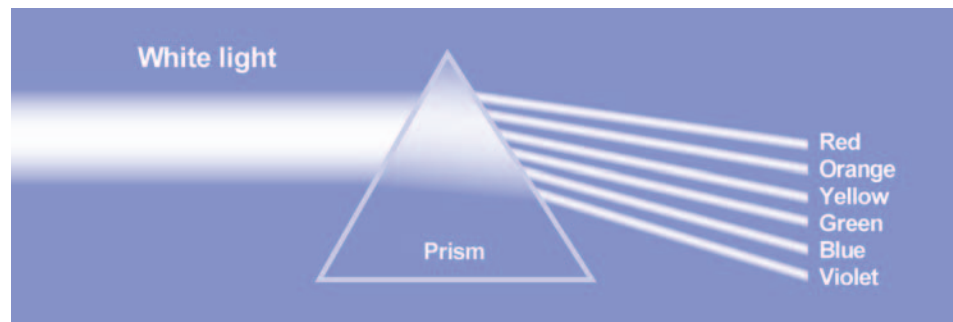


The index of refraction

The index of refraction Light waves travel at a slower rate through glass and other transparent materials than through air. This is because the wave has to constantly be absorbed and reemitted by all the atoms in a material (figure 15.13). Since not all atoms are alike, you might expect different materials to slow the light by different amounts. This is indeed true, and we have a ratio called the **index of refraction** that tells how much the speed of light is reduced when it passes through a material.

The index of refraction is a ratio of the speed of light in a vacuum (or air) compared with its speed in a material. The number is always greater than one because light travels fastest in a vacuum. We use the letter n to represent the index of refraction.

Higher index means more bending The higher the index of refraction, the more a light wave bends when crossing in or out of the material. Figure 15.14 gives some typical values of n for common materials. Light waves are strongly bent by a diamond. It is the high index of refraction that gives diamonds their sparkle and beautiful rainbows of color.



The prism A prism is a polished shape of glass that you can use to investigate refraction. A common shape for a prism is a triangle. Light coming into any face of the prism is bent by refraction. The light is bent again when it comes out of the prism.

Splitting colors with a prism The index of refraction varies slightly depending on the color of the light. Blue light is bent more strongly than red light. Because of this you can use a prism to split white light up into different colors. Blue light is on one end of our visible spectrum. Red light is on the other end.

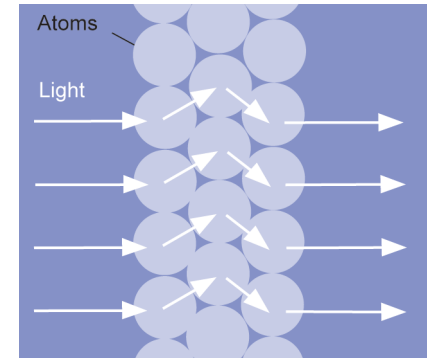


Figure 15.13: Light travels slower through glass because it is continually absorbed and reemitted by each atom it passes through.

The index of refraction (n)

$$n = \frac{\text{speed of light in air}}{\text{speed in material}}$$

Material	Index (n)
Air	1.00
Ice	1.31
Water	1.33
Ethyl alcohol	1.36
Fused quartz	1.46
Crown glass	1.52
Cubic zirconia	2.20
Diamond	2.41

Figure 15.14: Index of refraction (n) for some common materials.

The cover is an evocative montage of historic scientific achievements that demonstrate the incredible persistence of the human intellect. Around the border, DaVinci's graphics represent the start of an evolving tapestry of conceptual thinking. His fantastical mechanisms become the modern bicycle, a quintessential machine, which rolls into a graphical interpretation of wavelength division multiplexing on a fiber optic. These images follow 500 years of scientific and technological innovation. The Earth and DNA serve to remind us that this technological innovation will always remain deeply connected to the natural world. On the back cover, the elegant geometry of the chambered nautilus folds into a spiral defined by the Golden Rectangle. The interplay of organic and architectural forms represents the balance we seek between the power of technology and the fragility of our lives and our world. I hope this colorful interplay of images will inspire interest and excitement about the discovery of science.

Bruce Holloway - Senior Creative Designer

CPO Integrated Physics and Chemistry
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ISBN 1-58892-000-3
4 5 6 7 8 9 - VHG - 05 04

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Printed and Bound in the United States of America