Photography

Bit Depth, Colors, and Digital Photos

(from http://www.sciencebuddies.com)

Objective

The objective is to investigate the relationship between the number of bits in a digital image and the number of colors and file size of the image.

Introduction

A bit is the smallest unit of measurement regarding computer data. Each bit indicates one of 2 different states, on (represented by a 1) or off (represented by a 0). A single bit does not convey much information, but you can string bits together in binary codes to represent numbers, words, music, pictures, or any other type of computer data. In fact, all computer data is coded in binary numbers, and looks like a series of zeros and 1's:

00101011100100100101110110110101000000110111101001101010

For a digital photo, bit depth is the number of colors that can be shown in the image. Because the bits can only indicate one of 2 possible states (0 or 1), the number of colors can only be powers of 2. Some examples of bit depths (and the calculation of the decimal number for those of you who know exponents) for image files are: 2-bit (2^2 = 4 colors), 4-bit (2^4=16 colors), 8-bit (2^8=256 colors), 16-bit (2^16=65,536 colors), and 24-bit (2^24=16,777,216 colors).

"Every color pixel in a digital image is created through some combination of the three primary colors: red, green, and blue. Each primary color is often referred to as a "color channel" and can have any range of intensity values specified by its bit depth. The bit depth for each primary color is termed the "bits per channel." The "bits per pixel" (bpp) refers to the sum of the bits in all three color channels and represents the total colors available at each pixel. " (McHugh, 2005)

The larger the bpp is, the more colors can be used in the image. The smaller the bpp is, the less colors can be used in the image. Since images with more colors contain more information, they have larger file sizes. In this way, the bpp of an image is related to the file size and the number of colors.

In this experiment you will change the number of colors in a digital photo and measure the effect on file size and bpp and download time. Will the file size and download time always increase if the bpp increases? How will changing the bpp of an image change the number of colors that are possible? Is the relationship linear?

Terms, Concepts and Questions to Start Background Research

To do this type of experiment you should know what the following terms mean. Have an adult help you search the internet, or take you to your local library to find out more!

- bit
- binary code
- bit depth (bits per channel)
- bits per pixel (bpp)
- file size
- byte

Questions

- What is a bit?
- How many bits will make a good quality image?
- How will the number of bits change the number of colors and the file size?

Bibliography

- 2005a. "Color/Bit Depth and Image Resolution," Adobe Web Tech Curriculum, Adobe Systems, Inc. San Jose, CA. [accessed: 4/24/06] http://www.adobe.com/education/instruction/webtech/CS2/unit_graphics1/gb_res_bitdepth_id.htm
- 2005b. "Adobe Digital Kids Club." Adobe Systems, Inc. San Jose, CA. [accessed: 4/24/06] http://www.adobe.com/education/digkids/main.html
- Sean McHugh, S., 2005. "Tutorials: Bit Depth," Cambridgeincolour.com, Cambridge, UK. [accessed: 4/24/06] http://www.cambridgeincolour.com/tutorials/bit-depth.htm
- Wilson, Tracy V., Nice, K., and Gurevich, G. 2005. "How Digital Cameras Work." HowStuffWorks, Inc. Atlanta, GA. [accessed: 4/24/06] http://www.howstuffworks.com/digital-camera.htm

Materials and Equipment

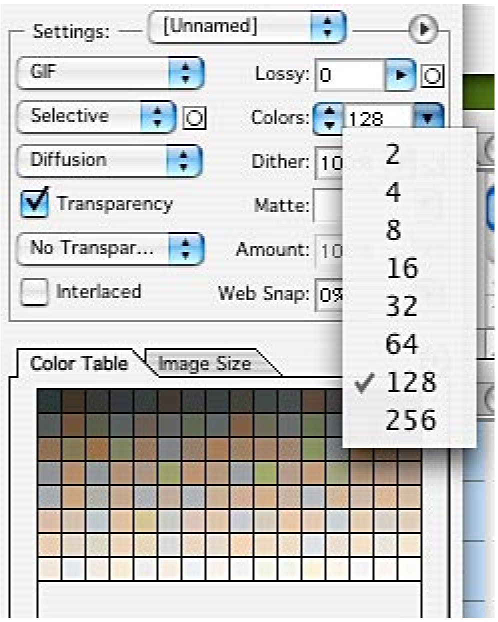
- computer
- Adobe Photoshop (while this project uses Photoshop, any picture editing software will work)

- your favorite photo
- color printer
- photo quality printing paper

Experimental Procedure

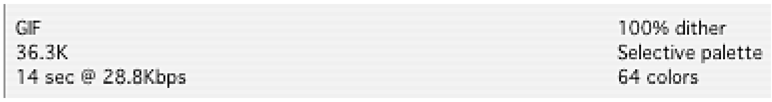
1. On your desktop, create a new folder called "My Photo Experiment" and place a copy of your favorite photo in the folder (like puppy.jpg).
2. Open the photo in Adobe Photoshop.
3. Click on "File" and "Save for Web..." from the file menu. A dialog box should appear showing your image in a new window. Choose the "4-Up" tab from the top of the window:

4. Four copies of your photo should appear in the window. One copy will be your original, and there will be three more copies of your photo in GIF file format.
5. Next you will make a series of changes to the settings in each frame. You will change the number of colors in each frame to a different value by clicking on the drop down menu on the right side of the screen:



Settings: [Unnamed]
GIF
Lossy: 0
Selective
Colors: 128
Diffusion
Dither: 10
☑ Transparency
Matte:
No Transpar...
Amount: 10
☐ Interlaced
Web Snap: 0%

6. Each time you change the number of colors, you will see the information below the image change. Make sure you can locate the number of colors, file size and download speed:



GIF
36.3K
14 sec @ 28.8Kbps

100% dither
Selective palette
64 colors

7. Write all of the information in a data table:

File Name	Number of Colors	Bits Per Pixel	File Size (Kb)	Download Time (sec)	Speed (Kbps)
puppy.jpg					
puppy1.gif					
puppy2.gif					
puppy3.gif					

8. You will need to calculate how many bits per pixel are in each image by using the number of colors in the image. Use this table to match up the bits per pixel with the number of colors chosen:

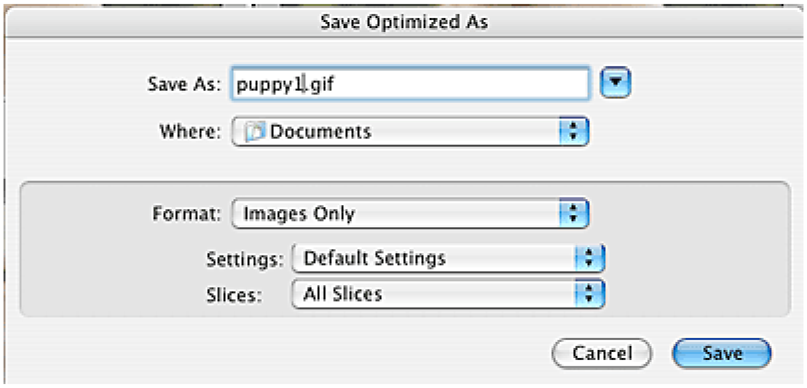
Bits Per Pixel	Number of Colors Available
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256

☑ Make graphs of your data from the data table. Each graph should highlight one relationship, for example:

- bits per pixel vs. number of colors
- bits per pixel vs. file size

    - bits per pixel vs. download time

- ☑ You will also want to save a copy of each "trial" photo. Do this by selecting one of your photo copies and clicking on the "Save" button. Save the file with the corresponding file name from your data table:



Save As: puppy1.gif
Where: Documents
Format: Images Only
Settings: Default Settings
Slices: All Slices

- ☑ Save each picture as a new file in the folder on your desktop named "My Photo Experiment", naming each new file with a different name to keep track of your experiments (like puppy1, puppy2, puppy3, etc.). Keep all of the settings and file extensions (.gif) the same.
- ☑ Print a copy of each picture on photo quality paper and label the image with the file name for your display board.
- ☑ Arrange your photos in a row and compare the images. How did changing the bits per pixel and number of colors in the image change the quality of the photo?

Variations

- To kick this project up a notch try counting the number of unique colors in each image. Photoshop can not calculate the unique colors used in an image, so you will need to use another program like PaintShop Pro, which is a shareware program available for a free download. Open each of your files with PaintShop Pro and choose Colors/CountColorsUsed. After a while PaintShop Pro will show a dialog box that tells you the number of unique colors in the image, (like 16,777,216). Does this number match the number you chose in the settings dialog box? Why or why not?

Color Profiles

(from http://www.sciencebuddies.com)

Objective

In this experiment you will investigate how different color profiles combine colors to produce an image.

Introduction

When thinking about digital photography, it is important to know what you will use your photo for. You want your photo to look good whether it is online or in print. Why should this make a difference?

There is a fundamental difference between how color is produced on a screen and by a printer. A screen lights up from behind, and shines the color out of the screen towards your eyes. A printer lays a pigment down on a sheet of paper (usually white) that will block some light from reflecting back to your eye. One process is additive (screen) and one is subtractive (paper).

Each color profile uses separate color channels that are combined to produce the final full color image. How does this work? In this experiment you will investigate two different color profiles, RGB Color and CMYK Color. Which color profile looks best on screen? Which one prints the best photos? You will dissect a full color image and learn to separate the individual color channels. What do the individual color channels look like?

Terms, Concepts and Questions to Start Background Research

To do this type of experiment you should know what the following terms mean. Have an adult help you search the internet, or take you to your local library to find out more!

- Color Profile
- RGB color (Red, Green, Blue)
- CMYK color (Cyan, Magenta, Yellow, Black)
- Color Channels
- Color Mixing

Questions

- How do the separate color channels mix together to form an image?

- What do the individual color channels of an RGB color image look like?
- What do the individual color channels of a CMYK color image look like?

Bibliography

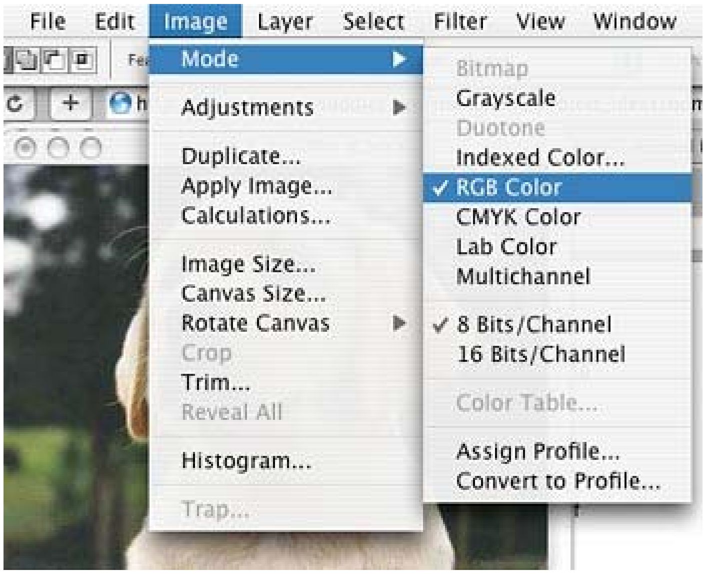
- Digital Expert, 2005. "Color Space Fundamentals," The Sheridan Group. [accessed: 4/24/06] http://dx.sheridan.com/advisor/cmyk_color.html
- 2005. "Adobe Digital Kids Club." Adobe Systems, Inc. San Jose, CA. [accessed: 4/24/06] http://www.adobe.com/education/digkids/main.html
- Wilson, Tracy V., Nice, K., and Gurevich, G. 2005. "How Digital Cameras Work." HowStuffWorks, Inc. Atlanta, GA. [accessed: 4/24/06] http://www.howstuffworks.com/digital-camera.htm

Materials and Equipment

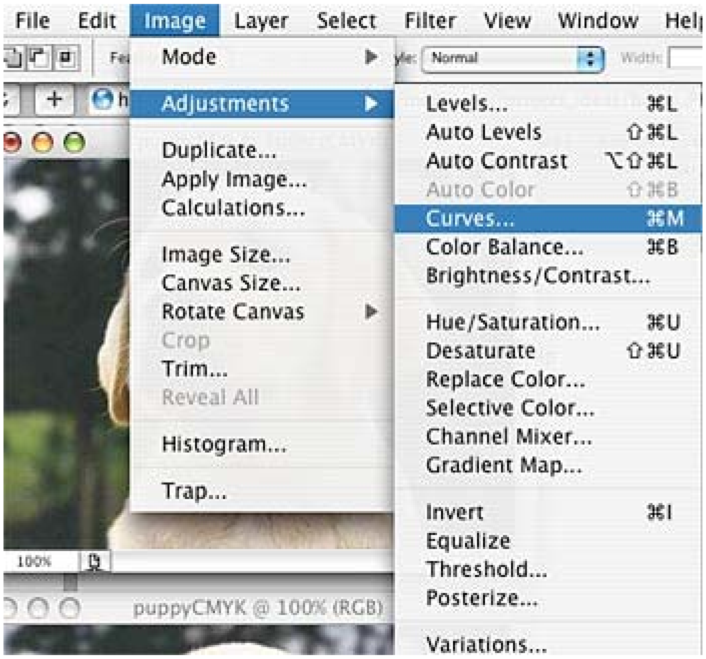
- computer
- Adobe Photoshop (while this project uses Photoshop, any picture editing software will work)
- your favorite photo
- color printer
- photo quality printing paper

Experimental Procedure

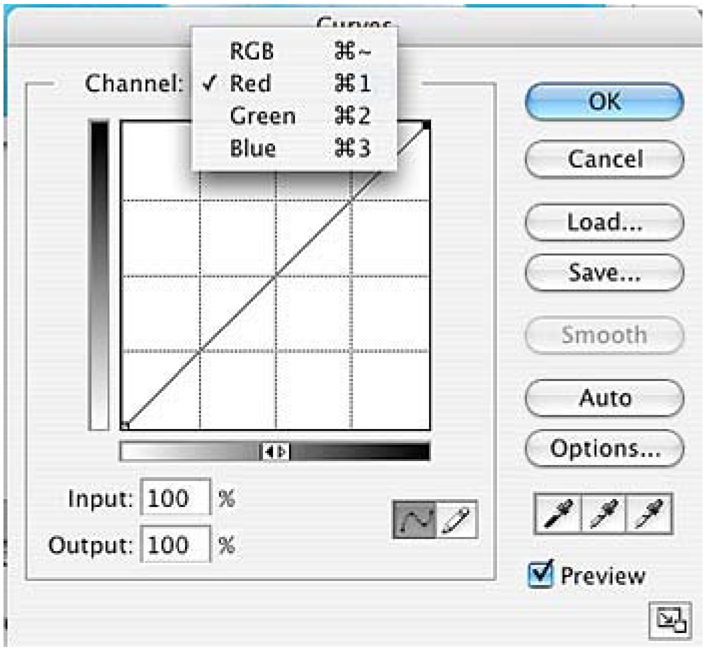
1. On your desktop, create a new folder called "My Photo Experiment" and place a copy of your favorite photo in the folder.
2. Open the photo in Adobe Photoshop.
3. To view the color profile for the image, click "Image" and then "Mode" from the file menu.
4. You will see a list of color profiles with a check next to "RGB" or "CMYK" indicating the current color profile.
5. To begin this experiment, we will start by using RGB color, because it only has three color channels. If the current profile is not RGB then click on "RGB" to select and change the color profile to RGB color.
6. Click on "File" and "Save As" to save this picture as a new file in the folder on your desktop named "My Photo Experiment", naming the file with the letters "RGB" at the end (like "puppyRGB"). Keep all of the settings and file extensions the same.



7. Print the picture on photo quality paper. This is your composite image, and includes all of the color channels.
8. Next, you are ready to view each individual color channel separately.
9. Click "Image" then "Adjustments" and then "Curves" from the file menu.



10. You will see a dialog box that has a square with a diagonal line running across it. Play around by clicking, moving and stretching the line to see what it does to change the image. When you are done experimenting click on "Cancel" and re-open the dialog box.



Channel: ✓ Red

Input: 100 %

Output: 100 %

☑ Preview

11. In RGB color, you will have three color channels. To isolate one color channel (Red), you will turn down the other two color channels (Green and Blue).
12. To see the Red channel:
    a. Click "Green" from the drop down menu, click on the top right hand corner of the line and drag it to the bottom right corner.
    b. Then click "Blue" from the drop down menu, click on the top right hand corner of the line and drag it to the bottom right corner.
13. Click "OK" and the dialog box will close. Your picture should look strange. This is your Red channel image, and does not have any of the Green or Blue color information in it.
14. Click on "File" and "Save As" to save this picture as a new file in the folder on your desktop named "My Photo Experiment", naming the file with the letters "Red" at the end (like "puppyRed"). Keep all of the settings and file extensions the same.
15. Print the picture on photo quality paper.
16. Close this image and re-open the RGB image from the desktop folder (puppyRGB).
17. Repeat steps 9-16 for each remaining color channel.
18. To see the Green channel:
    a. Click "Red" from the drop down menu, click on the top right hand corner of the line and drag it to the bottom right corner.
    b. Then click "Blue" from the drop down menu, click on the top right hand corner of the line and drag it to the bottom right corner.
19. To see the Blue channel:
    a. Click "Red" from the drop down menu, click on the top right hand corner of the line and drag it to the bottom right corner.

    b. Then click "Green" from the drop down menu, click on the top right hand corner of the line and drag it to the bottom right corner.
20. Arrange your four photos in a row and compare. How do the individual color channels resemble the composite image? How are they different? Does each color channel look the way you expected it to? How do you think they form the composite image when put together?
21. To compare how a color image is made in CMYK using four color channels (Cyan, Magenta, Yellow and Black), change the color profile to "CMYK" and repeat the experiment.
22. How do the two methods compare? Do any of the individual color channels in RGB look like one of the CMYK channels? Do the composite images look the same or different?

Variations

- You can investigate the physics of color mixing using paints or a color wheel. How to some colors mix to form other colors? Which colors are pure colors? Which colors are mixtures of other colors?
- You can also investigate the physics of light waves and color by using prisms. How do prisms separate the colors of light? Can you use containers of water as a color prism? What wavelengths of light correspond to the different colors of the visible spectrum?

Digital Pinhole Camera

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to measure the resolution of a pinhole camera as a function of pinhole diameter.

Introduction

Light passing through an aperture forms an image. Sunlight passing through spaces between the leaves on a tree projects an image of the sun. Make a loose fist with your hand on a sunny day and you can project an image of the sun through the aperture that your fingers make. For a great introduction to light and apertures, including many interesting demonstrations you can do yourself, see Bob Miller's "Light Walk" pages, in the Bibliography section (Miller, date unknown).

The resolution of the image projected from an aperture is determined by the size of the aperture (until the aperture becomes so small that diffraction of light dominates). Thus, the smaller the aperture, the greater the resolution of the image. When the size of the aperture approaches the wavelength of the light passing through it (roughly 400–750 nm for visible light) diffraction of the light by the aperture limits the resolution.

In this project, you will build a digital pinhole camera. You'll make several different-sized pinhole apertures for your camera, and you'll measure the camera's resolution as a function of aperture size. You can build a pinhole camera for film, but loading and unloading the film has to be done in total darkness. Also, you have to have the film processed before you can see the results. Determining the correct exposure time for a pinhole camera often involves some trial-and-error, and this can quickly become tedious when using film. A big advantage of using a digital camera is that you can see your results right away.

Since a pinhole does not let in much light, exposure times will be much longer for a pinhole camera than for a camera with a normal lens. Therefore, you must use a digital camera that provides a method for controlling long exposures (e.g., via a remote-control cable, or via infrared signal from a "Palm pilot" or similar device). For the lightbox camera described below, exposure times may need to be tens of seconds or even a minute.

There are two ways to make a pinhole camera with a digital camera. Which method you use depends on the type of digital camera you have. If your digital camera does have removeable lenses, you can make a pinhole for it using a spare body cap with a pinhole in place of the lens. With this type of camera, the light coming through the pinhole aperture forms an image directly on the light-sensitive component inside the camera.

If your digital camera does not have removeable lenses, you will use the "lightbox" (or *camera obscura*) method. With the lightbox, the pinhole projects an image onto a screen at the back of the box. Your camera takes a picture of this screen, through a small, light-tight "window" at the front of the box (see Figure 1, below).

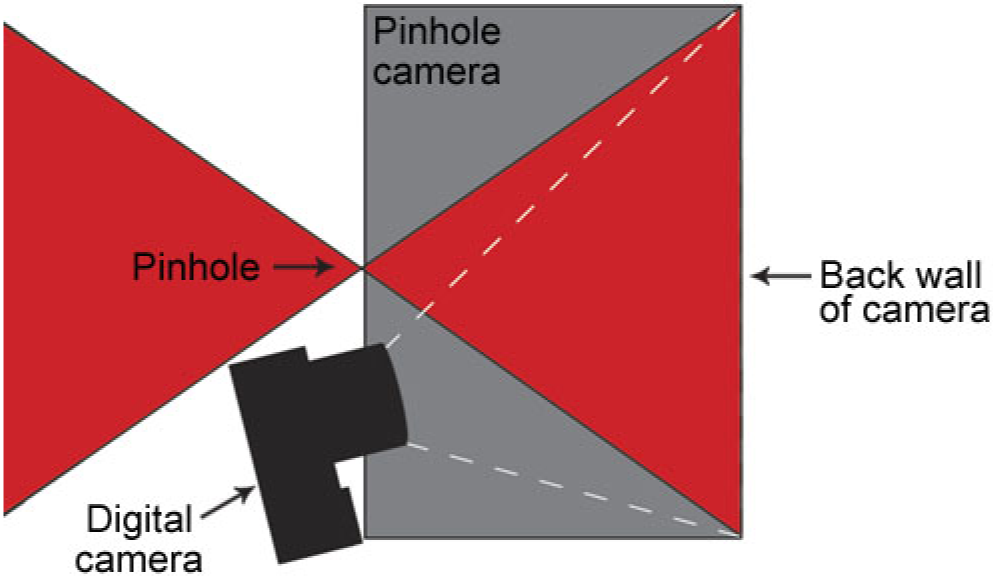


Figure 1. Diagram of a lightbox-type digital pinhole camera (Hanft, 2005).

With this type of camera, the exposures are even longer than typical pinhole cameras, because the light from the pinhole does not fall directly on the light-sensitive region of the camera. Instead, the camera is capturing some of the light that is reflected from the projection screen. This, in turn, is only a fraction of the light that originally passed through the pinhole.

The resolution of the image will be determined by how much the light is "spread out" as it is projected through the pinhole. With larger pinholes, this will be determined by the diameter of the aperture. As the pinholes become smaller, diffraction will begin to have a significant effect. Diffraction ultimately limits the resolution of an optical system, even something as simple as a pinhole.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- focal length,
- aperture,
- diffraction,
- Airy disk.

Questions

- How small does the pinhole have to be before diffraction becomes dominant in determining resolution?

Bibliography

- The following sites have useful information on pinhole cameras, including making pinholes, calculating exposure times, and calculating dimensions for building cameras:
    - Balihar, D., 2006. "Pinhole Camera: Photographs, Information, PinholeDesigner," Pinhole.cz [accessed April 3, 2006] http://www.pinhole.cz/en/index.php.
    - MrPinhole, date unknown. "Pinhole Photography and Camera Design Calculators," [accessed April 3, 2006] http://www.mrpinhole.com/index.php.
- This webpage has specific information on building a lightbox-type digital pinhole camera:
  Hanft, A., 2005. "Pinhole Camera (part 3)," Be A Design Group Blog [accessed April 3, 2006] http://www.beadesigngroup.com/blog/archives/2005/01/pinhole_camera_part_3.php.
- Bob Miller has created many exhibits at the Exploratorium in San Francisco built around light projected through apertures. If you can't visit Bob's exhibits at the Exploratorium, you can still visit his "Light Walk" pages online. They are a good intuitive introduction to pinhole optics. You can also learn how to make your own pinhole viewer.
  Miller, B., date unknown. "Bob Miller's Light Walk," Exploratorium [accessed April 3, 2006] http://www.exploratorium.edu/light_walk/pinhole_todo.html.
- Diffraction and the limit of resolution in photography:
  McHugh, S.T., date unknown. "Tutorials: Diffraction and Photography," Cambridge in Colour [accessed April 4, 2006] http://www.cambridgeincolour.com/tutorials/diffraction-photography.htm.

Measuring Resolution

- *Modern Photography*, a magazine now out of business, published a kit for performing lens tests using the 1951 USAF target. At the very bottom of this source you'll find links to scanned copies of the instructions for performing the tests. Unfortunately, these are rather clumsy to read:
  Monaghan, R., date unknown a. "Lens Testing," Medium Format Photography Megasite [accessed April 4, 2006] http://medfmt.8k.com/usaf/.
- This is a less detailed set of instructions, but much easier to use than the one above:
  Doty, J., 2000. "Lens Testing with the USAF 1951 Chart," JimDoty.com [accessed April 4, 2006]
  http://www.jimdoty.com/Tips/Equipment/USAF_Test/usaf_test.html.
- Norman Koren's site also provides relevant information:
  Koren, N., 2005. "Understanding Image Sharpness, Part 5: Lens Testing," Norman Koren Photography Page [accessed April 4, 2006]
  http://www.normankoren.com/Tutorials/MTF5.html#whytest.

Measuring Sharpness: The Modulation Transfer Function (MTF)

- A good, basic description of the gold standard for measuring sharpness, the modulation transfer function or MTF:
  Atkins, B., 2005. "MTF and SQF," Bob Atkins Photography [accessed April 4, 2006] http://bobatkins.com/photography/technical/mtf/mtf1.html.
- How to actually measure MTF for a lens:
  Koren, N., 2005. "Understanding Image Sharpness, Part 5: Lens Testing," Norman Koren Photography Page [accessed April 4, 2006]
  http://www.normankoren.com/Tutorials/MTF5.html#whytest.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- box,
- flat black paint,
- aluminum tape,
- scissors or hobby knife,
- rubber from bicycle inner tube,
- soda can,
- tin snips,
- needle,
- some pieces of scrap wood,
- coarse and fine sandpaper,
- digital camera (must be able to take long, controlled exposures without flash),

- photo editing software will be useful for analyzing results.

Experimental Procedure

1. The illustration below shows an example of a lightbox-type pinhole camera, suitable for use with a digital camera (Hanft, 2005).

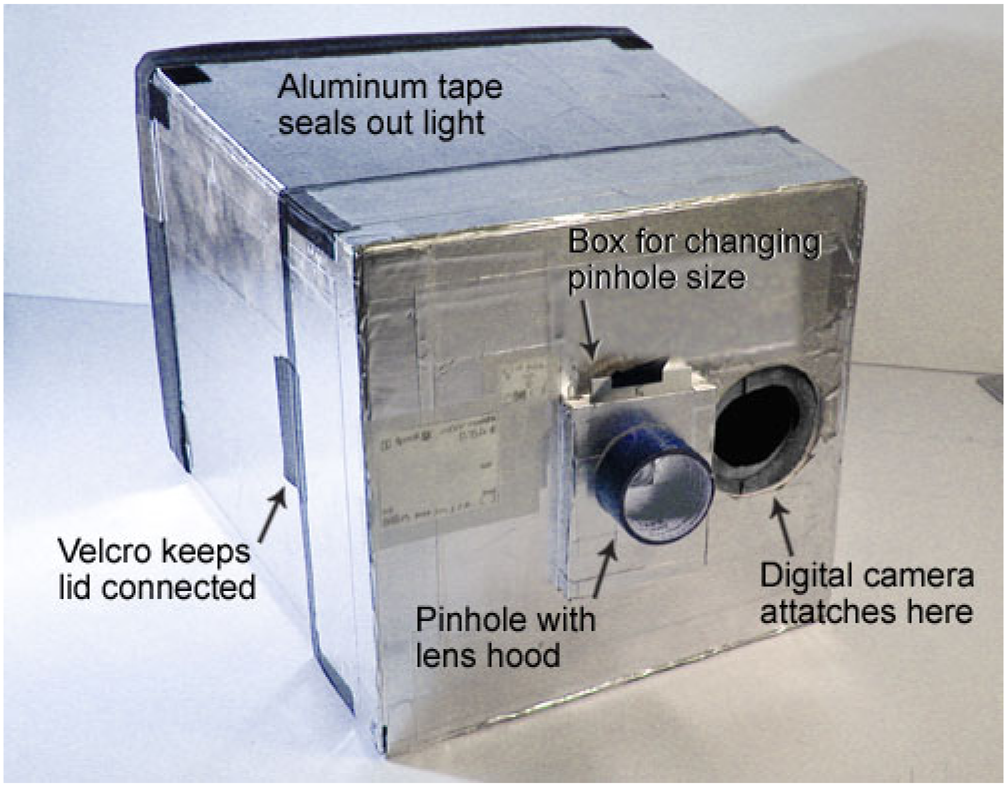


Figure 2. A lightbox-type digital pinhole camera (Hanft, 2005).

2. Below are some tips on constructing a lightbox-type camera (for more details, see Hanft, 2005):
    a. The box depth is determined by how close your camera can focus. The further your projection screen is from the pinhole, the dimmer the light will be, and the longer exposures you'll have to take, so try to keep this reasonably short (10–12 inches, if possible).
    b. Paint the inside of the box flat black to prevent stray reflections. This is especially important with the long exposures you'll be using.
    c. Cover the outside of the box entirely with aluminum tape, to ensure that your box is light-tight.
    d. For the "window" for your digital camera, use a piece of rubber tubing from an old bicycle inner tube to make a tight-fitting rubber seal that will fit around the lens of your camera. This will perform two functions: 1) make a light-tight seal, and 2) hold the camera firmly in place.

    e. Also, remember that the camera needs to be tilted down slightly so that it does not block light entering the pinhole (see Figure 1 in the Introduction).
3. Turning a digital SLR camera into a pinhole camera is much easier. All you need are some spare body caps, which you should be able to order from the camera store where you purchased the camera. Find the center of the body cap and drill a hole in it. Glue a pinhole made from thin aluminum (see below), over this hole, and make the glue joint light-tight by covering it with black tape.
4. Here are some tips on making and measuring a pinhole (used for either type of camera:
    a. Here are instructions for making a pinhole from David Balihar: "A piece of metal cut from a drinks [soda] can, approximately 4 × 4 cm, is sufficient. First, using coarse sandpaper, remove the paint from the area where the hole should be, and try to make the metal as thin as possible. Then finish the surface by using fine sandpaper. Place the plate on a flat wooden block and, using a sharp needle, make the smallest hole possible. Be careful not to injure your hand and use a hard block to press down on the needle. Remove the embossed material from the reverse side of the plate using fine sandpaper. Place the needle into the hole again and, by gently pressing and turning the needle between your fingers, make the hole round. Smooth the hole again using sandpaper. It is necessary to repeat the process until the required diameter is achieved. A regular round hole in a very thin plate can be made with a bit of patience." (Balihar, 2006) Use the same size for each of the aluminum pieces, so that your pinholes are easily interchangeable on your camera.
    b. Remember to paint the back side of the pinhole metal flat black after you have made the pinhole. The back side will be inside the camera, and you want to prevent stray reflections inside the camera.
    c. There are many ways to measure the diameter of your pinholes. You can use a alide projector, overhead projector, or enlarger to project light through the pinhole, and measure the diameter of the enlarged image. To check the scale (enlargement factor) also measure the projected size of the edge of the aluminum. Another method is to use a flatbed scanner at 600 or 1200 dpi.
5. Make a set of at least 3 different pinholes (more is even better) for your camera spanning a range of diameters from about 1.0 mm to 0.2 mm (or less).
6. Experiment with exposure times so that you can photograph the same scene with each different pinhole to achieve about equal gray levels in the photographs. (The references in the Bibliography have information and calculators that should help with this. Knowing the diameters of your pinholes will also help.)
7. If you are using a lightbox-type camera, it is best to keep the aperture setting constant, and change only the exposure time.

8. Keep the camera steady by attaching it firmly to something heavy (e.g., a brick).
9. The Bibliography has references that will show you how to quantify both resolution and sharpness for your photographs made with different-sized pinholes.

Questions

- How does resolution vary with pinhole diameter? How does sharpness vary with pinhole diameter? If you test a sufficient number of pinhole diameters, you should be able to identify when diffraction becomes the limiting factor in determining resolution and sharpness.
- What pinhole diameter maximizes resolution for your camera?
- What pinhole diameter maximizes sharpness for your camera?
- How do these compare to the predicted results from the pinhole calculators in the Bibliography? If there are differences, can you explain them?

Variations

- How does resolution with a pinhole compare to resolution with a normal camera lens?
- How does depth-of-field with a pinhole compare to depth-of-field with a normal camera lens?
- How does sharpness with a pinhole camera compare to sharpness with a normal camera lens?
- Examine exposure time in relation to pinhole size. Remember to keep digital camera aperture constant for lightbox-type camera. Use photo editing software and adjust exposure time to match gray values in the images taken with different-sized pinholes.

Measuring the Speed of Moving Objects with Stroboscopic Photography

(from http://www.sciencebuddies.com)

Objective

The goal of this experiment is to calibrate a variable-frequency strobe light and then use it to measure the speed of a ping pong ball (or some other moving object).

Introduction

How do you "freeze" motion with your camera? The first answer that probably comes to mind is "Use a fast shutter speed." If the camera sensor (or film) is only exposed to light for a very short time, the moving object may appear still. It depends on how fast the image projected by the lens is moving and how long the shutter is open. What types of motion can you freeze with shutter speed alone? We can do some calculations to see.

Let's imagine that we're going to take a photo of a paper airplane. The airplane will be flying parallel to the camera's film plane. For this thought experiment we will be making several assumptions. We'll use numbers that will make it easy to generate a "rule of thumb" for motion blur. Let's assume that the airplane is moving at a speed of 1 m/s. Additionally, we'll assume that we've placed the camera so that the field of view will capture exactly 1 m of the airplane's flight path. Finally, we'll assume that we're using a 35 mm film camera, with a shutter speed of 1/1000 s.

How far will the airplane travel while the shutter is open?

$$1 \text{ m/s} \times 1/1000 \text{ s} = 1/1000 \text{ m} = 1 \text{ mm}$$

How far will the image of the airplane travel on the film? For this calculation, we set up a proportion between the horizontal extent of the field of view and the image on film. The full frame of a typical 35 mm negative is actually slightly more than 35 mm across, something like 37 mm. So to find the distance, x, that the image of the airplane moves on the film, we can write:

$$1 \text{ mm}/1000 \text{ mm} = x/37 \text{ mm} = 0.037 \text{ mm}$$

The image will move 1/1000 of the horizontal extent of the frame. Will we notice this in a print? This is harder to say with precision (read the information on *Understanding Resolution* and *Understanding Sharpness* (Reichmann, 2006). The unaided human eye can resolve 4 lines per mm (lpm) with a fairly high-contrast target (Harris, 1991). For a snapshot-sized (4"×6") print, 1/1000 of the frame corresponds to:

$$6 \text{ in}/1000 \times 25.4 \text{ mm/in} = 0.15 \text{ mm}$$

Taking the reciprocal, we have 6.6 lpm, which is above the threshold. However, sharpness of the image depends not only on resolution, but also how we perceive edge transitions in the image. So this would be a borderline case. If we increase the image size to an 8"×10" print, we will be at the 4 lpm threshold, and would definitely expect to be able to notice a slight blur due to motion of the airplane.

From our back-of-the-envelope calculations, we conclude that shutter speed alone can give us borderline snapshot images of objects traveling at speeds corresponding to 1/1000 of the horizontal extent of the image. For larger prints, the speed must be even slower. Is there anything we can do for objects moving faster?

Another approach is to use a brief, bright flash of light to capture motion. With the lens aperture stopped down, most of the light collected during the shutter open time will be reflected light from the bright flash. Now the sharpness will be determined by the flash duration. There are many interesting possibilities for this project. One of these possibilities is to use a repeating strobe light (with adjustable frequency) to take a rapid series of images of a moving object during the same exposure. Depending on the amount of ambient light, and how reflective your moving object is, you may see a blurred "ghost image" of the object in between flashes (the less ambient light, the dimmer the ghost image). But the portion of the image recorded during the bright flash will generally be distinguishable from the background. If you know the frequency (i.e., repetition rate) of your strobe light, you can take measurements from your pictures to analyze the motion of an object.

Because the rotational speed of a typical window fan (usually in the range of 300–900 RPM, or 5–15 Hz) is simiilar to that of inexpensive strobe lights (maximum frequency usually in the range of 10–20 Hz), you can calibrate the strobe light with a fan rotating at known speed. When the strobe light is synchronized with the fan, the blade will be illuminated in the same position during each revolution. Because the bright illumination recurs when the fan blade is in the same position, the blade will appear to be "frozen." Think about what would happen if the strobe light flashed at exactly *double* the frequency of the fan. Where would you expect to see the fan blade? That's right, you would see it twice during each revolution, 180° apart. And if the strobe light flashed at exactly four times the frequency of the fan's rotation, the blade would be illuminated every 90°.

What would happen if the strobe flashed *slower* than the fan speed? Is it possible to adjust the strobe so that it illuminates the fan blade every one and a quarter turns? By taking advantage of patterns such as these, you can make several strobe calibrations with a single fan speed.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- xenon flash lamp,
- frequency,
- period,
- cycles per second (Hz),
- revolutions per minute (RPM).

Questions

- If a fan rotates at 500 rpm, how many times does it rotate per second?
- If a fan rotates at 300 rpm, what is its period, in seconds?
- If an adjustable strobe light can flash at frequencies from 1 to 10 Hz, with what range of fan speeds (in rpm) could it synchronize?
- If the strobe light is exactly synchronized with the fan, the blade will be illuminated at the same point in its rotational cycle every time, and will not appear to move. What will be the apparent motion of the fan blade if the strobe light is adjusted to a slightly higher frequency than the fan motor? To a slightly lower frequency?
- How would the strobe frequency have to be adjusted in order to illuminate the fan every half turn? Every three-quarter turn? Every one and a quarter turns?

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Materials and Equipment

To do this experiment you will need the following materials and equipment:

- strobe light with variable frequency adjustment (commonly available with 0–10 Hz or 0–20 Hz adjustment),
- fan with known speed(s) (in RPM),
- protractor,
- ruler,
- tape,
- marking pen,
- camera with adjustable shutter speeds and lens apertures,
- tripod for camera,
- cable release or remote control for camera,
- stable mounting position for strobe light, near camera,
- ping pong table, paddles and ball, with space alongside for camera on tripod,
- one or more helpers to hit the ball while you work the camera and strobe (or vice versa).

Experimental Procedure

Calibrating the Strobe Frequency

1. Do your background research and make sure that you understand the terms, concepts and questions above.
2. With your parent's permission, make a small, but easily visible mark near the end of one of the fan blades so that you can tell it apart from the others. For example, you could use a dark-colored marker on a light-colored blade, or attach a small piece of paper with a high-contrast pattern on a dark-colored blade. (Note that it will be best to make your observations from the intake side of the fan, so you don't have a big wind blowing in your face. It will also make it easier if you set things up so that the background contrasts well with the fan blades.)
3. Using a protractor, a ruler, and tape for labeling, mark off angles in 30° increments around the circumference of the fan.
4. For each of the fan speeds, calculate the strobe frequencies that will illuminate the marked blade every one-and-a-quarter and every one-and-a-third turns. If your strobe is fast enough, you may also be able to adjust it to illuminate the fan blade every three-quarter turn.

5. If your strobe light frequency adjustment does not have a dial indicator, cut a circle of paper of the appropriate size to make one. Use the following procedure to calibrate it the dial.
6. Turn the fan on to the lowest speed. Turn on the strobe light and adjust the frequency until the light "freezes" the motion of the marked fan blade. The fan motor speed may fluctuate slightly over time. You want to adjust the strobe so that the marked blade appears as motionless as possible.
7. Mark the position on the indicator. This frequency (in flashes per minute, or fpm) matches the speed of the fan motor (in rpm). Since it will be more natural to calculate speeds in terms of meters (or feet) per second, you will probably want to convert the numbers for your strobe dial to flashes per second (Hz), instead of fpm.
8. How will the marked fan blade appear to move if you adjust the strobe frequency slightly higher? Slightly lower? Try it and see.
9. If your fan has multiple speeds, repeat the procedure for each speed. Mark the new synchronization points on the dial.
10. It's always a good idea to double-check, so go back through the fan speeds again, and re-check your calibration marks on the strobe dial.

Ping Pong Strobe Photography and Velocity Measurement

1. For best results, make a dark-colored background alongside the ping pong table with hanging cloth.
2. It's a good idea to mark the cloth with a distance scale (e.g., using tape labels) for reference. Remember that you'll also need a distance scale in the plane of the ping pong ball (e.g., right down the center of the table). You can take a separate picture of a reference scale held in the plane of the ball. You can then use proportions to calculate a conversion factor from the background scale to the ball-plane scale. As long as you don't move the camera, and you keep the ball in the center of the table, you'll know how to calculate the distance by converting from your scale on the background cloth.
3. Set the camera up on the tripod on the opposite side of the table from the background, at a distance that allows you to capture most or all of the length of the table. Do your best to set the camera up parallel to the long axis of the table. (Think of ways to verify this in the viewfinder.)
4. You'll want to experiment with your setup to determine the best lens aperture for use with the strobe light. You need to take a series of pictures at different f-stops with only 1 strobe flash per picture. Set the strobe light at 1 Hz and the shutter speed to 1 s. Snap a picture just *after* a strobe flash. The shutter should remain open until the next flash and then close. Take a series of photos of still ping pong balls using successive apertures. Keep track in your lab notebook of

which settings were used for each picture. Use these pictures to select the best aperture setting for your experiment.

5. For the moving ping pong ball photos you will use the strobe light at a higher frequency, from your previous calibrations (above).
6. Try to keep the ball
7. Experiment with exposure durations of 1 s (usually available on the camera), or longer (with the B setting). Use a cable release (or remote control on newer cameras) to avoid shaking the camera.
8. Be sure to keep track of exposure settings, strobe light frequency and any additional notes (e.g., "ping pong ball off line on this shot") in your lab notebook.
9. Have the photographs processed and printed (or do it yourself).
10. Using your distance scales (see above), measure how far the ball traveled between successive flashes. Knowing the strobe light frequency, you can calculate the average velocity for each interval.
11. Suggestion: below each photograph, display a graph showing the ball's velocity at each point where the strobe flashed.
12. How fast does the ball travel? What is the fastest ball speed you can measure with this setup?
13. Try putting backspin on the ball and analyzing the resulting motion when the ball bounces.

Variations

- Use the strobe light and camera to analyze the motion of a pendulum, which accelerates and decelerates as it falls and rises, respectively.
- Can you think of other moving objects to photograph and analyze?
- Another (and probably more accurate) way to calibrate the strobe light would be to use a photodiode circuit connected to an oscilloscope or analog-to-digital converter. You could measure the frequency accurately on the oscilloscope screen or by analyzing the digitized data with your computer.

Seeing Beyond the Visible: Photography with Near Infrared Illumination

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to use infrared photography to measure the transmission and reflection of near-infrared light by ordinary objects in our everyday surroundings.

Introduction

This is a project that will have you looking at the world in a whole new way. You can use a camera to extend your vision into the near infrared, which is beyond the range of what our eyes can detect. Visible light is just a small portion of the electromagnetic spectrum. Visible light has wavelengths ranging from roughly 400 to 700 nm (1 nm = 10^{-9} m). The perceived color of the light changes with wavelength (see Figure 1). Shorter wavelengths have higher frequencies and higher energy. Longer wavelengths have lower frequencies and lower energy.

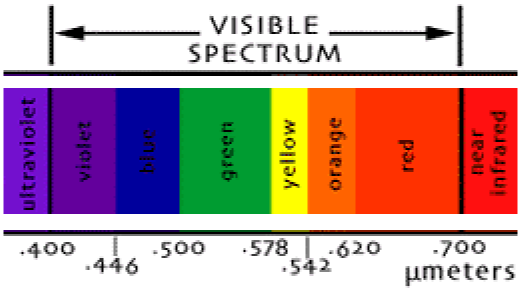

Figure 1. The visible portion of the electromagnetic spectrum. Longer wavelengths have lower energy. Note that wavelength is given in µm; to convert to nm, simply multiply by 1000.

Below 400 nm is the ultraviolet region of the electromagnetic spectrum. Ultraviolet light is not visible, but has higher energy than visible light (think of sunburn). At even shorter wavelengths are x-rays and beyond that, gamma rays, each with increasing frequency and energy. Infrared light is beyond the other end of the visible spectrum, with wavelengths longer than about 700 nm. This light has lower energy than visible light. Beyond the infrared region of the spectrum are microwaves, and then progressively longer-wavelength (and lower-energy) radiofrequency bands: TV and FM radio, shortwave and AM radio, and finally aircraft and shipping bands.

Infrared light is often divided into three different "bands": near, mid, and far infrared. For infrared photography, it is the near infrared (NIR) band that is detected. As with visible-light photography, NIR photography is capturing reflected light (*not* intrinsic heat of objects, which is emitted at longer IR wavelengths). What makes this project fascinating is that you get to find out how well (or how poorly) objects in the environment reflect or transmit NIR wavelengths. Since we are accustomed to seeing objects in the visible spectrum, this new way of looking at the world is often surprising.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- electromagnetic spectrum,
- visible spectrum,
- infrared spectrum,
- reflection,
- transmission,
- scattering.

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- Here you can find a good general introduction to NIR photography with a digital camera (most of the information is also applicable to shooting on IR film):
  McCreary, J., 2004. "Infrared Basics for Digital Photographers," Digital Photography for What Its Worth [accessed April 4, 2006] http://dpfwiw.com/ir.htm.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- tripod,
- NIR pass filter (blocks visible light; e.g., Hoya R72, Wratten 89b (passes some visible light), B+W 092),

- remote control (e.g., one used for TV, DVD, or VCR),
- a camera, this can be either:
  - a digital camera with near IR sensitivity and the ability to manually control long exposures, *or*
  - a film camera with manual exposure control (use both IR-sensitive and normal film).
- Photo editing software will be useful for analyzing results with digital photos.

Experimental Procedure

1. If you are planning to use a digital camera for this project, it is a good idea to test its sensitivity to NIR before spending your money on a visible light blocking filter. Sensitivity to NIR for digital camera determined by the intrinsic properties of the light-sensing chip, plus the IR transmission of the filters (color, and IR blocking) in the light path. Silicon-based sensors typically do have a measurable response to NIR. Because of this, camera manufacturers often use an IR-blocking filter in front of the sensor, so that only visible light is recorded. (For a film camera, sensitivity is determined by the film, so IR-blocking filters are typically not used.) Here's a "quick-and-dirty" method for testing the IR sensitivity of your digital camera (McCreary, 2004):
   a. Put your camera in Program mode at ISO 100.
   b. Have a helper point a TV, camera or other IR remote into the lens from no more than 12" away. (If you can see your camera's LCD screen from the front of the camera, you can do this yourself.)
   c. Have your helper press any button on the remote.
   d. Look for the IR beam in the camera's through-the-lens (TTL) LCD screen or electronic viewfinder.
   e. Compare the IR beam that you see with the images below in Figure 2. If the IR beam looks about as bright as the one on the left, you should be able to get handheld NIR images with a Hoya 72 or Wratten 89b filter. If the IR beam is as dim as the one on the right, you will need to use a tripod and long exposures. If the IR beam looks even dimmer, you should consider using a film camera or choose another project.

Figure 2. Example responses to IR remote signal. On the left is a bright image. If your camera responds similarly, you should be able to take handheld NIR photos in daylight. On the right is an example of a dim image. If your camera responds like this, you will need a tripod and long exposures for NIR photography.

2. Do background research to learn about how ordinary objects transmit and reflect NIR light. What are good sources of NIR light?
3. Take photographs of the same scene using NIR and visible light. It will be easier to make comparisons if you convert the images to grayscale (or use black-and-white film, if using a film camera).
4. Note that it is somewhat tricky to compare grayscale values between two images taken with different lighting. You will either have to use relative comparisons within each image, or find an object whose reflectivity is similar in visible and NIR and use it to set a common scale for both images.
5. Compare the sky in visible and infrared photos. What happens when the sky is hazy, or foggy? Hint: use known distances in your NIR and visible-light photographs to measure any effects.
6. Compare reflectivity of ordinary objects, both natural and manmade, in both visible and NIR illumination. What differences do you notice? Can you explain them?

Variations

- Try different light sources: sunlight, incandescent bulb, fluorescent tube, xenon flash.
- *Can* you "see" heat with NIR? Photograph identical cups holding water at different temperatures (or the same cup photographed sequentially with water at different temperatures). Use ice cold, room temperature and very hot water (be careful!) Do you see any differences?
- Investigate IR reflection and transmission of different types of window glass. Use either sunlight or incandescent light as the light source.