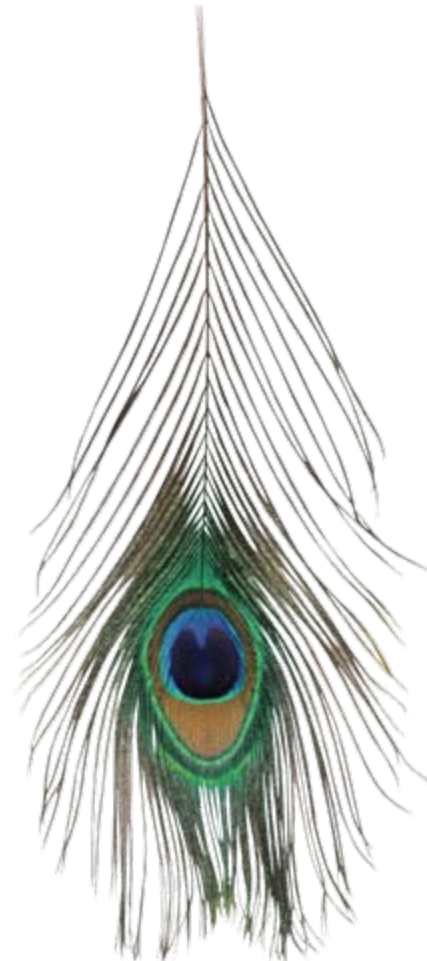


THE BIG IDEA

The wave model of light explains diffraction and interference.

Isaac Newton pictured light as a beam of ultra-tiny material particles. With this model he could explain reflection and refraction. In the eighteenth and nineteenth centuries, this particle model gave way to a wave model of light because waves could explain reflection, refraction, and everything else that was known about light at that time.



31.1 Huygens' Principle



Huygens stated that light waves spreading out from a point source may be regarded as the overlapping of tiny secondary wavelets, and that every point on any wave front may be regarded as a new point source of secondary waves.

31.1 Huygens' Principle

In the late 1600s, a Dutch mathematician-scientist, Christian Huygens, proposed a very interesting idea about light.

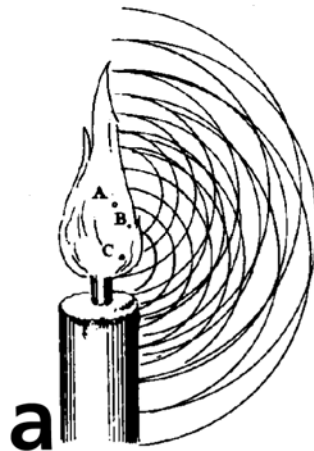
- Light waves spreading out from a point source may be regarded as the overlapping of tiny secondary wavelets.
- Every point on any wave front may be regarded as a new point source of secondary waves.

The idea that wave fronts are made up of tinier wave fronts is called **Huygens' principle**.

31.1 Huygens' Principle

These drawings are from Huygens' book *Treatise on Light*.

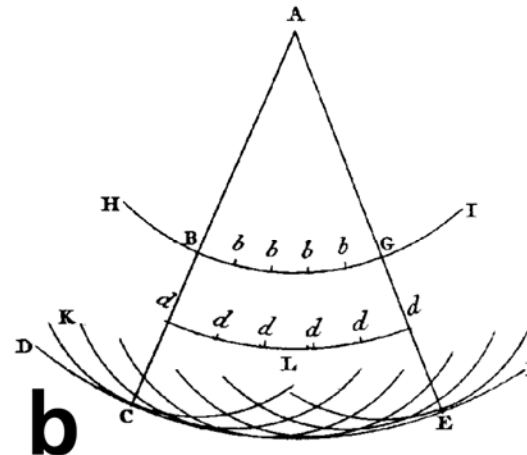
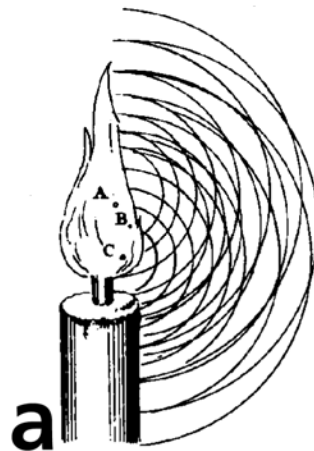
- a. Light from A expands in wave fronts.



31.1 Huygens' Principle

These drawings are from Huygens' book *Treatise on Light*.

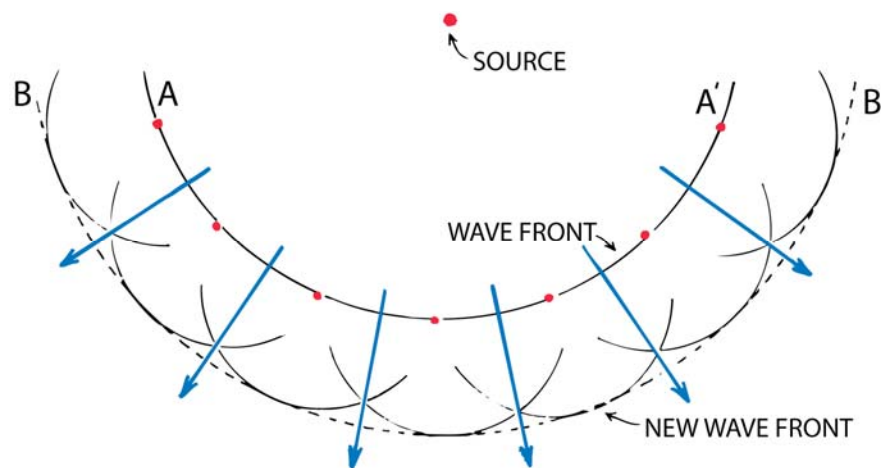
- Light from A expands in wave fronts.
- Every point behaves as if it were a new source of waves.



31.1 Huygens' Principle

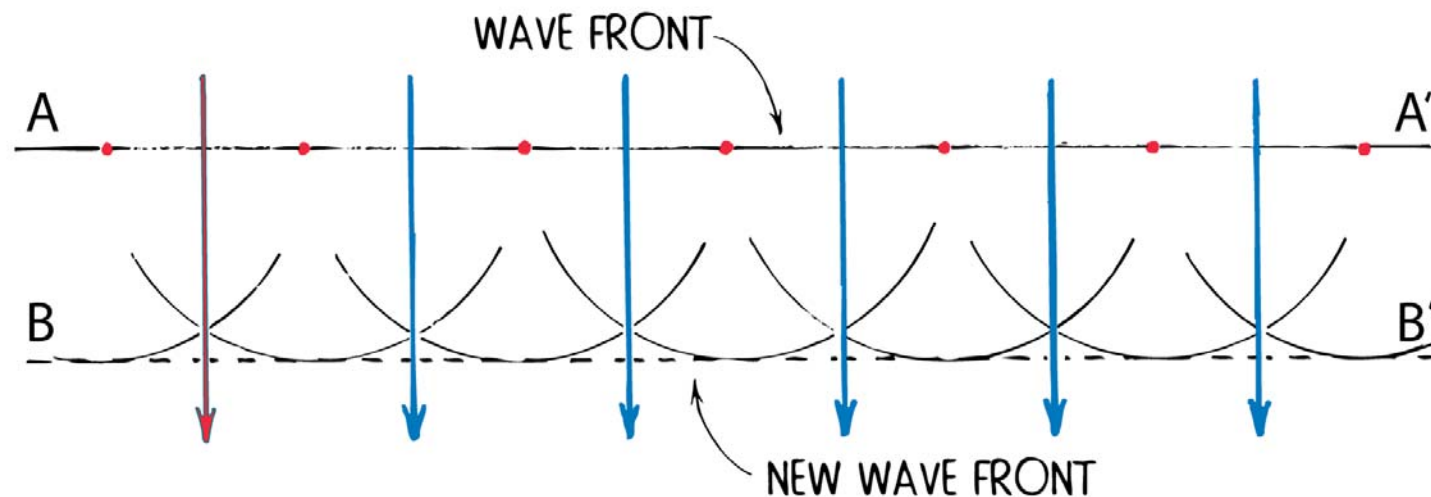
Wave Fronts

Every point along the spherical wave front AA'' is the source of a new wavelet. Only a few of the infinite number of wavelets are shown. The new wave front BB'' can be regarded as a smooth surface enclosing the infinite number of overlapping wavelets started from AA' .



31.1 Huygens' Principle

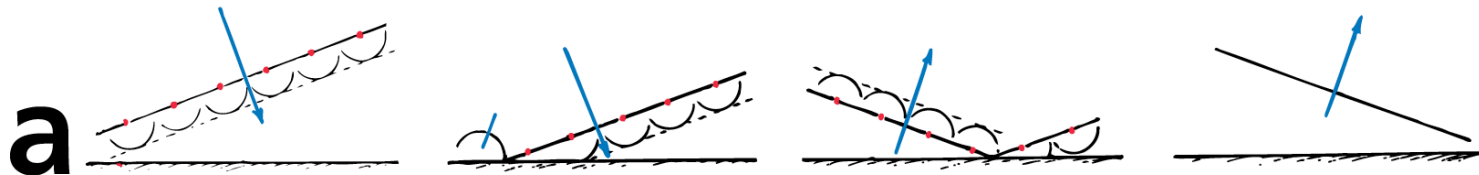
Far away from the source, the wave fronts appear to form a plane.



31.1 Huygens' Principle

Each point along a wave front is the source of a new wave.

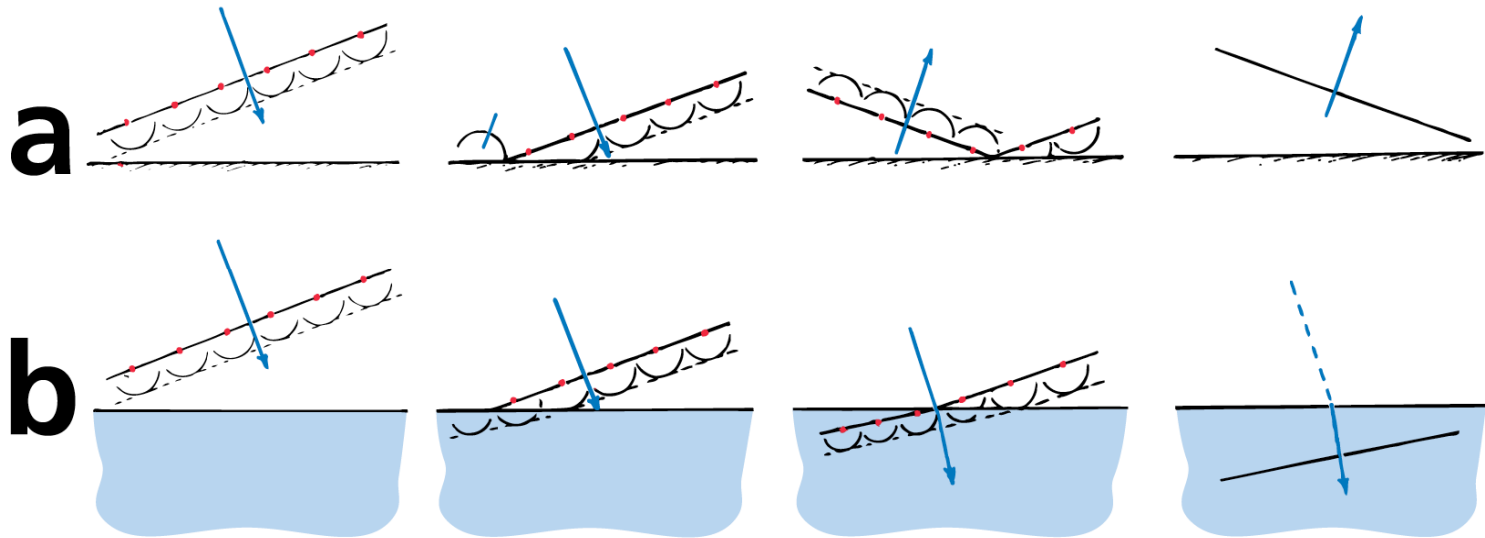
- The law of reflection can be proven using Huygens' principle.



31.1 Huygens' Principle

Each point along a wave front is the source of a new wave.

- The law of reflection can be proven using Huygens' principle.
- Huygens' principle can also illustrate refraction.

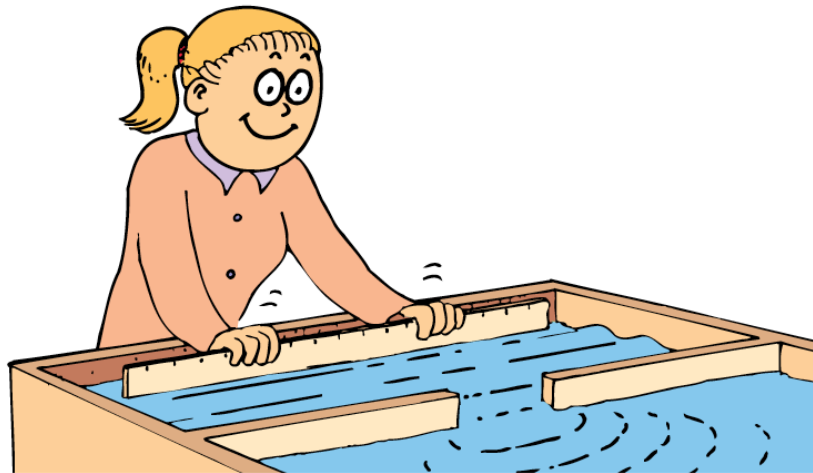


31.1 Huygens' Principle

Huygens' Principle in Water Waves

You can observe Huygens' principle in water waves that are made to pass through a narrow opening.

When the straight wave fronts pass through the opening in a barrier, interesting wave patterns result.



31.1 Huygens' Principle

When the opening is wide, straight wave fronts pass through without change—except at the corners.

At the corners, the wave fronts are bent into the “shadow region” in accord with Huygens' principle.

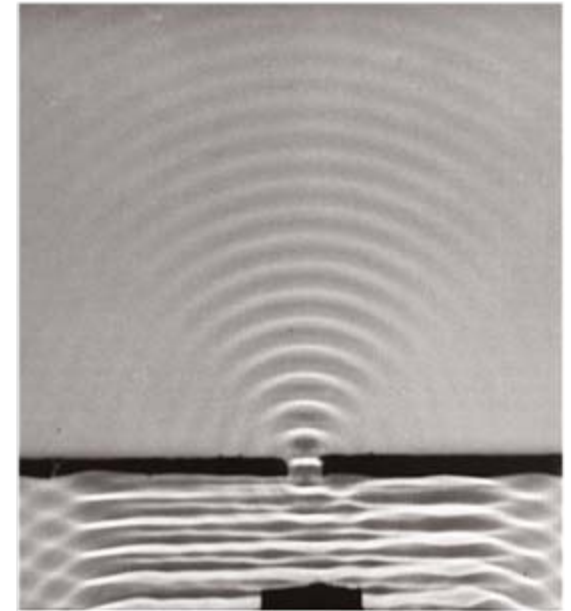
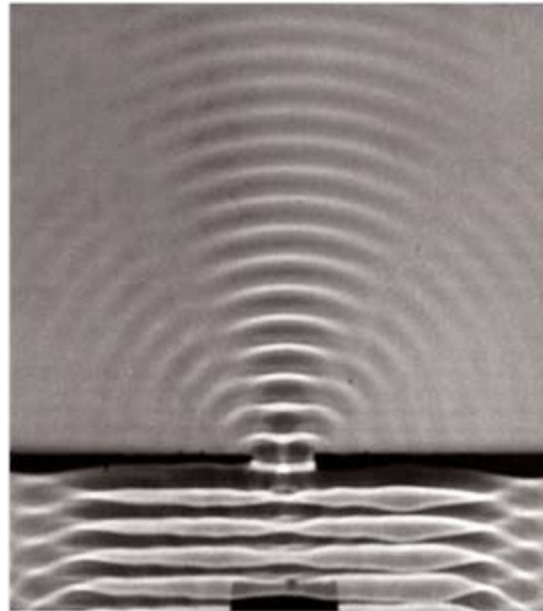
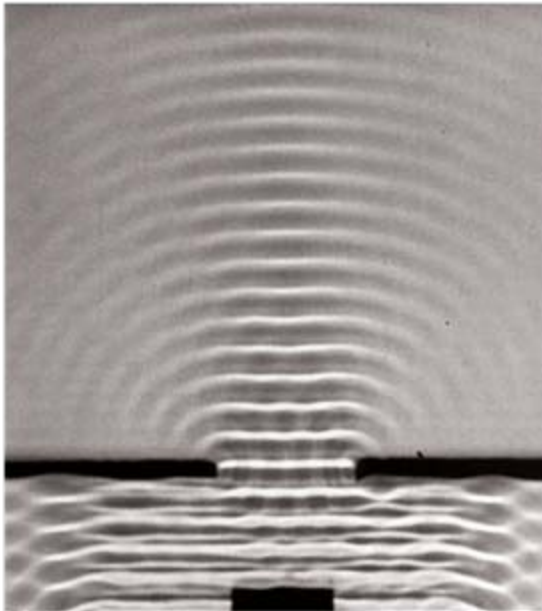
31.1 Huygens' Principle

Narrow the width of the opening and less of the wave gets through.

- Spreading into the shadow region is more pronounced.
- Huygens' idea that every part of a wave front can be regarded as a source of new wavelets becomes quite apparent.
- Circular waves fan out on the other side of the barrier.

31.1 Huygens' Principle

The extent to which the water waves bend depends on the size of the opening.



31.1 Huygens' Principle

**CONCEPT
CHECK**

What did Huygens state about light waves?

31.2 Diffraction



The extent of diffraction depends on the relative size of the wavelength compared with the size of the obstruction that casts the shadow.

31.2 Diffraction

Any bending of a wave by means other than reflection or refraction is called **diffraction**.

When the opening is wide compared with the wavelength, the spreading effect is small.

As the opening becomes narrower, the diffraction of waves becomes more pronounced.

31.2 Diffraction

Diffraction of Visible Light

When light passes through an opening that is large compared with the wavelength, it casts a rather sharp shadow.

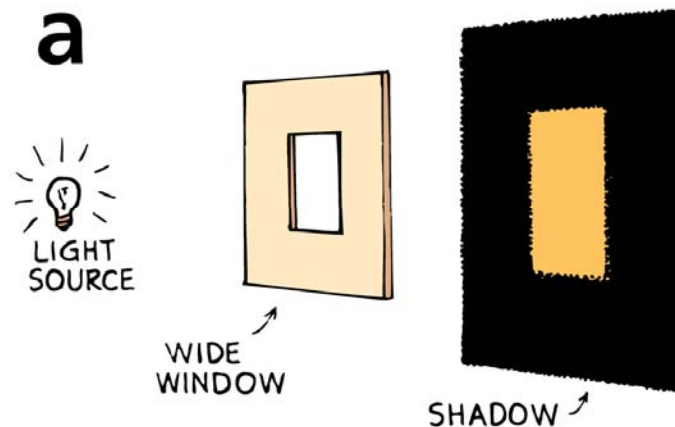
When light passes through a small opening, such as a thin slit in a piece of opaque material, it casts a fuzzy shadow.

The light fans out like the water through the narrow opening.

The light is diffracted by the thin slit.

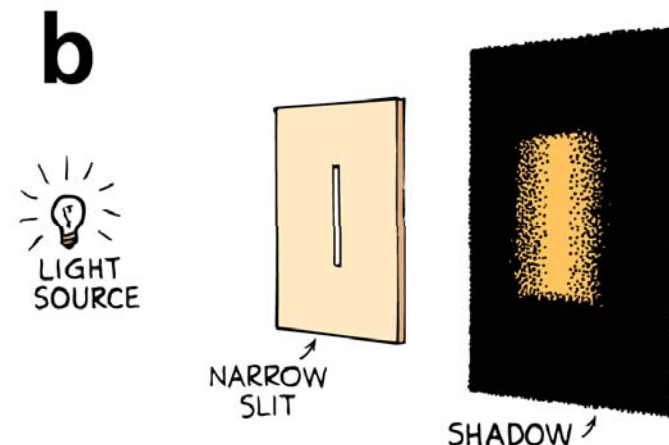
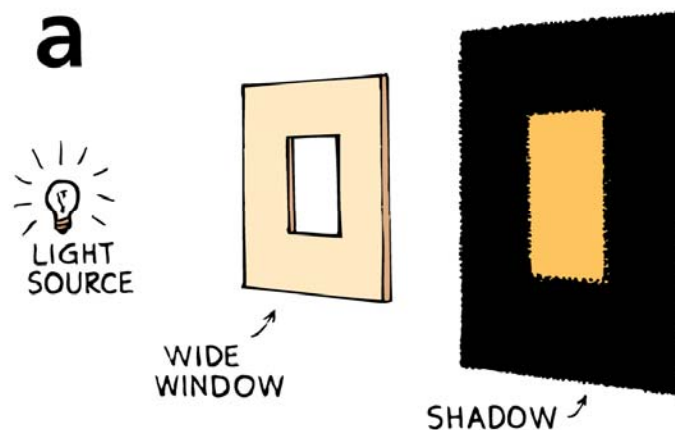
31.2 Diffraction

- a. Light casts a sharp shadow with some fuzziness at its edges when the opening is large compared with the wavelength.



31.2 Diffraction

- a. Light casts a sharp shadow with some fuzziness at its edges when the opening is large compared with the wavelength.
- b. Because of diffraction, it casts a fuzzier shadow when the opening is extremely narrow.



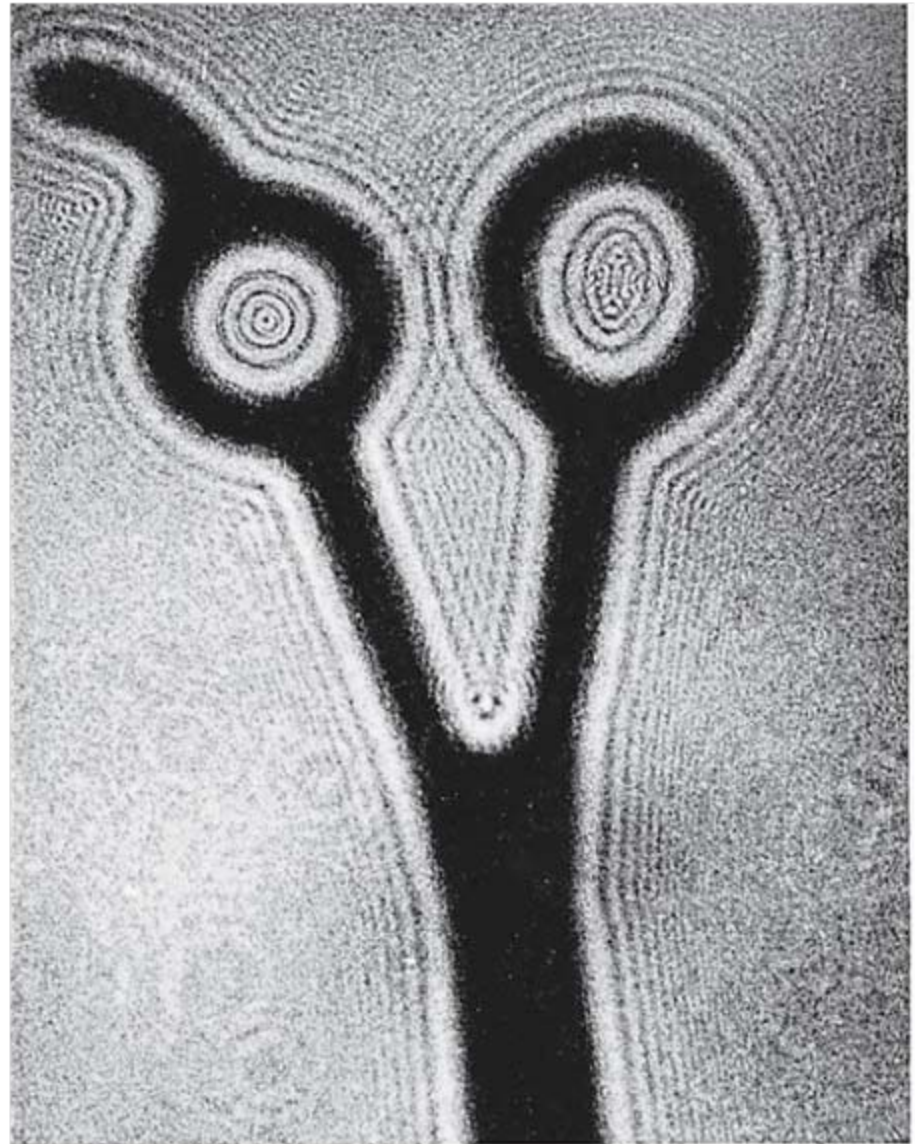
31.2 Diffraction

Diffraction is not confined to the spreading of light through narrow slits or other openings.

- Diffraction occurs to some degree for all shadows. Even the sharpest shadow is blurred at the edge.
- When light is of a single color, diffraction can produce sharp *diffraction fringes* at the edge of the shadow.
- In white light, the fringes merge together to create a fuzzy blur at the edge of a shadow.

31.2 Diffraction

Diffraction fringes around the scissors are evident in the shadows of laser light, which is of a single frequency.



31.2 Diffraction

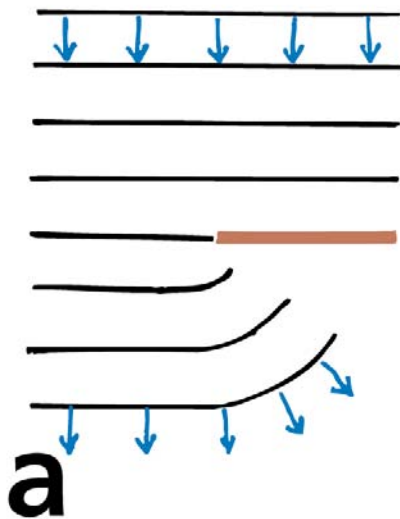
Factors That Affect Diffraction

When the wavelength is long compared with the obstruction, the wave diffracts more.

- Long waves are better at filling in shadows.
- Foghorns emit low-frequency (long-wavelength) sound waves—to fill in “blind spots.”
- AM radio waves are very long compared with the size of most objects in their path. They diffract around buildings and reach more places than shorter wavelengths.

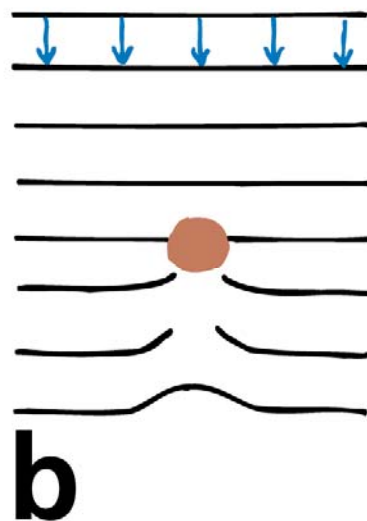
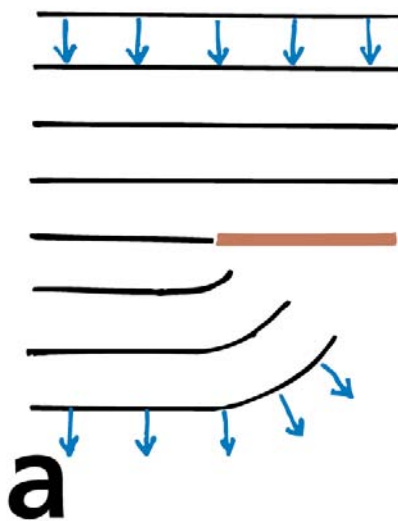
31.2 Diffraction

- a. Waves tend to spread into the shadow region.



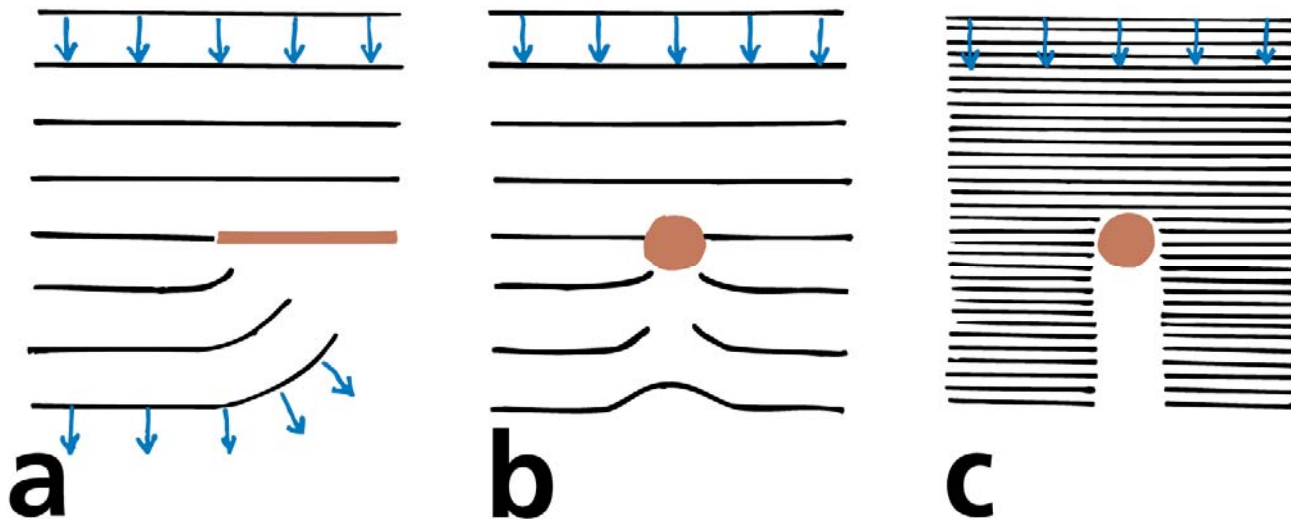
31.2 Diffraction

- a. Waves tend to spread into the shadow region.
- b. When the wavelength is about the size of the object, the shadow is soon filled in.



31.2 Diffraction

- a. Waves tend to spread into the shadow region.
- b. When the wavelength is about the size of the object, the shadow is soon filled in.
- c. When the wavelength is short compared with the width of the object, a sharper shadow is cast.



31.2 Diffraction

Diffraction of Radio and TV Waves

FM radio waves have shorter wavelengths than AM waves do, so they don't diffract as much around buildings.

- Many places have poor FM reception but clear AM stations.
- TV waves behave much like FM waves.
- Both FM and TV transmission are “line of sight”—obstacles can cause reception problems.

Cable TV avoids “line-of-sight” transmission problems by sending the signal through a cable or optical fiber rather than “over the air.” Satellite TV is line of sight, but normally without a mountain between you and the satellite!



31.2 Diffraction

Diffraction in Microscopy

If an object under a microscope is the same size as the wavelength of light, the image of the object will be blurred by diffraction.

If the object is smaller than the wavelength of light, no structure can be seen.

No amount of magnification can defeat this fundamental diffraction limit.

31.2 Diffraction

To see smaller details, you have to use shorter wavelengths:

- A beam of electrons has a wavelength that can be a thousand times shorter than the wavelengths of visible light.
- Microscopes that use beams of electrons to illuminate tiny things are called *electron microscopes*.
- The diffraction limit of an electron microscope is much less than that of an optical microscope.

31.2 Diffraction

Diffraction and Dolphins

The echoes of long-wavelength sound give the dolphin an overall image of objects in its surroundings.

To examine more detail, the dolphin emits sounds of shorter wavelengths.



31.2 Diffraction

With these sound waves, skin, muscle, and fat are almost transparent to dolphins, but bones, teeth, and gas-filled cavities are clearly apparent.

Physical evidence of cancers, tumors, heart attacks, and even emotional states can all be “seen” by the dolphins.

The dolphin has always done naturally what humans in the medical field have only recently been able to do with ultrasound devices.

31.2 Diffraction

think!

Why is blue light used to view tiny objects in an optical microscope?

31.2 Diffraction

think!

Why is blue light used to view tiny objects in an optical microscope?

Answer:

Blue light has a shorter wavelength than most of the other wavelengths of visible light, so there's less diffraction. More details of the object will be visible under blue light.

31.2 Diffraction

**CONCEPT
CHECK**

What affects the extent of diffraction?

31.3 Interference



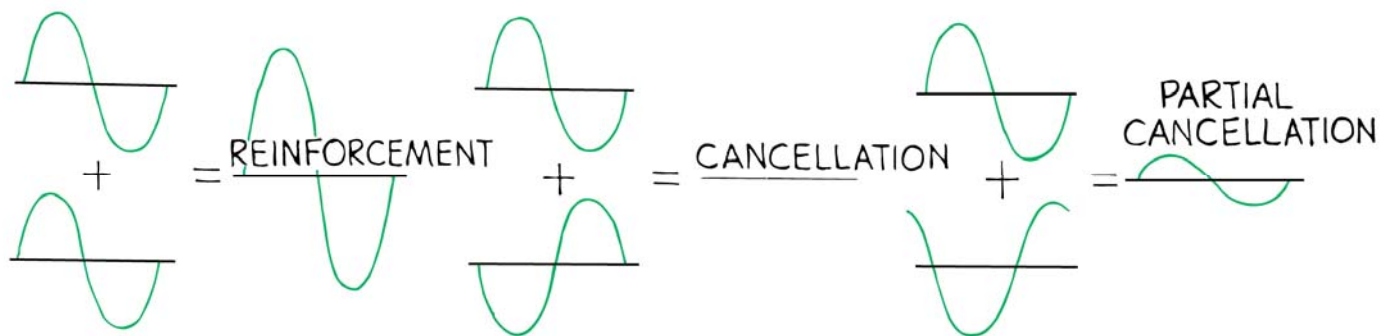
Within an interference pattern, wave amplitudes may be increased, decreased, or neutralized.

31.3 Interference

When two sets of waves cross each other they produce what is called an *interference pattern*.

When the crest of one wave overlaps the crest of another, they add together; this is *constructive interference*.

When the crest of one wave overlaps the trough of another, their individual effects are reduced; this is *destructive interference*.



31.3 Interference

Water waves can be produced in shallow tanks of water known as *ripple tanks*. The wave patterns are photographed from above.

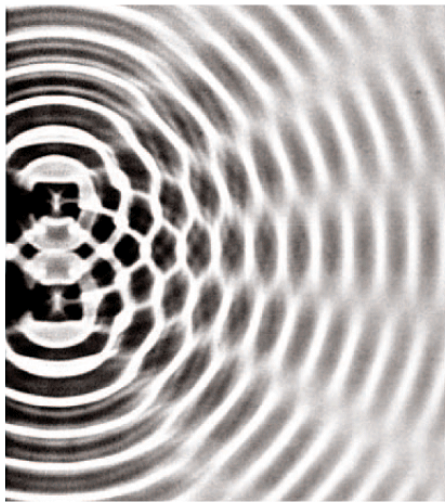
- Regions of destructive interference make gray “spokes.”
- Regions of constructive interference make dark and light stripes.

The greater the frequency of the vibrations, the closer together the stripes (and the shorter the wavelength).

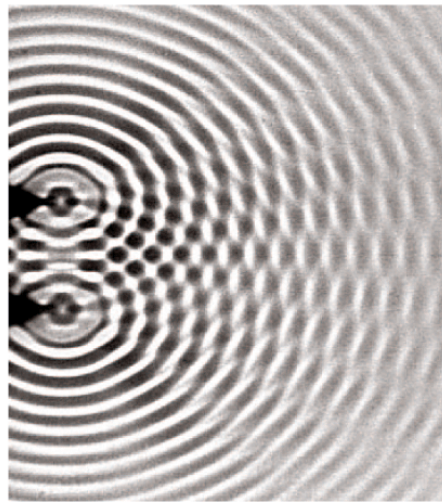
The number of regions of destructive interference depends on the wavelength and on the distance between the wave sources.

31.3 Interference

a–b. The separation between the sources is the same but the wavelength in (b) is shorter than the wavelength in (a).



a

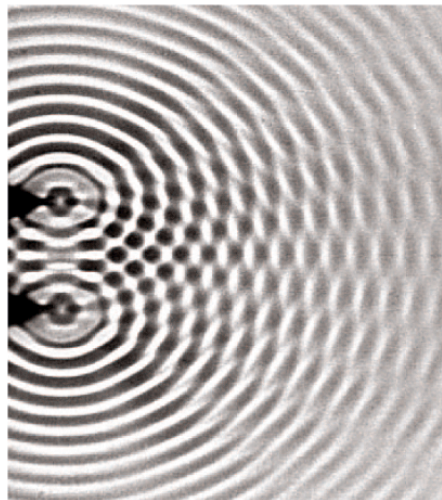
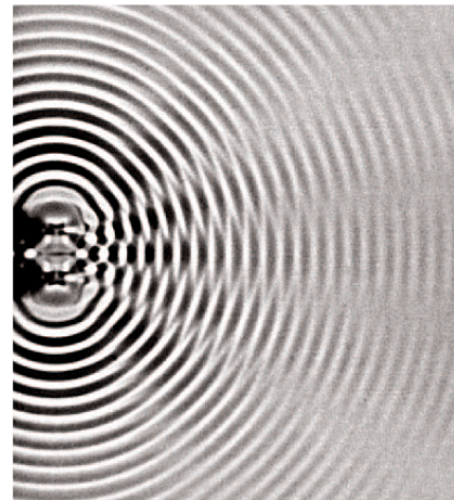


b

31.3 Interference

a–b. The separation between the sources is the same but the wavelength in (b) is shorter than the wavelength in (a).

b–c. The wavelengths are the same but the sources are closer together in (c) than in (b).

**b****c**

31.3 Interference

**CONCEPT:
CHECK**

How does interference affect wave amplitudes?

31.4 Young's Interference Experiment



Young's interference experiment convincingly demonstrated the wave nature of light originally proposed by Huygens.

31.4 Young's Interference Experiment

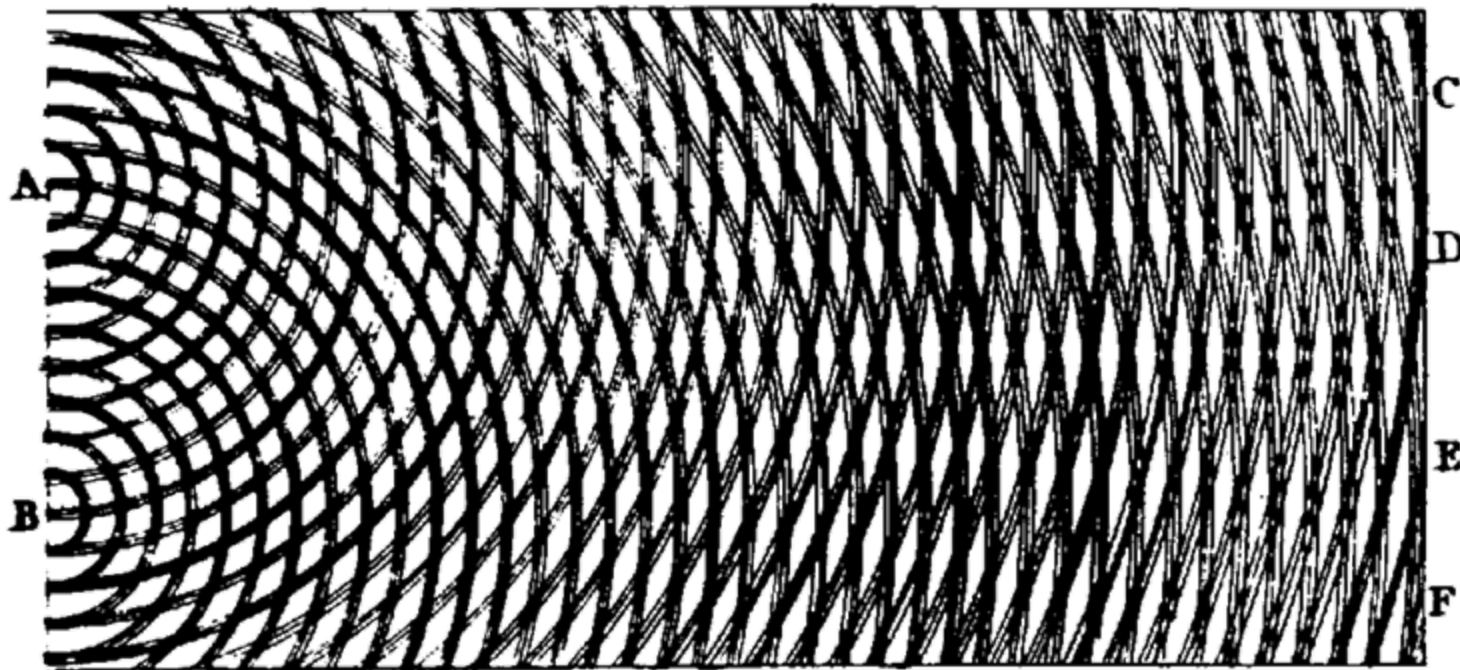
British physicist and physician Thomas Young discovered that when **monochromatic** light—light of a single color—passed through two closely spaced pinholes, fringes of brightness and darkness were produced on a screen behind.

He realized that the bright fringes resulted from light waves from both holes arriving crest to crest (constructive interference—more light).

The dark areas resulted from light waves arriving trough to crest (destructive interference—no light).

31.4 Young's Interference Experiment

In Young's original drawing of a two-source interference pattern, the dark circles represent wave crests; the white spaces between the crests represent troughs. Letters *C*, *D*, *E*, and *F* mark regions of destructive interference.



31.4 Young's Interference Experiment

Double Slit Experiment

Young's experiment is now done with two closely spaced slits instead of pinholes, so the fringes are straight lines.

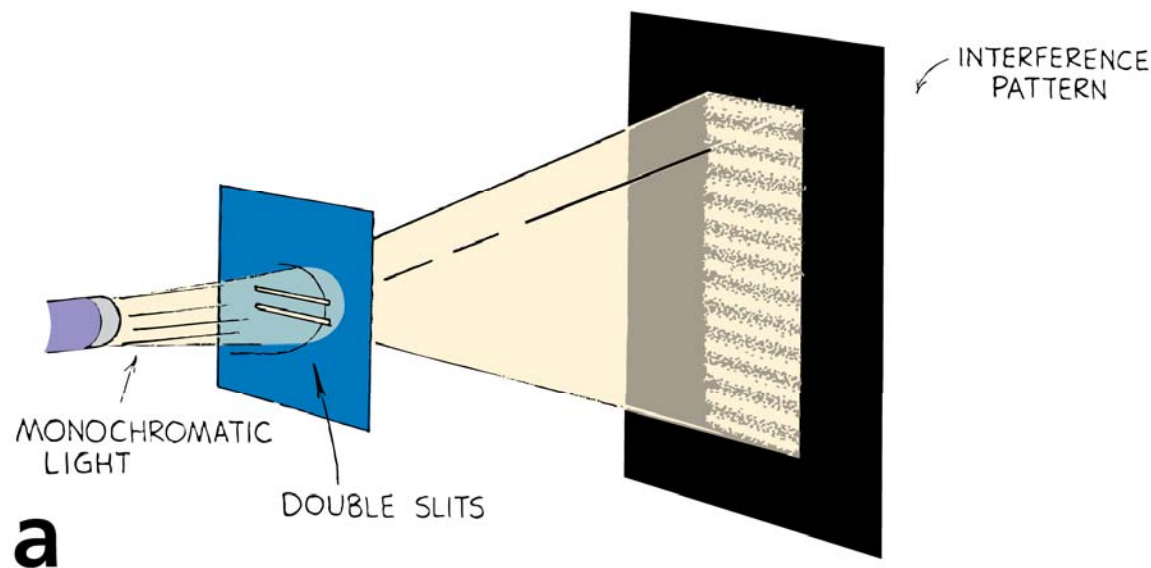
A bright fringe occurs when waves from both slits arrive in phase.

Dark regions occur when waves arrive out of phase.

31.4 Young's Interference Experiment

Young's experiment demonstrated the wave nature of light.

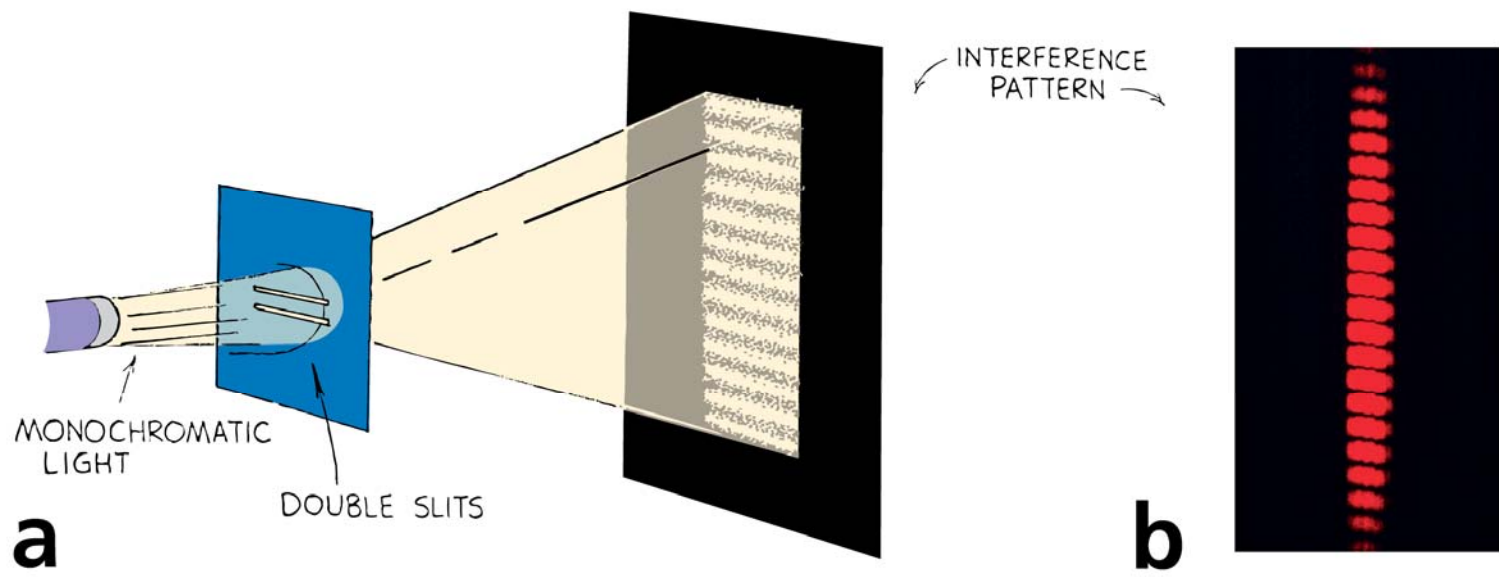
- The arrangement includes two closely spaced slits and a monochromatic light source.



31.4 Young's Interference Experiment

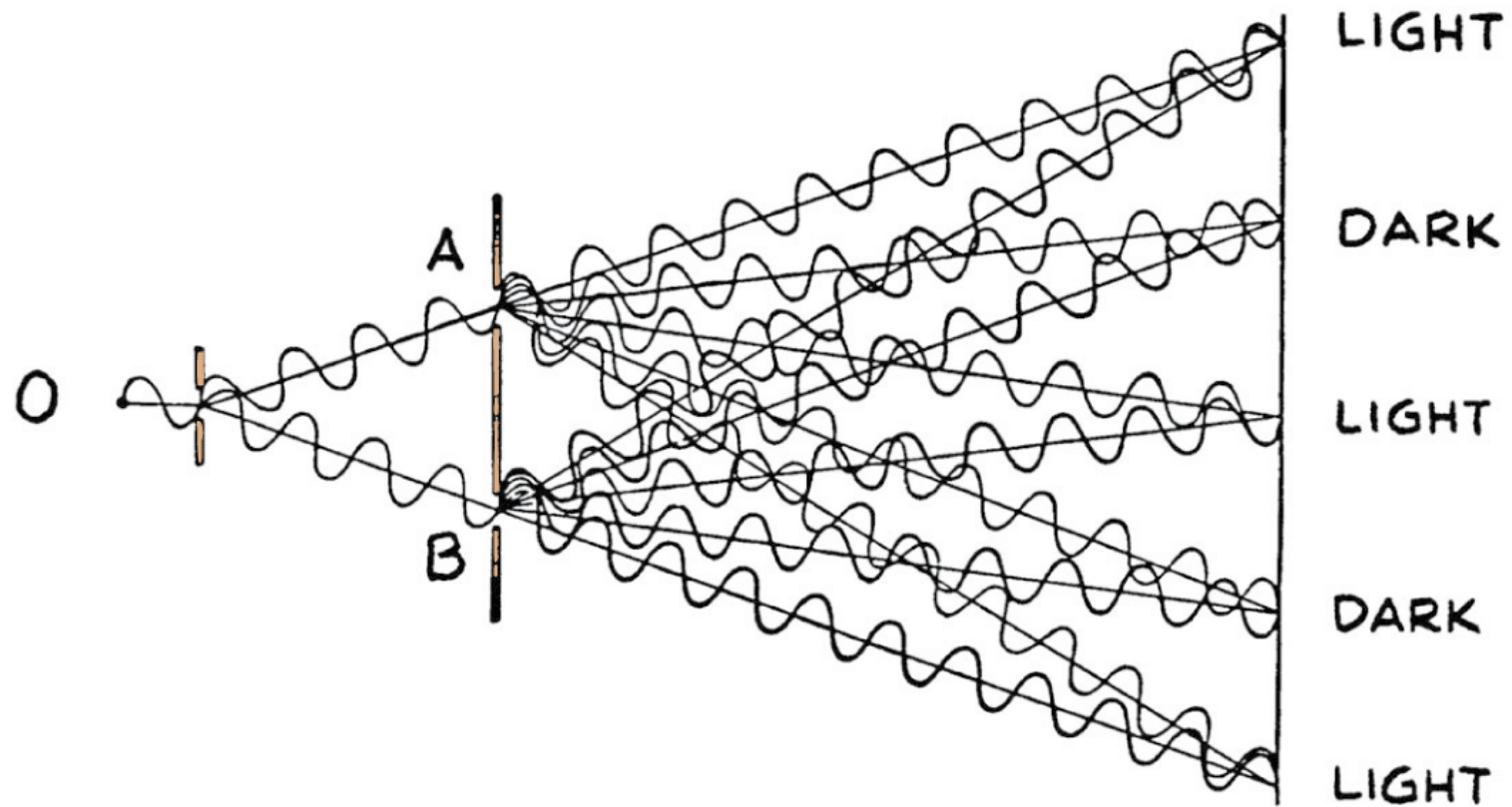
Young's experiment demonstrated the wave nature of light.

- The arrangement includes two closely spaced slits and a monochromatic light source.
- The interference fringes produced are straight lines.



31.4 Young's Interference Experiment

Light from O passes through slits A and B and produces an interference pattern on the screen at the right.



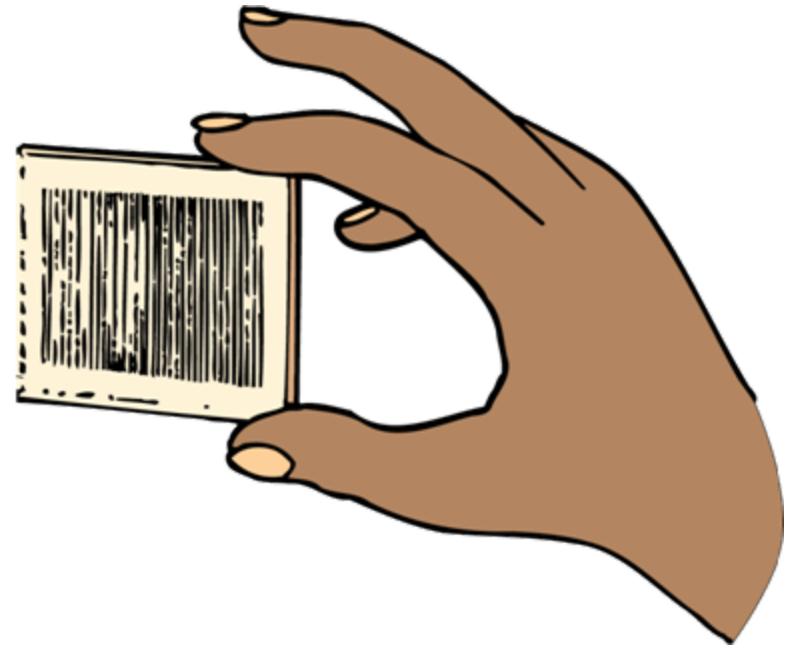
31.4 Young's Interference Experiment

Diffraction Gratings

A multitude of closely spaced parallel slits makes up what is called a **diffraction grating**.

Many spectrometers use diffraction gratings rather than prisms to disperse light into colors.

A prism separates the colors of light by refraction, but a diffraction grating separates colors by interference.



31.4 Young's Interference Experiment

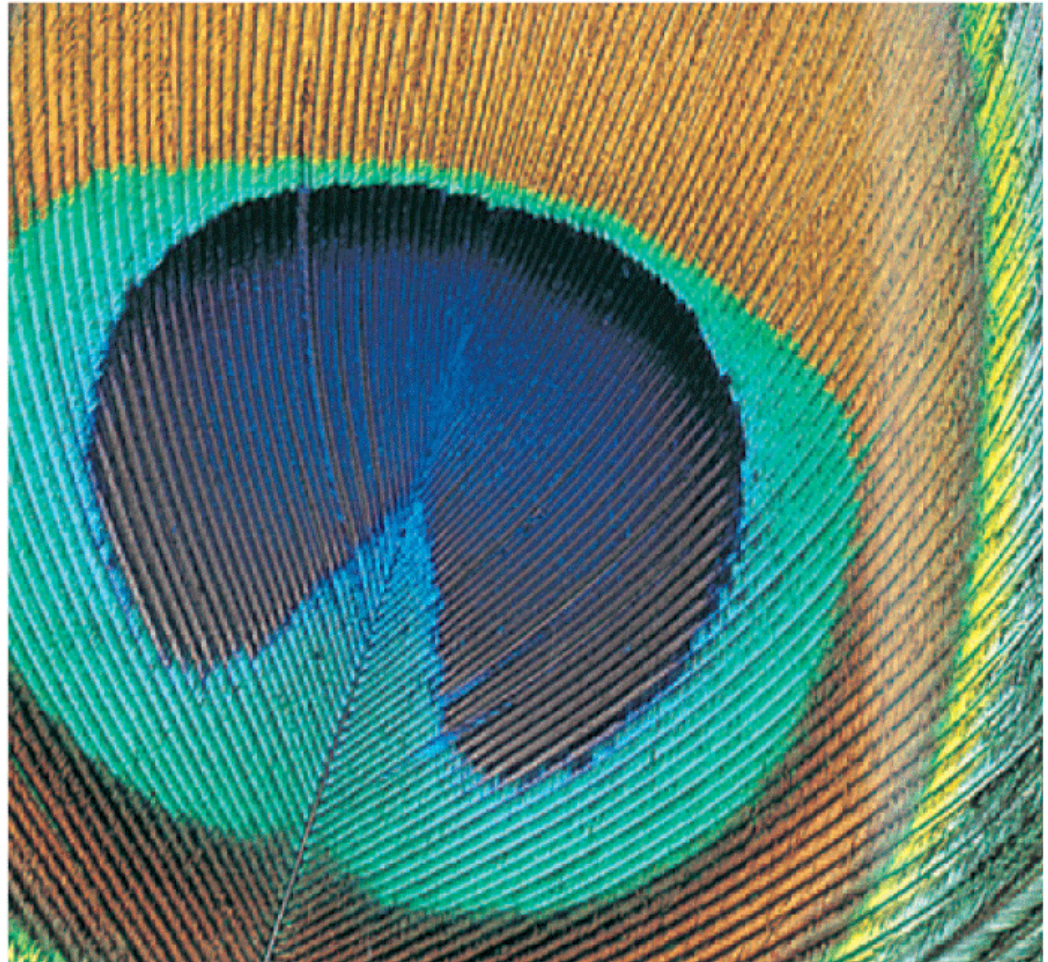
Diffraction gratings are seen in reflective materials used in items such as costume jewelry and automobile bumper stickers.

These materials have hundreds or thousands of close-together, tiny grooves that diffract light into a brilliant spectrum of colors.

31.4 Young's Interference Experiment

The pits on the reflective surface of a compact disc diffract light into its component colors.

The feathers of birds are nature's diffraction gratings. The striking colors of opals come from layers of tiny silica spheres that act as diffraction gratings.



31.4 Young's Interference Experiment

think!

Why is it important that monochromatic (single-frequency) light be used in Young's interference experiment?

31.4 Young's Interference Experiment

think!

Why is it important that monochromatic (single-frequency) light be used in Young's interference experiment?

Answer:

If light of a variety of wavelengths were diffracted by the slits, dark fringes for one wavelength would be filled in with bright fringes for another, resulting in no distinct fringe pattern. If the path difference equals one-half wavelength for one frequency, it cannot also equal one-half wavelength for any other frequency.

31.4 Young's Interference Experiment

**CONCEPT
CHECK**

What did Young's experiment demonstrate?

31.5 Interference From Thin Films



The colors seen in thin films are produced by the interference in the films of light waves of mixed frequencies.

31.5 Interference From Thin Films

A spectrum of colors reflects from soap bubbles or gasoline spilled on a wet street.

Some bird feathers seem to change hue as the bird moves.

The colors seen in thin films are produced by the interference in the films of light waves of mixed frequencies.

Iridescence is the interference of light waves of mixed frequencies, which produces a spectrum of colors.

31.5 Interference From Thin Films

The intriguing colors of gasoline on a wet street correspond to different thicknesses of the thin film.



31.5 Interference From Thin Films

A thin film, such as a soap bubble, has two closely spaced surfaces.

- Light that reflects from one surface may cancel light that reflects from the other surface.
- The film may be just the right thickness in one place to cause the destructive interference of blue light.
- If the film is illuminated with white light, then the light that reflects to your eye will have no blue in it.
- The complementary color will appear so we get yellow.

31.5 Interference From Thin Films

In a thicker part of the film, where green is canceled, the bubble will appear magenta.

The different colors correspond to the cancellations of their complementary colors by different thicknesses of the film.

Soap-bubble colors come from interference of reflected light from inside and outside surfaces of the bubble.

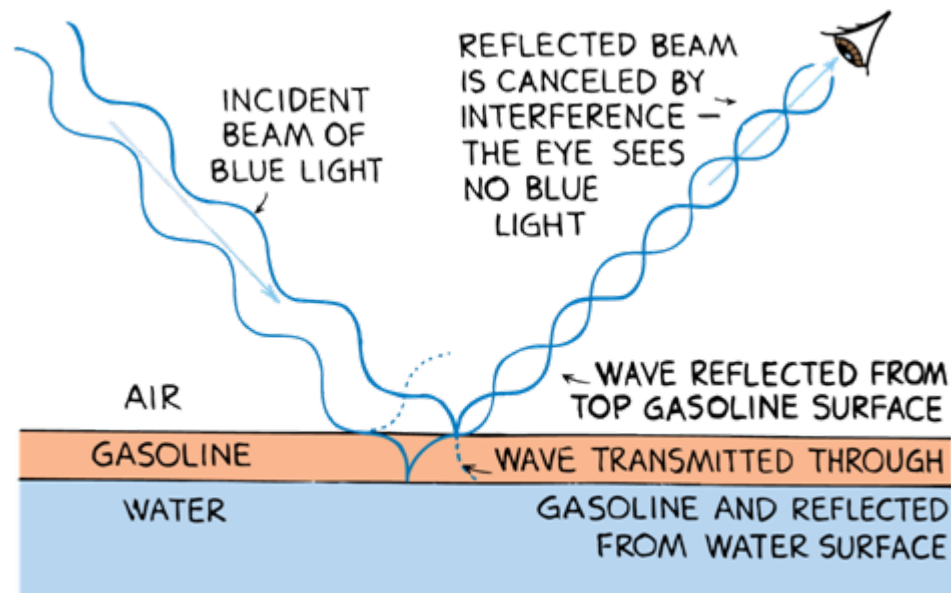


31.5 Interference From Thin Films

For a thin layer of gasoline on a layer of water, light reflects from both the gasoline-air surface and the gasoline-water surface.

If the incident beam is monochromatic blue and the gasoline layer is just the right thickness to cause cancellation of light of that wavelength, then the gasoline surface appears dark.

If the incident beam is white sunlight, the surface appears yellow.



31.5 Interference From Thin Films

Colors reflected from some types of seashells are produced by interference of light in their thin transparent coatings.

So are the sparkling colors from fractures within opals.

Interference colors can even be seen in the thin film of detergent left when dishes are not properly rinsed.

31.5 Interference From Thin Films

Physicist Bob Greenler shows interference colors with *big* bubbles.



31.5 Interference From Thin Films

Interference provides the principal method for measuring the wavelengths of light.

Extremely small distances (millionths of a centimeter) are measured with instruments called *interferometers*, which make use of the principle of interference.

They are among the most accurate measuring instruments known.

31.5 Interference From Thin Films

think!

What color will reflect from a soap bubble in sunlight when its thickness is such that red light is canceled?

31.5 Interference From Thin Films

think!

What color will reflect from a soap bubble in sunlight when its thickness is such that red light is canceled?

Answer:

You will see the color cyan, which is the complementary color of red.

31.5 Interference From Thin Films

**CONCEPT
CHECK**

How are the colors seen
in thin films produced?

31.6 Laser Light



Laser light is emitted when excited atoms of a solid, liquid, or gas emit photons.

31.6 Laser Light

Light emitted by a common lamp is **incoherent** light—the crests and troughs of the light waves don't line up with one another.

Incoherent light is chaotic.

Interference within a beam of incoherent light is rampant.

An incoherent beam of light spreads out after a short distance, becoming wider and wider and less intense with increased distance.

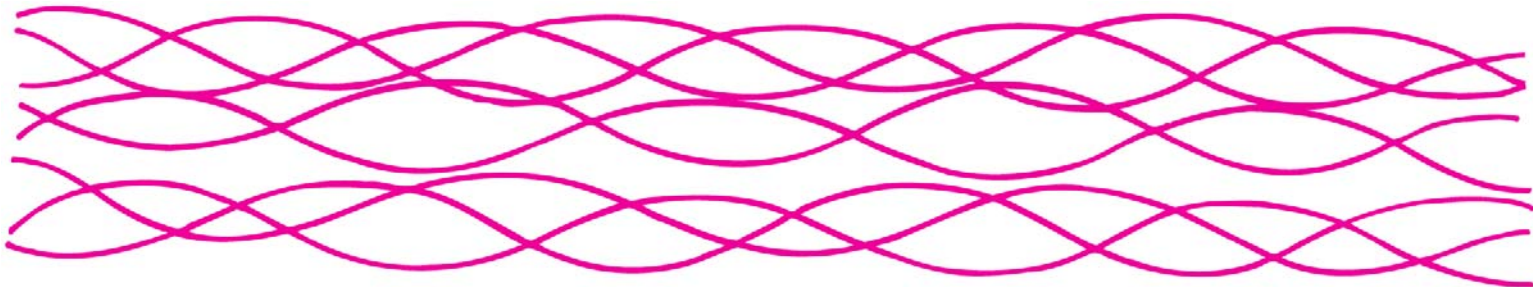


31.6 Laser Light

Even if a beam is filtered to be monochromatic, it is still incoherent.

The waves are out of phase and interfere with one another.

The slightest differences in their directions result in a spreading with increased distance.



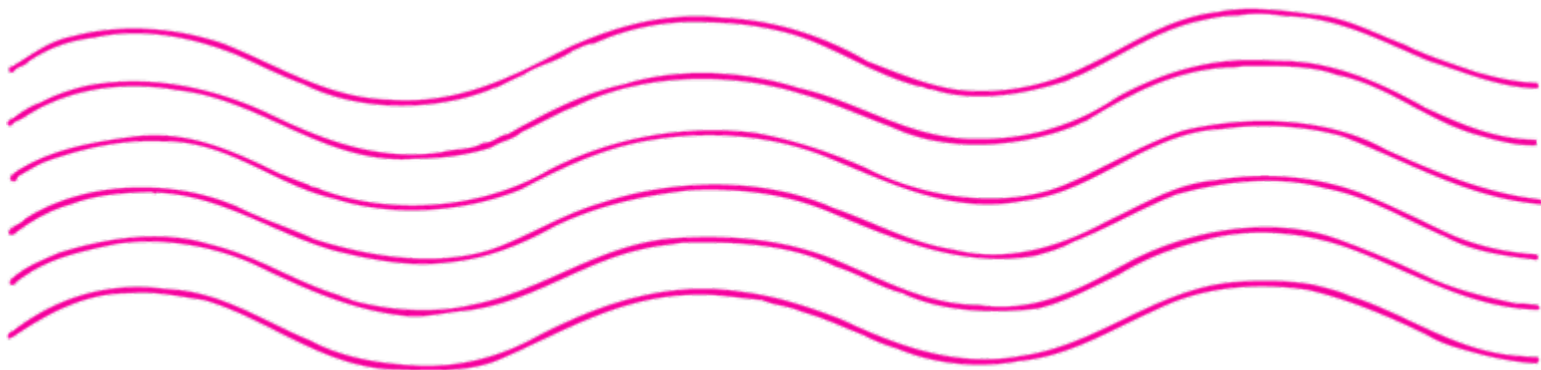
31.6 Laser Light

Coherent Light

A beam of light that has the same frequency, phase, and direction is said to be **coherent**.

There is no interference of waves within the beam.

Only a beam of coherent light will not spread and diffuse.



31.6 Laser Light

Coherent light is produced by a **laser** (whose name comes from *light **a**mplification by **s**timulated **e**mission of **r**adiation*).

In a laser, a light wave emitted from one atom stimulates the emission of light from another atom so that the crests of each wave coincide.

These waves stimulate the emission of others in a cascade fashion, and a beam of coherent light is produced.

31.6 Laser Light

Operation of Lasers

A laser is not a source of energy.

It converts energy, using stimulated emission to concentrate some of the energy input (commonly much less than 1%) into a thin beam of coherent light.

Like all devices, a laser can put out no more energy than it takes in.

31.6 Laser Light

In a helium-neon laser, a high voltage applied to a mixture of helium and neon gas energizes helium atoms to a state of high energy.

Before the helium can emit light, it gives up its energy by collision with neon, which is boosted to a matched energy state.

Light emitted by neon stimulates other energized neon atoms to emit matched-frequency light.

The process cascades, and a coherent beam of light is produced.



31.6 Laser Light

Applications of Lasers

There are many applications for lasers.

- Surveyors and construction workers use lasers as “chalk lines.”

31.6 Laser Light

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- Surgeons use them as scalpels.

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Applications of Lasers

There are many applications for lasers.

- Surveyors and construction workers use lasers as “chalk lines.”
- Surgeons use them as scalpels.
- Garment manufacturers use them as cloth-cutting saws.

31.6 Laser Light

Applications of Lasers

There are many applications for lasers.

- Surveyors and construction workers use lasers as “chalk lines.”
- Surgeons use them as scalpels.
- Garment manufacturers use them as cloth-cutting saws.
- They read product codes into cash registers and read the music and video signals in CDs and DVDs.



31.6 Laser Light

- Lasers are used to cut metals, transmit information through optical fibers, and measure speeds of vehicles for law enforcement purposes.
- Scientists have even been able to use lasers as “optical tweezers” that can hold and move objects.

31.6 Laser Light

**CONCEPT
CHECK**

What causes a laser to emit light?

31.7 The Hologram



A hologram is produced by the interference between two laser light beams on photographic film.

31.7 The Hologram

A **hologram** is a three-dimensional version of a photograph that contains the whole message or entire picture in every portion of its surface.

It appears to be an imageless piece of transparent film, but on its surface is a pattern of microscopic interference fringes.

Light diffracted from these fringes produces an image that is extremely realistic.



Holograms viewed with white light are common on credit cards. Watch for them on money.

31.7 The Hologram

Producing a Hologram

A hologram is produced by the interference between two laser light beams on photographic film. The two beams are part of one beam.

- One part illuminates the object and is reflected from the object to the film.
- The second part, called the *reference beam*, is reflected from a mirror to the film.

Interference between the reference beam and light reflected from the different points on the object produces a pattern of microscopic fringes on the film.

31.7 The Hologram

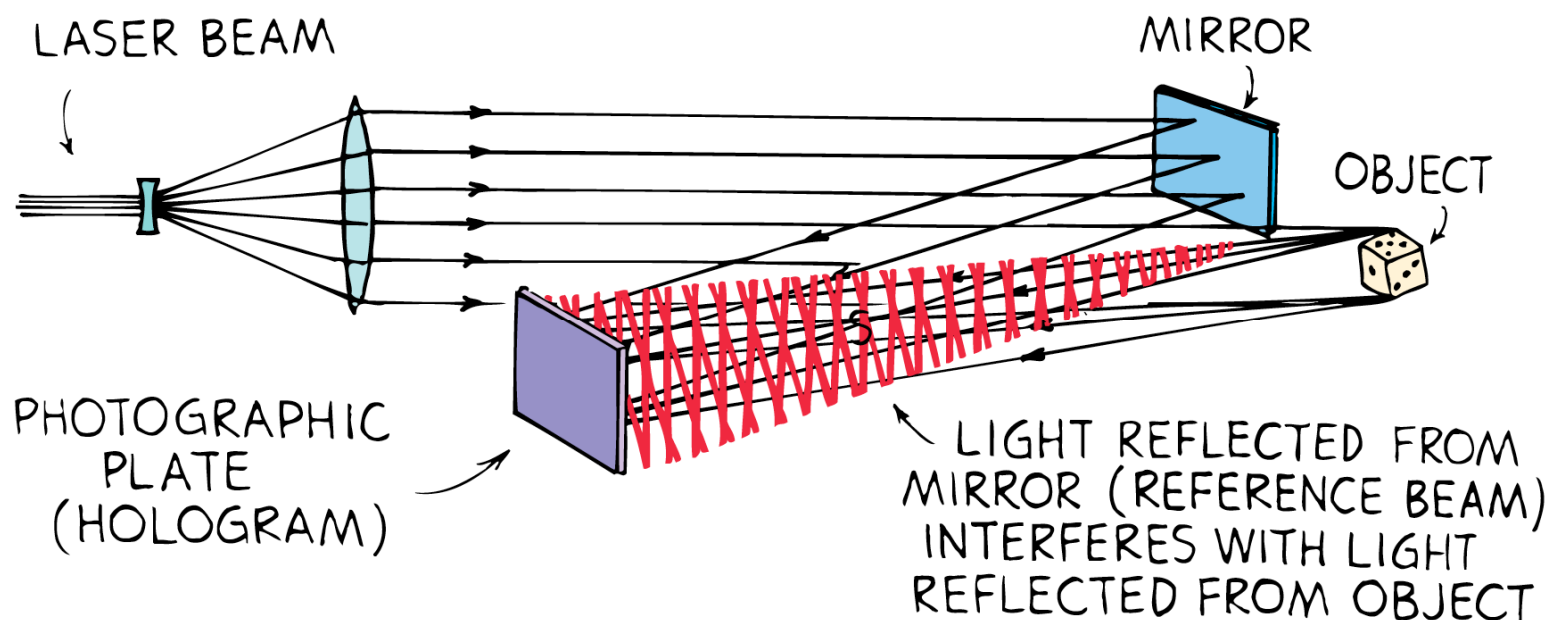
Light from nearer parts of the object travels shorter paths than light from farther parts of the object.

The different distances traveled will produce slightly different interference patterns with the reference beam.

Information about the depth of an object is recorded.

31.7 The Hologram

The laser light that exposes the photographic film is made up of two parts: one part is reflected from the object, and one part is reflected from the mirror.



31.7 The Hologram

Looking at a Hologram

When light falls on a hologram, it is diffracted by the fringed pattern.

It produces wave fronts identical in form to the original wave fronts reflected by the object.

The diffracted wave fronts produce the same effect as the original reflected wave fronts.

31.7 The Hologram

When you look through a hologram, you see a three-dimensional virtual image.

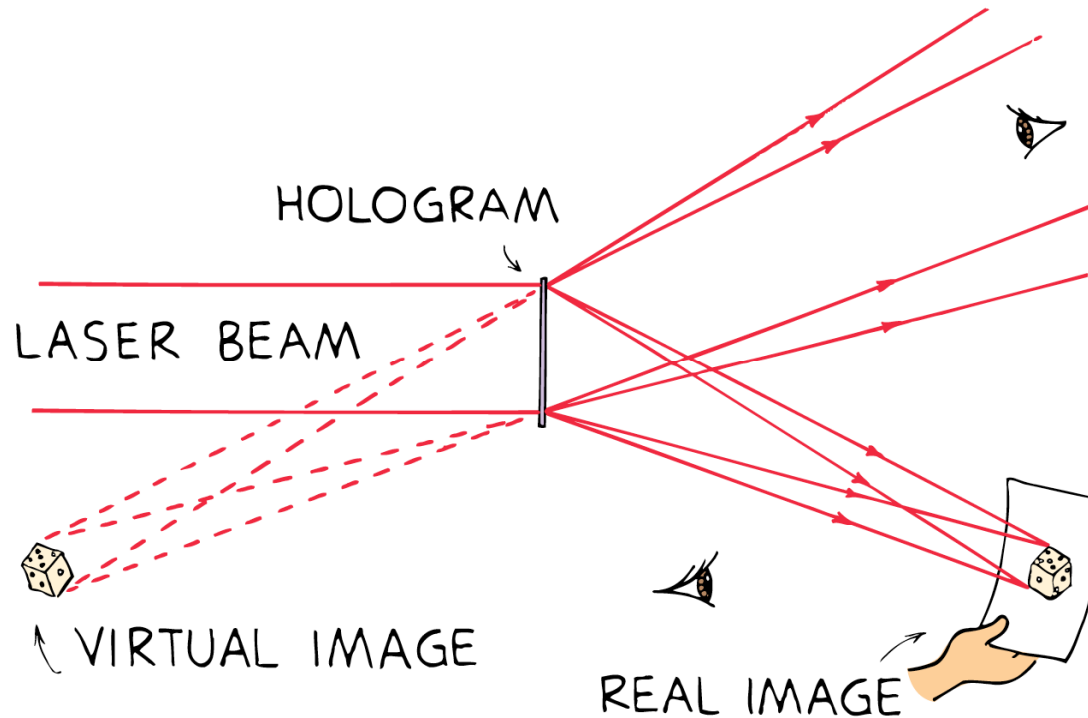
You refocus your eyes to see near and far parts of the image, just as you do when viewing a real object.

Converging diffracted light produces a real image in front of the hologram, which can be projected on a screen.

Holographic pictures are extremely realistic.

31.7 The Hologram

When a hologram is illuminated with coherent light, the diverging diffracted light produces a three-dimensional *virtual* image. Converging diffracted light produces a *real* image.



31.7 The Hologram

If the hologram is made on film, you can cut it in half and still see the entire image on each half.

Every part of the hologram has received and recorded light from the entire object.

31.7 The Hologram

If holograms are made using short-wavelength light and viewed with light of a longer wavelength, the image is magnified in the same proportion as the wavelengths.

Holograms made with X-rays would be magnified thousands of times when viewed with visible light.

31.7 The Hologram

**CONCEPT:
CHECK**

How is a hologram produced?

Assessment Questions

1. Huygens' principle for light is primarily described by
 - a. waves.
 - b. rays.
 - c. particles.
 - d. photons.

Assessment Questions

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Answer: A

Assessment Questions

2. At a lake surrounded by hills, you want to listen to a game. The only radio stations that come in are the AM stations, because the radio waves of AM broadcast bands are
- a. high-frequency, which diffract more.
 - b. high-frequency, which diffract less.
 - c. low-frequency, which diffract more.
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Assessment Questions

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Answer: C

Assessment Questions

3. When light undergoes interference, it
 - a. can sometimes build up to more than the sum of amplitudes.
 - b. can sometimes cancel completely.
 - c. never cancels completely.
 - d. can never be destructive interference.

Assessment Questions

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- a. can sometimes build up to more than the sum of amplitudes.
 - b. can sometimes cancel completely.
 - c. never cancels completely.
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Answer: B

Assessment Questions

4. A diffraction grating relies on light
 - a. interference.
 - b. amplitudes.
 - c. variations in brightness.
 - d. being composed of photons.

Assessment Questions

4. A diffraction grating relies on light
- a. interference.
 - b. amplitudes.
 - c. variations in brightness.
 - d. being composed of photons.

Answer: A

Assessment Questions

5. When a beam of light reflects from a pair of closely spaced surfaces, color is produced because some of the reflected light is
- a. converted to a different frequency.
 - b. deflected.
 - c. subtracted from the beam.
 - d. amplified.

Assessment Questions

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- a. converted to a different frequency.
 - b. deflected.
 - c. subtracted from the beam.
 - d. amplified.

Answer: C

Assessment Questions

6. Unlike incoherent light, light from a laser
- a. sometimes has the same frequency and phase.
 - b. has the same speed and frequency and is out of phase.
 - c. has the same phase, frequency, and speed.
 - d. is chaotic.

Assessment Questions

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- a. sometimes has the same frequency and phase.
 - b. has the same speed and frequency and is out of phase.
 - c. has the same phase, frequency, and speed.
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Answer: C

Assessment Questions

7. A hologram makes best use of the phenomenon of
- a. reflection.
 - b. refraction.
 - c. diffraction.
 - d. polarization.

Assessment Questions

7. A hologram makes best use of the phenomenon of
- a. reflection.
 - b. refraction.
 - c. diffraction.
 - d. polarization.

Answer: C