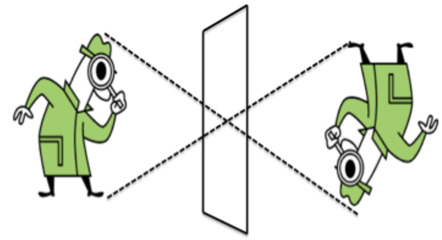
The Photo Lab

Louis Abramson, Yeunjin Kim, & Nicole Fields



Driving Questions:

By the end of this lab, you will be able to answer the following:

- What is the **DETECTOR** in photography and what are its **INPUTS** and **OUTPUTS**?
- What **SUPER SENSING** abilities does photography give us?
- What sources of **ERROR** can distort a photographic image of reality?

Introduction

Today, you can snap a photograph from a cell phone and if you do own a dedicated camera, it's almost certainly digital. These advances have made the act of taking a picture so fast and easy that you probably never think about what the images actually are, how accurately they represent the scenes you were trying to capture, or how they were created in the first place. In today's lab, you'll explore these questions by returning to the analog roots of photography, building your own camera, and diving into the amazing chain of electronic, mechanical, and chemical events that occurs every time you press that little button.

Before we start our discussion of photography, however, let's review a few basic concepts by examining an older type of imager: the human eye.

The Physics of Sight

Whenever we "see something", this is what physically occurs:

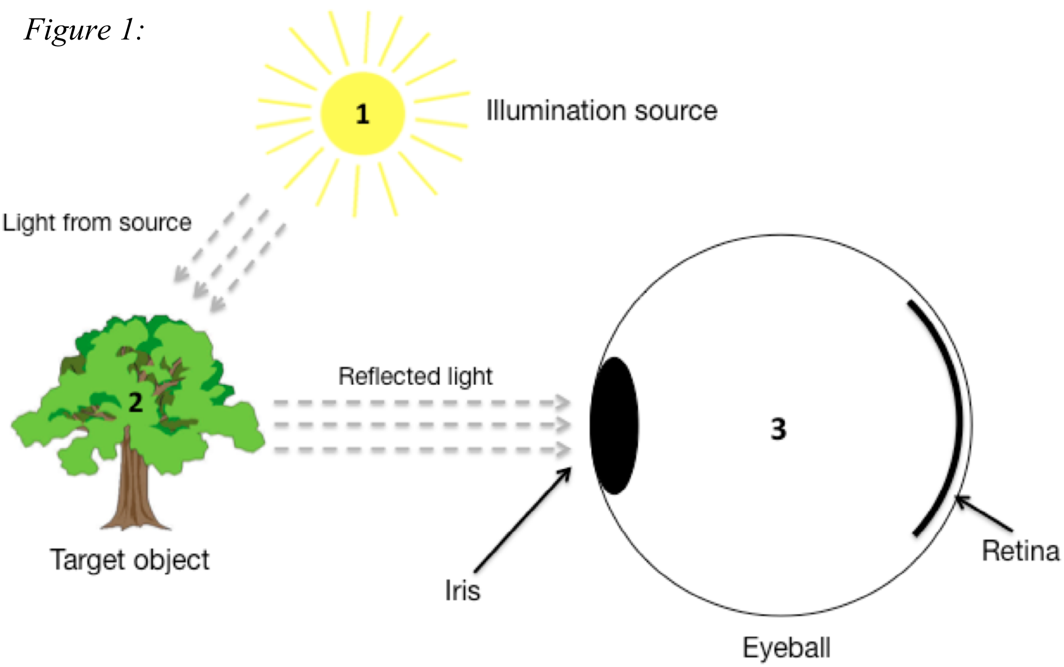
1) Light from an illumination source (the sun, a light bulb) hits an object and reflects off of it in all directions. Some of that light—made of particles called **photons**—reaches our eye.
2) The eye registers the photons and moves its internal machinery to focus the light into a sharp image on a photo-sensitive organ called the **retina**.
3) The retina transforms the image into **electrical pulses** and sends these to your brain.
4) The brain processes the pulses—pulling out information like color and shape—and compiles the final picture you will "see".

So, for the sense of sight:

INPUT		DETECTOR		OUTPUT
Photons	→	*Retina*	→	*Electrical nerve pulses*

Notice that the **DETECTOR** here is not your whole eye: *photons are only physically registered by the retina*. The other equipment in your eye (e.g., iris, pupil, lens) is there *to control how the incoming light gets onto the retina*.

Figure 1:



The steps involved in seeing a tree. Light from the sun (1) illuminates the tree (2) and is reflected towards your eye (3) where it is focused onto your eye's photo-detector: the retina.

If you are thinking, "Wow, that's complicated!" you're right: it turns out your eyes are pretty remarkable apparatus. However, they have their limitations.

SUPER SENSING Opportunity 1: Record an Image

One thing the eye/brain combination *can't* do is store the details of the image it works so hard to construct. We can't create a **permanent record** of the actual photons we see at any given moment in time. This means our ability to analyze the visible world is limited by the accuracy of our memory.

SUPER SENSING Opportunity 2: Increase Integration Time

Our vision system is also incapable of **collecting photons for long periods of time**. In a staring contest, you may keep your *eyes* open for minutes, but your *retina*—your

DETECTOR—is actually "blinking" many times each second. This is because it needs to dump the light that just hit it into nerves that run to your brain in order to receive new photons and continue sensing. Think of light from an object as water from a faucet and the retina as a bucket which must get emptied periodically. If the flow from the tap is strong (the object is bright), the bucket will easily get filled before it is emptied (you will see the object). However, if the faucet is only dripping (the object is dim), the bucket will contain very little water when it gets dumped (you won't be able to see anything). The process of catching and adding input (water or light) is called **integration** and the collection time (time between water dumps) is known as the **integration time**. If you were able to control your integration time, you could keep your retina open for as long as you liked and be able to see very dim objects. Humans, however, *can't* control our integration time, limiting us to seeing only relatively bright objects.

Figure 2:

The oldest surviving photograph. Taken by the Englishman William Fox Talbot in 1835, it is an image of a window in an abbey. How does this photo compare to one you might take today?

In order to **store a permanent record** of events we witness or **learn about objects too dim** for our eyes to register, we need a **SUPER SENSOR**. Fortunately, in 1826, the Frenchman Joseph Nicephore Niepce gave us this technology by inventing **photography**. From the Greek words *phos*— "light"—and *graphy*—"to write"—this "light writing" has enabled us to study worlds too faint and moments too fleeting for any human eye to see or mind to remember. We'll focus on this type of detection, today.

The Science of Photography

The fundamental goal in photography is to **measure and record amounts of light at given positions**. We want to count up all the photons that hit our detector at a certain spot (**INPUT**) and present/store this information in an intelligible way (**OUTPUT**). We call this eventual output a **photograph** and, in black-and-white imaging, we'll see that different shades of grey represent how much light hit each spot on the detector.

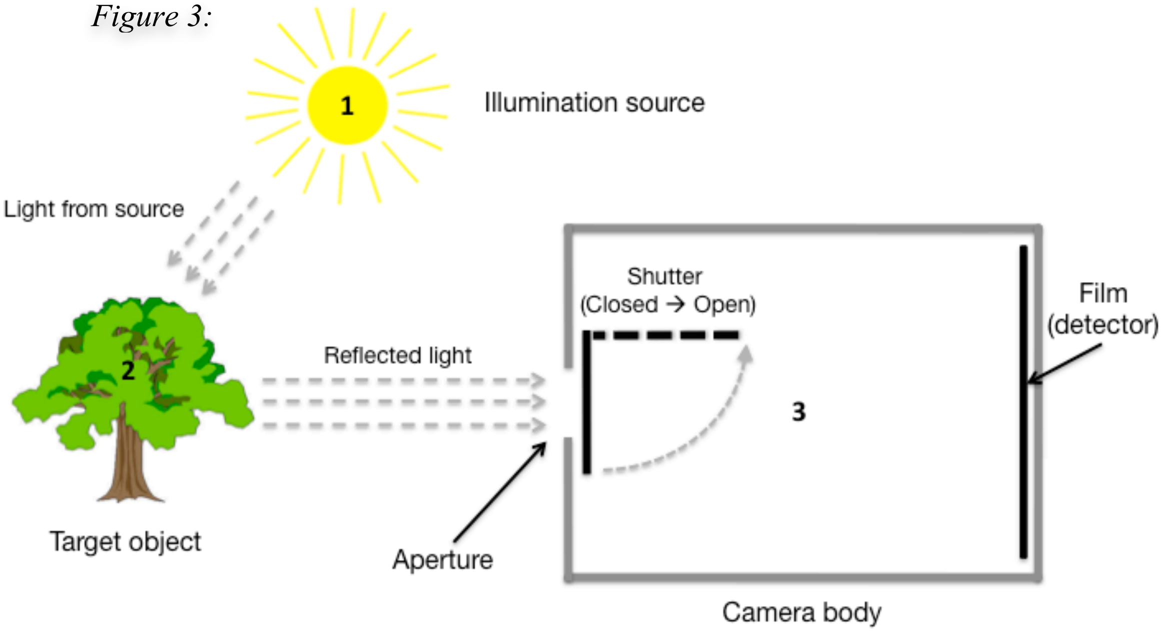
At it's core, then, a photo is a **brightness map**. But how is it made?

To answer this question, we first need to identify our detector. In photography, your camera is actually *not* doing the detecting: though crucial to making pictures turn out well, a camera is really just a box of lenses and mirrors that channel light to the true detector: **photographic film**[1]. This might seem strange, but it's the same situation we learned about with the human eye: the whole eyeball isn't the light sensor, *only the retina*. Cameras are

[1]In digital cameras, the detector is actually a silicon chip called a "Charge Coupled Device" or CCD. Some of you will explore this technology in the extension, but, for today's lab, we can think of all photography as film-based.

similar to your eyes with the film directly analogous to your retina: all of the machinery in the camera is designed to get light properly to the film, just like all of the machinery in the eye is designed to get light properly to the retina.

Figure 3:



The steps involved in taking a picture of a tree. Light from the sun (1) illuminates the tree (2) and is reflected towards your camera (3) where it is focused onto film, the true photo-detector. Note the similarity between this the diagram and Fig. 1 illustrating the process of viewing a tree with your eye.

Now you know what the detector is, but how does it actually work?

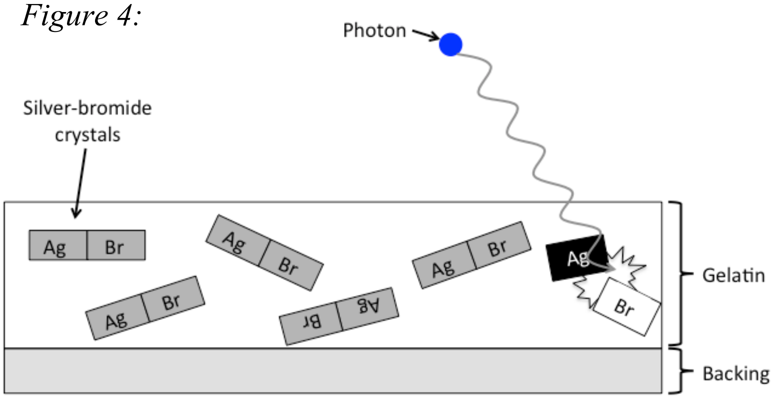
Photographic film is essentially a sheet of backing material coated by a layer of gelatin almost exactly like the kind we eat for dessert. A key difference, though, is that this gelatin contains grains of silver-bromide molecules (AgBr) instead of fruit. AgBr molecules are special in that they are very easily destroyed by light: the bonds holding them together are so weak that the energy of ordinary visible photons is enough to break them apart into free silver and bromine atoms. Thus, wherever photons hit film, they produce little specks of silver:

AgBr + Energy from light → Ag + Br

This is the key reaction in photographic detection. When we talk about **exposing** film, what we mean is **the process of representing photon counts as silver atoms.**

Usefully, silver is **opaque** to light, meaning that exposed areas of film are slightly *darker* than unexposed areas. Since more photons hitting a location will create more silver, *the brightest parts of the scene you are capturing become the darkest spots on the film*. This inverted brightness map is called a **negative image** (or just "**negative**"). It is the immediate output of a photographic detector.

Figure 4:



Schematic of film being exposed. Light hits the film and interacts with the AgBr crystals suspended in the gelatin, breaking them into silver and bromine atoms and creating a dark spot. These spots form the negative image described above. More light hitting an area means more AgBr → Ag + Br and the darker the film.

Photons have now been converted into solid silver, but this isn't the whole story. Unlike the other labs at YSI, this detector produces only an **intermediate output**. The grains of silver on the film are too small to be seen by the naked eye, meaning the data are there, but you can't get to them yet[2]! To make a "human-readable" output (a photograph), the silver specks need to be made bigger through a process that occurs *outside the detector*: **development**. Development takes place in three stages:

1) Exposed regions are amplified by a factor of about *one hundred billion* by washing the film in a chemical fittingly called **developer**. This seeks-out silver atoms freed by photons and turns all of the nearby AgBr crystals into pure silver, too. The amount of time the film spends in the developer affects the **contrast** of the final photograph (the difference in darkness between exposed and unexposed regions on the film): more time → more silver → darker grey patches. Development *must be done in the dark* to avoid exposing all of the film and destroying your image.

2) The developer is stopped by placing the film in a **stop** bath. Developers are bases so, to neutralize them, the stop bath is acidic. Vinegar works well.

3) Remaining AgBr, developer, and stop are cleared away by a **fixer** bath. This step ensures there is nothing left to expose when you take your film into the light to show your friends, thereby *fixing* the image.

Figure 5:

A positive (top) and negative (bottom) image of downtown Chicago. Which corresponds to the actual output of the camera? (Photo credit: Louis Abramson.)

[2]For this reason, the silver atoms on the film itself are said to make up a "latent image".

Only after *all of this* is the **final output** obtained: a crisp, negative image of whatever was in front of your camera when you opened the shutter. And you thought you were just pressing a button!

Activity 1 – Sun Printing

To prove you don't need a mechanical camera to take a picture, we'll first make a sun print. Here, an object is placed directly on top of photosensitive paper and exposed to sunlight. Let's see what happens.

Procedure:

1) Get an envelope containing a piece of printing paper from an instructor. KEEP IT COVERED.
2) Go outside and find an object you'd like to image. (Example: a leaf.)
3) Place the object directly on top of blue (photo-sensitive) side of the printing paper and expose it to sunlight for about a minute.
4) Bring the print and your target object inside and run the print under cold water. This acts as a fixer and will make sure your image stays in place. Leave to dry.

Questions:

1. What was the **INPUT**, **DETECTOR**, and **OUTPUT** of this photographic process? Use the word "positive" and/or "negative" where appropriate.

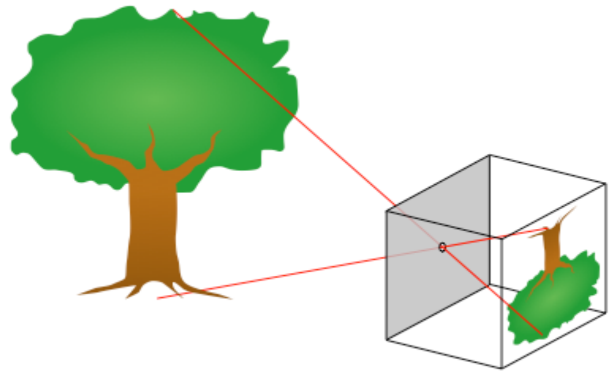
2. Compare the image to the target object. What **ERRORS** are present in the image? What information about the target was lost? What was retained?

Activity 2 – Making and Using a Pinhole Camera

Even though it's not actually part of the detector, a camera is as important a part of photography as the lens of your eye is in seeing. This is because the camera *controls how light* (**INPUT**) *gets to the film* (**DETECTOR**). We can see two ways a camera does this by looking back to *Figure 3*. First, note the entrance window to the camera called the **aperture**. The larger it is (the larger the **aperture size**), the more light enters the camera in a given amount of time. Covering the aperture is a door called the **shutter**. When you press the trigger on your camera the shutter opens and allows light through the aperture onto the film. The amount of time the shutter stays open is called the **exposure time** and the longer the exposure time the more light gets to the film.

The camera controls (1) how much light enters the aperture per unit of time and (2) the amount of time that light interacts with the film. Different combinations of aperture size and exposure time affect the **INPUT** to the **DETECTOR** and, thus, its **OUTPUT**. In the rest of this lab, we'll explore the relationship between light, the camera, the film, and the image.

The simplest type of camera has no lenses or mirrors; it's just a light-proof box with a very small hole. This is a **pinhole camera**. We'll make and use this type of camera in this lab. Here's a cartoon illustrating how it works:



Light from an object enters the pinhole and strikes the back of the camera where the film is located. The pinhole lets in enough light for an image to form but not so much that the entire piece of film is exposed at once.

Procedure:

1) Obtain a coffee can or a shoe box from an instructor.
2) Using a hammer and nail, punch a hole in the center of the curved wall of your can, *OR* get an instructor to help you cut a window in the long side of your shoebox.
3) Cover the inside of the can/box with black construction paper to prevent light from bouncing inside the camera and over-exposing the film.
4) Using the small (**0.2 mm**) needle, poke a hole in a sheet of aluminum foil.
5) Tape the foil to the outside of the can/box so that the pinhole is centered on the nail hole.
6) Cut out a square of black paper for your shutter and tape it so it covers the pinhole but can be folded open.
7) Close the can/box and get and instructor to help you check your camera for light leaks. The instructor will help you patch any you find.
8) Go to the darkroom and CLOSE THE DOOR. The red safety light should be on. Get a piece of photographic paper (our film) and cut it to fit in your camera.
9) Load the paper into the camera. **Make sure the GLOSSY side of the paper is facing the pinhole**. (Only this side is light-sensitive.) You're ready to go shooting!
10) Take a stopwatch and your camera and go outside. Point your camera at an object you want to image and set it down. Place a weight on top to keep the camera from moving in the wind.
11) **BEFORE EXPOSING, BUILD AS DETAILED A MENTAL PICTURE OF YOUR TARGET AS POSSIBLE, MEMORIZING AS MANY DETAILS AS YOU CAN WITHOUT WRITING ANYTHING DOWN. You will be asked about this at the end of the lab.**
12) Open the shutter and start the stopwatch. You're now exposing the photographic paper. Continue exposing for about a minute.
13) Close the shutter. DO NOT OPEN THIS AGAIN TILL YOU'RE BACK IN THE DARKROOM! Return to the darkroom.
14) In the darkroom, with the red safety light on and the door closed, open the camera and remove the exposed paper. It's time to develop the photo.

15) Place the paper in the **developer** tray **glossy side up**. Using tongs, gently slosh the paper around for a few seconds, ensuring it gets entirely covered. Dark areas should start to emerge. Keep the paper in the developer until the image ceases to change.
16) Move the paper to the **stop** bath. Slosh it around using tongs for another 30 seconds.
17) Move the paper to the **fixer**. Slosh it around for a few seconds using the tongs and then leave it submerged (or image side down) for about 2 minutes
18) You now have a fully-developed photograph(!). Place it on the clothes line to dry and reload your camera with fresh paper.

Repeat this process two or three times, imaging whatever you like using 1 minute exposures. When you feel comfortable that you know what you're doing, record in your lab book your observations/reactions to the development process.

Questions:

1. Draw a picture of your pinhole camera in your notebook and label the following items: **aperture**, **shutter**, **detector**.

2. Why must the darkroom be kept dark while you load your camera or develop your photographic papers?

3. Compare an image taken using a coffee can camera to one taken using a shoebox camera. Discuss their differences in terms of the ERROR, field of view, etc.

Activity 3 – Shedding Some Light on the Subject

Now that you're an expert photographer, it's time for some science. You know the essence of photography is **putting light on film**. Three quantities affect this process:

1) Illumination from/of target
2) Exposure time
3) Aperture size

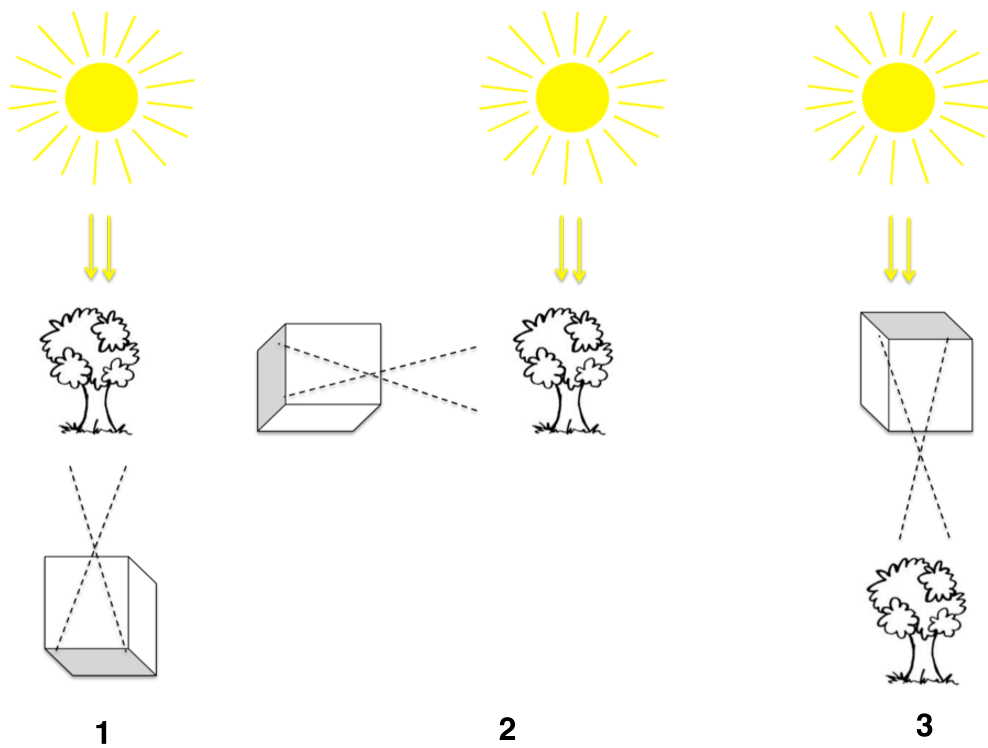
We'll now focus on each of these aspects individually, investigating how they change the relationship between **INPUT** and **OUTPUT** in photographic detection.

3.1 – Lighting Angles

To start, let's see how the direction/source of light affects the final photograph. The more directly the illumination source (sun) points at the pinhole, the more light gets into the camera. Your target for this exercise will be Yerkes Observatory, itself.

Procedure:

1) Go outside and walk around the observatory until it is **between** you and the sun, standing far enough away so the entire building is in the field of view. From your perspective, the target should be illuminated from the **back** (graphic #1, below). This type of lighting is called **backlighting**.
2) Aim your camera at the building and expose for 1 minute.
3) Go to the darkroom and, with the doors closed, write "**backlighting**" on the BACK OF THE PAPER with a pencil.
4) Develop.
5) Reload and walk around until the sun, camera, and observatory make a **90 degree angle** (graphic #2). Aim at the bulding and expose for 1 minute.
6) Develop, noting the lighting angle ("**90 deg.**") on the back of the photo.
7) Reload and walk around until **you are between** the sun and the observatory. The sun should now be hitting Yerkes from the **front** (**front-lighting**). Aim at the building and expose for 1 minute (graphic #3).
8) Develop, writing "**front-lighting**" on the back of the photo.



Questions:

Recreate the chart below in your lab notebooks, leaving yourself enough room to write in each box. Note the following:

1. What effect does the sun-object-camera angle have on the **exposure level** (overall darkness/lightness of the photo) and the parts of the image that are most exposed? (Think about how much light hit the detector and **where that light came from**.)

2. How does the **contrast** (difference in darkness between dark and light areas) vary with illumination angle?
3. How do the ERRORS (image quality, distortions, etc.) change with angle? What aspects of the output are enhanced at each sun angle? What are degraded?
4. Which angle do you think produced the "best" picture and why?

Sun Angle	Back-lit	90-degrees	Front-lit
Exposure / Contrast			
Enhanced / Degraded / ERROR			
Best?			

Next, answer the following:

5. If you wanted to take a picture of your best friend's face, would you use backlighting? Explain.

3.2 – Exposure Time

Now let's see how the exposure time affects the photo. The more time the shutter is open, the more light gets onto the detector.

Procedure:

1) Go outside and select a target you're especially fond of. NOTE THE LOCATION FROM WHICH YOU WILL SHOOT IT. Make sure it's not backlit.
2) Expose for 10 seconds.
3) Go to the darkroom and, with the lights off and door closed, mark the BACK OF THE PAPER with the exposure time and the shooting location.
4) Develop.
5) Reload and go outside. Aim at the same target from the same spot.
6) Double the exposure time to 20 seconds and expose.
7) Develop, noting the exp. time as before.
8) Continue, doubling the exposure time each exposure to 40, 80, and 160 seconds.

Questions:

Recreate the chart below in your lab notebooks, leaving yourself enough room to write. Note:

1. What effect does the exposure time have on the exposure level/exposed regions? (Think about how much light was hitting the paper and from what source it came.)

2. How does the contrast of the image change with exposure time?
3. How do the ERRORS (image quality, distortion, etc.) change with exposure time? Which aspects of the photo are enhanced or degraded?
4. Which exposure time do you think produced the "best" picture and why?

Exp. Time (sec)	10	20	40	80	160
Exposure / Contrast					
Enhanced / Degraded / ERROR					
Best?					

Next, answer the following:

5. What are the "pros and cons" of using long exposure times in general? Think about what your targets might be and how they behave over time.

3.3 – Aperture Size

Finally, let's study the effect changing aperture sizes has on the final image. We know that the larger apertures let more light hit the film every second, but is changing the aperture the same as changing exposure time or lighting angle?

Procedure:

1) Ask an instructor for the two, larger-diameter pins.
2) Punch these through new squares of foil, creating two more apertures for your camera. You now have three apertures total (original + 2 new) with sizes:

0.20 mm
0.40 mm
0.80 mm

3) Label each piece of foil with the appropriate aperture size.
4) **This part is tricky:** Since we only want to study the effect of increasing aperture size on the image, we must make sure we keep the *total amount of light constant* for all apertures. The bigger the aperture, the more light hits the film every second, so *increasing* aperture size means *decreasing the exposure time to ensure the total amount of light doesn't change*. We can calculate the amount of light as follows:

Total light = exposure time × area of aperture.

Since your apertures are factors of **2** bigger than one another in diameter, they are a factor of **4** apart in area. Thus, the exposure time needs to drop by a factor of **4** as you move from one to its larger neighbor.

5) Start with 60 seconds of exposure on the original (smallest; **0.20 mm**) aperture. Calculate exposure times for the other apertures based off this amount of total light.
6) Choose a target you're especially fond of and image it using the original aperture with 60 seconds exposure. Make sure you remember the location from which you shot it.
7) Develop. Note the **aperture size AND exposure time** on the back of the photo.
8) Switch to the next largest aperture (**0.40 mm**) and shoot the same target from the same spot using the appropriate exposure time you calculated earlier.
9) Develop and repeat for the largest aperture.

Questions:

Recreate the chart below in your lab notebooks, leaving enough space in each box to write. Note:

1. How does the **blurriness** of your images change with aperture sizes?
2. What about exposure and contrast levels?
3. How do the ERRORS (image quality, distortions, etc.) change with aperture size? Which aspects of the photo are enhanced or degraded?
4. Which aperture produced the best image and why?

Aperture Diameter (mm)	0.20	0.40	0.80
Exp. Time (sec)	60	?	?
Blurriness			
Exposure / Contrast			
Enhanced / Degraded / ERROR			
Best?			

Next, answer the following:

1. What effect does changing the aperture size have on the OUTPUT that is **different** from changing exposure times and sun angles?
2. Why does the exposure time drop like the aperture size *squared*? (Hint: think about the area of a circle.)

Big Questions

In your lab notebooks, answer the following:

MANDATORY:

1. Answer the **DRIVING QUESTIONS** found on **page 7**.

2. Recall the subject of the first photo you took today (you were asked to memorize details about this object/scene). WITHOUT LOOKING AT THE PICTURE, write down everything you remember in as great detail as possible. Sketch the image if helpful. Now, look at the picture. How does it compare with what you wrote down from memory? What aspects have you forgotten that the photo reveals? Relate your findings to photography as a **SUPER SENSE**. How has it increased our understanding of the world and given us access to important new perspectives? How has the photograph affected our interpretation of modern (versus ancient) history? Art?

CHOOSE ONE:

3. In your own words, explain fundamentally what a photograph is. Try to describe, at the most basic level, what you are actually seeing when you look at a picture. Include a description of the process by which the **DETECTOR** translates the **INPUT** into the **OUTPUT**.

4. What is different between what your eyes see and what a photograph captures? What sources of **ERROR** are present in the final photograph that the image from your eyes doesn't contain? Relate this **ERROR** to the processes involved in creating a photograph. Which image is more "real"? Why?