

OPTOELECTRONICS OF CAMERAS EXPERIMENT

Summary

This experiment gives students a general introduction to optoelectronic devices through an investigation into how digital cameras work. Students begin by exploring the most basic of all cameras - the pin hole camera - before experimenting with different sized apertures and lenses with different focal lengths. Building on this, students then investigate image capture and processing using a photo diode array. Using computer software students investigate the effects of light intensity on detector array, analogue to digital conversion and colour capture. They can then explore resolution and other optoelectronic devices such as a thermal imaging camera.



Below is a summary of the steps for this experiment. This is to be used as a guide and we encourage you to make it your own by bringing on board any of your own knowledge and experiences.

Introduction to experiment

Start the experiment by saying who you are and what you do for a living. Tell the students that they are going to do an experiment relating to cameras. As an ice-breaker you may want to ask questions, such as:

- Does anyone have a camera? What kind?*
- Does anyone have an idea how cameras work?*
- How is an image stored in a camera?*

Explain that a camera is essentially a box that captures light and stores it, whether on a film or using a sensor and that they are going to find out the answers to these questions and more during the experiment, where they will be making the most basic camera and then converting that into a digital camera, to see how all cameras work using the same principles.



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Activity 1	The pin hole camera.
Time	8 minutes
Equipment	<ul style="list-style-type: none"> ▪ 6 x pin hole camera boxes ▪ Black card and map pins to create aperture. ▪ Tracing paper screen housed in a plastic casing. ▪ Carbon filament lamp or some other bright object. ▪ Lenses housed in plastic casing and some others lens examples of different focal length.
Keywords	Lenses, focus, focal length, aperture, exposure, shutter.

Procedure

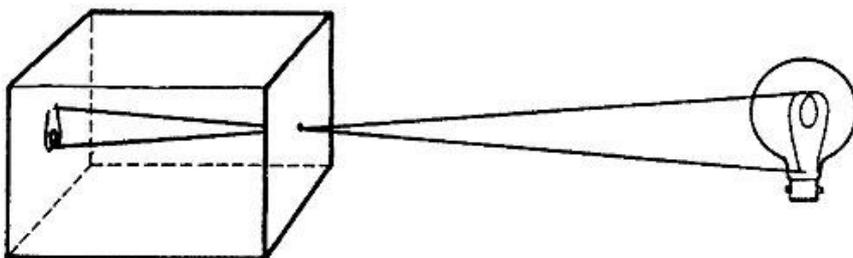
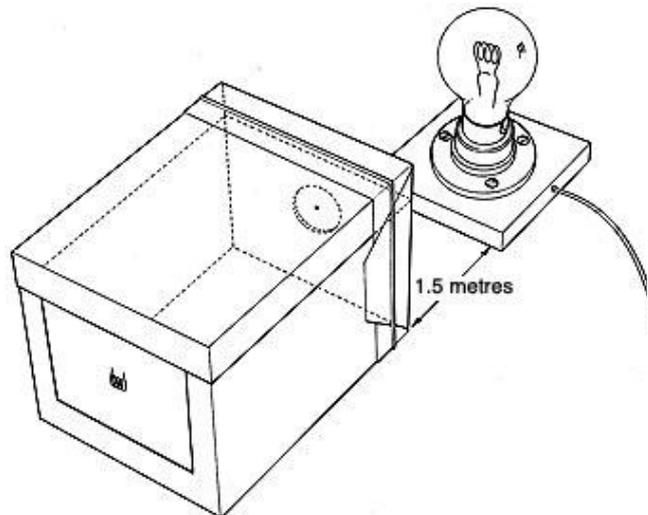
Give each student a pin hole camera kit. The black card goes into the slot with the circular opening. Get the students to pierce a pin hole into the black card. **Tell students to be careful with pin so that they don't injure themselves, then collect the pins back in and store them away securely before continuing.**

The tracing paper screens have a metal strip in the housing; this will clip into the slot on the other end of the camera box.

Once all students are ready, ask them to stand back so they have plenty of room, switch on the lamp, switch the room lights off and then get students to investigate the following:

i) Look at the screen as they move the box closer to or farther from the lamp. Note that they should view the screen at book length i.e. not right up to their eye.

What does the image look like? Can you notice anything strange about the image? It is inverted, draw the diagram below and explain the reason for this.





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How can we let more light into the box?

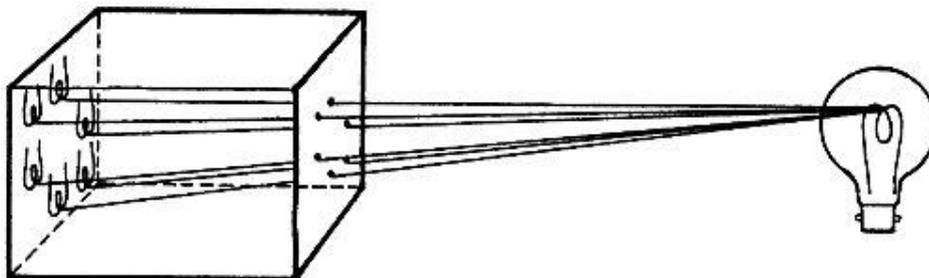
- ii) Enlarge the pinhole, trying to ensure sharp edges, and repeat the observation.
- iii) Add several more small pinholes and repeat the observation.
- iv) Pepper the whole sheet with pinholes and repeat the observation and use a pencil to create a much larger hole.

Is it better to have a big hole or a small hole? What is the result of each?

The larger the hole, the more light will get through but at what cost? The image becomes blurred. If we have more holes we get multiple images.

Explanation

The sketch shows rays of light from just two specimen points on a lamp filament contributing to the picture at the back. Light travels in straight lines, point to point. Each point on an object provides rays for a little spot in the picture at the back, a spot slightly larger than the pinhole. With a small enough pinhole, the depth of field is basically infinite and you get a fairly sharp picture. With a large pinhole, you no longer get a point-for-point copy of the object. You get a patch-for-point copy - rather a fuzzy picture but brighter.



When there are several pinholes, each lets through rays of light from every part of the object. So each pinhole leads to a whole picture of the object.

How do you think we can make the image look sharp again?

- v) Give each student a lens and ask them to slide it into the slot as well as the card, if this is too difficult just hold the lens in front of the aperture. You may need to tell students to move nearer to the lamp and farther from it and see what happens. They will soon find the position for a single brilliant image.

Ask them to remove the card entirely and they will be able to see everything in the room projected onto the screen. You may wish to switch the room lights back on at this point. They will enjoy looking at each other through the cameras because they appear upside-down on the screen and try to rectify this by turning the cameras upside-down! At this point you may wish to discuss the human eye and how it contains a lens. *What does this mean for the way we see the world? Upside down!*

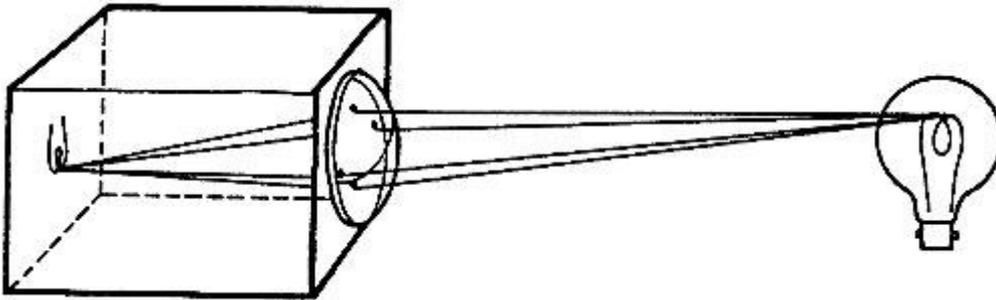


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Explanation

Look at the diagram and imagine what the lens does.



For light starting from a single point, the lens seems to collect up the rays that go through different pinholes regardless of the size of the pinholes. It bends them so that they all run together through a point. That point is called the **image**.

vi) You can also show how focal length varies by using the various lenses to image the roof lights onto the table. Simply hold the lens so that a bright spot appears on the table and observe the different heights the lenses are above the table to achieve this spot.

Time Filler

Let them experiment with the eye model and see how the image is affected by changing the lens using the syringe.

Further information:

http://www.practicalphysics.org/go/Experiment_600.html?topic_id=2&collection_id=89



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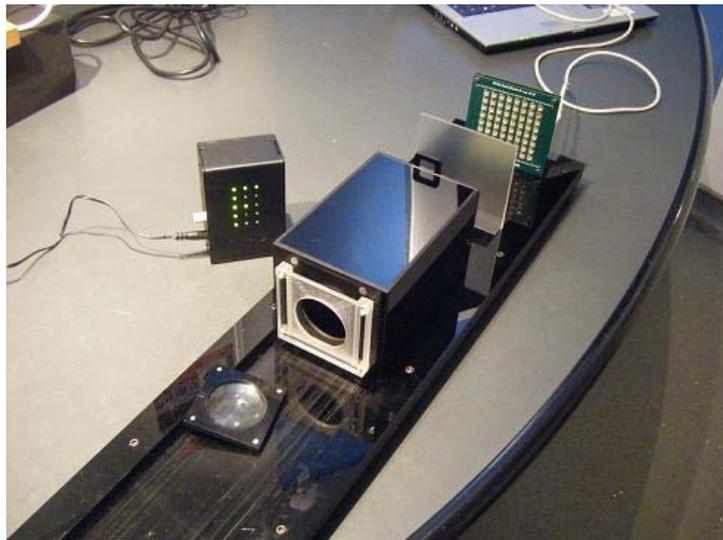
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Activity 2	Investigating digital cameras
Time	12 minutes
Equipment	<ul style="list-style-type: none"> ▪ One camera, one lens, camera tray, opaque plastic screen. ▪ LED light sources, one single colour, one multi-coloured. ▪ Photo diode detector array. ▪ Red, Green and Blue gels. ▪ Resolution software. ▪ Laptop.
Keywords	Photo diode, current, voltage, semi-conductor, Charge Coupled Device (CCD), analogue, digital, bit, resolution, pixel, megapixels.

Having made a basic pin-hole camera, students can now learn about optoelectronic detectors used in digital cameras and convert one of their pin-hole cameras to produce a digital image.

Switch on the single colour LED light and chose any of the letters it can produce. Give the students the tray, camera, plastic screen and lens and ask them to set it up so that the letter is projected onto the plastic screen. **Do not set it up for them;** get them to work as a team to do this.



Real digital cameras use an array of sensors so introduce the photo diode array that they will use to capture the image. Explain that the diode converts light energy into electrical energy similar to a solar cell. Digital uses binary digits of 0 or 1 or “off” or “on”. These digits are also referred to as “bits”. For example, the number 10011010 is 8 bits long. For 8 bit information there are 256 different combinations thus 256 different alternatives for storing information, represented on screen as a number from 0 to 255. For a comparison you can mention music storage – that’s an analogue signal, but it’s stored digitally (as 1s and 0s) on CDs and mp3 players.

Ask the students to replace the screen with the detector to shoot their image using the computer software. Make sure the lights in the room are off otherwise the detector is flooded with light. By experimenting with different orientations, they should produce a clear image of the LED source on the screen. The larger the number from 0 to 255, the higher the intensity of light falling on that diode, the lighter the square/pixel on the screen, giving a grayscale image.



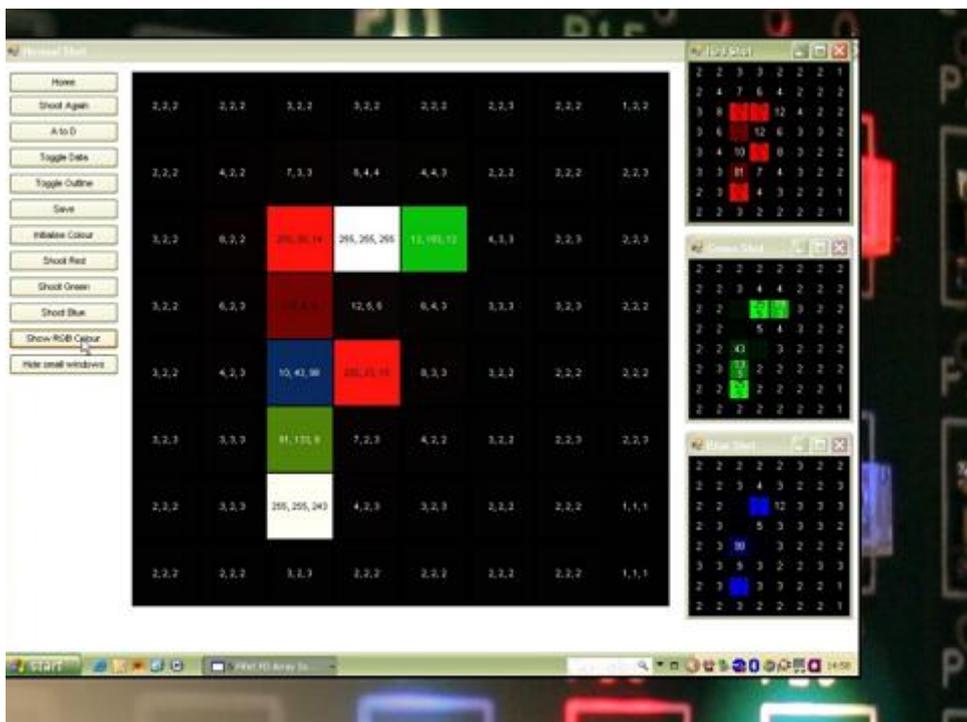
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How can we produce a colour image?

To capture colour images, the photodiode array has to have a filter placed over it which only allows penetration of a particular color of light. By using a red, green and blue filter, we can measure the intensity of each of the three primary colours of light and then combine them to form an 8-bit colour image.

On the computer program, click the “initialise colour” button, give the students the red, green and blue filter gels and take a “red shot”, “green shot” and “blue shot” by placing the filter in front of the array and hitting the appropriate button on the computer. Once you have taken each shot, click the “Show RGB image” button and you will see the result. In each square the relative intensity of each colour is shown, again from 0-255. This can be interesting to compare the amount of each primary colour in various LEDs, for example you may have a few white LEDs, but the values they produce are different, showing that they are emitting different amounts of each primary colour. Allow the students to all have a go setting up and shooting the images.



The image sensor employed by most digital cameras is a charge coupled device (CCD). Some cameras use complementary metal oxide semiconductor (CMOS) technology instead. Both CCD and CMOS image sensors convert light into free moving electrons or current. Similar to how a solar cell works. To obtain a colour image there are a variety of methods. Beam splitters can be used to split the light falling onto the sensor into a red, green and blue channel or filters can be used, such as a Bayer array, which has alternating rows or red-green and blue-green filters and then measurements are processed by “demosaicing” to produce a full colour image.

Ask the students how many pixels our photodiode array has? Our array has 64 photodiodes so is a “64 pixel camera”, is this a good or a bad camera? Obviously it is a low quality because it



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produces a crude image as seen on the screen; you could not take it on holiday with you!

The amount of detail that the camera can capture is called the resolution, and it is measured in pixels. The more pixels a camera has the more detail it can capture and the larger pictures can be without becoming blurry or "grainy." In this experiment, each photo diode represents one pixel of information. Ask the students if they have a digital camera. Some may have them in their pockets or on their mobile phones, if so ask them to inspect them and tell you how many pixels are in them or just ask how many pixels are in their cameras. They usually say "3.0, 5.2" etc, without mentioning units. So again ask them, 5.2 what? Introduce megapixels, ask what the prefix mega means and get them to realise how many pixels are in their cameras. You can show them the example CCDs that we have taken out of mobile phones, to show the real world size of them. These were manufactured in Edinburgh by ST Microelectronics, the largest example is from an iPhone, with a resolution of 2.0 megapixels (1600 by 1200 pixels).

Currently (Autumn 2011) you can buy a digital camera with roughly 16 megapixels being the best available. *The resolution of 35mm film cameras is estimated to be equivalent to 20 Megapixels, so why have we gone digital?* Ease of use, instantaneous image, upload them to websites, etc.

The students can explore resolution further using the webcam and computer software. Two images are shown on the screen, on the left the original image being detected by the webcam and on the right the altered image. By changing the "pixel size" dial, students can increase and decrease the size to see how it affects the resolution of the altered image. They will often mention "pixelation" which they may have seen on news programmes and the like.

Most digital cameras have infra red filters, but the webcam does not. If you point the TV remote controller at the webcam, it shows that while we can't see the infra red signal it is emitting with our eyes, the webcam can and is translating it into a visible image that we can see on the screen.



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Activity 3	Investigating the thermal imaging camera
Time	5 minutes
Equipment	<ul style="list-style-type: none">▪ Irisys 1011 thermal camera▪ Laptop▪ Digital thermometer
Keywords	Infra red, spectrum, heat radiation.

Show the students the thermal camera without telling them what it is and ask them what they think. Allow one of them to hold it, ensuring they put their hand through the strap so it is not dropped. Get the rest of the students to stand at the other side of the room. Switch it on using the silver button and wait a few moments for it to start registering on the screen. They should soon realise it is a thermal camera detecting infra red radiation, which is emitted when a body is warm. The colours stay the same, from black representing lower temperatures through to white representing higher temperatures, but the scale auto ranges itself. *Ask them what would this camera be used for?*

The students can use a plastic bag to hide their arm which the camera can still detect heat through. There is a large piece of plastic to hold in front of them which we can see through but the camera can not as it will not allow the IR through. It is to replicate glass, which allows the wavelengths of visible light to pass but not the slightly longer IR wavelengths. If you or anyone is wearing glasses point the camera at them or use the glass lenses and hold them in your hand to show this effect, it is very dramatic as you can see large black spots where the IR is stopped.

You can use the camera to measure exact temperatures. In the centre of the screen you will see a green square; this is where the exact temperature given in the top right hand corner is measured from. The light bulbs on the roof are good for this, particularly to show the temperature difference between a halogen and LED bulb. They can also make thermal hand prints on the table or wall, ask them to press their hand on the table and leave it there while one of their friends uses the camera to get the image, remove the hand but keep the camera still and the hand print should appear after a few seconds while the camera auto ranges.

Thermal camera lenses are not made out of glass but more exotic materials like germanium, silicone, sapphire, etc. The Irisys 1011 is an entry level camera with a 16 x 16 pixel detector.





Modern Application of optoelectronics to tell students.

The eye can be thought of as an optoelectronics device with the retina acting in a similar way to the photo-diode array. In fact the retina consists of photoreceptor cells which capture and process light, helping people to see. Some blind people have retinitis pigmentosa (RP) which is a group of inherited eye diseases which causes the photoreceptor cells to degenerate thus causing progressive vision loss. Researchers at the USC Doheny Eye Institute in the US have created Argus II, a second generation of electronic retinal implants designed for the treatment of blindness due to RP, with the Argus device essentially designed to replace the photoreceptors. Their first generation of implants contained 16 electrodes laid out on an array; the Argus II is designed with 60 electrodes, which is intended to allow for higher-resolution images. The new device is also approximately one quarter the size of the original, reducing surgery and recovery times. The array is attached to the retina and used in conjunction with an external camera and video processing system to provide a rudimentary form of sight to implanted subjects.

REVISION AND WEB LINKS

If you would like some revision on cameras and optics prior to this experiment then in addition to most standard physics text books, we recommend the following sites:

- School level optics (recommended) - <http://www.practicalphysics.org/>
- Photography with a pinhole camera - <http://accept.asu.edu/PiN/rdg/camera/camera.shtml>
- General physics search engine - www.physics.org
- World's first photograph story relating to photograph from 1805 - <http://www.timesonline.co.uk/tol/news/uk/science/article3882776.ece>
- Optoelectronic retinal implants - www.doheny.org/PDF/doheny_view.pdf
- CCDs and digital conversion - <http://www.cambridgeincolour.com/tutorials/camera-sensors.htm>
- Pinhole cameras - http://en.wikipedia.org/wiki/Pinhole_camera
- How digital cameras work - <http://electronics.howstuffworks.com/cameras-photography/digital/digital-camera.htm>

www.labinalorry.org.uk