

The  
Video  
Encyclopedia  
*of*  
Physics  
Demonstrations<sup>TM</sup>

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# DISC TWENTY - FOUR

## ***Chapter 64      Polarization***

Demo 24-01	Polaroid Sheets Crossed and Uncrossed.....	6
Demo 24-02	Polaroids Cut at 45 Degrees .....	8
Demo 24-03	Rotation by Polarizing Filter .....	10
Demo 24-04	Microwave Polarization.....	12
Demo 24-05	Polarization by Reflection.....	14
Demo 24-06	Polarization by Double Reflection .....	16
Demo 24-07	Polarization by Scattering .....	18
Demo 24-08	Artificial Sunset.....	20

## ***Chapter 65      Optical Activity***

Demo 24-09	Optical Activity in Cellophane Tape .....	24
Demo 24-10	Polarized Lion.....	26
Demo 24-11	Optical Activity in Corn Syrup .....	28
Demo 24-12	Polage .....	30
Demo 24-13	Photoelastic Stress Figures.....	32
Demo 24-14	Barbershop Sugar Tube .....	34
Demo 24-15	Quarter Wave Plate .....	36
Demo 24-16	Double Refraction in Calcite.....	38
Demo 24-17	Liquid Crystal Sheets.....	40

## ***Chapter 66      Quantum Physics***

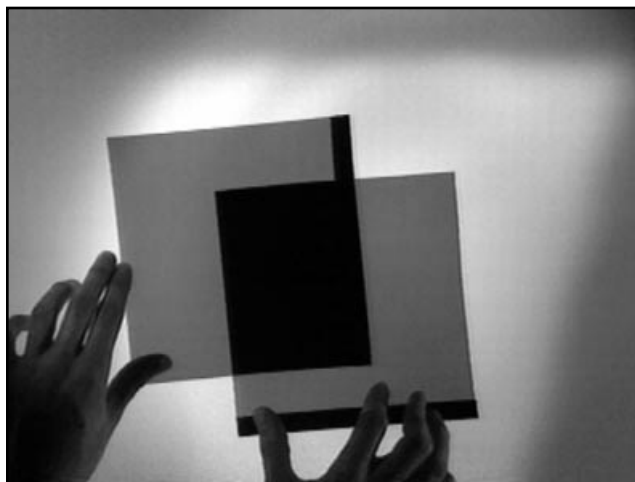
Demo 24-18	Radiation Spectrum of a Hot Object .....	44
Demo 24-19	Photoelectric Effect in Zinc .....	46
Demo 24-20	X-ray Ionization.....	48
Demo 24-21	Solar Cells .....	50
Demo 24-22	Microwave Barrier Penetration.....	52
Demo 24-23	Electron Diffraction .....	54
Demo 24-24	Millikan Oil Drop .....	56
Demo 24-25	Bichsel Boxes .....	58



# C H A P T E R 6 4

## P O L A R I Z A T I O N

This demonstration illustrates the effect of two polarizing sheets used as polarizer and analyzer.<sup>†</sup> A polarizing filter placed in front of a light acts as a polarizer. Another sheet in front of the polarizer acts as analyzer, passing that component of the polarized light for which the plane of vibration is parallel to the transmission axis of the polarizing sheet, and stopping all the light when the axes are perpendicular, as shown in *Figure 1*.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstration L-122, Polarizing Plates.  
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Om-9, Polaroid as Polarizer and Analyzer.

These two sheets are examples of polarizing filters. Unpolarized light passing through the filters becomes polarized by selective removal of light with certain polarization directions.

If the filters are placed on top of one another in this direction, the light passing through both filters is only slightly dimmer than the light passing through one filter.

If we rotate one of the filters 90 degrees, very little light passes through the second filter.

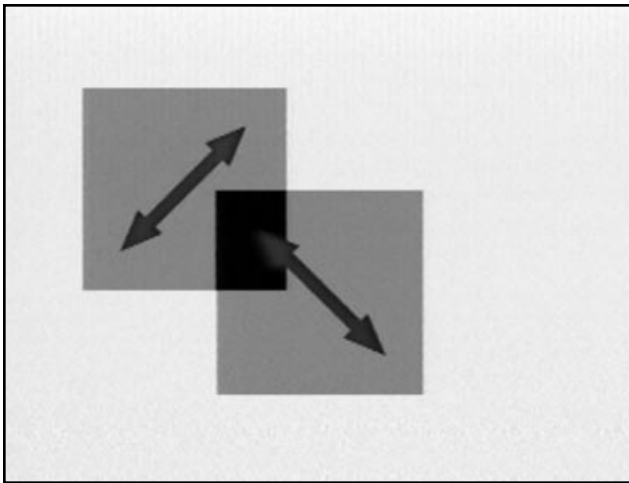
### ***Equipment***

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1. Two sheets of Polaroid.
2. Overhead projector and screen.
3. AC power for the overhead.

Two polarizing sheets have their polarizing axis at  $45^\circ$  to the edges of the sheets, as shown in *Figure 1*. Initially the two sheets are placed on top of each other such that their polarization axes are parallel, so light can pass through the two polarizing sheets. When the top sheet is turned upside down by rotating it about an axis parallel to one of the sides, the two polarization axes become perpendicular, and no light is transmitted.

This demonstration has a counterintuitive aspect. In most cases polarizing sheets are cut so that the polarization axis is in the same direction as one of the sides, so flipping one of the sheets in the above manner will not affect the light coming through. Let the students argue about this and try to figure out why it works!



*Figure 1*



Light passes through these two polarizing filters when they are in this orientation, but not when one is rotated by 90 degrees.

If we line them up again and flip one filter over, they are still lined up and the light passes through.

These two polarizing sheets show the same effect when one is rotated;

but when the top sheet is flipped, the light will not pass through. How is this pair of sheets different from the first pair?

This animation shows the polarization axes for the first set of polarizing sheets, and how their relative orientation changes as the top sheet is first rotated, then flipped. Here are the polarization axes for the second set of sheets.

---

**Equipment**

1. Same setup as Demonstration 24-01.
2. Second pair of Polaroids where the electric field vector is oriented  $45^\circ$  from that of the first pair.

Two polarizing sheets are arranged with their polarization axes perpendicular, so that no light gets through the two sheets. When a third polarizing sheet is inserted between the original two with its axis at  $45^\circ$  with respect to the two original sheets, as shown in *Figure 1*, light can be seen. This demonstration illustrates the idea of a component of the electric field of the light. The second and the third sheet both pass that component of the light incident on them with its electric field at  $45^\circ$  from the original polarization direction.



*Figure 1*

When these polarizing sheets are in the proper orientation, light can pass through the first sheet but not the second.

If we insert a third polarizing filter between the other two at 45 degrees to both, some of the light now passes through all three polarizing sheets.

***Equipment***

---

1. Three sheets of Polaroid.
2. Overhead projector and screen.
3. AC power for the overhead.

This demonstration illustrates one mechanism for the polarization of electromagnetic waves, using the apparatus as shown in *Figure 1*.<sup>†</sup> The result is counterintuitive in that the waves that pass through the polarizer are polarized perpendicular to the direction of the conductors, not parallel to that direction.

This demonstration provides insight into how polarizing material actually works for the case of electromagnetic, and therefore light, waves. In the case of a rope wave passing through a series of parallel wires, the polarization direction for the wave is parallel to the slots through which the rope must oscillate. In the case of microwaves, just the opposite result occurs. The oscillating electric field is absorbed by wires parallel to the direction of oscillation, causing electrons in the conductor to oscillate.

Light waves are polarized by small iodide crystals that absorb light parallel to the axis of the crystal.



*Figure 1*

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<sup>†</sup> Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Om-1, Polarization of Electromagnetic Waves.

This device consists of a microwave emitter, a microwave receiver, and a bar-graph whose length is proportional to the intensity of the microwaves picked up by the receiver.

If we rotate the emitter 90 degrees, the intensity drops, then returns to its original value as the emitter is rotated another 90 degrees.

If we now place a metal disc with slots in the path of the beam, the intensity of the beam is reduced, but the beam still passes through.

If we rotate the disc 90 degrees, the beam no longer passes through the slotted disc. If the disc is rotated another 90 degrees, the beam passes through.

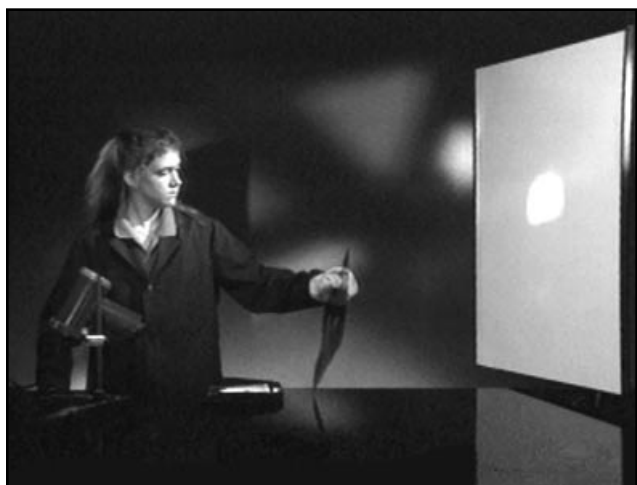
This animation shows how the electric field vector of the microwave is reduced as it passes through the slots. When we rotate the disc to this orientation, currents set up along the metal strips dissipate the energy of the electric field and the microwave intensity is greatly reduced.

---

***Equipment***

1. Brett Carroll microwave board.
2. Magnetic bar.
3. Metal mask with a center hole covered with a rotating disc containing multiple slits.

Light waves can be polarized by reflection from a dielectric surface, as shown in *Figure 1*.<sup>†</sup> The amount of polarization depends on the angle at which the light strikes the surface, with the maximum effect occurring at an angle called the Brewster angle, where the reflected light is completely polarized.



*Figure 1*

---

<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstration L-123, Polarization by Reflection—Norrenberg's Polariscope.  
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Om-2, Polarization of Light by Reflection.

We'll use this glass plate, a light source, and a polarizing filter to demonstrate polarization by reflection. If we pass the beam through a polarizing filter onto a screen and rotate the filter, the intensity of the light on the screen does not change. The light beam is not initially polarized.

If we reflect the beam off a pane of glass,

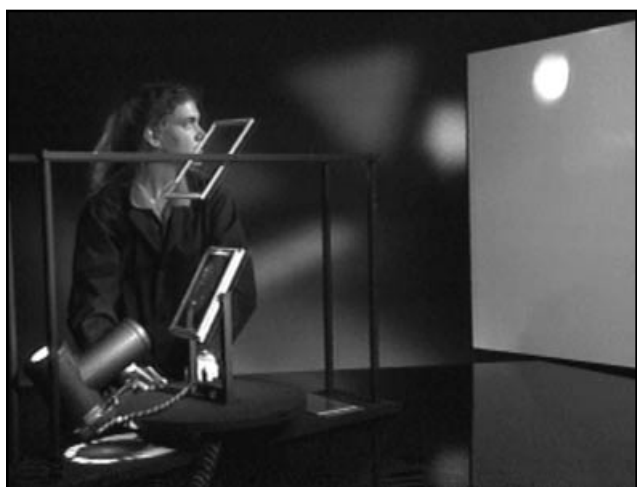
rotating the polarizing filter in the beam causes variations in the light intensity on the screen. The reflected beam is polarized.

***Equipment***

---

1. Light source.
2. Piece of flat black cloth or paper.
3. Piece of plate glass.
4. Projection screen.
5. Single Polaroid.
6. Gloves to manipulate the hot light source.
7. AC power for the light source.

Polarization of light is obtained by using two reflections from dielectric plates, as in *Figure 1*.<sup>†</sup> This demonstration illustrates the effect of double reflection on the polarization of an initially unpolarized light beam. The upper mirror acts as an analyzer, so as the lower mirror and light source are rotated the spot on the screen becomes brighter (when the two surfaces are parallel) and darker (when the two surfaces are more nearly perpendicular). If the dielectric plates are replaced by metal plates, no change in intensity of the spot is observed as the light and lower mirror are rotated.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstrations L-123, Polarization by Reflection—Norrenberg's Polariscope, and L-125.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Om-2, Polarization of Light by Reflection.



Light reflected by a glass surface can be polarized by the reflection. We'll demonstrate that effect using a light source and two glass plates.

The light source is aimed at the bottom plate, which reflects the beam straight up. Both the light source and the plate can rotate together, causing no apparent change in the beam.

When the beam is reflected by a second glass plate onto the screen, rotating the lower glass plate by 90 degrees causes the light on the screen to fade out. The beam is polarized by reflection from the lower glass sheet and will only reflect from the upper sheet if the two sheets are in the proper relative orientation.

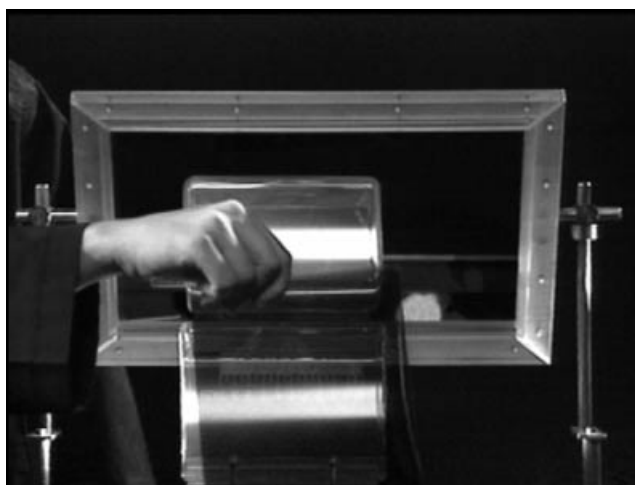
If we replace the glass sheets with two metal sheets, the effect can no longer be seen. Light is not polarized by reflection from metal surfaces.

---

**Equipment**

1. Polarization by reflection apparatus consisting of two pieces of ordinary plate glass; one mounted on a Lazy Susan along with a light source, while the other is suspended from a framework directly above and parallel to the first—with both orientations adjustable and set for two reflections.
2. Translucent screen and its support system.
3. Two sheets of metal with the same dimensions as the glass plates.
4. AC power (switchable) for the light source.

Light is polarized when it scatters from materials like air or water.<sup>†</sup> This demonstration shows some of the properties of this polarization, using the apparatus of *Figure 1*, in which the light beam passes through a water tank into which a small amount of powdered cream has been dissolved. Light scattered in a given plane is preferentially polarized in the direction perpendicular to that plane. Light viewed from the front is polarized vertically, and light viewed from the top, seen by its reflection from a conducting mirror surface above the tank, is polarized horizontally, as is demonstrated in the video by rotating a polarizing filter in the incoming light beam.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstrations L-127, Polarization by Scattering, and L-128.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstrations On-1, Light Scattering, and On-2, Polarization of Scattered Light.

When light is scattered from small particles, like those produced when milk is added to water, the scattered light can be polarized. A polarizing sheet rotated in front of the scattered light shows this effect clearly.

A mirror above the tank allows us to see the light that is scattered vertically. If we put the polaroid sheet in the light beam before it reaches the tank and rotate the sheet, the light scattered in the two directions now brightens and dims alternately.

---

**Equipment**

1. Optics bench.
2. Carbon arc with its lens.
3. Beam mask.
4. Double convex lens.
5. Small glass tank and its support stand.
6. Mirror mounted above the tank at an angle so that the top of the tank can be easily observed.
7. Five optical bench clamps.
8. Supply of water.
9. Supply of powdered coffee creamer.
10. Stirring rod.
11. Single Polaroid.
12. DC power for the carbon arc.

Light from the sun is both scattered and polarized as it passes through the atmosphere near sunrise and sunset. The demonstration of the scattering and polarization effects is often termed the “artificial sunset,” or “colloidal sunset.”<sup>†</sup> Light shines through a water tank, shown in *Figure 1*, containing colloidal particles that grow larger and more dense with time. This increasing colloid density acts like the atmosphere in scattering the white light from the source, initially producing bluish, polarized scattered light, like the atmosphere, with red light passing through the tank, like the red light of the setting sun.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstrations L-46, Scattering of Light—“Sunset Experiment,” and L-128.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration On-1, Light Scattering.

During the day most of a clear sky appears blue but a setting sun is noticeably red.

We'll use a beam of light shining through this tank of water to simulate these color effects, which are caused by sunlight passing through the atmosphere.

To simulate the atmosphere we'll dissolve sodium thiosulfate in the water, then add sulfuric acid to precipitate small particles of sulfur. These particles will simulate the air molecules in the atmosphere. Here is the light that passes through the tank and strikes a screen. It appears red like a setting sun.

And here is the light that is scattered sideways by the sulfur particles. It appears blue like the sunlight that is scattered sideways from the air molecules in the atmosphere.

---

**Equipment**

1. 35-mm slide projector.
2. Beam mask in the slide position of the projector.
3. Small aquarium.
4. Supply of lukewarm water: 1 1/2–2 gallons.
5. 30 grams of sodium thiosulfate.
6. 4 milliliters of concentrated hydrosulfuric acid in a graduated cylinder that can also be used as a stirring rod after dumping the acid in the hypo solution immediately before the demonstration is to begin.
7. Projection screen.
8. Elevation shims for the tank, if needed.
9. AC power for the projector.



# C H A P T E R    6 5

## O P T I C A L    A C T I V I T Y

Certain varieties of cellophane tape are optically active materials, that is, they are able to rotate the plane of polarization of polarized light.<sup>†</sup> In this demonstration, collages of cellophane tape are placed between two polarizing sheets, illuminated from behind one of the sheets, and viewed from the opposite end, as shown in *Figure 1*. The amount of rotation of the plane of polarization depends on the wavelength, or color, of the light. The second polarizing filter, acting as an analyzer, stops the color(s) of light with polarization perpendicular to its axis of transmission, leading to very dramatic and beautiful negative, or subtractive, colors. The effects of thickness of the tape, creating greater rotation of the plane of polarization, and rotating the second polarizing sheet, are seen in the video to produce changes in the color of the tape figures.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstration L-136, Doubly Refracting Materials in Polarized Light.



When we cross these two polarizing sheets, lights cannot pass through both sheets.

With these glass slides covered with strips of cellophane tape placed between the sheets, light of many different colors passes through. Different colors correspond to different thicknesses of tape where the layers of tape overlap. Rotating the top filter changes the colors.

### ***Equipment***

---

1. Pair of Polaroids.
2. Collection of glass slides covered with differing thicknesses of cellophane tape, some cut into interesting designs.
3. Overhead projector.
4. AC power for overhead.

A “polarized lion” created out of cellophane tape mounted on a glass plate is illuminated from behind with polarized white light. Reflection of the light from a horizontal glass plate performs the function of an analyzer. The optical activity of the tape rotates the plane of polarization of the transmitted light. Those colors whose electric field vibration is horizontal (parallel to the reflecting surface) will be preferentially reflected, giving the lion a variety of colors, shown in the video and in black and white in *Figure 1*.



*Figure 1*

Here is the outline of a lion made with transparent tape on a sheet of glass. The lion is colorless, but when we insert a polaroid sheet behind it striking colors appear in the reflection of the lion in a pane of glass.

What could cause this effect?

The polarizing sheet polarizes the light before it passes through the tape. The tape is optically active, so it rotates the plane of polarization of the light passing through, with different colors rotated by different amounts. Different thicknesses of tape also produce different amounts of rotation.

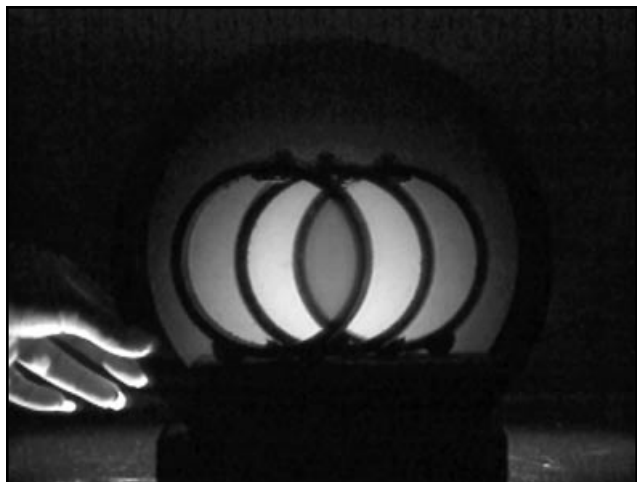
Reflection in the second glass sheet is strongest for light with a horizontal electrical field component, so the colors of light that have rotated to that orientation are brightest in the reflection.

---

**Equipment**

1. Sheet of glass with the figure of a lion located near its center made, from cellophane tape.
2. Similarly sized sheet of Polaroid.
3. Diffused light source to serve as the lion's background.
4. Appropriate height support for the lion sheet and the Polaroid.
5. Table-sized piece of flat black cloth.
6. One, or more, pieces of plate glass to serve as the reflecting surface for the lion's image.
7. This can be set up on either a table or a large Lazy Susan for the necessary rotation.
8. AC power for the light source.

This demonstration presents another example of optical activity. Because of its molecular shape, corn syrup is optically active.<sup>†</sup> Saturated negative, or subtractive, colors will be produced if a bottle of corn syrup is placed between the polarizer and the analyzer, and the analyzer rotated. In this video, overlapping flat cells of corn syrup are used to provide large regions of pure saturated colors, as shown in *Figure 1* in black and white.



*Figure 1*

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<sup>†</sup> The mechanism by which the plane of polarization is rotated and the properties of an optically active substance that allows this to happen are discussed in *The Feynman Lectures on Physics*, Chapter 33, Polarization (Addison-Wesley Publishing Company, Reading, MASS, 1977).

We will now demonstrate optical activity in corn syrup.

A bottle of corn syrup is placed between two polarizing filters. As the front polarizing filter is rotated colors appear, due to the optical activity of the corn syrup.

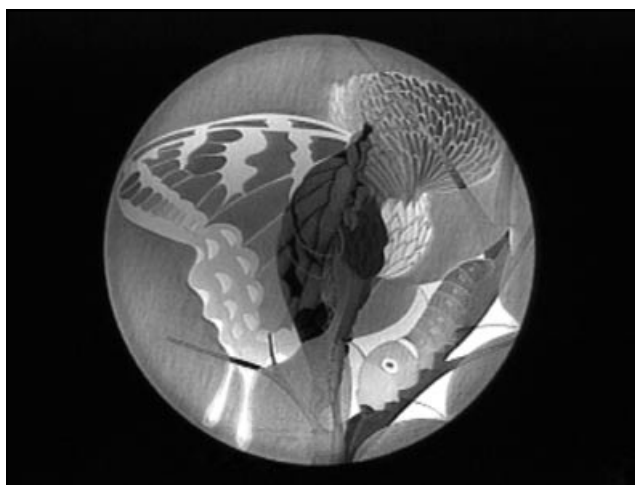
Three uniform cylinders of corn syrup are now placed in overlapping positions between the polarizing filters. The front polarizing sheet is again rotated, showing areas of uniform color where the light has passed through the same thickness of corn syrup.

### ***Equipment***

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1. Light source.
2. AC power for light source.
3. Two circular Polaroids in a base with slots to enable the smooth rotation of one Polaroid in relation to the other and separated enough to allow placement of the syrup between them.
4. Bottle of corn syrup.
5. Three identical cylindrical containers of corn syrup.

A polage is a collage of optically active materials. Artist Austine Wood has combined polarizing materials and optically active materials in an extremely clever and imaginative way to produce works of art to which she gave the name polage.<sup>†</sup> The polage is illuminated from behind by polarized white light, and has a second polarizing sheet mounted on the front surface of the polage. As the polarizing sheet behind the polage is rotated, the figure on the polage undergoes a metamorphosis. The polage shown in the video and in *Figure 1*, called “Swallowtail,” changes from a cocoon to a butterfly as the polarizing sheet rotates.



*Figure 1*

---

<sup>†</sup> Polages are available from The Rachael Collection, 285 South Mill Street, Aspen Colorado 81611, and can be seen in several art and science museums.

Optical activity and other polarization effects have been combined in an extremely clever and creative way by artist Austine Wood in an art form called the polage. A polage consists of a collage of optically active materials, and it is therefore viewed between two polarizing filters, one of which is attached to the front of the polage.

The polage is placed on the front of this light box. The fluorescent light at the rear of the light box passes through a slowly rotating polarizing filter, then through the polage and the polarizing filter on the front of the polage.

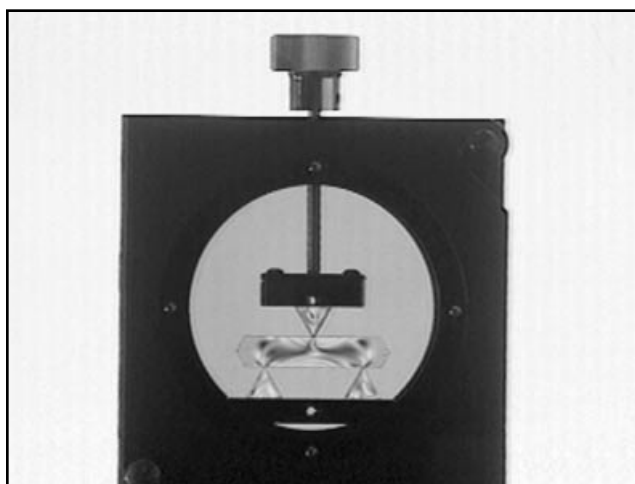
This example, called “Swallowtail,” shows the metamorphosis of a cocoon into a butterfly as the rear polarizing filter rotates.

---

***Equipment***

1. A polage.
2. Diffused light background.
3. Two Polaroids.
4. AC power.

If an optically active material positioned between two polarizing sheets is subjected to stress, the resulting strain in the material modifies the structure of the material and thus the nature of the optical activity, creating photoelastic stress, or strain, patterns.<sup>†</sup> Using the apparatus shown in *Figure 1*, plastic figures are stressed and the resulting strain patterns are viewed in polarized light. The positions of greater stress are seen by the rapid changes in color and texture of the pattern. A variety of samples are demonstrated in the video.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstration L-134, Induced Double Refraction—Photoelasticity.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Om-15, Polarization with a Slide Projector.



Some materials rotate the plane of polarization of polarized light when put under stress, an effect called photoelasticity.

We'll place these acrylic figures between two polarizing filters to show the effect. When the acrylic is unstrained, the polarized light from the first filter is not rotated by the plastic and the plastic is colorless.

When we put stress on the plastic figure by tightening this screw, areas of high stress rotate the light from the first Polaroid, allowing only certain colors to pass through the second Polaroid.

The plastic now appears colored at the stress points with different colors corresponding to different levels of stress.

### ***Equipment***

---

1. Commercially available photo elastic stress demonstrator.
2. Overhead projector and screen.
3. AC power for the overhead.

An initially plane polarized beam of white light passes through a tube of sugar water, as shown in *Figure 1*. The sugar water is optically active, so it rotates the plane of polarization of the light, by different amounts for the various colors.<sup>†</sup> The light seen by the video camera has been scattered by the sugar solution, so that it is polarized parallel to the screen, and not in and out of the screen, so it acts as an analyzer, only scattering toward the camera that light which is polarized in the plane of the viewing screen. As in other examples of optical activity, saturated negative or subtractive colors result, as seen in the video.



*Figure 1*

---

<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstrations L-129, Rotation of Plane of Polarization by Sugar Solution, and L-130.

When white light shines up through this tube filled with corn syrup, different colors of light are scattered equally, and the solution appears colorless.

When a polarizing filter is placed in the beam before it enters the tube, colors appear in the solution. When the polarizing filter is rotated, the colors move down the tube in a pattern similar to a barbershop pole.

If a red filter is placed in the beam, the tube appears light in some areas and dark in others. These areas move down the tube as the polarizing filter is rotated.

---

***Equipment***

1. Glass tube with an optically flat end.
2. Supply of corn syrup.
3. Three-fingered clamp.
4. Two right-angled clamps.
5. Circular Polaroid mounted in a supporting framework that permits the Polaroid's rotation.
6. Heavy ring stand.
7. Strong light source.
8. AC power for light source.
9. Red filter.

Monochromatic polarized light is incident at an angle of  $45^\circ$  between the two axes of a double refringent material. The light divides into two components, which undergo a relative phases change as they propagate through the material. If the thickness of the material is appropriately chosen, a specific phase change can be obtained. If the phase difference between the two perpendicular directions is one-quarter of a wavelength, the element is called a quarter-wave plate.<sup>†</sup> Under the above conditions a quarter-wave plate produces circularly polarized light. Using a small disc-shaped quarter-wave plate and a polarizing sheet, as shown in *Figure 1*, this video illustrates the properties of an anti-reflecting filter. When the quarter-wave plate and the filter are in the proper relative orientation, no external light is reflected by the mirror, as seen clearly in the video.

This type of arrangement is used in the anti-reflecting screens for computer terminals.



*Figure 1*

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<sup>†</sup> Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Om-11, Quarter-wave Plate.

This disc is made of an optically active material that rotates the plane of polarization of light passing through it.

When the disc is placed in front of a polarizing sheet and the combination is held in front of a mirror, the disc appears clear.

When we place the disc between the mirror and the polarizing sheet, the disc appears dark for certain orientations of the sheet. At those orientations, light reflected from the mirror through the disc can no longer pass out through the polarizing sheet.

---

***Equipment***

1. Quarter wave plate.
2. Polaroid sheet.
3. Mirror.
4. Light source.
5. AC power for light source.

Calcite is a common example of doubly refractive material. An object illuminated with polarized light is viewed through a calcite crystal. Two images can be clearly observed, as seen in *Figure 1*, with different polarization states, which is demonstrated in the video by rotating a polarizing sheet in front of the object. A light spot passing through a calcite block exhibits the same behavior. A graphic segment is included in the explanation.



*Figure 1*

This calcite crystal demonstrates an unusual optical property known as double refraction.

When the crystal is placed over a printed sheet, two images of the printing can be seen.

We'll now place the calcite crystal over a metal plate with a small hole in the center and we observe two images of the hole.

A polarizing sheet rotated in front of the crystal shows that the two images are produced by light with two different polarization directions.

Here's how it works: When randomly polarized light enters the crystal, the light with one polarization direction is refracted more strongly than light which is polarized at right angles to that direction. The result is two different paths for the beams, which produces two distinct images made by orthogonal polarization.

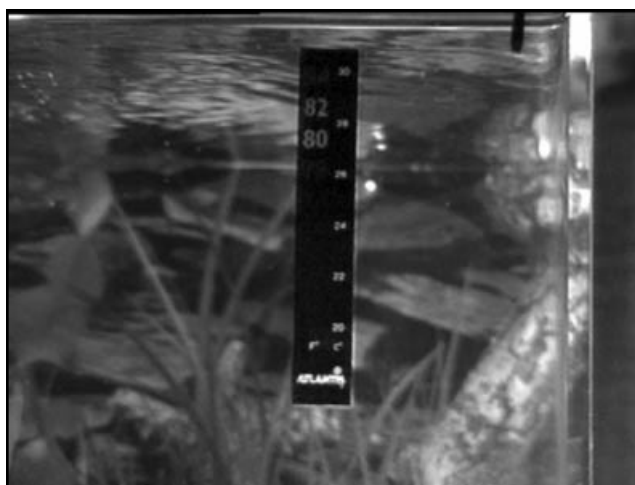
### ***Equipment***

---

1. Clear calcite crystal.
2. Sheet of paper with printing on it.
3. Light source.
4. Metal plate with a small hole at its center.
5. Polaroid disc that can be rotated.
6. Overhead projector and screen.
8. AC power for the overhead.

Liquid crystals are optically active materials that change the character of their optical activity with temperature. The liquid crystal is sandwiched between Polaroid sheets and illuminated either from behind or by light reflected behind the rear Polaroid, so that as its optical activity changes it creates a variety of negative colors, as shown in the video.

A large number of contemporary applications of liquid crystals are found in various digital meters and clocks, including the digital aquarium thermometer shown in *Figure 1*.



*Figure 1*



This plastic sheet is imbedded with liquid crystals which change color at different temperatures.

This sheet changes color at about 40 degrees centigrade. If we put a dish of water at 45 degrees on top of the sheet, the area under the dish changes color. As the sheet cools, it returns to its former color.

This aquarium thermometer has liquid crystals which react at different temperatures, each under a window in the shape of its transition temperature.

### ***Equipment***

---

1. Plastic sheet containing liquid crystals.
2. Large crystallization dish.
3. Supply of warm water.
4. Thermometer.



# C H A P T E R    6 6

## Q U A N T U M   P H Y S I C S

As an object is heated, the radiation spectrum emitted by the object shifts higher in frequency, or becomes more bluish. In this demonstration the filament of a projector light bulb is heated to increasing temperatures, at which the blue components in its spectrum become stronger. Analysis of the light produced by the projector is carried out using a prism as a spectroscope and using the setup of *Figure 1*.



*Figure 1*

You've probably seen how a lamp changes from red hot to white hot as its temperature increases. But how does the spectrum of light from the lamp actually change with rising temperature?

We'll use the lamp in this slide projector to find out.

Light from the projector is spread into a spectrum using a prism. A variac controls the voltage on the bulb and thus its temperature.

Here's the spectrum of the lamp running at a low temperature.

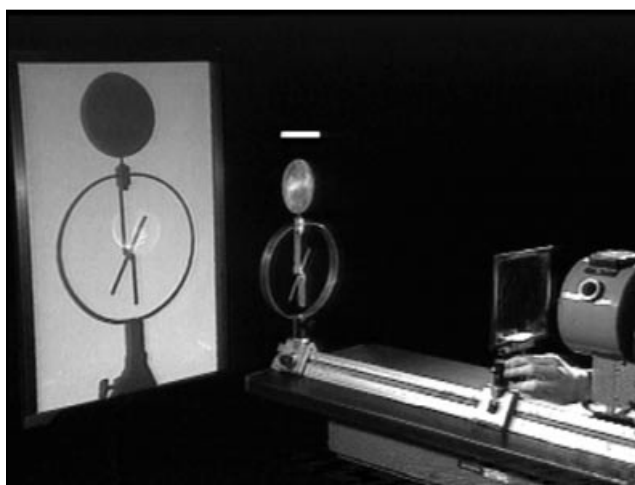
Now we'll turn up the voltage and gradually increase the temperature of the bulb. Notice how the spectrum spreads out from red to include orange, then yellow, green, and blue.

### ***Equipment***

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1. Slide projector.
2. Mask with a one-millimeter vertical slit in it in the projector's slide carrier.
3. Prism with the highest possible index of refraction set at the angle of minimum deviation.
4. Screen.
5. Variac.
6. AC power for the variac-projector combination.

A zinc plate, charged negative and connected to an electrometer that measures the charge on the plate, can be discharged by the photoelectric effect using the setup of *Figure 1*.<sup>†</sup> Ultraviolet photons from the arc lamp have sufficient photon energy to eject electrons from the zinc plate. When a glass plate is inserted into the light in front of the arc lamp, the ultraviolet radiation is removed, leaving less energetic visible photons striking the zinc plate, and the photoelectric discharge ceases, as illustrated in the video. If the plate is charged positive, shining any light on the plate has no effect.



*Figure 1*

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<sup>†</sup> Sutton, *Demonstration Experiments in Physics*, Demonstration A-89, Surface Photoelectric Effect.

Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration MPb-1, Photoelectric Effect.

We will now use an arc lamp and a zinc plate to demonstrate the photoelectric effect.

A polished zinc plate electrically connected to a projection electroscope is illuminated by a carbon arc lamp. This glass plate absorbs ultraviolet light from the arc lamp but lets visible light pass through.

The zinc plate is first charged positive by touching it with a glass rod which has been rubbed with silk. The electrometer shows that the zinc plate is charged and does not discharge when the light from the arc lamp shines on it, either with the glass plate in or with the glass plate removed.

Now the zinc plate is charged negative by touching it with a hard rubber rod which has been rubbed with fur.

The electroscope shows that the zinc plate is charged, and that it is not discharged by the light from the arc lamp shining through the glass plate.

However, when the glass plate is removed, the zinc plate immediately begins to discharge, as seen by the electroscope.

Visible light photons do not have sufficient energy to eject electrons from the zinc.

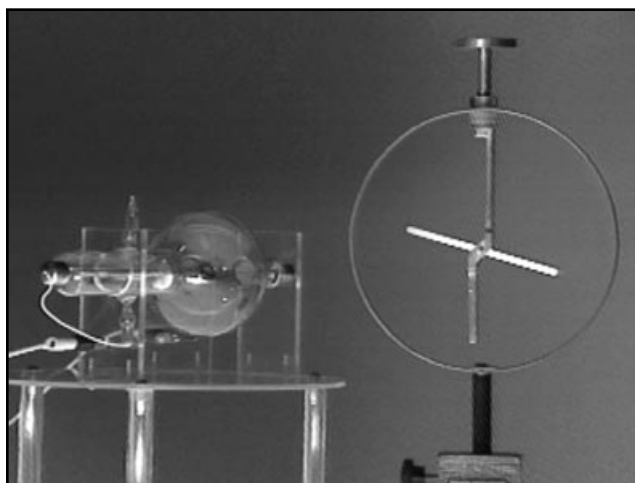
Ultraviolet photons from the arc lamp, which are absorbed by the glass plate, have sufficient energy to eject electrons from the zinc by the photoelectric effect.

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### ***Equipment***

1. An arc lamp.
2. Zinc plate (recently sanded to remove the oxide) mounted on an electroscope.
3. Glass plate that can be readily moved in and out of the light beam.
4. Screen.
5. Glass rod and silk cloth to produce a positive charge.
6. Hard rubber rod and fur to produce a negative charge.
7. Electrical power for the arc lamp.

An electrometer is charged negative and exposed to X rays using the apparatus of *Figure 1*. The X-ray photons have sufficient energy to eject electrons by the photoelectric effect, and the electrometer rapidly discharges, as clearly shown in the video.



*Figure 1*



We'll use this X-ray tube to demonstrate the ionizing ability of X rays.

A high voltage from this induction coil applied to the tube accelerates electrons and slams them into this metal electrode. X rays then spray off into a cone centered around this direction.

If we charge this electroscope by touching it with a charged rod, it will normally hold a charge for a long time. When X rays from the tube are beamed at the electroscope, it discharges almost immediately.

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**Equipment**

1. X-ray tube.
2. Induction coil.
3. Battery eliminator.
4. Electroscope.
5. Rod and cloth.
6. AC power.
7. Lead shielding is necessary if people are near the equipment.

Solar cells convert light energy into electrical energy. This is illustrated in the video by holding an array of photocells close to a light bulb and observing the photocurrent with a milliammeter. The electrical energy produced may be used to run a small electric motor such as that shown in *Figure 1*.



*Figure 1*

These selenium solar cells produce a current when a light shines on them. The more intense the light, the more current flows.

If the light is intense enough, the current can be used to drive a small motor.

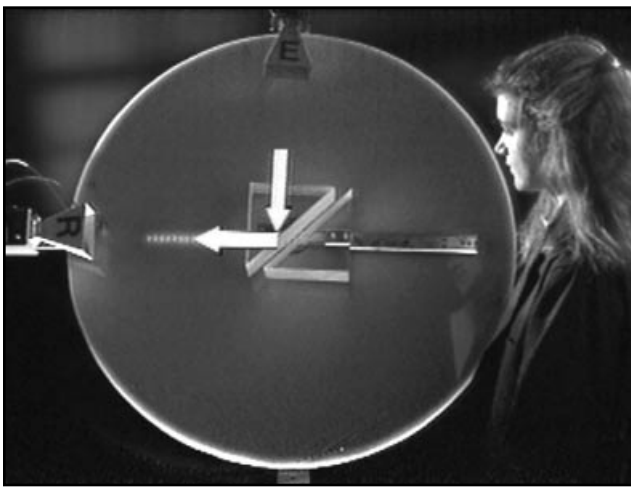
***Equipment***

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1. Solar cell unit.
2. Lecture table galvanometer.
3. Appropriate electrical leads.
4. Light source.
5. AC power for the light.
6. Small electric motor equipped with a visible disc on its shaft.

A beam of 3-cm microwaves reflects from the internal surface of the 90° plastic prism shown in *Figure 1* and are seen by the microwave receiver at the left. When the surface of a second prism is brought close to the first prism, the tail of the wave function of the microwave beam is picked up by the second prism and some of the microwaves are transmitted straight into the second prism. When the second prism becomes very close to the first, but not in contact, virtually the entire microwave intensity is transmitted out of the first prism, and virtually none is reflected internally, as is clearly shown in the video.

This effect is called quantum mechanical barrier penetration.



*Figure 1*

This device consists of a microwave emitter, a microwave receiver, and a bargraph display whose length is proportional to the intensity of the microwaves picked up by the receiver.

The microwaves are sent down into this prism; the beam is totally internally reflected off the inner surface of the prism. None of the radiation makes it through the prism to the bottom of the board.

As the second prism is brought in closer to the first, the reflected beam gradually disappears.

The energy now begins to penetrate the air barrier between the pair of prisms and reaches the receiver at the bottom of the board.

### ***Equipment***

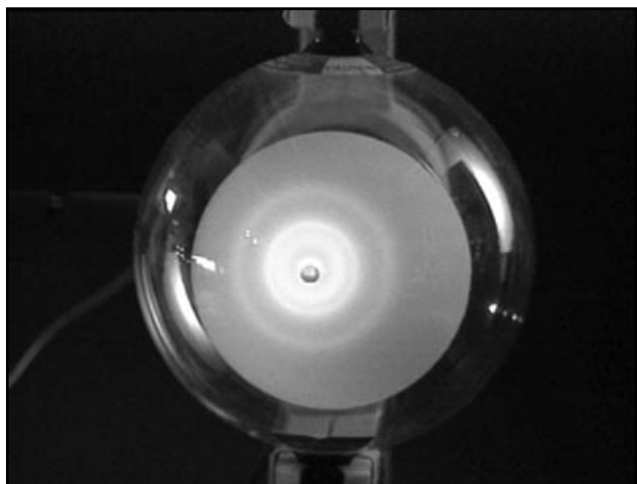
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1. Brett Carroll microwave board.
2. Two 45° prisms mounted on a drawer roller guide so their hypotenuses can smoothly come into contact with one another by sliding one movable prism toward the other that is fixed near the center.
3. AC power.

Electrons have wave properties, and under the proper circumstances will exhibit behavior more characteristic of waves than of “particles.” This demonstration shows that electrons can undergo diffraction when they have the right energy and are passed through a crystal with appropriate spacing. In this demonstration electrons are diffracted from powdered graphite crystal, creating the series of diffraction circles seen in *Figure 1*. As the energy of the electrons is increased, their wavelength decreases:

$$\lambda = \frac{h}{p}$$

where  $h$  is Planck’s constant and  $p$  is the momentum of the electron. When the wavelength decreases the pattern shrinks, as in the case of white light passing through an interference or diffraction grating, where the blue light is bent less than the red light. The effect of changing the energy of the electrons is shown in the video.



*Figure 1*

Electrons have characteristics of waves as well as of particles. We'll demonstrate that wave nature with this electron diffraction tube.

An electron emitter in the back of the tube is electrically heated until electrons escape the surface. A voltage between the emitter and a thin graphite film accelerates the electrons toward the film. The electrons are diffracted as they pass through the graphite, then strike a phosphor screen.

Notice the ring pattern marking where the electrons strike the screen.

If we increase the voltage on the emitter, the rings shrink.

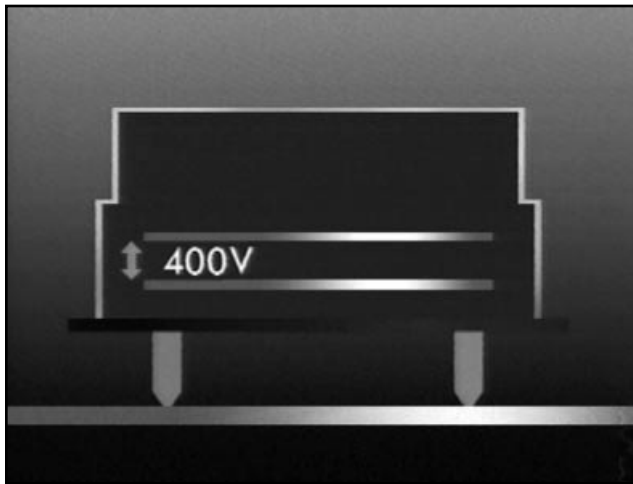
Decreasing the voltage expands the rings.

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***Equipment***

1. Commercially available electron diffraction tube and its power supply.
2. AC power.

The Millikan oil drop experiment is the original classic experiment in which the charge on the electron was determined. Small oil droplets from an atomizer are squirted between two metal plates, with opposite charges on the plates. If there is a net charge of one electron on the oil droplet, electric fields can be found that create an electric force on the droplet which exactly balances the downward force of gravity, makes the oil drop move upward, or makes the drop move downward faster than gravity would pull it. This information can be used to determine the charge on the electron. A graphics section discusses this determination in some detail and explains some of the important details of the measurement of the charge on the electron using this apparatus.



*Figure 1*



This Millikan Oil Drop apparatus is similar to the device used in the first successful measurement of the charge on a single electron.

Inside this chamber are two horizontal metal plates separated by about 2 centimeters.

We'll spray a fine mist of oil droplets between the plates and observe them as they fall.

If we apply a high voltage to the plates, some of the oil droplets are accelerated upward or downward because of the presence of minute electrical charges on the drops.

We can reverse the direction of the field with this switch. Let's follow the motion of one of the drops as the field is reversed.

First the field is vertically upward-

then off—

then vertically downward.

Notice how the droplet has reversed direction.

Off—

upward—

off—

downward.

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### ***Equipment***

1. Millikan oil drop apparatus and a support system if necessary.
2. Power supply.
3. Appropriate electrical leads.
4. Slide projector.
5. Aspirator containing a fine oil.
6. AC power for the projector and the power supply.

“Bichsel boxes” are two black boxes with identical holes in their tops, shown in *Figure 1*. Although the inside of one of the boxes is white and the inside of the other box is black, the darkness of the holes appears the same. This demonstration illustrates that the radiation emerging out of the box from a hole is characterized only by the temperature within the box.



*Figure 1*

These two boxes with holes in the front appear similar—the holes seem to be about the same shade of black.

But when they are opened, they are obviously different. Even though the inner surface of one is black and the other white, the amount of light reflected back out through the holes is about the same in both cases, and the holes appear the same.

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***Equipment***

Two file card boxes, both painted flat black on their exteriors with one painted black inside, the other interior is painted white. Both boxes have a small hole in the center of their lids.