BEAM Fall 2011 Lesson Plan

Chemistry and Optics – Pinhole Cameras!

Type: Exploration and Activity

Last updated 24-Oct 2011 (Michael Song)

Figure 1. A collection of pinhole camera images.

Overview

This lesson covers the basic optics and chemistry involved in producing images on film using a simple pinhole camera. Students will have the opportunity to construct their own pinhole cameras and learn how various design parameters influence the final images that appear on their film. Students will also have the chance to develop their own black-and-white negatives using a custom development process with an instant coffee mixture. By emphasizing key principles throughout the construction process such as the importance of shielding unexposed film from light, students will gain insights into the nature of light propagation and how the energy carried by light is able to effect a chemical reaction on the film.

In its simplest form, the pinhole camera is a light-tight box with a pinhole on one side and a piece of film or photographic paper taped to the other side. Compare this to one of those fancy digital cameras that are in vogue these days! All one needs is a dark box with a pinhole and shutter to produce some really nice images!

Figure 2. The materials (left) needed to construct our pinhole camera (right).

Background for Mentors

How does a digital camera work? When we press down on the shutter button, the camera quickly opens and closes its **shutter** with a "click" and allows light to fall on a sensor, recording the image and storing it in its memory. Depending on the camera, a **lens** might be used to magnify the image of interest or focus on particular aspects of the scene. While a digital camera relies on an array of sensor elements based on semiconductor technology to record an image, a film camera relies instead on a chemical reaction induced by light on the surface of the film.

For black and white film, the surface is coated with an emulsion of **silver salts** that reacts with all visible wavelengths of light. In contrast, for color film, the surface is coated with three different layers of silver salts that individually react with red, blue, and green wavelengths of light. The more light that falls on the film, the more concentrated the reaction will be and the more intense the image that is formed. This is what allows the film to faithfully replicate any image that is projected and "exposed" onto the film, whether through a pinhole or a combination of a lens and aperture in more advanced cameras.

After the film has been exposed, it must undergo **development** and **fixation**, chemical processes which serve to harden the exposed silver salts and wash away the unreacted chemicals. This is why photographers develop their film in specialized "dark rooms"—before their film is properly developed and fixed, the film is still sensitive to light and the image is prone to contamination!

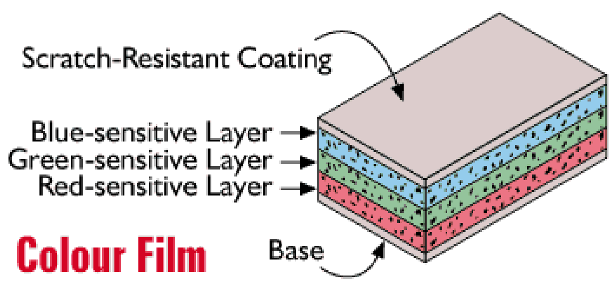


Figure 3. Colour film schematic showing three layers.

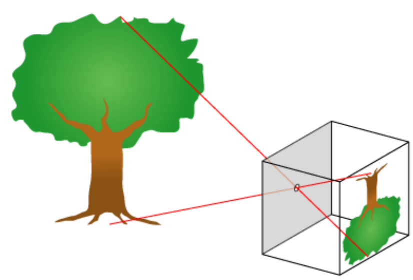


Figure 4. Imaging with a pinhole camera.

When we view an object with our eyes, what are we actually seeing? We are seeing the light from the sun or some other light source being reflected off the objects in our field of view. Red objects appear red for the most part because the object's material happens to reflect red light. Black objects appear black because the object's material happens to absorb all visible wavelengths of light such that light is not reflected to a significant extent. This is an important principle of light—it can be visualized to travel in straight lines or **rays** until it impinges on an object, at which point it is either **reflected** or **absorbed** as energy in the form of heat or a chemical reaction. The images that appear in a pinhole camera are actually upside-down relative to the object that is imaged! Can you draw a diagram to understand why this is so?

When building the cameras, students should be encouraged to understand the significance behind each step as each piece has a specific purpose in the design of the working camera. Engineering is, at heart, design!

Key Concepts for Mentees

Light

What is light and how does it help us to form images? Light is a form of energy which exhibits wavelike behavior and generally travels in straight lines through space. Specifically, it is a form of **electromagnetic radiation** with frequencies in the visible range, unlike **ultraviolet** (UV) or **infrared** light which humans are not able to visualize. When light hits an object, it can do one of two things—it can be reflected or absorbed as energy in the form of heat or a chemical reaction. This is why objects left in sunlight gradually warm up over time, because as the objects absorb light rays from the sun over time, the energy from the light is converted to heat.

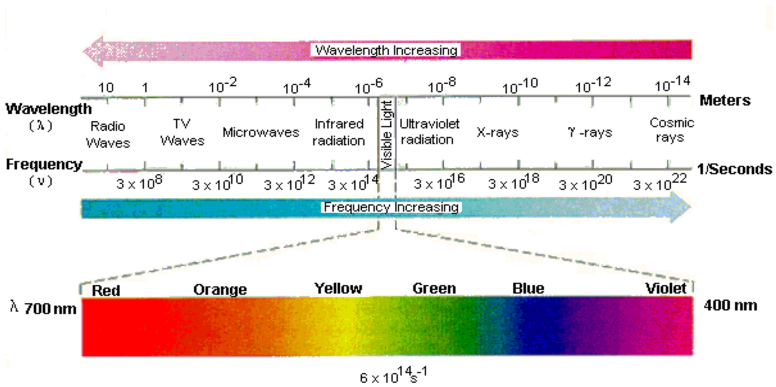
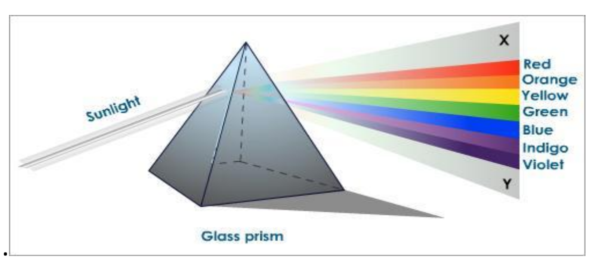


Figure 5. Electromagnetic spectrum showing the visible light wavelengths.

However, not all the light rays are absorbed! It is the light rays that are reflected off objects that allow us to visualize or see the objects with our eyes! How exactly does this work? The reflected light bounces off the objects and enters our eyes through very tiny openings in the center of our eyes called **pupils**. (This is what dilates when the room is very dim or when your optometrist gives you eyedrops to check your eyes.) Objects that are red appear red because all the other wavelengths of light (green, blue, violet) are absorbed by the object. Can you come up with an explanation of why black objects heat up the fastest in direct sunlight? The essential point to remember is that white light contains all the wavelengths of light, whereas light that appears colored is missing certain wavelengths of light. This is why we can use a **glass prism** to separate all the different wavelengths of light into individual beams!



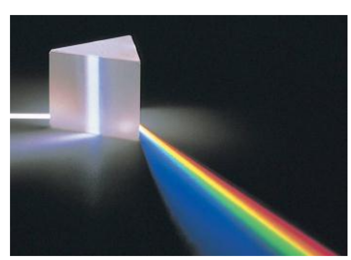


Figure 6. A glass prism splits white light into its constituent beams of colored light.

Pinhole Imaging

The simplest example of a pinhole camera might be more familiar to you than you think. Our own eyes are perfect examples of pinhole cameras! Just like pinhole cameras, our eyes have tiny pupils through which light enters, and instead of flat pieces of film onto which the light is projected, we have dense layers of nerve cells in the backs of our eyes which help to communicate to our brains what we are seeing! **Our eyes are extremely smooth and detailed versions of pinhole cameras which provide us with beautiful, continuous images of the world around us.**

But one important question remains—how exactly does an image fit through a tiny hole the size of a pin? Let's draw a diagram to help us visualize how this might work. For each point on the vase below, reflected light bounces off in all directions as shown in the figure. The light that is reflected from the flower at the highest point in the vase will pass through the pinhole in the center and appear at the lowest point in the picture. Similarly, the light that is reflected off of the bottom of the vase will be projected onto the highest point in the picture. You might notice that what you get is an upside-down image, and this is actually what happens in real life! Your eyes actually create an upside-down image of the world, but your brain cleverly flips the image vertically such that everything appears normal. Tricky, huh?

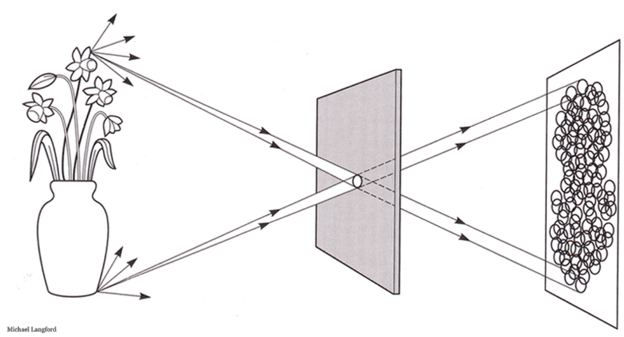


Figure 7. How pinhole imaging works. We can see that the light that is reflected off each point on the vase passes through the pinhole to create an upside-down picture on the image plane!

One last interesting question might be, what happens if you change the size of the pinhole? Can you draw a picture to show that as you increase the size of the pinhole, the projected image will become increasingly blurry? What happens to the size of the projected image as you increase the distance between the pinhole and the image plane?

Film Development

Coming soon!

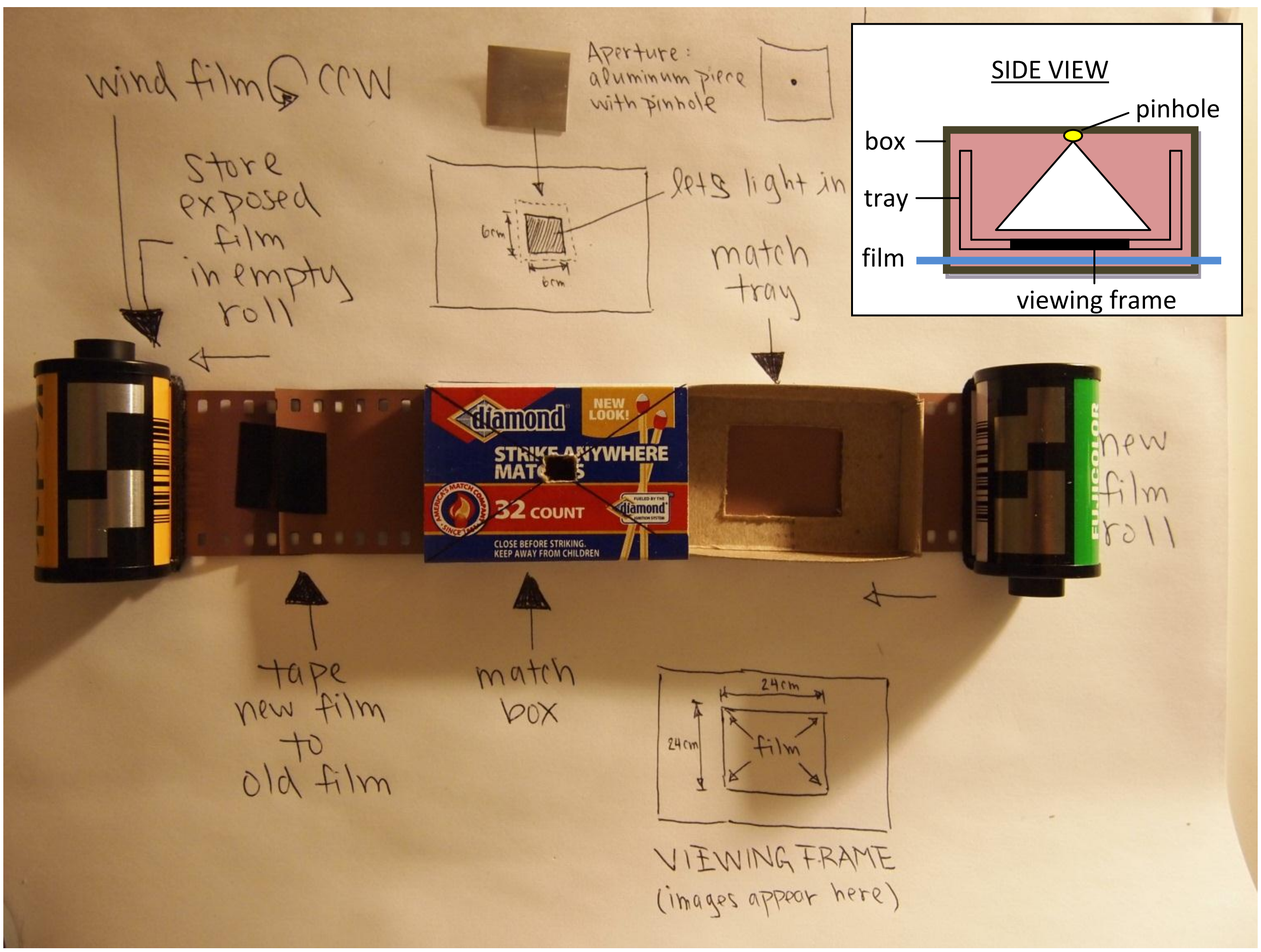
Constructing the Pinhole Camera

(25 to 45 minutes, depending on age group)

Overview

Our camera will consist of a very simple setup. The matchbox will serve as the body of the camera, and film will pass between the tray and the back of the matchbox as we take pictures. The viewing frame that we cut from the tray defines the area of the film that is exposed and the boundaries of the image that is formed.

To progress the film, we wind the empty canister (left) counter-clockwise until fresh film sits in the viewing frame. As we take pictures, film is fed into the empty canister and stored there until we are ready for the development process. It is very important to light-proof the camera such that no leaks will expose the film and contaminate the image!

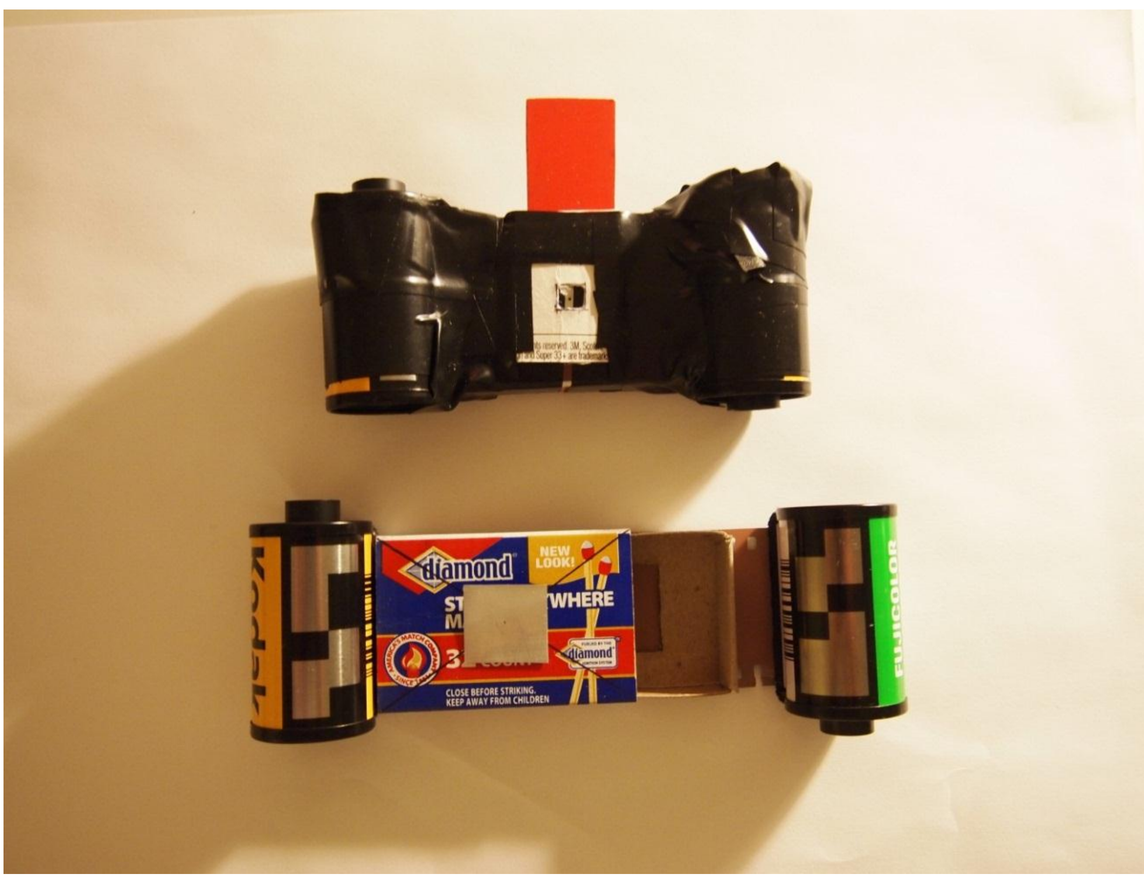


Materials (for 1 pinhole camera)

Name of material	Amount	Price
new roll of 35-mm film	1	$2.00/roll
used, empty roll of 35-mm film	1	-
aluminum piece (from soda can)	1 cm^2	-
paper clip	1	-
plastic clicker from binding comb	1	-
tissue/cotton	1	-
sewing pin	-	-
scissors	-	-
electrical tape (black)	-	$.79/roll
permanent marker (black)	-	-

Organization

Students should split into groups of 2 or 3 such that each mentor may lead up to 2 groups in constructing their own pinhole cameras. Unfortunately, there is not enough film for every student to build his or her own pinhole camera, so please follow these group guidelines so that we do not run out of film! Students should be encouraged to work together and share the use of the cameras after they are built.

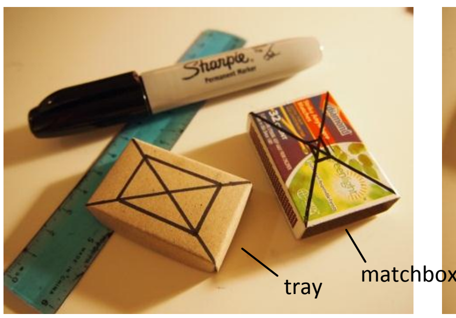


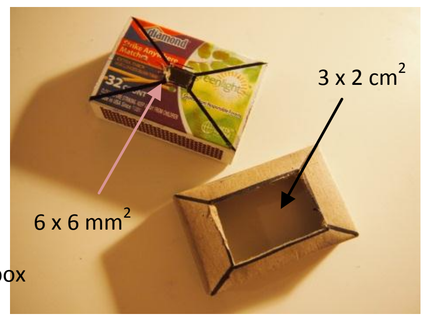
Preparing the Camera Body

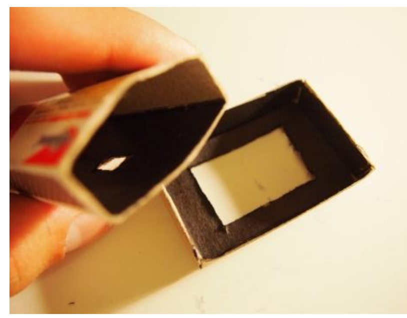
1. Remove **the tray from an empty matchbox**. Turn the tray over and <u>cut out a large rectangle in the center for the viewing frame</u> (3 by 2 cm is recommended). The film will be exposed through this window when a picture is taken.

2. Now take **the matchbox** and <u>cut out a small 6 by 6 millimeter square in the center</u>. The pinhole will sit on top of this opening and let light in when we wish to expose the film.

3. Use a <u>black marker to color the inside of the tray and the matchbox</u>. This will help to reduce internal reflections inside the camera body (remember that what we see with our eyes is the light reflecting off various objects).







Tip: It is a good idea to make these cuts beforehand for younger students!

Making the Pinhole (Aperture)

4. Take **a small piece of aluminum** (cut out from soda can) and <u>carefully use **a pin** to puncture a hole in the center of the aluminum</u>. Try to make the hole as smooth and circular as possible. The larger the hole, the less time you will need to expose your film to take a picture as more light is entering the camera. However, a larger pinhole will also result in a blurrier image!

5. Again, use the black marker to <u>color the back of the aluminum piece</u>.

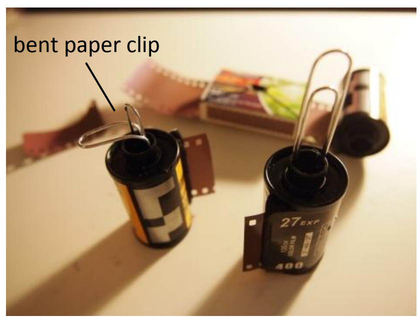


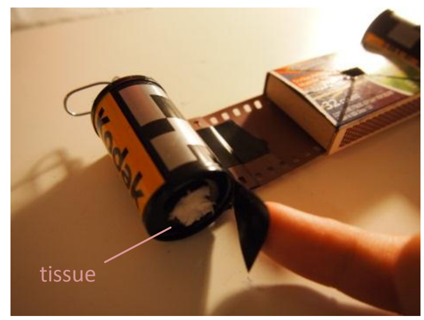
<u>Loading the Film</u>

6. Obtain **a roll of new film** and pull out the leader. <u>Feed the film through the matchbox</u> with the tray removed, then slide the tray in such that the film is sandwiched between the back of the matchbox and the bottom of the tray (left). The emulsion (non-shiny) side should be facing outwards towards the small 6 by 6 millimeter hole.

7. Obtain **a roll of used film** and ensure that a small piece is still sticking out from the end. We will need this piece to splice together the ends of the two film rolls. <u>Take **a paper clip** and insert it into the top of the used film</u>, bending it 90 degrees to form a rudimentary crank (middle). We can turn this crank counterclockwise ( ) to progress the film and wind it into the empty canister as we take pictures.

8. (Optional.) As the film is wound, the take up spool might tend to spring back and uncoil itself. To prevent this, <u>take **a small piece of tissue** and pack it tightly into the base of the used film canister</u>. Secure it in place with a piece of tape (right).

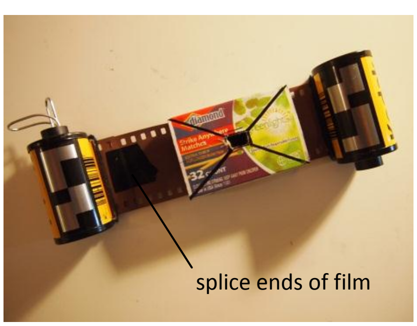


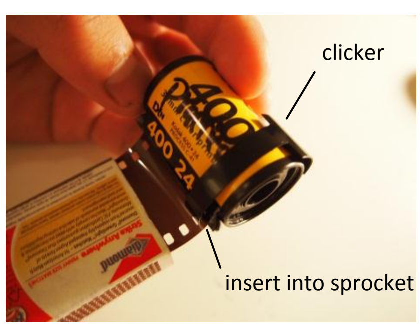


9. Use a small piece of tape to cleanly <u>splice the two ends of the film together</u> (bottom left).

10. <u>Take **a black clicker piece** and insert the pointed end into a sprocket hole adjacent to the roll of new film</u> (bottom middle). Reposition the clicker until it makes a small "click" every time it falls into a sprocket hole as the film is wound. (Take care to not force the sprocket lest the film tears.)

11. <u>Wind the film</u> until the two rolls are flush with the side of the matchbox (bottom right). *Almost there!*

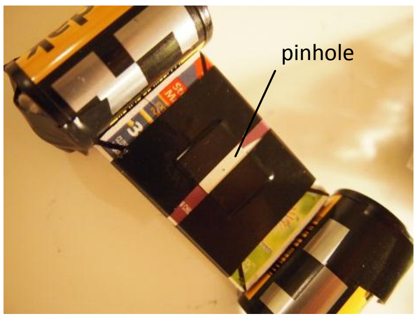




Adding the Pinhole and Shutter

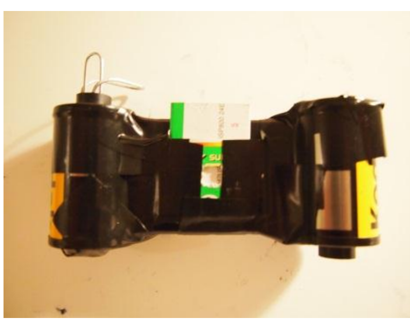
12. Center the aluminum with the pinhole on the small square that was previously cut from the matchbox and secure with tape (left).

13. A small piece of tape can be used to cover and uncover the pinhole for taking picture. Alternatively, two pieces of thin board may be used to construct a movable shutter by cutting a hole in one piece and fixing it over the pinhole (right). The other piece is free to slide vertically behind the window and act as a shutter.



Lightproofing the Camera

14. The final step is to lightproof the camera using **electrical tape** to ensure that the film does not get exposed to light between shots. Make sure to apply tape over all possible openings while taking care not to impede the movement of the film.



Now we've constructed our pinhole camera! We can use it to take pictures by exposing the pinhole to our scene of choice! Keep in mind that there is no "correct" amount of time to expose the film to produce good pictures. That's why we have a picture diary! Do be sure to **keep the camera steady during exposure** and **wind the film for 8 clicks between shots** though. The camera should be good for at least 20 to 25 exposures. When the film stops winding, it's time to open up the camera and develop the film!

-BEAM Fall 2011-

Pinhole Camera Diary

Instructions: Fill out this worksheet as you take pictures! This will help you track the effects of how you take your pictures! Make sure to keep the camera stable when you take pictures!

Recommended exposure times
(For ISO 100-200 film)

Outdoors, Sunny: **1 to 3 seconds**
Outdoors, Cloudy: **1 minute**
Indoors: **5 to 10 minutes**

Picture #	Conditions (sunny, cloudy, indoors)	Exposure time	Scene description	Notes
Example	*cloudy outside*	*1 minute*	*playground + swing*	*camera shook a little due to wind*
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				