6: Optics

6A: Geometrical Optics
6B: Photometry
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6F: Color
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6J: The Eye
6Q: Modern Optics

6A: Geometrical Optics

Various Light Sources -- a collection of show and tell light sources from candles and carbon arcs to noble-gas discharge tubes, LEDs, and lasers.

6A01. Speed of Light

6A02. Straight Line Propagation

Light and Siren in Vacuum (6A02.10) -- a small electronic siren and a LED are mounted inside a bell jar. The air is then evacuated from the jar, and although the LED can still be seen, no sound can be heard from the siren. Also listed as 3B30.30.

Straight Line Propagation (6A02.15) -- cast shadows of a hand, etc. from a carbon arc lamp without a lens, and/or show laser beam through chalk dust cloud.

6A10. Reflection from Flat Surfaces

Angle of Incidence and Reflection (6A10.11) -- a beam of white light falls on a mirror mounted on a large rotating protractor. Various angles of incidence and reflection can be compared to show that I=R.

Microwave Reflection (6A10.18) -- Reflect a microwave beam off a metal plate into a receiver.

Diffuse and Specular Reflection (6A10.20) -- reflect white light or a laser off a rough surface to show diffuse reflection. Compare with a mirror, metal surface, etc.

Corner Reflector (6A10.30) -- three plane mirrors joined to form the corner of a cube. This has retroreflecting properties, and is similar to the reflectors left on the moon for laser distance determinations and the reflectors in those brightly reflecting roadway lane dividers.
Parity Reversal (6A10.37) -- two ball-and-stick figures (Cartesian coordinate systems) of opposite "handedness" are used with a plane mirror to show parity reversal of reflected images.

Image Reversal (DIXIE/SOUTH) -- DIXIE has mirror symmetry along the horizontal axis and appears unchanged in the mirror, but SOUTH looks quite different. Also CHECK/THIS.

Image Perversion (TIME/EMIT) -- the word "TIME" is printed on a clear sheet of acrylic which is backed with an opaque sheet of cardboard. When you turn it around to face the mirror, the students will see that the word is reversed left-to-right ("EMIT" with a backwards E). Many students think that the mirror has reversed the word left-to-right. Pull the cardboard off and they will see that the image has the same left-to-right orientations the original - you reversed it left-to-right when you turned it around.

Hinged Mirrors (Multiple Reflections) (6A10.40) -- two plane mirrors are joined with a hinge and can be adjusted to various angles. A small flashlight bulb mounted between the mirrors is the object, and the number and positions of its images are noted as the angle between the mirrors changes.

Parallel Mirrors ("Barbershop Mirror" Effect) (6A10.45) -- two plane mirrors are placed parallel to and facing one another. An object is placed between them and multiple images are seen in the view past the edges of the front mirror.

Beer Sign -- a commercial sign using the "Barbershop Mirror" effect. Beer logo is placed between two mirrors, the front mirror being partially transparent. Some of the light bouncing between the mirrors escapes through the front mirror, and multiple images of the logo are seen.

Location of Image (Candle in a Glass of Water) (6A10.60) -- a vertical glass window pane stands between two objects - a candle in front and a beaker of water in the rear at the position of the candle's image in the glass. The image of the candle appears to be burning under water. The entire stand can be rotated to show that the position of the candle's image relative to the glass does not change with different viewing angles.

6A20. Reflection from Curved Surfaces

Concave and Convex Mirrors On Optics Board (6A20.10) -- uses the optics board to trace incident and reflected rays from concave and convex mirrors. See also Lenses On Optics Board (6A60.20).

Large Concave Mirror (6A20.31):

- Strawberry -- real image of plastic strawberries placed in front of the mirror.
- Candle Burning at Both Ends -- a burning candle placed slightly above the center of curvature of the mirror has a real image of the flame at its bottom - it appears to be burning on both ends.
- One Candle Searchlight -- burning candle placed at the focus of the mirror throws a roughly parallel beam to the far wall.

6A40. Refractive Index

Broken glass in Oil (6A40.30) -- Broken glass fragments will disappear in mineral oil because they have near identical indices of refraction. Tip the container to see the effect.

Mirage with a Laser (6A40.47) -- A laser beam almost grazing a hot surface will show deflection.
6A42. Refraction from Flat Surfaces

**Refraction and Reflection from a Plastic Block (6A42.12)** -- a large rectangular acrylic block on the optics board (see above) will refract and partially reflect incident beams. Can be rotated to various angles to vary the angle of incidence/refraction.

**Small Refraction Tank (6A42.43)** -- A lamp is positioned in an opaque tank so the filament cannot be seen. Add water until the light from the filament is refracted and seen over the edge of the tank.

**Refraction from Water Tank (6A42.45)** -- A stick appears bent or broken when inserted into water at an angle.

**Acrylic and Lead Glass Refraction (6A42.47)** -- Hold a stick behind a block of acrylic (n=1.4) and lead glass (n=2). At each interface (air to acrylic and acrylic to lead glass), the image of the stick is shifted when viewed off the normal to the surface of the blocks.

**Apparent Depth** -- the lead glass and acrylic blocks mentioned above, when viewed from an angle, demonstrate the apparent depth effect. The edge which is viewed directly shows the true depth of the blocks; the edge viewed through the blocks appears shorter, or closer to the surface.

6A44. Total Internal Reflection

**Critical Angle and Total Internal Reflection (6A44.20)** -- a parallel beam of light traveling underwater is reflected up to the water/air interface by a small mirror. The mirror may be rotated to change the angle of incidence. Fluorescein in the water and a thread screen above the water allow the incident, refracted, and reflected beams to be seen clearly. As the angle of incidence reaches the critical angle, the refracted beam is seen to skim just over the surface of the water. Increase the angle slightly from that, and the refracted beam disappears while the reflected beam jumps in intensity (total internal reflection).

**Light Pipes and Fiber Optics (6A44.40)** -- Transmit white light or a laser beam through straight and curved Lucite rods, or various optical fibers.

6A46. Rainbow

**Rainbow on Optics Board (6A46.30)** -- using a single beam of white light and large acrylic disc on the optics board.

Note: The following two rainbow demonstrations are only viewable individually or in small groups.

**Artificial Rainbow (Water Flask)** -- a round flask filled with water simulates a raindrop, casting a small rainbow on the screen when illuminated with a carbon arc.

**Rainbow (Glass Beads)** -- a point source of light situated above a black velvet board covered with tiny glass beads creates a rainbow.

6A60. Thin Lens

**Lenses On Optics Board (6A60.20)** -- concave and convex lenses on the optics board show the basic properties of lenses, ray tracing, etc. See also Concave and Convex Mirrors On Optics Board (6A20.10).

**Image Formation (6A60.30)** -- light from a backlit "object" is focused by a convex lens onto a translucent screen. Image reversal and magnification can be shown.

**Conjugate Focal Positions** -- the above arrangement is used to show that there are two lens positions which will form an image on
Magnification (6A60.35) -- a backlit black-and-white grid and a large (12 in.) lens are used to demonstrate magnification by convex lenses. Also good for showing spherical and chromatic aberrations. Note: See also Fresnel Lens Magnification (6A65.70).

6A61. Pinhole

Pinhole Camera Effect (6A61.20) -- large but workable pinhole camera projects the image of a lamp filament onto a translucent screen.

6A65. Thick Lens

Chromatic Aberration (6A65.21) -- shows different points of focus for red and blue light through a large plano-convex lens. Can also show colored halo around focused white light.

Achromatic Pair -- shows correction of chromatic aberration using a correcting lens.

Spherical Aberration (6A65.40) -- shows different points of focus for different areas of a large plano-convex lens. First the outer half of the lens is blocked off, and an image is brought to focus using the lens. Then the inner half is blocked off, and the image is seen to be out of focus. The image can now be brought back to focus by moving the lens. The image formed by the outer half of the lens is seen to be fuzzier than that formed by the inner half.

Fillable Air Lenses (6A65.52) -- air-filled lenses held under water in a parallel beam of light show "reverse" refraction in going from a higher to a lower index of refraction. Concave lens focuses beam, etc. Removing your finger from the top of the handle tube allows the lens to fill with water, so that the medium of the lens is the same as the surroundings and the parallel beam of light passes through without effect. Remove the water-filled lens thus formed from the optics tank and insert it in the thread screen to show that its focusing properties are now the opposite of the original air-filled lens.

Glass Lenses in Air and Water -- a lens is inserted in the thread screen to show the focal length, then is dipped into the optics tank to show a much longer focal length in water due to the greater refractive index of the medium. Can also be done with the optics tank half-full to show both focii simultaneously.

Cylindrical Lens -- shows properties of a cylindrical lens.

Fresnel Lens Magnification (6A65.70) -- Magnification (6A60.35) using a large plastic Fresnel lens.

6A70. Optical Instruments

Microscope Model (6A70.10) -- A working model of a simple microscope. Note: This works quite well with the Telescope Models (6A70.20).

Projection Microscope -- a self-contained projection microscope magnifies the grids from two fine wire mesh screens.

Microscope Chart -- an overhead transparency chart showing the components of a microscope.

Telescope Models (6A70.20) -- Choose any or all of the three types listed below. We use an eye chart for the object, and small video cameras for class viewing.
Galilean (Non-inverting) Telescope -- uses a converging objective lens and a diverging eyepiece lens to produce a non-inverted image.

Keplerian (Inverting) Telescope -- uses two converging lenses to produce an inverted image (but with a wider field of view and greater magnification).

Newtonian (Reflecting) Telescope -- a simple off-axis Newtonian reflector gives an upright (but mirrored left-right) image.

Zoom Lens -- a slide projector so equipped.

6B: Photometry

6B10. Luminosity

Inverse Square Law (6B10.20) -- Double or triple the distance between a point light source and a photometer.

Light Meters -- electronic photometers, one with digital and one with analog output.

6B30. Radiation Pressure

6B40. Blackbodies

Bichsel Boxes (6B40.20) -- two 3x5 index card boxes each with a small hole in the lid; one is painted black inside and the other white. Hold the boxes up to the students with the holes facing them and they appear almost identical. Open the lids and the difference is obvious. Useful in discussing blackbody cavity radiation.

Blackbody Radiator (6B40.26) -- a small metal cube has a narrow hole drilled in the side. As viewed with a video camera, the hole appears darker than the surrounding metal. If the cube is heated with a blowtorch to a high enough temperature, the hole will glow brighter than the surrounding metal.

Infrared in the Spectrum (6B40.41) -- light from a hot carbon arc is spread into a spectrum, then various portions of the spectrum are scanned with a thermopile. It is shown that the greatest amount of energy is in the infrared portion of the spectrum where no visible light exists, then tapers off into the visible and disappears in the ultraviolet. Note: This is done on the same setup as Ultraviolet in the Spectrum (7B13.40).

Radiation Spectrum of a Hot Object (6B40.55) -- light from a slide projector powered by a variac is spread into a spectrum. With the variac at a low setting the projector bulb is red-hot and the spectrum consists of red light only. Turn the variac up slowly, and as the temperature of the bulb increases the spectrum comes to include orange, yellow, green, and (at white heat) blue light.

6C: Diffraction

Please see section 3B50. Interference and Diffraction for ripple tank demonstrations.

6C10. Diffraction Through One Slit

Laser and Single Slit (6C10.10) -- a laser beam passes through a slide with four single slits of known widths.
Laser and Single Slit (Cornell Slide) (6C10.12) -- The Cornell slide has several single slits of various widths as well as a gradually widening slit.

Laser and Adjustable Single Slit (6C10.15) -- a variable-width single slit shows diffraction of a laser beam.

Microwave Single Slit Diffraction (6C10.50) -- single slit diffraction of microwaves.

6C20. Diffraction Around Objects
Arago's (or Poisson's) Bright Spot (6C20.10) -- Light from a laser is diffracted by a small ball bearing and is viewed using a camera and TV. This is on the same table as Point and Eye of a Needle (6C20.22).

Hair or Thin Wire (6C20.20) -- projected diffraction pattern from a thin wire in a laser beam.

Point and Eye of a Needle (6C20.22) -- Light from a laser is diffracted by the point or eye of a needle and is viewed using a camera and TV. This is on the same table as Arago's (or Poisson's) Bright Spot (6C20.10).

Knife Edge Diffraction (6C20.15) -- a projected edge diffraction pattern using a razor blade, laser, and lens.

Aperture Diffraction (Airy Disk) (6C20.30) -- projected circular diffraction pattern from passing a laser beam through a small aperture.

Diffraction from a Feather (6C20.62) -- a laser beam passing through the closely-spaced hairs of a feather will spread into a diffraction pattern on the screen.

6D: Interference
Please see section 3B50. Interference and Diffraction for ripple tank demonstrations.

6D10. Interference From Two Sources
Laser and Double Slits (6D10.10) -- A laser passes through a slide with four double slit combinations (two different slit widths and two spacings).

Laser and Double Slits (Cornell Slide) (6D10.11) -- The Cornell slide has various double slits as well as a gradually widening double slit.

Microwave Double Slit Interference (6D10.20) -- three double slit spacings for the microwave apparatus.

6D15. Interference of Polarized Light
6D20. Gratings
Laser and Multiple Slits (6D20.10) -- A laser passes through a slide with 2, 3, 4, and 5 slits.

Laser and Multiple Slit Interference (Cornell Slide) (6D20.10) -- The Cornell slide has five sets of multiple slits.

Transmission Gratings with White Light and Lasers (6D20.20) -- White light and two lasers (one red, one green) are passed
through four diffraction gratings of various line densities. The white light produces a continuous spectrum and the two lasers produce different diffraction patterns.

**Two Dimensional Gratings (6D20.35)** -- very fine wire mesh slides (100 to 3,000 lines per inch) and a laser produce two dimensional patterns.

**Crossed Gratings and a Laser (6D20.50)** -- a pair of 1D gratings at right angles diffracts laser light into a two dimensional pattern.

**Point Source and Wire Mesh (6D20.55)** -- a point source of white light is viewed through small pieces of wire mesh handed out to the students. The weave of the mesh is fine enough to diffract the light.

**Reflection Gratings** -- concave reflection gratings can simultaneously disperse and focus white light.

**6D30. Thin Films**

**Newton's Rings (6D30.10)** -- white light projection of interference patterns from a thin layer of air between two layers of glass; one flat and the other curved but nearly flat. A concentric circular interference pattern is obtained which can be varied by squeezing the plates of glass.

**Soap Film Interference (6D30.20)** -- white light is reflected off a thin soap film onto a screen. Dazzling multicolor interference patterns are formed, with rough bands of different colors indicating the varying thickness of the film. Eventually a dark area forms at the top (where the film is less than a quarter wavelength thick), spreads down throughout the pattern, and the film pops.

**Glass Plates in Sodium Light (6D30.30)** -- two large flat glass plates are stacked and illuminated by a sodium lamp. The yellow and black interference fringes are easily visible to the entire class.

**Pohl's Mica Sheet (6D30.40)** -- violet light from a mercury arc is reflected from a thin sheet of mica onto a screen to produce a circular interference pattern from the interference of reflections from the front and back surfaces of the mica.

**Interference Filters (Dichroic Filters) (6D30.60)** -- thin film layers of various thicknesses on glass are inserted in the thread screen to demonstrate their effect upon a beam of white light. Both reflected and transmitted colors can be seen simultaneously, and the reflected color is seen to be different than the transmitted color. Changing the angle of incidence changes the colors.

**6D40. Interferometers**

**Michelson Interferometer - Laser (6D40.10)** -- The Michelson Interferometer and laser.

**Michelson Interferometer - Microwaves (6D40.20)** -- Interference maxima and minima from microwaves are detected as one of the "mirrors" is moved.

**Fabry-Perot Interferometer (6D40.35)** -- a workable interferometer but with poor mirrors (low finesse).

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**6F: Color**

**6F10. Synthesis and Analysis of Color**

**Additive Color Mixing Box (6F10.10)** -- a box containing red, blue, and green light sources with individual brightness controls shows
aspects of additive color mixing, primary and secondary colors, etc.

**Color Filters (6F10.20)** -- various color filters used with white light.

**Subtractive Color Mixing** -- colored filters are stacked on the overhead to show subtractive color mixing.

**Newton’s Color Disk (6F10.25)** -- a disk sectioned into primary colors “smears” into white light when rotated.

**Spinning Black and White Disks** -- illusion of color on a spinning black and white disk due to the eye’s different reaction speeds to different colors.

**Recombined Spectrum (6F10.30)** -- a continuous spectrum from a prism is recombined into white light with a second prism.

**Colored Objects in Spectrum (6F10.75)** -- objects colored with fairly pure hues are moved through a white light spectrum to show reflectivity and apparent color in different colors of light.

**Polaroid-Land Effect** -- Two black and white slides of the same image are projected so that they overlap on the front screen. Specific red and green filters are placed in front of each slide projector. This causes the black and white image to appear in full color.

6F30. Dispersion

6F40. Scattering

**Artificial Sunset (6F40.10)** -- A beam of white light is scattered when passing through a water tank that also contains a hypo solution (Sodium Thiosulfate) and acid.

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**6H: Polarization**

**6H10. Dichroic Polarization**

**Polaroid Sheets (6H10.10)** -- 12” x 12” sheets of Polaroid material for use on the overhead projector.

**Polarization of Microwaves (6H10.20)** -- polarized microwaves pass through a metal grating; the orientation of the grating (vertical or horizontal) greatly affects the intensity of the transmitted beam.

**Slotted Boxes (6H10.30)** -- a rope passes through slots in wooden boxes which can be horizontal or vertical. Wiggle the rope and the first box “polarizes” the wave. The wave will either stop at the second box or pass through, depending on whether the slot is crossed or parallel to the first.

**Vector Models** -- dowel rod models for plane and circular polarization.

**6H20. Polarization by Reflection**

**Polarization by Reflection (Brewster’s Angle) (6H20.10)** -- a beam of white light reflects off a glass plate and appears on the wall. Interpose a Polaroid sheet and rotate it to show that the reflected beam is polarized. Do the same with the beam shining straight onto the wall to show that the unreflected beam is not polarized. The angle of incidence can be changed to show that there is an optimum angle of reflection for maximum polarization of the beam.
Polarization by Double Reflection (6H20.20) -- a parallel beam light source mounted on the edge of a rotation stand strikes a glass plate mounted at the center of the stand and is reflected up along the axis of rotation. The beam then strikes a second glass plate and is reflected onto a translucent screen. The spot of light will be either bright or dim depending on the relative angle between the two glass plates as the stand is rotated through a full turn or more. Polarization state of the transmitted beams may also be checked, using a polaroid sheet.

6H30. Circular Polarization

Three Polaroid Sheets (6H30.10) -- Two polaroid sheets (6H10.10) are placed on the overhead projector with their axes of polarization perpendicular to each other (no light passes through). A third polarizer is then placed in between the original two sheets and rotated so that light will pass through.

Sugar Tube (6H30.40) -- light passes through a flask of sugar solution (corn syrup) sitting between two Polaroid sheets on the overhead. Adding more syrup increases the path length, changing the transmitted color due to increased optical rotation.

6H35. Birefringence

Polarization by Double Refraction (6H35.15) -- a small beam of light passes through a calcite crystal, is doubly refracted, and is projected on a screen as two dots. Rotating a Polaroid analyzer atop the crystal makes the dots appear and disappear in alternation, showing that the beams are polarized perpendicular to one another. Rotating the crystal makes one dot revolve around the other.

Quarter Wave Plate (6H35.40) -- A birefringent plate produces ordinary and extraordinary waves of equal amplitudes, but 90° out of phase. Linearly polarized light will be changed into circularly polarized light. Can be used with a linear polaroid sheet and a mirror.

Polarization by Stress in Plastic (6H35.50) -- transparent acrylic shapes are held between two crossed Polaroid sheets and squeezed. The top polarizer can be rotated or removed.

6H50. Polarization by Scattering

Polarization by Scattering (6H50.10) -- White light passes through a Polaroid analyzer, then is scattered by passage through a tank of water with a little milk added. The polarized light is scattered preferentially in the direction of its polarization, and by rotating the analyzer the direction of most intense scattered light can be varied. A mirror atop the tank allows simultaneous viewing of top and front views for comparison of vertically and horizontally scattered light.

6J: The Eye

6J10. The Eye

Human Eye Model (6J10.10) -- A take-apart model of the human eye.

Resolving Power of the Eye (6J10.80) -- A black screen with four double slit patterns is placed in front of a bright sodium lamp. The double slit patterns vary in separation and the class is asked in which pattern can they resolve both slits.

6J11. Physiology

Eye Defects Transparency -- overhead transparency shows the optical causes of various eye defects.

Color Blindness (6J11.70) -- color blindness slides are projected to test the class.
Holograms (6Q10.10) -- A variety of holograms are available using lasers or white light. A video camera allows for whole-class viewing if desired. Note Please give us at least two days notice!