# IS SEEING BELIEVING?

## *Directions for Teachers*

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### Synopsis

Students will conduct activities that elicit “contrast effects” and successive contrast effects called “afterimages” in their vision to develop an understanding of the structure and function of the eye as it relates to color perception. They will design experiments that demonstrate how the eye and brain work together to create what we perceive visually.

### Level

Exploration Phase

Concept/Term Introduction, Application Phases

## Getting Ready

See sidebars for additional information regarding preparation of this lab.

## Directions for Setting Up the Lab

### Introduction

1. Locate shoeboxes with lids, colored construction paper, scissors, colored magazines, and microscopes.
2. Cut each square of colored construction paper into a simple shape, such as a triangle. Place each shape into the bottom of each of the shoeboxes, and place the lids back on the boxes.

### E Exploration

#### E-I Exploration I

Purchase index cards and red dots.

#### E-II Exploration II

Photocopy class templates for the class (Figures 6 and 7).

### A Application

If students wish to construct their own template using different colors, they may use the black-white template for a pattern, taping different colors of paper together and cutting holes as appropriate.

## Teacher Background

Vision is a magnificent, specialized sense that gives us the ability to observe movement, shape, perspective, and color in our environment. It has one of the most complicated and sophisticated neural systems of all the senses. Yet, more information is known about this system than any other vertebrate sensory system. Well-developed vision is based on using two eyes to process light information.

### STUDENT PRIOR KNOWLEDGE

Before participating in this activity, students should be able to:

- Explain that white light is composed of all colors of the visible spectrum.
- Describe the anatomy and function of the eye.

### INTEGRATION

*Into the Biology Curriculum*

- Biology II
- AP Biology
- Anatomy and Physiology
- Genetics

*Across the Curriculum*

- Physics
- Psychology

### OBJECTIVES

At the end of this activity students will be able to:

- Explain how “afterimages” are produced.
- Describe why the brain can be “misled” by contrast effects.
- Design and perform experiments to examine contrast effects and afterimages as they relate to the colors of the visible spectrum and the effect of adjacent or surrounding colors on the perception of shades of color.

## LENGTH OF LAB

A suggested time allotment follows:

### Day 1

E-I *10 minutes* — Teacher introduction.

*10 minutes* — Conduct activity.

*10 minutes* — Discuss introduction and activity.

E-II *10 minutes* — Teacher introduction.

*25 minutes* — Conduct activity.

*10 minutes* — Discuss introduction and activity.

### Day 2

C *45 minutes* — Brainstorm to develop hypotheses and designs for experiments.

### Day 3

A *45 minutes* — Conduct experiment and analyze data.

## Teaching Tips

## MATERIALS NEEDED

For the *optional* teacher introduction, you will need the following materials for a class of 24 students:

- 1 prism
- 1 light source

In addition, you will need the following for each group of four students in a class of 24:

- 1 shoebox with lid
- 1 10 x 10-cm piece colored construction paper
- 1 microscope (*optional*)
- 1 pair of scissors (*optional*)
- 1 colored magazine (*optional*)

***—Continued***

Each eye is connected to the brain by an optic nerve that contains numerous nerve fibers. Between the eye and brain at an area known as the optic chiasm, fibers from each optic nerve cross the midline of the brain. As a result, some fibers from each eye make connections with the opposite side of the brain. The fibers going to the left and right sides of the brain are now a combination of the fibers from the optic nerve for each eye, as shown in Figure 1. This new combination of fibers at the optic chiasm is known as the optic tract.

This arrangement allows visual messages from both eyes to reach each side of the brain. Because fibers cross over to the opposite side of the brain, the right hemisphere of your brain "sees" the left half of whatever you are looking at, while the left hemisphere "sees" the right half, as shown in Figure 2. This phenomenon of nerve signals crossing to register information in the opposite side of the brain, and vice versa, occurs also with the sense of touch and the control of movement.

Light reflected from the objects in our visual field enters through the cornea and the lens of the eye. The cornea and lens help to focus a clear image of the visual world on the retina that is composed of three layers: ganglion cells, bipolar cells, and photoreceptors. See Figure 3. Before the light strikes the photoreceptors, it must go through the ganglion and bipolar cell layers.

The photoreceptors are composed of approximately 125 million rods and approximately 7 million cones (Pirenne, 1967) that convert light into electrical signals. Rods are more sensitive to light than cones and respond in dim light, but do not relay color information. Cones are specialized for bright light and supply the brain with information about fine detail and color,

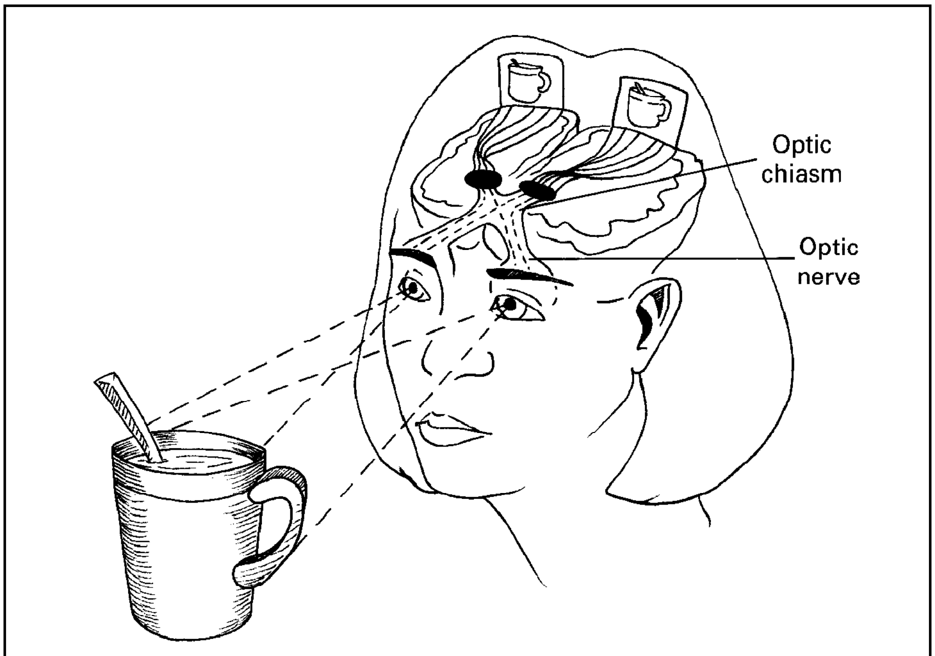


*Figure 1. Note the visual pathway of the left and right eyes and the crossing of some fibers at the optic chiasm.*

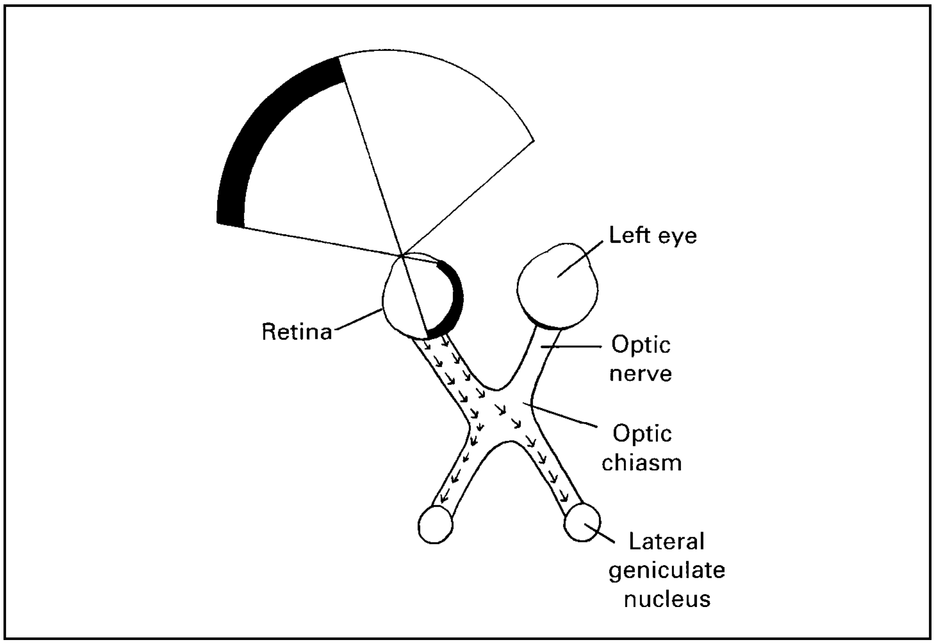


*Figure 2. View of the visual pathway from below. The images received by the lateral half of the retina reach ganglion cells whose fibers do not cross at the optic chiasm. Those detected by the medial half of each retina reach ganglion cells whose fibers do cross at the optic chiasm.*

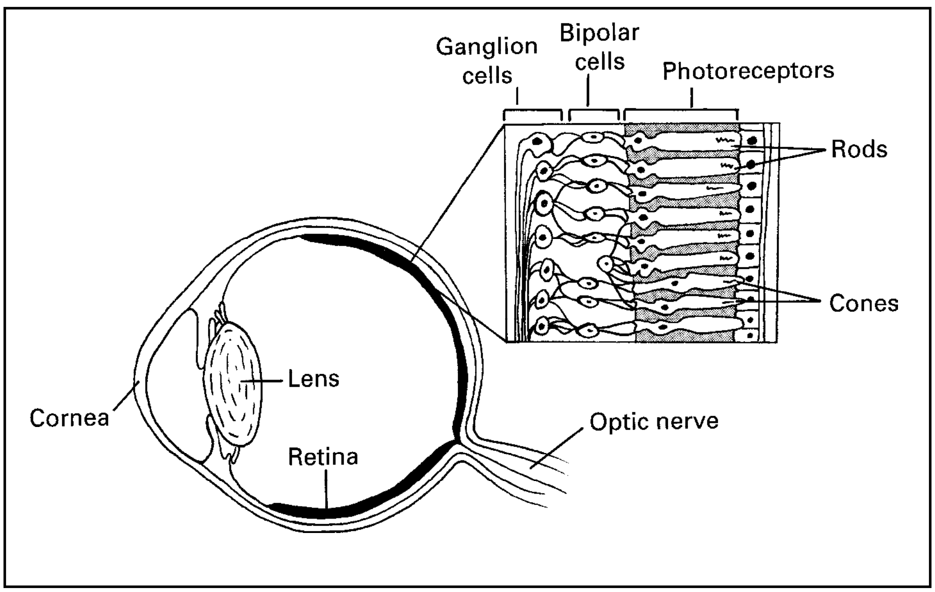


*Figure 3. Diagram of the eye showing the cornea, lens, and retina. The enlarged area shows a section of the retina containing the rods, cones, ganglion cells, and bipolar cells.*

including black and white. The visible spectrum of light contains the following wavelengths: red, orange, yellow, green, blue, indigo, and violet. There are three different kinds of cones that respond to the wavelengths of light. One cone is sensitive to the longer wavelengths and detects reds more readily, while another is sensitive to shorter wavelengths and detects blue more strongly. The third type of cone detects wavelengths in the middle

### MATERIALS —*Continued*

For the ***Exploration*** phase you will need the following for each group of four students in a class of 24:

E-I
- 1 2-cm diameter bright red adhesive dot
- 1 10 x 18-cm white unlined index card
- 1 metric ruler

E-II
- 1 metric ruler
- 1 black-white template
- 1 gray-scale template

C For the ***Concept/Term Introduction*** phase, you will not need any additional materials.

A For the ***Application*** phase, you will need the following in addition to the materials for E-I for each group of four students in a class of 24:

- 1 watch/clock with second timer

### PREPARATION TIME REQUIRED

E-I or E-II

*1 hour* — Purchase and gather materials.

E-II

*10 minutes* — Photocopy templates for the class.

### SAFETY NOTES

Use care with scissors. Do not point them at anyone.

- If the gray template is not used, shades of gray paper are available from paper companies. Alternatively, teachers can acquire paint samples from a local paint store.
- It would be helpful to demonstrate the properties of light prior to beginning the experiment. If a glass prism is available, pass a beam of light from a slide projector through the prism to show that white light is composed of all of the colors of the visible spectrum.
- If a prism is not available, cut a 5 x 5 cm square from a white unlined index card. Cut a slit in the middle of the card about 1 x 15 mm. Place the card into the slide projector. As the light from the slide projector passes through the slit, a color spectrum will be produced.
- Large 2-cm diameter red adhesive dots for the ***Exploration*** activity are available at office supply stores.

range of the visible spectrum and detects green more efficiently. The response of the cones is over a wide range of the visible spectrum with overlap between their sensitivity ranges, especially red and green. See Figure 4. Information from all three types of cones is analyzed by the brain. Working together, these three types of cones detect all the thousands of colors humans can see.

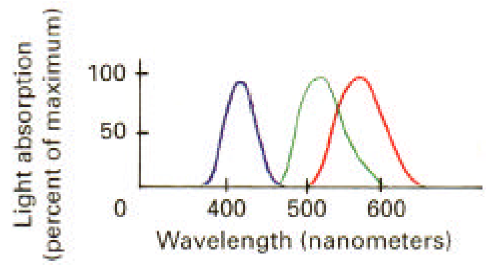


*Figure 4. Absorption spectra for the three types of cones.*

Images appearing on the television screen consist of small dots of red, green, and blue that combine to display any color. In the same way, the receptors for red, green, and blue in the eye can detect any color. Our perception of color is influenced by contrast effects. The perceived brightness of an object depends not only on the intensity of the light from that object at the moment the eye is looking at it, but also on the intensity of the light the eye has received and the intensity of the light around the object (Gregory, 1990).

Color blindness is a visual disorder that occurs when the cones that detect color are not working properly or are completely absent. Although color blindness may be acquired through retinal diseases, the most common cause is genetic, due to a recessive mutation on the X chromosome. Since the defect is on the X chromosome, approximately 8% of the males and only 0.5% of the females in the population experience this disorder (Velle, 1987). Work done by Jeremy Nathans on the arrangement of the red and green pigment genes on the X chromosome offers an explanation for red-green color blindness. He found that color-blind males either do not have the gene for green pigment or possess a hybrid gene composed of parts of the red and green pigment genes. The lack of the gene or the hybridization of the red and green pigment genes contributes to the red-green color-blind condition.

In ***Exploration I***, the phenomenon of seeing an afterimage of an object is experienced. It is the result of the human vision's reliance on contrast effects. Light from the sun appears golden or white, but it actually is composed of all wavelengths of the visible spectrum. As light strikes a red object, we see it as red because the red wavelength of the white light is reflected back, while the other wavelengths in the white light are absorbed. When the red wavelength of light is reflected from the object, it passes through the cornea and lens of the eye, striking the cones. The red-sensitive cones convert the light into an electrical signal that travels through the bipolar cells to the ganglion cell layer. Here, the axons of the ganglion cells form the optic nerve that leads to the brain where the color red is perceived in the visual cortex. The process of staring for 30 seconds at a bright red spot overstimulates and fatigues the red-sensing cones. When the white only side of the paper is viewed immediately after staring at the red dot, white light composed of all the visible wavelengths of light is reflected back to the eye. Although the white light contains the red wavelength of light received by the eye, the red-sensing cones have been overstimulated (Hurvich, 1981) and do not respond to the red wavelength. On the other hand, the cones that sense green have not been overstimulated and absorb the green wavelengths in the white light. The electrical signals from the cones detecting green reach the visual cortex and a green spot is perceived, even though no spot of any color is present on that side of the paper. This spot is called an afterimage.

A question that may arise is whether other colors besides red can cause an afterimage. The answer is *yes*. Afterimages will occur with the following pairs: red/green, yellow/blue, and black/white colors. Red paper will give an afterimage of green, green gives red, yellow gives blue, blue gives yellow, white gives black, and black gives white. Colors that appear to be of two colors such as red-yellow will give a green-blue afterimage (Hurvich, 1981).

In ***Exploration II***, contrast effects will be examined using shades of black and white. The same shade of gray will appear darker when surrounded by a white background and lighter when surrounded by a black background (Hurvich, 1981). The retina and the visual area of the cerebral cortex, working together, adjust the perceived brightness of two adjacent objects. The process of distinguishing between shades of gray begins in the retina where the ganglion cells respond most effectively to contrast in their visual receptive fields. Thus, the greater the contrast between shades of gray, the more stimulated these cells become. This produces a visual perception whereby a gray color appears darker against a white background than it does against a black background. The closer the background color is to the gray color being tested, the less the cells are stimulated. As a result, less contrast is perceived. How the retina and the brain do this has been the subject of much research, but is not yet fully understood.

## Procedure

### Introduction (optional):

You may introduce the activity in one of the following ways:

- Pass light through a prism to show how white light is separated into the colors of the visible spectrum. See Figure 5.

  Ask students why this occurs. Then, turn out the lights in the room and ask the students what they can see. Keep the room dark and repeat the prism demonstration. Ask the students what is visible now within the room. In the dark room have each group of students open up the shoebox on their desk and state the color of the paper shape in

### SUGGESTED MODIFICATIONS FOR STUDENTS WHO ARE EXCEPTIONAL

Below are possible ways to modify this specific activity for students who have special needs, if they have not already developed their own adaptations. General suggestions for modification of activities for students with impairments are found in the AAAS *Barrier-Free in Brief* publications. Refer to p.19 of the introduction of this book for information on ordering **FREE** copies of these publications. Some of these booklets have addresses of agencies that can provide information about obtaining assistive technology, such as Assistive Listening Devices (ALDs); light probes; and talking thermometers, calculators, and clocks.

#### Blind or Visually Impaired

- For students who are blind, prepare raised line drawings of figures and the prism demonstration using a Sewell Drawing Kit. Alternatively, make tactile diagrams of these figures using string or liquid glue.
- Have a partner who is sighted describe all events to the student who is blind.
- A student who is blind can participate as a data recorder for ***Exploration II***.
- Make sure a student who has low vision is seated in a well-lit area. If possible, increase the size of the red dot and the size of the cards for this student.

—*Continued*

**SUGGESTED MODIFICATIONS — Continued**

- A student who is color blind may report a different color after looking at the red dot, but the student should see something. He/she, however, will probably have no difficulty with ***Exploration II***.

**Mobility Impaired**

A student with limited use of his/her arms may need assistance in cutting and holding the card in ***Exploration II***.

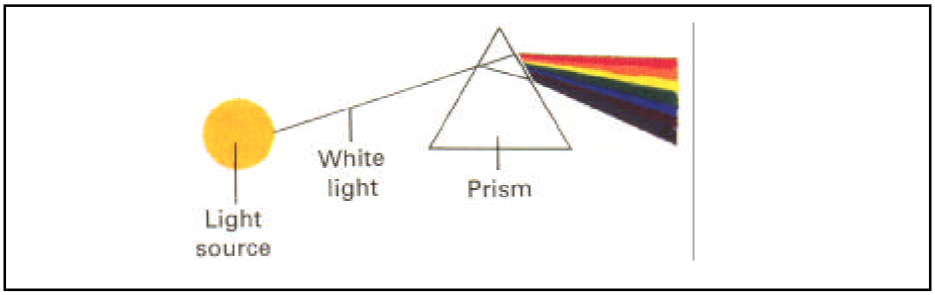


*Figure 5. Dispersion of light to form a spectrum.*

the box while the room is dark. Then, turn on the lights and have the students verify their answers. Ask them what was necessary for them to see the colors. Why was it necessary?

- Have students observe a colored picture from a magazine and state the colors they see. Then have them clip a piece of one of the colors they observed in the picture and observe it under the microscope. Ask them how what they see under the microscope compares with what they saw when they looked at the same portion of the picture in its entirety.

## E Exploration

Conduct one or both of the following ***Exploration*** activities.

### Exploration I

Have each student place a bright red adhesive dot 2 cm in diameter in the center of a 10 x 18 cm white, unlined index card. Instruct them to hold the card so that the red dot is visible, and then to move the card toward their eyes until it is about 20 cm away and fills most of their visual field. They should hold the card very still and stare at the red dot for approximately one minute. After one minute, each student should flip the card over and look at the side without the dot and write down what he/she sees. After all students in the class have completed the activity, the results should be shared. You may wish to ask students the following questions:

- What did you see when you flipped the card over?
- Why did this occur?
- What structures of the eye were involved?
- How does the nervous system perceive a colored object that is not really there?
- What color did you see? Can you explain why?
- Did anyone see a different color?
- If the shade of red were changed on the index card, would the dot you saw on the other side of the card be a different shade of the color you perceived when the card was flipped?

## Exploration II

In this activity, students place the same shade of gray paper behind the two holes of the black-white template (Figure 6). Three different shades of gray paper are found in the gray-scale template (Figure 7).

A suggested way for students to proceed with this activity follows:

1. Cut out the holes of the black-white template.
2. Cut the six rectangles from the gray-scale template with scissors.
3. Lightly mark each piece of gray paper in one corner with a number for identification: light gray with a “1”, medium gray with a “2”, and dark gray with a “3”.
4. Designate one member of the team to serve as the experimenter, one as the data recorder, and one as the subject. Team members should take turns in each role. The subject should turn his/her back to the table while the experimenter sets up trial number 1.
5. The experimenter should select two shades of gray paper and place one color behind each hole of the black-white template, so that a shade of gray paper shows through each of the two holes. The gray paper should show only through the holes and not extend beyond the edges of the black-white template. Several combinations of grays should be tried. For example, place gray shade 1 under the black, and gray shade 2 under the white. Also be certain to include three trials where each shade of gray is placed under BOTH holes.

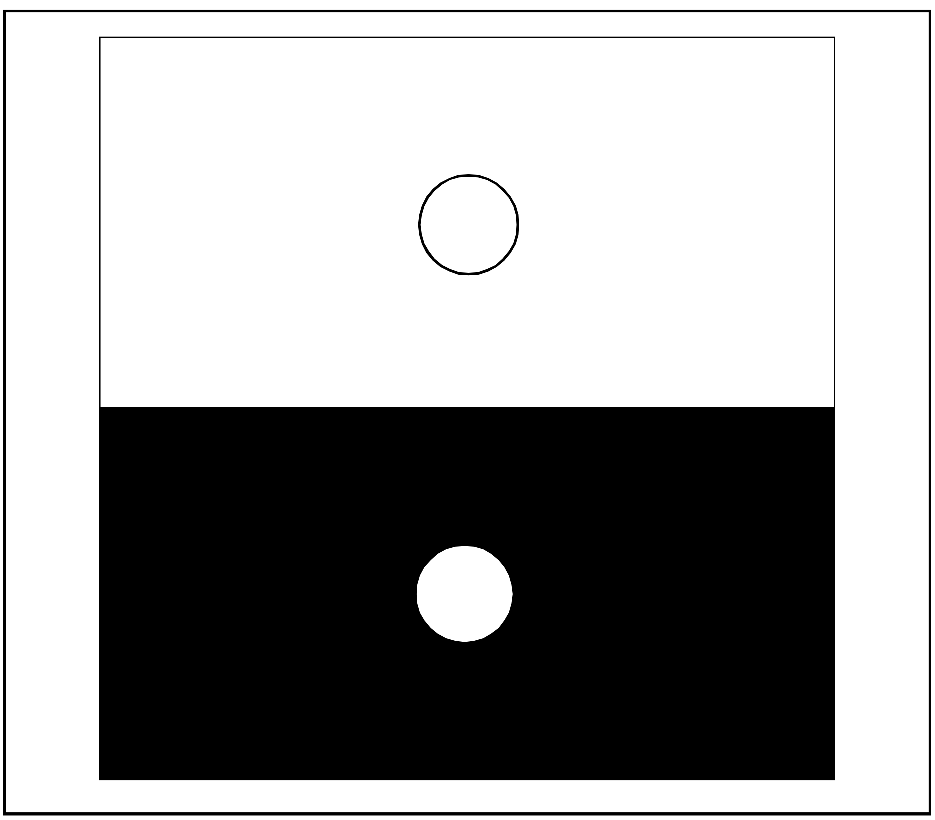

*Figure 6. Black-white template.*

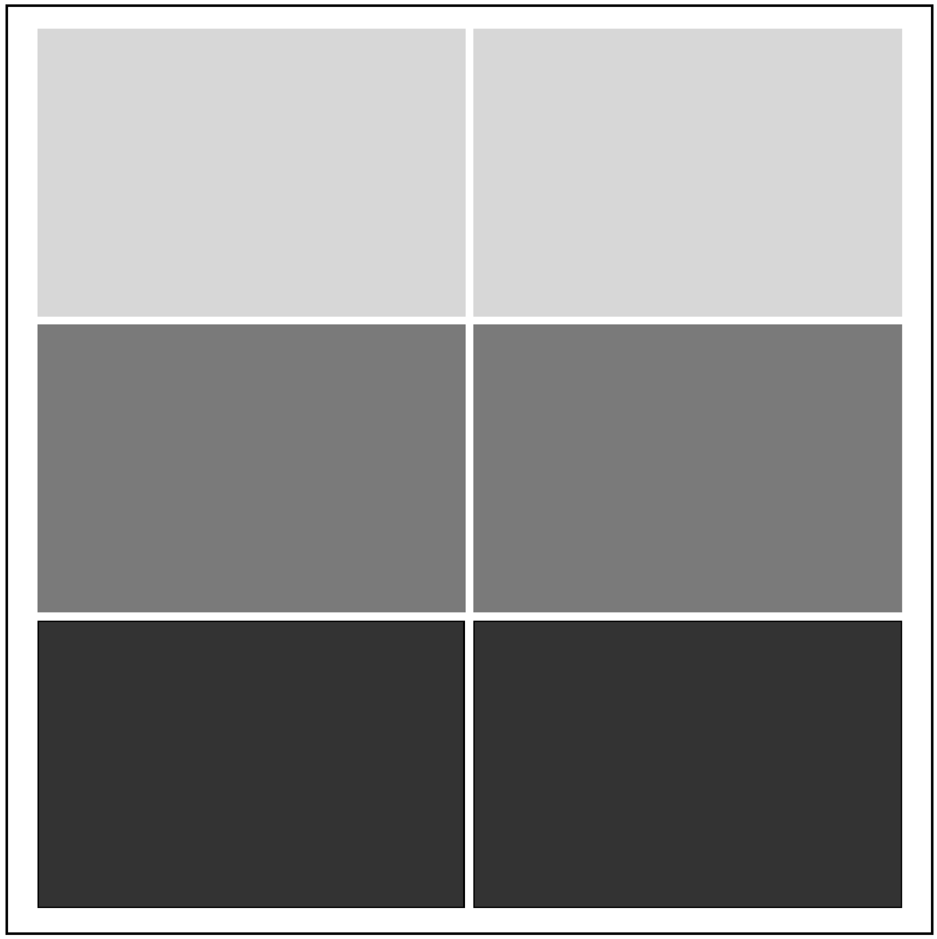

*Figure 7. Gray-scale template.*

6. During the trials, the subject should stand or sit at least one meter away when observing the gray papers through the template holes. For each trial, have the subject indicate which gray is darker, the one on the white side of the template or the one on the black side.
7. The data recorder should record the responses in a data chart similar to the following example:
8. Place only the data with incorrect responses for trials on the chalkboard, overhead projector, or wall chart.

   Have students examine the class data on the chalkboard and determine circumstances under which most of the students had errors.

Sample Data Chart

| Shade Under White | # Correct | # Incorrect | Shade Under Black | # Correct | # Incorrect |
|---|---|---|---|---|---|
| 1<br>2<br>3 | | | 1<br>2<br>3 | | |
| 1<br>2<br>3 | | | 1<br>2<br>3 | | |
| 1<br>2<br>3 | | | 1<br>2<br>3 | | |
| 1<br>2<br>3 | | | 1<br>2<br>3 | | |

## C Concept/Term Introduction

After they have conducted their explorations, present students with information and terms describing the anatomy and physiology of the human eye. Show students where the visual cortex is located in the cerebrum and how information from the rods and cones travels, via the optic nerve, to the visual cortex. See Figure 1. Be sure to include a discussion of the function of the rods and cones, ganglion cells, and color blindness. Introduce the terms color perception, afterimage, and contrast effects. Students should relate these to the ***Exploration*** done by the class.

## A Application

With the information from the ***Exploration*** and ***Concept/Term Introduction*** phases of this activity, students should work in groups to design and conduct experiments to learn more about color perception. Students should quantify their data where possible. Afterwards, each group should share its results with other members of the class.

Suggested questions students may wish to investigate include the following:

- Can other colors, such as green or blue, cause an afterimage?
- If the color observed is a mixture of two colors, how will this affect the afterimage?
- Does the color of the afterimage change with the shade of red?
- How is color perception affected by color blindness?
- Do animals see color? If so, how would one design an experiment to determine if they were able to perceive color?
- Is there a relationship between the time the dot is stared at and the intensity of the afterimage color?

**SAMPLE HYPOTHESIS**

If the red dot on the white background is stared at for two minutes instead of one minute, it will take longer for the afterimage to disappear from view.

**SAMPLE PROCEDURE**

This may be done in groups of four. One member of the group may be the subject; one, the card holder; one, the data recorder; and one, the time keeper.

1. Prepare a card with a red dot as done in ***Exploration I***.
2. The subject should keep his/her eyes closed while the card holder positions the card so that the red dot is in the visual field and approximately 20 cm away from the subject's eyes. The card should be held very still.
3. The time keeper should indicate to the subject to open his/her eyes and stare at the red dot. After one minute, the time keeper should tell the subject to flip the card over and look at the side without the dot.
4. The subject should stare at the white side of the card and indicate when the afterimage is first seen and when it is no longer visible. The time keeper should note the elapsed time and the data recorder should record this time.
5. After five minutes, Steps 2 to 4 should be repeated. This time, however, the subject should stare at the red dot for two minutes.

In the sidebar is a sample hypothesis and procedure that students might derive related to this activity. This example has been included as a suggested outcome of the activity and is not meant to be given to the students. Students should develop their own hypotheses and procedures. Make sure they understand that there is not just one correct hypothesis and procedure.

## Answers to Questions in "Directions for Students"

### C Concept/Term Introduction

#### Focus Questions

1. Eye, brain, and optic nerve.
2. The light on the object, the light received by the eye, and the time of exposure.
3. Nothing would be seen without light. In colored light, depending upon its intensity, there may still be an afterimage.
4. This effect will occur with other colors, specifically, the antagonistic colors of red/green, yellow/blue, and black/white.
5. Color blindness is most prevalent among males. The cones of the retina are involved in color blindness. A person could be tested for color blindness by showing him/her a colored picture in which the shape of an object is visible only if the person is not color blind.

### A Application

#### Analysis

1–5. Answers will vary depending on experiment students conduct.

## References

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## Suggested Reading

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# IS SEEING BELIEVING?

## *Directions for Students*

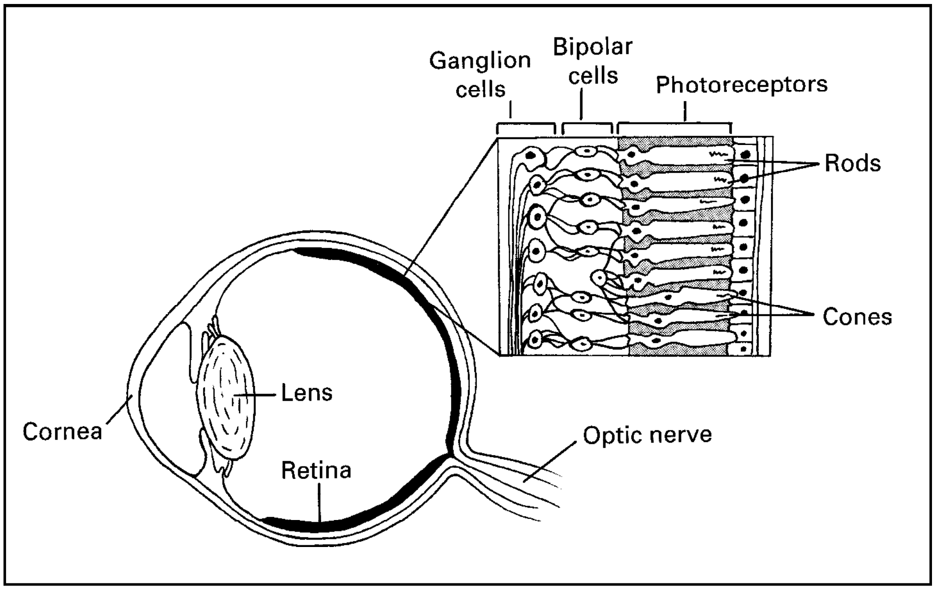


*Figure 1. Diagram of the eye showing the cornea, lens, and retina. The enlarged area shows a section of the retina containing the rods, cones, ganglion cells, and bipolar cells.*

### Introduction

You turn the overhead light off before you go to bed, but when you close your eyes you still see the shape of the light. Someone takes a flash picture of you and all you can see is a giant spot afterwards. The floodlights on the football field go off in the dark night, but you can still see images of the lights. In each case, you don't see the light, but an image of the light. Why does this happen? Is it a protective mechanism? Does it occur in animals? Does your pet dog or cat also see an image of the light when it is gone? What common elements do you find in each situation that could help you explain what is occurring? You will perform one or more activities to help you develop an explanation for what is occurring in each of these instances. Then, you will design experiments about other questions you may have had as you did these activities.

### Procedure

#### E Exploration

After your teacher introduces the activity, you may perform one or two activities while working in groups of three or four. Your teacher will give you instructions and materials to conduct each activity. Group members should take turns performing the activity.

### MATERIALS

Materials will be provided by your teacher and consist of the following per group:

#### Introduction

- 1 shoebox with lid
- 1 10 x 10 cm piece colored construction paper
- 1 microscope (*optional*)
- 1 pair of scissors (*optional*)
- 1 colored magazine (*optional*)

#### E Exploration

**Exploration I**

- 1 2-cm diameter bright red adhesive dot
- 1 10 x 18 cm white unlined index card
- 1 metric ruler

**Exploration II**

- 1 metric ruler
- 1 black-white template
- 1 gray-scale template

### SAFETY NOTES

Use care when using scissors. Do not point them at anyone.

## C Concept/Term Introduction

Discuss what has occurred within your groups. Brainstorm as to what the common elements were in the activity and the introduction and how they affected what occurred. Develop a list of hypotheses to explain what happened. As a group, select one hypothesis to present to the class. Your teacher may give you terminology that will help explain what has occurred. Answer the **Focus Questions** to help you develop an explanation for what has occurred.

**FOCUS QUESTIONS**

1. What components of the nervous system were involved in this activity?
2. What external factors contributed to the results of this activity?
3. What would happen if this activity were done without light? In a colored light?
4. Does the contrast effect apply only to the colors used in the ***Exploration II*** activity, or is the human perception of other colors influenced by adjacent colors?
5. Do you know anyone who is color blind?
   In what sex is it more prevalent? What structure in the eye would be involved in color blindness? How could you test for color blindness?

## A Application

Develop a hypothesis to answer one of the questions that arose as you conducted the ***Exploration*** activity, discussed your results as a class, and answered the **Focus Questions**. Your group may develop a modification of the materials used for the ***Exploration*** to collect data to test your hypothesis about other colors. Decide as a group how to design an experiment to test your hypothesis. Write your procedure in a numbered list. Make sure that your group does the following:

- Writes the question as a hypothesis or in the form of an “if...then” statement.
- Gathers quantifiable data.
- Decides what variable(s) must be controlled, and plans how to control these.

**Teacher approval must be obtained before you begin this activity!**

### Analysis

1. Did your group obtain the results you expected? How do you explain your results in terms of what you learned during group sharing?
2. Draw a concept map to explain your results.
3. How did you express your data quantitatively?
4. If you were to repeat this experiment, what would you do differently?
5. What might have been sources of error in your experiment?

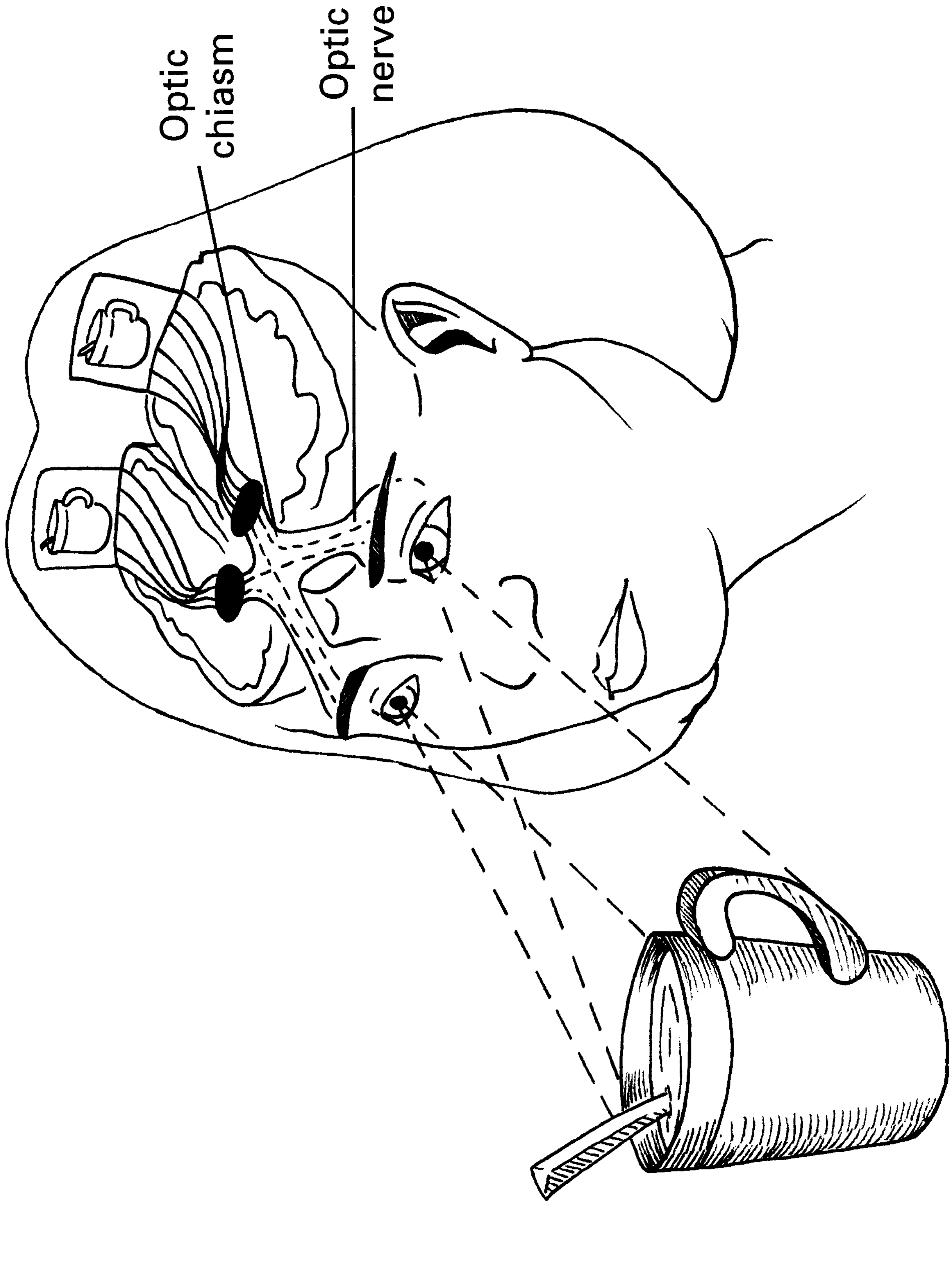


*Figure 1. Note the visual pathway of the left and right eyes and the crossing of some fibers at the optic chiasm.*

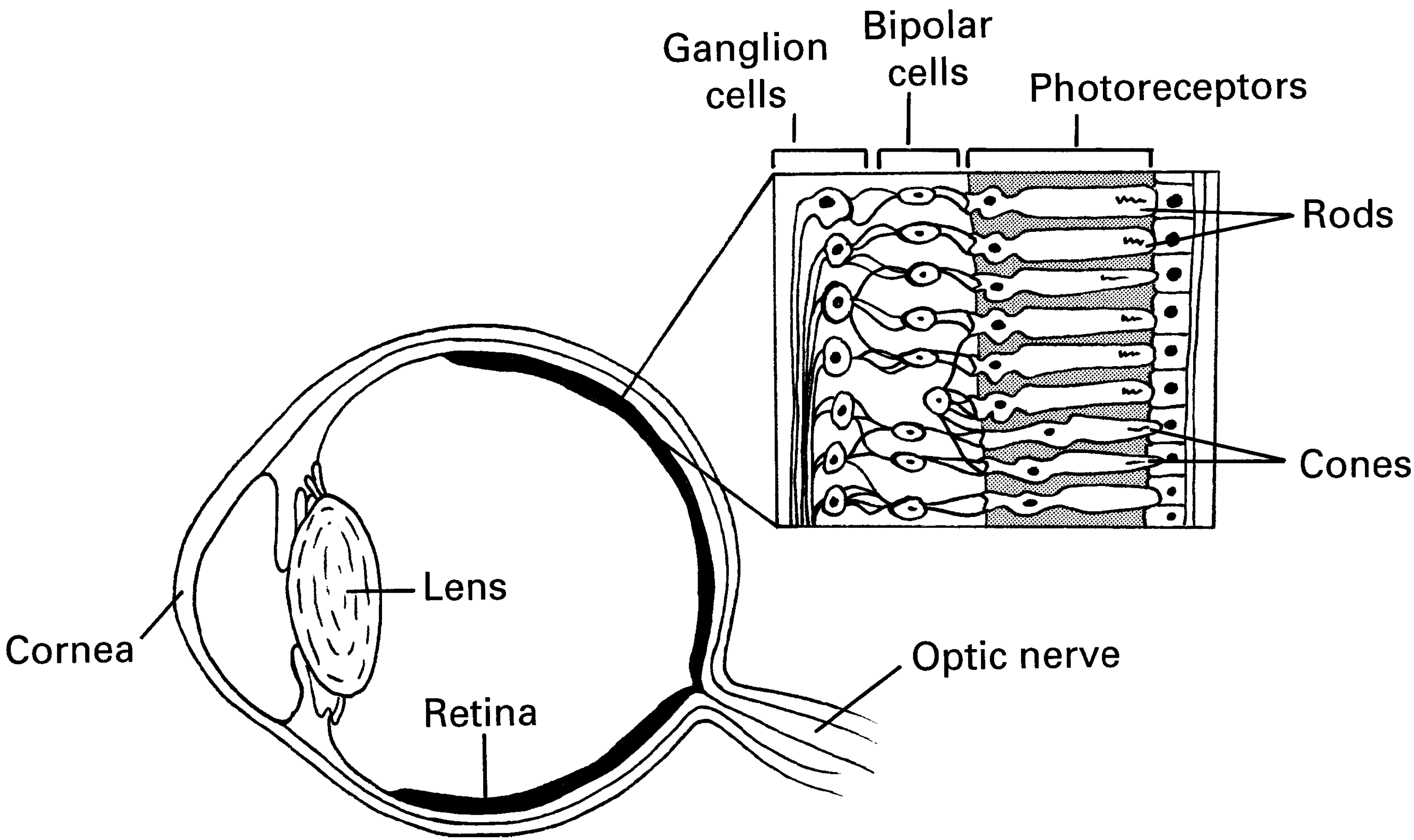


*Figure 3. Diagram of the eye showing the cornea, lens, and retina. The enlarged area shows a section of the retina containing the rods, cones, ganglion cells, and bipolar cells.*

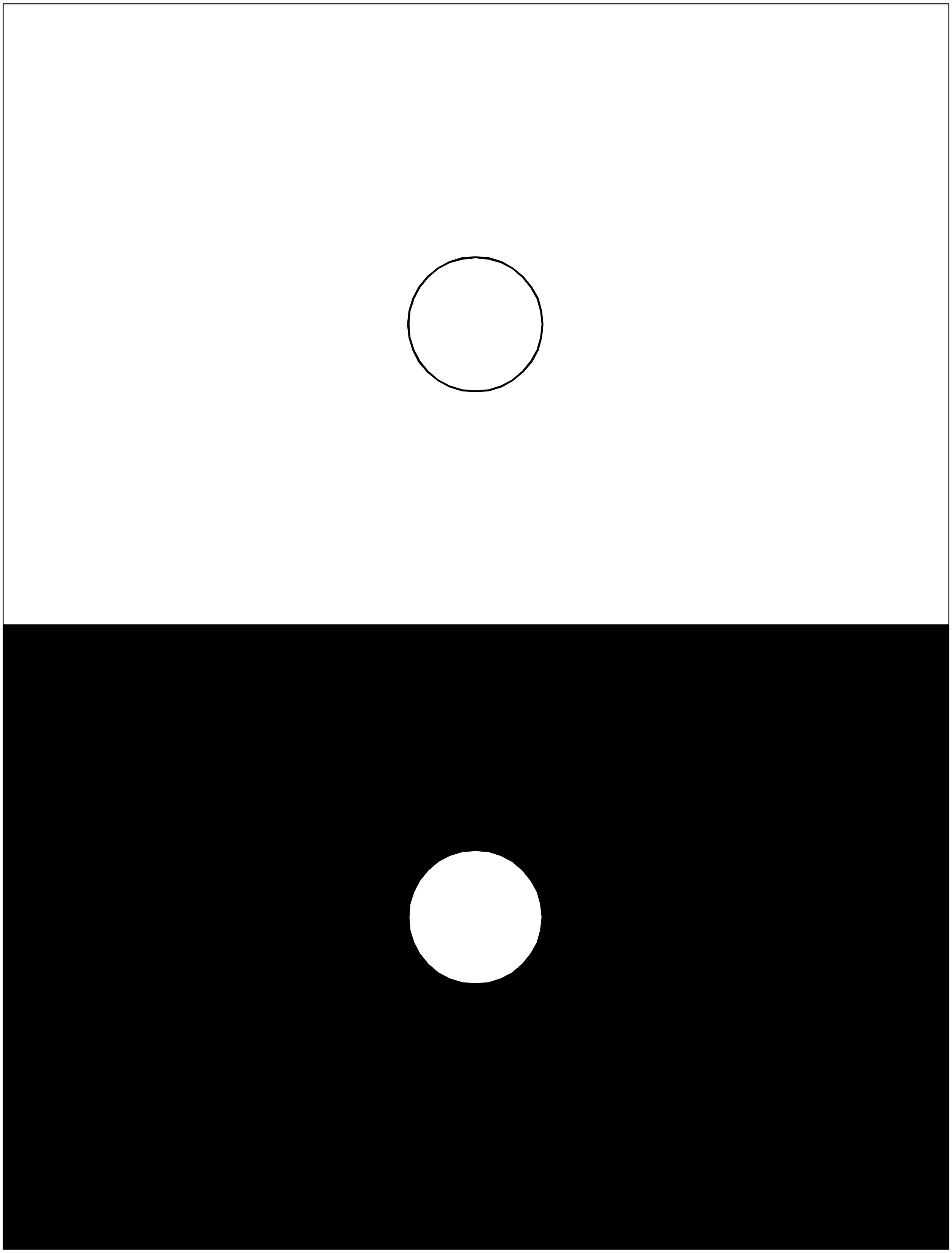

*Figure 6. Black-white template.*

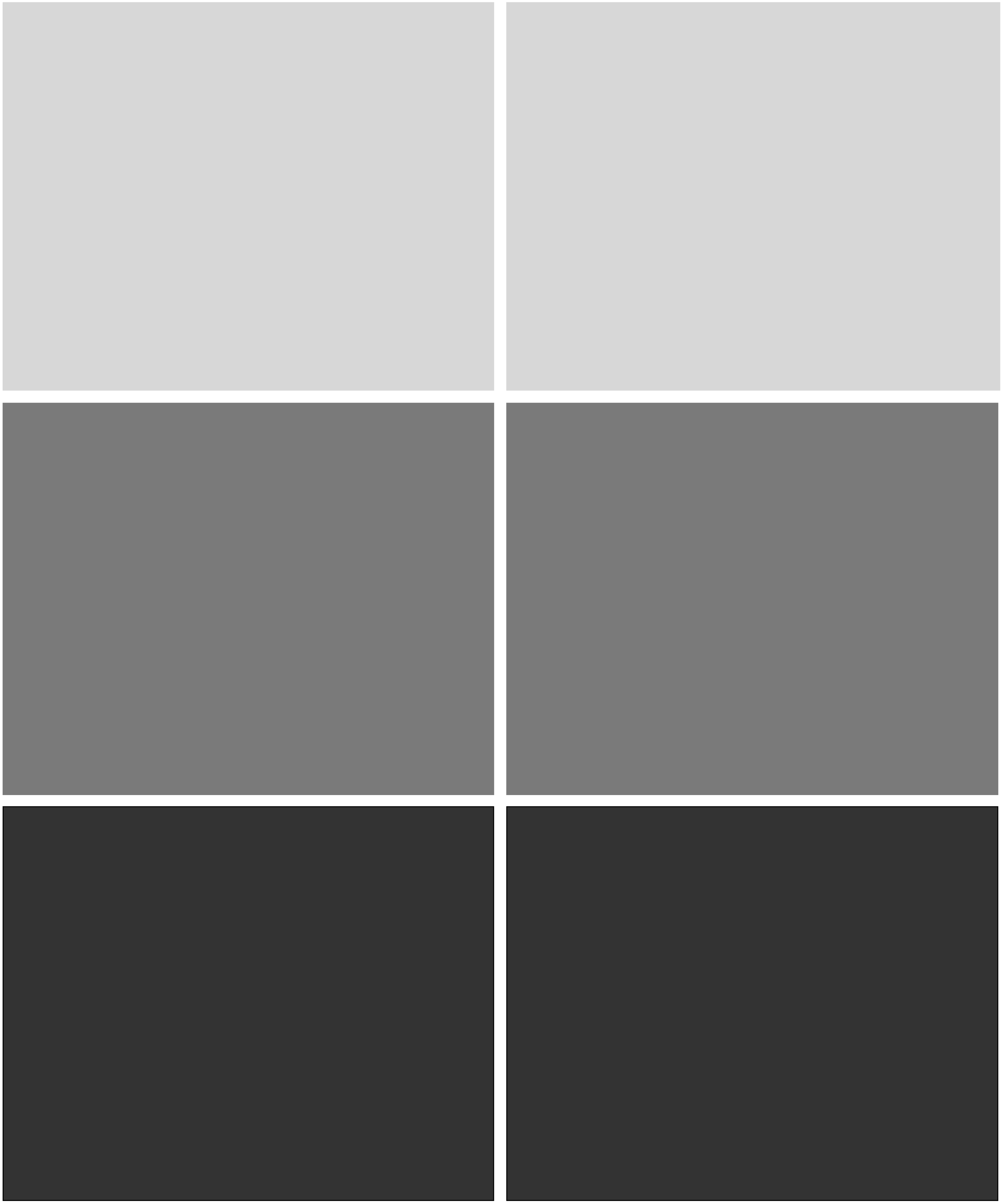

*Figure 7. Gray-scale template.*