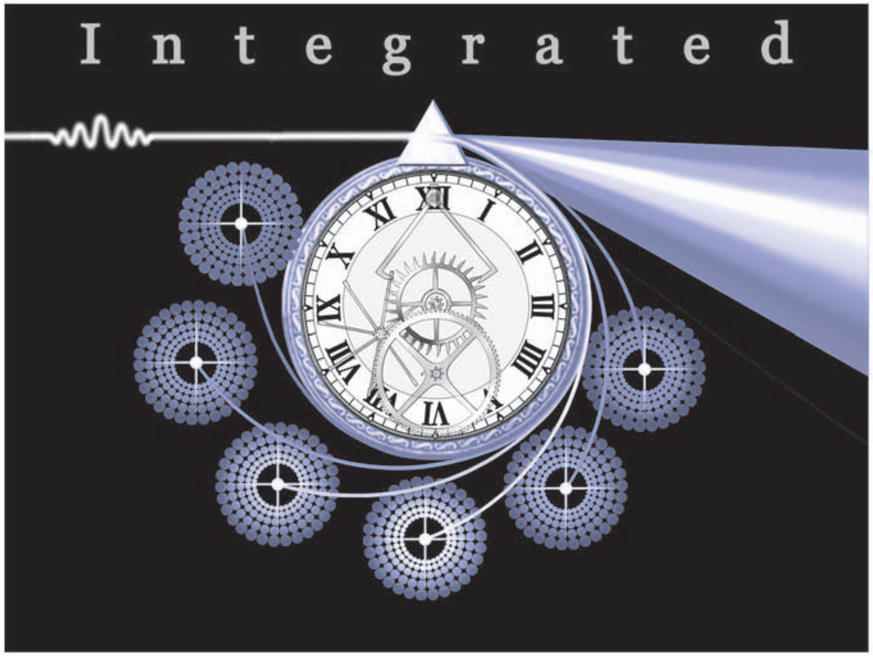
Integrated Physics and Chemistry



Tom Hsu, Ph.D.

FIRST EDITION
Cambridge Physics Outlet
Peabody, Massachusetts 01960

cpo science

15.1 Seeing an Image

Learning Goals	Reading Synopsis	Materials and Setup	IPC TEKS
• Calculate the magnification level of a lens. • Plot the reflected rays from a mirror. • Measure and compare the angles of incidence and reflection from a mirror. **Key question:** What does magnification really mean and how do you plot a reflected image? **Leading questions:** • How can you determine the magnification of a lens? • How does light interact with mirrors and lenses to produce images? • How can you plot a reflected image?	Optics is the study of how light is bent and collected for the formation of images and the transfer of information. In diagrams, light rays show the direction of light. A light ray is an imaginary arrow that represents the path of a light beam reflected or emitted from an object. A collection of light beams forms an image. In diagrams, a collection of light rays indicates where an image appears relative to a lens or mirror. An image is a place where many rays from the same point on an object meet again in a point. Optical systems, such as telescopes, contain lenses and mirrors that are used to magnify or focus down the size of images. Geometry is used to analyze the paths. Rays of light reflect from a mirror at an equal (but opposite) angle to which they are incident on the mirror. Lenses refract light. Refraction is bending of light as it enters a material that changes its speed. **Sequence:** Students complete the reading before the Investigation.	• A convex, magnifying lens • The optics kit (a laser with diffraction filter and a flat mirror) • A few sheets of white copy paper • Colored pencils • A protractor • A metric ruler **Duration:** One class period	2A.2 2B.1 2C.5 5B.3 5B.4

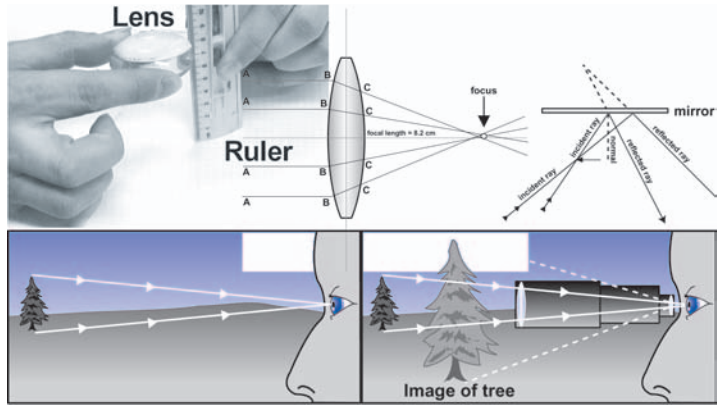
15.2 The Human Eye

Learning Goals	Reading Synopsis	Materials and Setup	IPC TEKS
• Use and understand the rules of refraction. • Plot a ray through a lens. • Calculate the index of refraction. **Key question:** How does a lens form an image? **Leading questions:** • Why is it possible to bounce a rock off of water? • What is total internal reflection? • What is fiber optics technology?	The human eye works with the optic nerve to form images that can be interpreted by the brain. The parts of the eye include the lens, fovea, and rod and cone cells. The lens of the eye focuses light on the fovea, a spot on the retina at the back of the eye. Rod and cone cells, also at the back of the eye, respond to light. Rod cells are sensitive to shades of grey, including black and white. Cone cells are sensitive to color. The portion of light information gathered by each of these special nerve cells is like a pixel on a computer screen. The image that forms on the fovea is upside down. The brain re-interprets this image as right-side up. The lens of the eye moves and changes shape in order to focus. Our ability to judge distances (also known as depth perception) is possible because the brain receives two images, one from each eye. Images in mirrors and optical illusions occur as they do because the brain interprets all light as traveling in a straight lines. Reflected, angled light off the surface of a mirror appears to come from an image in front of you. **Sequence:** Students complete the reading before the Investigation.	• The optics kit: A small laser, a prism, a protractor • A sheet of white copy paper • Colored pencils • A protractor • A ruler or straight edge **Duration:** One class period	2B.2 2C.2 2C.4 5B.4

15.1 Seeing an Image

Key Question: What does magnification really mean, and how do you plot a reflected image?

In this Investigation, students experimentally determine the magnification of a lens using graph paper. They also discover that magnification changes with distance and that there is a limit to how much magnification you can have with a given lens. In the second part of the Investigation, students plot reflected rays of light from a mirror using a laser. The plotted rays are compared with the visual image. Finally, students are introduced to the difference between incident and reflected rays. By completing the activities in the Investigation, students learn how light is bent by the processes of reflection and refraction and how this leads to image formation.



Reading Synopsis

Students read section 15.1 Seeing an Image after the Investigation.

Optics is the study of how light is used to form images and transfer information. In diagrams, light rays show the direction of light. A light ray is an imaginary arrow that represents the path of a light beam reflected or emitted from an object. Optical systems (such as lenses & mirrors) bend light rays to create an image which may be larger, smaller, or in a different place from where the object is. In diagrams, an intersection of light rays indicates where an image appears relative to a lens or mirror. An image is a place where many rays coming from the same point on an object meet again in a point.

Optical systems, such as telescopes, contain lenses and mirrors that do the work of bending the light. Geometry is used to analyze the path that light rays follow in an optical system. Rays of light reflect from a mirror at an equal (but opposite) angle to which they are incident on the mirror. Lenses refract light. *Refraction* is the bending of light as it enters a material that changes its speed.

The Investigation

Leading Questions

- How can you determine the magnification of a lens?
- How do mirrors and lenses produce images?
- How can you predict where an image will be?

Learning Goals

By the end of the Investigation, students will be able to:

- Demonstrate the use of a lens to magnify an image and experimentally determine the magnification.
- Identify which factors affect the magnification of a lens, such as distance to the image and curvature of the lens.
- Demonstrate how to trace incident and reflected light rays from a mirror and relate them to the creation of an image in the mirror.
- Measure and compare the angles of incidence and reflection from a mirror.

Key Vocabulary

images, lens, light rays, incident, reflected, refraction, magnification, normal

Setup and Materials

Students work in groups at tables.

Each group should have:

- Optics kit: bi-convex sphere lens, laser, flat mirror
- Two to three sheets of graph paper
- A protractor
- A metric ruler
- Pencils

Details

Time One class period

Preparation Gather materials for the Investigation. Work through the Investigation before class begins so that you can anticipate student questions.

Assignments Section 15.1 Seeing an Image in the **Student Edition** after the Investigation.

Skill Sheets 15-A Ray Diagrams

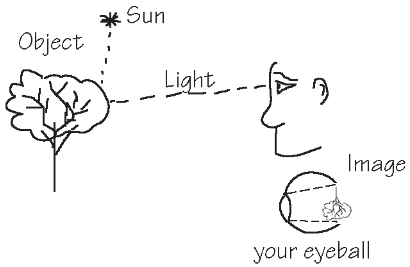
Reference Guide Equipment Setup: The Optics Kit

Teaching the Investigation

1. Introduction to optical systems
2. Determining the magnification of a lens
3. Drawing the rays of light
4. Thinking about what you have learned
5. Wrapping up

Introduction to optical systems

Applications of lenses: Eyeglasses, telescopes, microscopes, cameras
Reflection: The way that objects or waves "bounce" off a surface.
Refraction: The way that light bends when it crosses a boundary into a material that changes its speed.



Can someone give me an example of some uses of lenses? What do these objects have in common?

Prompt students to come up with applications (see notes to the left). List these objects on the board. All of these objects use lenses to bend, magnify, or focus light (or the images formed by light).

Can anyone tell me another way we can bend light other than using a lens?

A mirror (reflection), a prism (refraction), diffraction grating (diffraction).

Can anyone give me some examples or applications of reflection?

Shaving mirrors, security mirrors, side and rear-view mirrors in cars. Discuss curved mirrors, too.

These are examples of optical systems. Optical systems use lenses, mirrors, prisms, and other devices to work with light. Can someone name some optical systems that are used to magnify an image?

Examples include magnifying glasses, telescopes, microscopes, binoculars, overhead projectors, and a shaving mirror. You might demonstrate some of these items.

Can someone name an optical system where the image looks smaller?

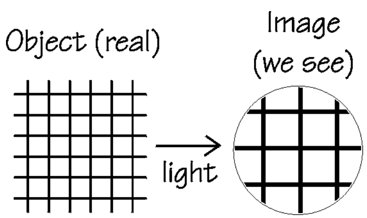
Objects look smaller in security mirrors and in the rear-view mirror in a car. A camera focuses a large object onto a small piece of film. A solar collector focuses sunlight onto a small point.

Lenses bend light. Does anyone remember the term used to describe the process of bending light?

Refraction. Write this term on the board. Refraction is the bending of a wave at a boundary.

To understand how optical systems work, we start with the idea of objects and images. Objects are the real things that exist. We see objects because light bounces off them. Images are what we see. Technically, we DON'T ever see objects directly. We see images of the light that bounces off objects and is collected by our eyes. If we make the light go through mirrors or lenses, the images may be changed. The images could be bigger, smaller or appear to come from a different place.

Determining the magnification of a lens



Magnification power of lens:

$$\frac{\text{\# of squares equal to lens diameter}}{\text{\# of squares seen through lens}}$$

1 In part 1, you will figure out the magnification of a small lens. Magnification is the ratio of the size of an image to the actual size of the real object. A magnification greater than 1 means the image appears to be bigger than the object really is. Look through the lens at your graph paper. Move the lens closer and farther from the paper. Do you see an image of the graph paper in the lens?

For step 1.2, students will need to look directly down at the lens when they hold it above the graph paper. If they look through the lens at an angle, they will see more of the graph paper and obtain an inaccurate reading. In steps 1.2 and 1.3, they are trying to obtain the largest magnified squares before recording the measurement. Some students may have lenses of different sizes and magnification.

What is the object? What is the image?

The object is the graph paper squares. The image is the magnified squares seen through the lens.

Note: Traditionally, magnification is found by dividing image size by object size. It can be tricky to find the size of the image—you would have to hold the lens perfectly still and try to measure the image with a ruler held above the lens. A simpler, more accurate "shortcut method" is provided here. Instead of measuring size, we count the number of squares that can be seen in the lens. This works because as the magnification increases, the field of vision decreases. For example, if you double the width of each square, you will only be able to see half as many squares across the lens. By counting the number of unmagnified and magnified squares, we can figure out the magnification power of the lens. Simply divide the number of unmagnified squares by the number of magnified squares. If you would like to use the traditional image size ÷ object size calculation, the ratio on the next page can help your students find the image size accurately.

UNIT 5: Light and Optics

15.1 Seeing an Image

Question: What is magnification and how do you plot a reflected image?

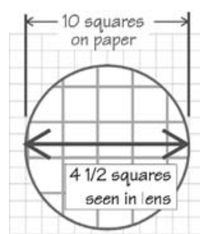
In this Investigation, you will:

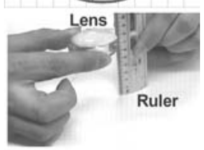
1. Determine the magnification of a converging lens.
2. Trace incident and reflected rays from a mirror using a laser.
3. Learn how images are formed in optical systems.

We see **images** that are formed by the eye from light that comes from objects. Because light can be bent by lenses or mirrors, the image we see can be different from the object that produced it. With a magnifying lens, we can make an image seem larger than the object. The magnification is the ratio of image size to actual object size. In this Investigation, you will learn a shortcut method for finding the magnification of a single lens. Another way an image can be different from the object is in its orientation and location. For example, the image you see reflected in a mirror is reversed left-to-right and appears to be behind the mirror. In part 2 of this Investigation, you will learn how to predict where the image in a mirror appears by tracing the incident and reflected rays of light from a laser.

1 Finding the magnification of a lens

1. Set your lens directly on the graph paper and count the number of *unmagnified* squares that cross the diameter of the lens. In the example, the lens is 10 squares wide.
2. Next, examine a section of graph paper with your lens held above the paper. Move the lens closer and farther away until you have the biggest squares you can still see clearly in the lens.
3. Count the number of *magnified* squares that cross the diameter of the lens. For example, the picture shows 4 1/2 squares across the lens.
4. The magnification can be calculated by dividing the number of *unmagnified* squares by the number of *magnified* squares. In the example, you see 10 *unmagnified* squares and 4.5 *magnified* squares. The magnification is 10 ÷ 4.5, or 2.22.
5. Try the experiment again using a ruler to measure the distance between the lens and the paper. Notice that the magnification changes with different distances.
6. Fill in the table by measuring the magnification of your lens for at least four different distances. The number of squares on the graph paper will be the same for all distances.





Measuring the distance from the lens to the paper

Table 1: Magnification of a lens

Distance to paper	# of squares on graph paper (unmagnified squares)	# of squares in lens (magnified squares)	Magnification
10.5 cm	8	4.5	1.8
8 cm	8	5	1.6
5 cm	8	6	1.3
3 cm	8	6.5	1.2

Using units to calculate magnification

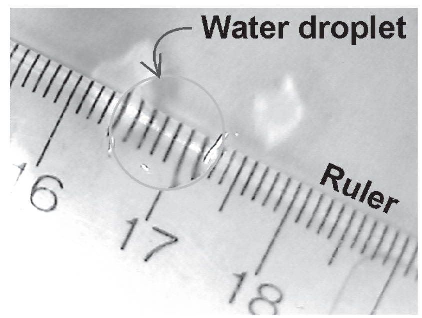
The graph paper used to obtain example answers for this Investigation had squares with sides equal to 0.5 centimeters. A lens that is 8 squares across has a diameter of 4 centimeters. To figure out the size of the image squares, you can use this ratio:

$$\frac{\text{\# of squares, lens diameter}}{\text{\# of squares, through lens}} = \frac{\text{Size of square seen in lens}}{\text{Size of square on paper}}$$

Using cross-multiplication, you can find that the size of a square seen through a 1.8X lens is 0.89 centimeters.

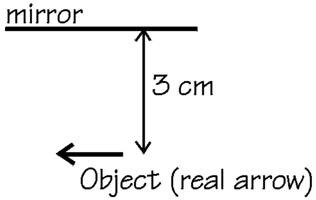
The magnifying power of water

Water droplets on a plastic surface act as a lens. Students can find the magnification power of a water droplet, using the plastic cover of a compact disc jewel case (these covers are easily detached and reattached), a pipette and a metric ruler.

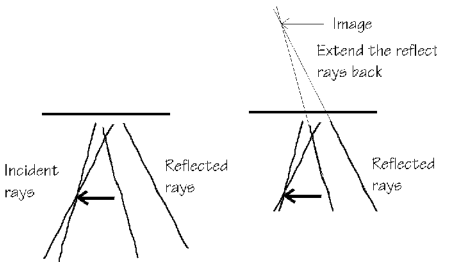


Students should find the diameter of a one droplet of water on the plastic cover by holding a ruler above the droplet. By gently sliding the ruler under the plastic cover, students will see that the droplet magnifies the ruler. The magnification is the diameter divided by the length of the ruler seen through the droplet. The magnification is about 2X. Ask students to see if they can change the magnification power of the droplet. They will find that the magnification stays about the same for beads of water with 1 to 5 water droplets. The magnification DOES depend on the curvature of the droplet, but over this range of sizes, the water droplets flatten out on top so the curvature does not change too much.

Drawing the rays of light



Safety note: Remind students not to look into the laser beam or shine it at another person's eyes.



Incident ray: The beam of light that first encounters the mirror.
Reflected ray: The beam of light that is reflected from the mirror.

Thinking about what you have learned

The incident ray and the reflected ray might not meet in a point. This is because the actual reflection takes place at the back of the mirror.
The law of reflection: The angle between the normal and the incident ray is equal to the angle between the normal and the reflected ray.

Wrapping up

2

In part 2 of the Investigation, we are going to use a mirror to see how an image is formed. Take some clean graph paper and draw a line and arrow like this (draw on board). Set the paper on your optics table and set the mirror standing up with its silver edge right on your line. Can you see an image of the arrow in the mirror?

> It is fine if the students play around with the mirror while doing this activity. Circulate and make sure each group has the sketch correct and that everyone has seen the image in the mirror. Students will have to move their heads around to get the right angle to see the image.

Where is the object? Where is the image? Where does the image appear to come from?

> The object is the arrow they drew on the paper. The image is in the mirror. It appears to come from behind the mirror.

To figure out why the image appears where it does, we need to use the laser to trace one ray of light at a time. Move your laser so the beam passes right over the tip of the arrow and bounces off the mirror. Use your pencil to trace where the beam of light goes.

> When the students are ready to trace the laser beam, explain that they must keep the beam centered on one spot on their pencil. Alternately, you can use a thin object such as a toothpick to locate the beam. As they move the pencil (or toothpick) toward the mirror, they will mark the path of the beam on the paper. The same technique can be used to trace the reflected ray. The students will need to stand for this activity so that they can look at the beam from above rather than from the side.

Now adjust the laser so the beam again passes over the tip of the arrow, but from a different angle. The laser beam simulates two rays of light that both come from the tip of your arrow. Trace the second ray on the same sheet as the first.

> The diagram at the left shows what students should have drawn after completing part 2 of the Investigation. Make sure they understand the difference between the incident ray and the reflected ray.

Take the mirror off and extend the two *reflected* rays by drawing lines. They should meet at a point behind the mirror! This is the same point where you "saw" the tip of the arrow reflected in the mirror. The place where the reflected rays meet tells you where the image is. An image forms where many rays that leave an object from the same point meet up again.

3

Part 3(d) asks you to draw a line "normal" to where the mirror was. "Normal" refers to a line drawn at a right angle to another line. Carefully draw the normal from the point where the two rays meet the mirror line. Measure the angles between the normal and the incident ray and the normal and the reflected ray.

> Students measure the angles between the normal and the incident and reflected rays.

What is the relationship between the angle of incidence and the angle of reflection?

> They should be equal, so if they differ at all it should only be by a few degrees.

This is known as the law of reflection. For the law of reflection, we always measure the angle to the normal and not to the surface of the mirror.

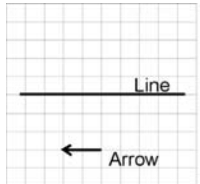
> To justify measuring the angle from the normal, you might show the students what happens if the laser beam hits a makeup or shaving mirror, which is curved. Using the normal makes measuring the incident and reflected rays easier and less dependent on the surface of the reflective material.

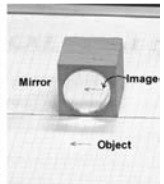
Now that you have learned about the law of reflection, what are some situations in which the law of reflection might apply (even if light is not involved)?

> At this point, discuss and perform the demonstration described on the facing page.

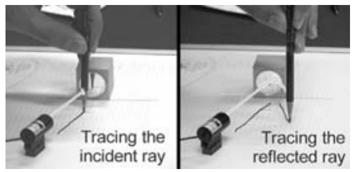
2 Reflections in a mirror

1. Secure a sheet of graph paper to the optics table with the magnetic strips.
2. Draw a line on the paper to mark where you will place a mirror. Place a mirror along this line.
3. Draw a 1-centimeter-long arrow on the graph paper about 3 centimeters away from your line. The arrow should be parallel to the line.
4. Move your head until you can see the reflection of the arrow in the mirror. The image of the arrow appears to be behind the mirror.





5. Hold your pencil straight up with the point on the tip of your arrow. Use the pencil to set the laser beam so it passes right over the tip of your arrow, and hits the mirror.
6. Trace the laser beam using your pencil as a guide. Trace the beam before it hits the mirror and after it hits the mirror.
7. Move the laser so the beam passes over the tip of your arrow from a different angle, but still hits the mirror. Trace the beam with your pencil like you did in steps 5 and 6.



8. The lines you drew represent rays of light before and after they hit the mirror. The **incident ray** shows the light before it hits the mirror. The **reflected ray** shows the path of the light after it bounces off the mirror.
9. Remove the mirror and use a ruler to extend the two reflected rays. They should meet in a point on the other side of the line where the mirror was. This point is where you saw the image of the tip of the arrow. The image is where all rays that leave the same point on an object meet together again.

Safety Tip: NEVER look directly into a laser beam. Some lasers can cause permanent damage to your eyes.

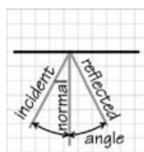
3 Thinking about what you observed

a. Describe how the magnification changed as you changed the distance from the paper to the lens. Does the magnification get larger or smaller with distance?

b. Could you adjust the distance between the paper and the lens to get any magnification you wanted, or was there a point where the lens could no longer create a sharp image?

c. Describe why the image formed by a mirror appears to come from the place where the reflected rays meet. In your answer, refer to the fact that each point on an object is the source of many rays of light. You might want to include a sketch.

d. Pick one pair of incident and reflected rays. Draw a straight line perpendicular to the point where the rays hit the mirror. This perpendicular line is called the **normal** in optics. Use a protractor to measure the angle between the incident ray and the normal, and between the reflected ray and the normal. From your angles, what can you say about the relationship between the direction of the incident ray and the direction of the reflected ray?



Demonstrating the law of reflection

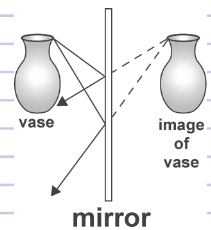
Like light, particles such as bounced objects obey the law of reflection. To demonstrate the law, have one student bounce a tennis ball off the chalkboard to another student. Measure the angle of the path the ball takes relative to the normal. To do this, stretch a string between the incident ray student and the board and the reflective ray student and the board (the two strings will make a "v" with the point of the "v" on the board). Using another string, make a normal to the board. Measure the angles with a large protractor made for chalkboard use.

Example Answers

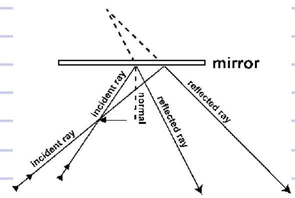
3a. The magnification increased as the distance from the lens to the paper increased. At 3 cm, the magnification was 1.2. At 10.5 cm, the magnification of the lens was 1.8.

3b. If the lens was more than 10.5 cm from the paper, the image was blurred. The maximum magnification I could get was 1.8.

3c. In my drawing, rays of light bounce off the top of the vase and hit the mirror. The black lines are the reflected rays. The dashed lines show that the reflected rays appear to be coming from a point behind the mirror. My eyes assume that the rays traveled in a straight line from that point, so the image of the vase seems to be behind the mirror.



3d. The angle formed by my incident ray and the normal measured 33°. The angle formed by the normal and my reflected ray also measured 33°. The incident ray and the reflected ray travel at the same angle to the normal, but in opposite directions.



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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