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Digital Pinhole Camera

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In this article we describe how the classic pinhole camera demonstration can be adapted for use with digital cameras. Students can easily explore the effects of the size of the pinhole and its distance from the sensor on exposure time, magnification, and image quality. Instructions for constructing a digital pinhole camera and our method for calculating the effective focal length of the "lens" are included.

The pinhole camera, or camera obscura, is a simple device; essentially a small hole is made in one end of a box (the traditional demonstration uses an oatmeal container or shoebox) and an image is formed on the other side of the box (see Fig. 1). The optics of how the pinhole camera works has been described in detail elsewhere.[1,2] Traditionally, the pinhole camera was built using photographic film.[3] But with the advent of digital cameras and decline of film photography, we decided to adapt the activity for a digital camera, and the results were quite nice (Fig. 2). Other recent publications have explored the use of digital cameras[4] and pinholes[5,6] for studying optics in secondary physics classes. This activity brings together technology and optics.

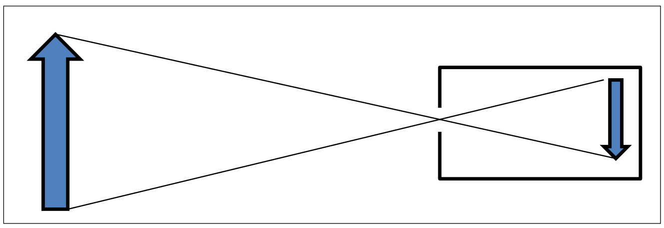

Fig. 1. Ray diagram for a pinhole camera (camera obscura).

Fig. 2. Image taken with the digital pinhole camera.

The pinhole camera activity aligns with Next Generation Science Standards disciplinary content standards for high school physical science[7] (i.e., HS-PS4 Waves and their Applications in Technologies for Information Transfer.) Additionally, these activities required students to actively engage in scientific practices. Specifically, they will gain skills in observation and data collection as they study the relationships between the pinhole size, length of the tube, exposure time, and how changing those parameters influence the quality and size of the image. The process of constructing the "lenses" requires that students behave as engineers and engage in an iterative design cycle. They also work on building a mathematical model for the "effective focal length" of the pinhole "lens" to help them make sense of their observations.

We constructed the pinhole camera using a Pentax K-01 digital camera (any digital camera with removable lenses would work). The camera's lens mount was fitted with an M42 screw-mount adapter, which allowed us to use old M42 accessories that can be purchased inexpensively online (e.g., eBay, KEH.com). For this project, we built our pinhole "lenses" using modified extension tubes (see Fig. 3). Extension tubes are empty rings placed between the camera body and a lens (typically used in macro photography to increase magnification). Typically, extension tubes come in sets of different lengths that can be combined in a variety of ways. The shortest distances from pinhole to image plane were constructed using a small extension tube. Greater distances from the pinhole to the image plane were made by attaching different length paper towel or toilet paper tubes onto the extension tubes.

First, aluminum foil is taped over the end of the extension tube. Since the tube needs to be light tight, the entire pinhole lens-tube assembly may need to be covered with additional foil or black paper to block stray light. Make sure that the tube is light tight by mounting the lens on the camera and taking a picture. If the picture is anything but solid black, you need to add more layers of tape, paper, or foil. Once the tube is light tight, a small hole is made in the foil using a straight pin.

The tube is then remounted on the camera, and the camera placed on a tripod. It is important to use a tripod because of the long exposure times required to get a properly exposed image. Pictures can be taken either indoors or outdoors, but the exposure time will have to be modified accordingly. Pictures we took indoors needed exposure times of 10-15 seconds. Outdoor photos required only one to two seconds. The exposure time depends on the size of the pinhole and the brightness of the scene being photographed. Using the digital camera allows students to check their images immediately and adjust the exposure time accordingly. Our camera's internal meter did a reasonable job selecting an exposure and provided a good starting point. We then could adjust the exposure compensation to either increase or decrease exposure time. Students may also wish to experiment with how the size of the pinhole affects image quality.

Once the students had taken some reasonable photos, we calculated the magnification of the image. To do this, they needed to know the physical size of the camera's sensor (not the megapixels). This information is available in the instruction manual for the camera. For the Pentax camera we used, the sensor was 23.7 mm x 15.7 mm. They then used the image on the computer screen to find the conversion factor between the size of the image on the screen and the size of the image

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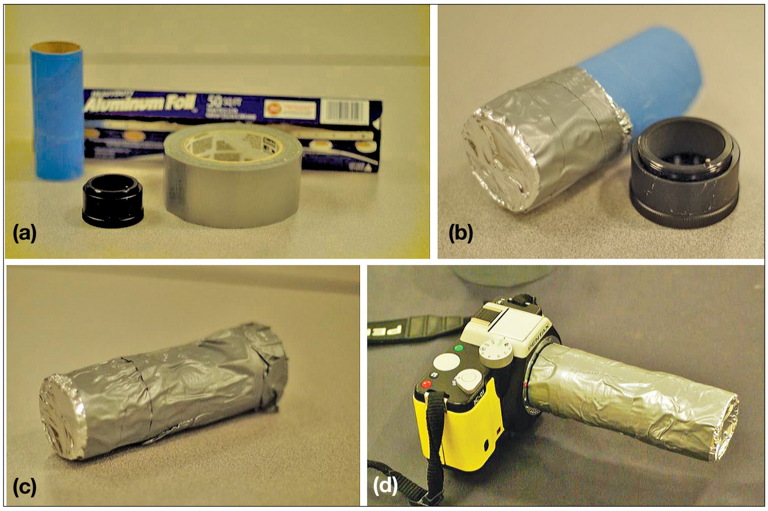

Fig. 3. Construction of the digital pinhole camera. (a) The materials needed (toilet paper tube, aluminum foil, duct tape, and an extension tube, (b) cover one end of the tube with foil, (c) tape the toilet paper tube onto the extension tube and cover with duct tape, and (d) attach to camera, check to make sure the tube is light tight, and use a pin to put a small hole in the foil.

on the sensor:

$$\frac{\textit{width of sensor}}{\textit{width of photo on screen}} = \frac{\textit{height of image on sensor}}{\textit{height of image on screen}}. \quad (1)$$

They could then measure the size of the object in the photo on their computer and use the conversion factor to calculate the actual image size. Then they could use the following equation to find the magnification of the system:

$$M = \frac{h_i}{h_0} = -\frac{d_i}{d_0}, \quad (2)$$

where M is the magnification, h_i is the image height (on the sensor), h_0 is the object height, d_i is the image distance, and d_0 is the object distance.

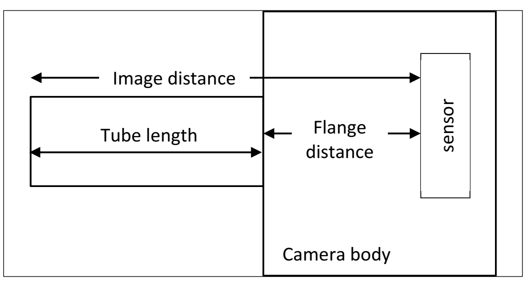

Fig. 4. Measuring the image distance from pinhole to sensor.

The image distance is the length of the tube plus the "flange distance" to the sensor inside the camera (Fig. 4), which can be looked up online.[8] For our camera the image distance was 45.46 mm. (Note that this value overestimates the precision of our experiment.) By using different length tubes, students can see how image size depends on image distance. By using different length tubes, the students can see the effect that image distance has on magnification of the final image.

Note that the camera automatically inverts the image so that it looks right-side up. Because the image is actually inverted, you will need to include the negative in the image height. To demonstrate this to the students, we had them look at the image formed by a traditional oatmeal canister pinhole camera. The oatmeal canister works well because the translucent lid can be used as a screen, and the students can easily see the image.

Once the students calculated the magnification, they can use this to find the effective focal length of the pinhole "lens." To do this, we started with the thin lens equation, and eliminated the object distance because objects were often far away and this would be difficult to measure. (Alternatively, you could have them measure the object distance to check that they get the same result for the magnification.)

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_0} = \frac{1}{d_i} - \frac{M}{d_i}. \quad (3)$$

Using Eqs. (2) and (3), the students developed an understanding of how changing the length of the tube affects the magnification of the object. It is important to note to students that these pinhole "lenses" don't really have a focal length because they are not actually focusing the light, but this provides a way for us to compare the effect to real glass lenses that do focus the light.

The pinhole camera can be used to demonstrate a range of optical phenomena. The use of digital cameras makes this traditional demonstration accessible for today's technologically engaged students, and gives them the opportunity to use technology in a productive way to explore the physics of optics.

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