Physics 109 Digital Photography Laboratory—Draft (5/02/07)

In this lab we ask you to investigate a typical modern point-and-shoot digital camera to see how it works.

In particular you will learn about *focus*, *exposure time*, *aperture*, and *ISO*. A modern point-and-shoot digital camera will attempt to choose the focus, exposure, aperture, and ISO for every picture you take. If you want to take creative photographs, you have to know how to choose them yourself.

The camera measures focus, exposure time, aperture, and ISO in terms of numbers. In the first part of the lab we ask you to decide whether those numbers actually mean anything, or whether they are just numbers used for the sake of reference. In the second part of the lab we ask you to take photographs of the same scene using different combinations of focus, exposure time, aperture, and ISO. You will thus learn what is meant by *depth of field*, *reciprocity*, and *graininess*. These are some of the most important of the many measurable optical qualities in photography. We hope that after you do the lab, you have the desire to conduct further photographic experiments.

We also hope that after you complete the lab you will feel more comfortable that yes, after all, even digital cameras must follow the physical principles you have learned about this course!

Digital cameras vs. film cameras

For our purposes the most important difference between digital cameras and film cameras is the *image sensor*. In a film camera the image sensor is a piece of *film*, where film is a length of plastic that has been coated with certain chemicals that undergo chemical reactions when exposed to light. When a picture is taken, the piece of film is exposed to light in a controlled manner, using lenses, an aperture, and a shutter. After the picture is taken, you have to wind the camera to move the film to a chamber of total darkness inside the camera, so that it isn't exposed to any more light. If you wind the camera enough times, you reach the end of the film strip and have to change film.

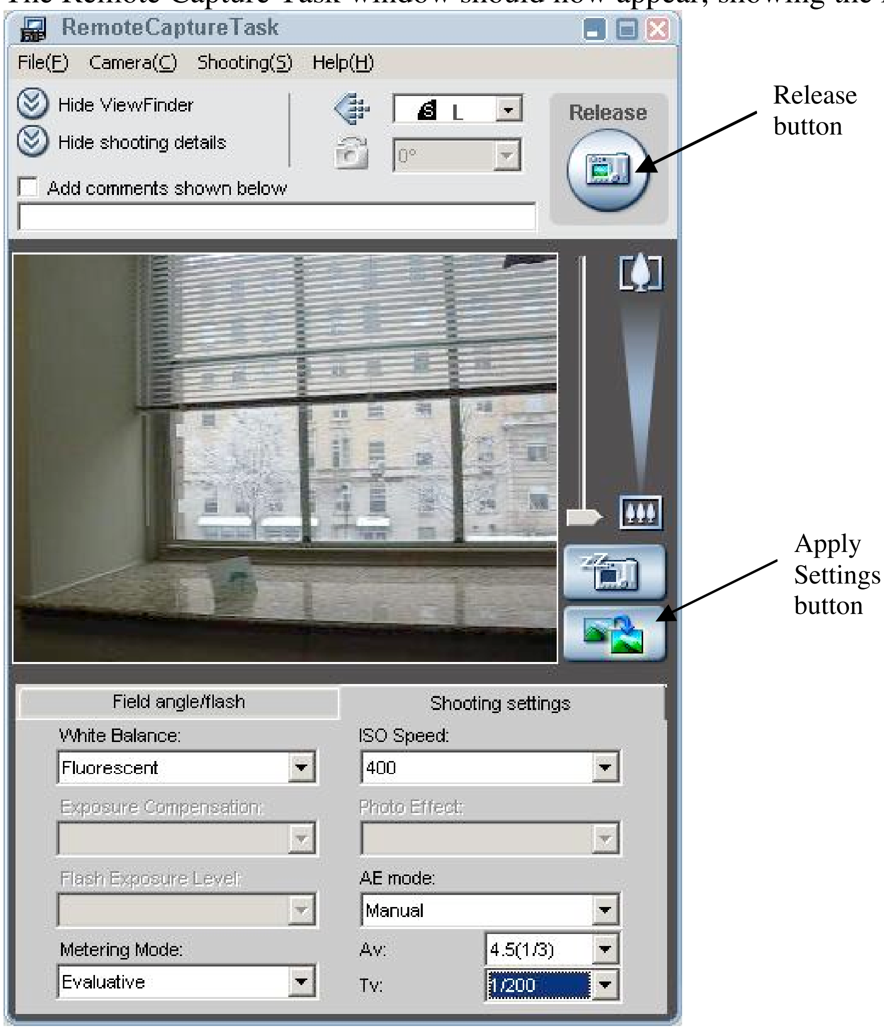
In most digital cameras, the image sensor is a *charge-coupled device*, or "CCD". A charge-coupled device consists of rows and rows of individual elements, called *sensels*. There are millions of sensels in a typical digital camera. A sensel builds up an electrical charge when it is exposed to light. When a picture is taken, the sensels are exposed to light in exactly the same controlled manner as in a film camera. After the picture is taken, the electrical charge on the sensels is read off by a miniature computer inside the camera, and stored in the miniature computer's memory. If you store enough pictures the memory becomes full, and you have to erase some pictures.

The camera: you will be using a Canon G7, a very nice point-and-shoot digital camera that was first manufactured in the fall of 2006. This camera can be connected to a computer and then controlled from the computer.

Setting up the Camera

--Turn the computer and monitor on, and login, so that you can see the desktop.
--Plug camera power cord in and turn on camera (on/off button is on the top)
--Connect camera to computer using the white USB cable ("Camera Window—Canon PowerShot G7" window should appear on computer screen)
--Click "remote shooting" tab
--Click "Start Remote Shooting" icon
--Save images on Student>My Documents>My Pictures
--click "OK"

The Remote Capture Task window should now appear, showing the live preview:



Under the “shooting settings” tab make the following entries:

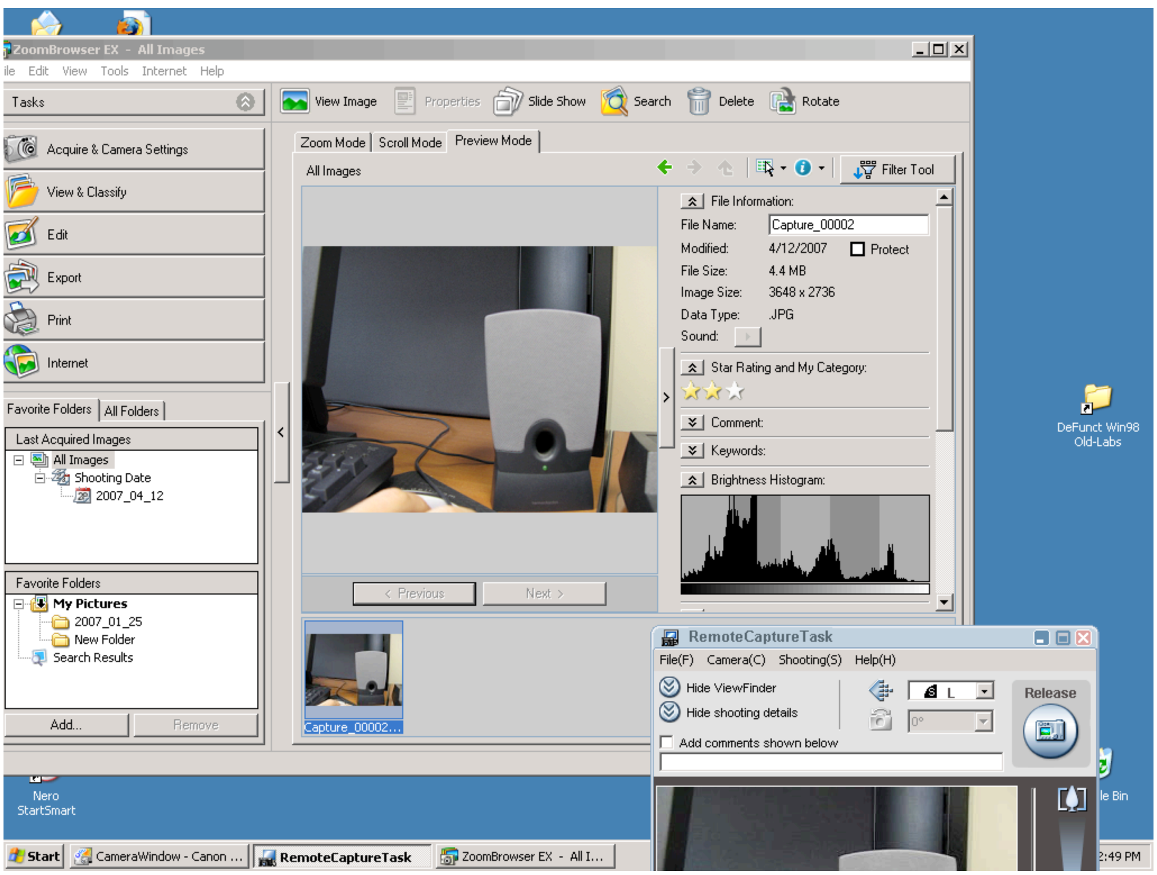
ISO Speed	400	Sets sensitivity of camera to light—to be discussed in part V, below
AE Mode	Manual	Gives you full control over all camera settings
Av	4.5(1/3)	Controls the camera aperture—we’ll experiment with this in part IV
Tv	1/200	Controls the exposure time (measured in seconds)
White balance	fluorescent	Not really important for this lab—feel free to play with it to see what it does!
Metering mode	evaluative	Not really important for this lab—feel free to play with it to see what it does!

Pixels

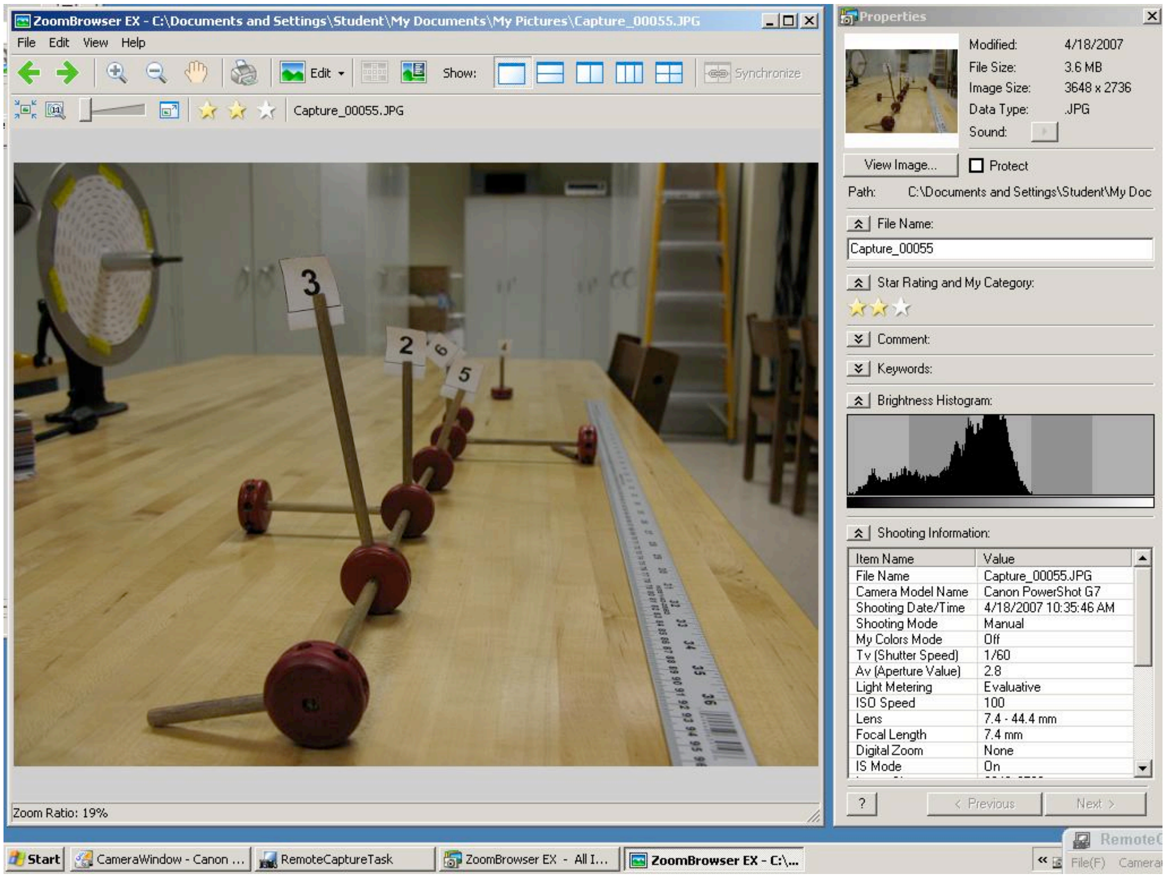
If you look at a color picture taken by a digital camera closely enough, you will see that it is made up of a large number of tiny rectangles. These are called “pixels”. The more pixels are used in a picture, the smaller they are, and the more difficult it is to tell that they are there. But if you look closely enough, you can always tell.

Press the “Release button” to take your first picture. The “ZoomBrowser EX” window appears automatically. Examine the picture following the instructions below.

--Click on the “Scroll Mode” tab in the Zoom Browser EX Window (see picture below).
--Double click on the image you want to examine (a new window appears showing the image)
--Go back to the Zoom Browser EX window and click “Properties” which should now no longer be grayed-out (a new window appears called “Properties”)



--You should now see the two windows shown below.
--Use the slider on the upper left of the window with the picture in it to zoom in and out.



Zoom in until you can see the pixels, and out again until you can't see the pixels any more. How many pixels do you think there are in the picture? If you go to the properties window and scroll down you will see a entry labeled "picture size" that will help give you the answer.

Each pixel has a particular color. The colors of the pixels on the screen are produced by adding different amounts of red, blue and green light in exactly the method you will learn about in the Additive Color Mixing lab later on in the course. If you were to print the picture out on a color printer, the colors of the pixels on the paper would be made by adding different amounts of cyan, magenta, and yellow ink. There is no one "right" way to figure out the proportions of cyan, magenta, and yellow ink that look the same as a given combination of red, blue, and green light, so people who are interested in making good prints on paper from digital color images spend a lot of time fiddling with the translation from red-green-blue to cyan-magenta-yellow.

Focus

Before reading this section, write down the lens equation.

When you change the focus on a camera, you are changing the "image distance"—the distance from the lens to the image sensor--while leaving the focal length the same. This is done by moving the lens relative to the image sensor.

If the image distance is changed, but the focal length is not, this has the effect of changing the "object distance"—that is, the distance from the lens to objects that are sharply imaged on the image sensor (can you use the lens equation to see why?). We say that an object that is sharply imaged is "in focus".

Actually, digital cameras have many lenses inside them—some are necessary to avoid aberrations, others may be moved relative to each other so that the focal length of the camera can be changed. Changing the focal length of the camera is what you are doing when you use the "zoom": "zooming in" on an object means increasing the focal length of the lens system in the camera. The zoom slider is to the right of the preview picture in the RemoteCapture Task window. Listen and watch while you move the zoom slider from one place to another, and you will hear and see the camera moving lenses around inside itself until it decides what it the best image distance for the picture. The focal length of the G7 can be changed from 7.4 mm to 44.4 mm. Increasing the focal length of the camera while keeping a particular object in focus increases the magnification of the object (can you see why?). Can a camera focus on an object that is one focal length away from the camera? No!—that is too close.

Make sure that the zoom is zoomed all the way out before continuing.

Go to the "settings" tab in the RemoteCapture window and make sure the camera is on "manual" setting, then go to the "controls" tab set the "focus" to "AF unlock".

AF unlock	Camera chooses the best focus for the picture (by choosing the best image distance)
AF lock	Focus is locked (image distance is kept fixed)

"AF" stands for "autofocus", and this setting allows the camera to decide the best image distance for the picture.

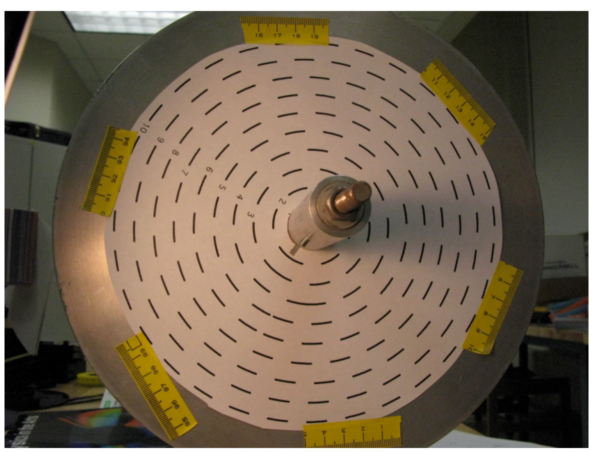
However, we want YOU to decide the best image distance. Place the circle disk 30 cm from the front of the camera, and press the "apply settings" button. If the picture in the preview window now looks like it is in focus, then go to the computer and change the focus setting to "AF Lock". This means from now on objects that are 30 cm from the front of the camera will be in focus. You shouldn't hear any more whirring noises from the camera as it moves lenses around. If you do, that means the camera has gone back into "AF unlock" mode. Note: if you use the zoom the camera will take itself out of AF lock mode, because it has to move lenses around in order to zoom.

You can always change the focal length of this camera by putting it back into AF unlock mode, pointing it towards an object a particular distance away, and clicking the "apply settings" button. Be sure the object fills the field of view. Don't forget to put the camera back into AF lock mode once the focal length is what you want.

When it is time to take a picture, there are two ways to control the amount of light that is let into the camera: the *aperture* and the *exposure time*. The aperture is a hole through which light has to pass in order to make the picture. Making the aperture bigger lets in more light and making it smaller lets in less light. Most of the time the aperture is covered by a *shutter* so that no light gets in at all. When it is time to take the picture, the shutter is moved away, uncovering the aperture, and then moved back. The length of time the aperture is uncovered is called the "exposure time". In the next two sections we will examine the aperture and exposure time.

Exposure time

There is big money to be made selling digital cameras, so you should not necessarily believe every camera specification you read. Here we will test the exposure time, using the circle disk (see picture). The dashes on the circle disk are 1 cm long and 1 mm wide. Each "circle" is labeled by its radius in centimeters: the dashes on the innermost circle are 2 cm from the center, and on the outermost are 10 cm from the center.



The Circle Disk

Place the circle disk 30 cm from the front of the camera. Place the light so that the circle disk looks as bright as possible, when seen on the "Remote Capture" window. Turn the handle on the circle disk so that the circle disk goes around once per second. Take a picture. Call this "Picture 1". Examine Picture 1.

The dashes are 1 mm wide. How many pixels wide is a dash?

Put your answer here: | 1 mm = pixels |

You will see that the dashes near the outside are more blurred than the dashes near the center. Zoom in to a dash in the innermost ring, and count the pixels that make up the "blur". How many pixels long is the blur? (Choose a dash that is nearly horizontal or nearly vertical). How long is that in millimeters?

You can calculate how long you expect the blur to be. If the disk is spinning once every second, then the dashes go around the circle once every second. How far do they travel? If I tell you that the radius of a circle is r, then you can tell me the circumference of the circle, C, by using the following formula:

$$C = 2\pi r$$

The innermost dashes form a ring with a radius of 2 cm. Therefore, a dash on the outermost ring travels 2*π*2cm = 12.6 cm every second. In 1/200th of a second the dash travels 1/200th of this distance, which is 0.63 mm. You therefore expect the blurs of the innermost ring to be 0.63 mm long. How does this compare with what you measured in the last paragraph?

The outermost dashes form a ring with a radius of 10 cm. How far does one of these dashes travel in a second? (Hint: it should be five times as far as the innermost dashes travel, because 10 cm is five times 2 cm). Measure the length of the blurs on the outermost dashes. How do the measured blurs compare to the expected blurs?

Take two more pictures, one with the exposure time (called Tv by the software) set at 1/1000 second (call this "Picture 2"), and one with the exposure setting at 1/40 second (call this "Picture 3"). The blurs should be 5 times less in Picture 2 than in Picture 1, and five times more in Picture 3 than in Picture 1. Measure them and see. To help you keep track of your results, you can use this table:

Exposure time (seconds)	Predicted length of blur (mm)	Measured length of blur (pixels)	Measured length of blur (mm)
Outermost circle dashes (radius = 10 cm)			
1/40			
1/200	3.14		
1/1000			
Innermost circle dashes (radius = 2cm)			
1/40			
1/200			
1/1000			

Do you believe that the "exposure times" correspond to reality?

There is more than one way to make a blurry picture. As you've found, you can make a blurry picture if you use too long an exposure time to take a picture of something that is moving. You can also make a blurry picture by moving the camera while the picture is being taken. Hold the camera in your hands and take a picture. What is the longest exposure time you can use without making a blurry picture?

Aperture

The aperture of a camera is the hole through which light has to pass in order for a picture to be made. The bigger the aperture, the more light gets in. Apertures on most cameras are measured in terms of focal length.

Inspect Picture 3 (remember, this means go to the ZoomBrowser EX window, click "scroll mode", and double click on the last picture you took). Then click "properties". In the middle of the long list of properties you should find "focal length" and "Av (Aperture Value)". The focal length should be something like 7.4 mm, and Av should be 4.5 (because that's what you set it to earlier!). This means that the diameter of the aperture should be the focal length (f) divided by 4.5. So right now the diameter of the aperture should be 7.4mm/4.5 = 1.5 mm right now. (Many cameras will actually write out the aperture using characters f and /: f/4.5 on another camera means the same aperture setting as 4.5 on ours).

If you get in front of the camera and look inside the lens, then you can see the aperture right in the center; you can't see anything behind it because the shutter is in the way. Look at a ruler and then look at the aperture—does 1.5 mm look right?

Set the AE mode under "Shooting Settings" to "Program AE" and make sure the focus is set to "AF unlock". Look closely at the aperture while you press the "apply settings" button. You should be able to see the aperture getting bigger and smaller as the camera tries to decide what is the best size for the aperture. Can you see a difference in aperture size if you point the camera at something bright, as compared to something dark?

Remember that the amount of light that comes in through the aperture is proportional not to the diameter of the aperture, but to the area of the aperture. The area of the aperture is proportional to the diameter squared.

ISO

This setting controls the sensitivity of the image sensor to light. The higher the ISO number, the more sensitive the camera is. If you have ever bought film for use in a film camera, then you know you have to choose the proper ISO number for the film you buy, based on the pictures you intend to shoot. The ISO number of a piece of film is determined by the chemicals in the film. The number itself doesn't mean anything, but it does provide you with a relative scale: a picture taken with ISO 400 (for example) will be twice as bright as the same picture taken with ISO 200 (if the exposure time and aperture are the same).

In a digital camera, on the other hand, there is no film, and the "ISO" is a made-up number that is supposed to be similar to the ISO for film. The "ISO" for a digital camera is like the volume control on a radio. If the incoming signal is very weak you can turn the volume control up so that you can hear it. This is the equivalent to a high ISO number. However, as you know, if you turn the volume control up, you are likely to hear a lot of unwanted noise in addition to the signal you want to hear. Visual noise is called *graininess*.

Re-enter the values shown in the table on page 2. Set the camera 30 cm from the circle disk and set the focus, as you did in the procedure on page 6. Set the exposure time at 1/1000 second. This is just the way things were for picture 2—a pretty dim picture (you won't see anything at all if you don't have the light turned on!).

Now set the ISO at 1600, and take a picture ("Picture 4"). Compare it to Picture 2. Much brighter. Good. Now change the ISO back to 400, and change the exposure time to 1/250 second. Take another picture ("Picture 5"). Can you see that Picture 4 has higher graininess? Going to high ISO lets you take pictures in the dark, at the price of higher noise.

Exposure vs. Aperture—Reciprocity

We have already tested whether we think the exposure time settings correspond to reality. Now we are going to do another test to see whether the aperture settings are consistent with the exposure time settings: we are going to test the camera *reciprocity*.

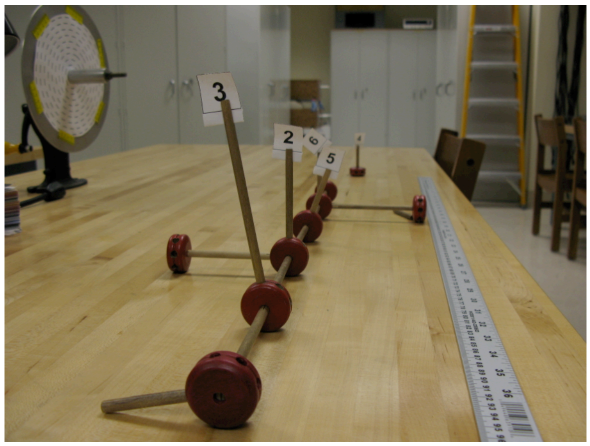
Set the ISO to 400 and the exposure time to 1/200 (this recreates the settings of Picture 1). Now change the aperture (Av) to 4.0. Does this make the aperture bigger, or smaller? Take a picture ("Picture 6"). Compare Picture 6 to Picture 1. Is it brighter, or dimmer? Now change the aperture to 8.0, and change the exposure time to 1/50, and take another picture ("Picture 7"). Compare Picture 7 to Picture 6. Do they look equally bright? Are they exactly the same? If the camera is well-designed, the two pictures should look equally bright. You made the picture darker by making the aperture smaller, but you also made it brighter by increasing the exposure time (why did you have to quadruple the exposure time in order to cancel out halving the aperture?) The two effects should exactly cancel out for these two pictures. If they do, you have established that the camera reciprocity is good. If they don't, and one picture is brighter than the other, then you have established *reciprocity failure*, which means the camera aperture (or exposure time) is not accurate.

Exposure vs. Aperture—depth of field

If you carefully compare Picture 6 and Picture 7, you may notice the two pictures are not exactly the same, even if they are equally bright. They have different *depth of field*.

The depth of field in a picture is the range of distance over which objects are in focus. The smaller the aperture, the larger the depth of field. Absent-minded people who wear glasses are likely to know this. Such people sometimes lose their glasses, and then everything looks out of focus to them. One way they can regain sight is to make a pinhole in a sheet of dark paper and look through the pinhole. Since a pinhole is a very small aperture, everything seen though it looks in focus (of course, this will only work in a brightly-illuminated space, since the very small aperture also blocks most of the light!). Many a pair of glasses have been found by this method.

Go to the RemoteCapture Task window and click the Field/Angle Flash tab. Unlock the autofocus ("AF unlock") and set Macro to On ("Macro" is the setting you use to allow the camera to focus on objects that are very near). Position the circle disk so that it is 20 cm in front of the camera lens and click "apply settings". Then set "AF Lock". Now objects 20cm in front of the camera should be in focus.



The Tinkertoy Axis

Set up the tinkertoy axis so that one post is 7 cm from the lens, the next post is 20 cm in front of the lens, the next is at 33 cm, and the last is at 46 cm. In addition put a post at 1 m from the lens. Make a picture with a large depth of field: set the aperture to 8.0 and the exposure time to 1/50 second (Picture 8). Make a picture with a small depth of field: set the aperture to 2.8 and the exposure time to 1/400 second (Picture 9). Can you see the difference in depth of field between the two pictures?

Now see if you can affect the depth of field by putting your own aperture in front of the camera. Hold an aperture from the Pasco aperture ring in front of the camera (use the smallest one that you can) and take a picture without changing the camera settings on the computer. Are you able to perceive an increase in the depth of field?

We hope that you are able to use the things you learned in today's lab when you next have a chance to take a photograph (using either a digital or a film camera). Good luck!