**Light Demos from grade 10 to grade 12**

1. **Pinhole Camera Hat: Grade 10**
* **Materials**: A cardboard box – the bigger the better, dark duct tape, dark T-shirt.

You want to make the box as dark as possible, make sure you seal up all the holes along the edges with the wide, dark tape. You also want the light outside the box to be as bright as possible (outdoors is best) or with strong contrast (looking at a window in a darkened room. A dark T-shirt is the easiest way to make sure that light doesn’t sneak in through the neck hole. The bigger the box, the less stuffy it will feel and the larger the image will be. The hole should be about the size of a pencil.

* **Predict/Observe**: What will you see in the box? What type of image is this? What will happen if you make the hole smaller by covering it partially with your finger?

You will notice an image in front of you. It shows you what is behind you – but upside down. The sun will be the clearest image and safe to look at. Next easiest to see are trees and roofs silhouetted against the sky. It gets better as your eyes adjust to the dark. It is good to have many examples, so that there is at least one box for three students. The image is real, inverted and smaller. If you make the hole smaller the image gets fainter (less light) but sharper. (less overlapping of images from different points in the hole.)

* **Analyse**: Draw a diagram of how the image is formed.
* Why start with this instead of mirrors or lenses?

The image formation is much simpler – the only thing simpler is casting shadows, which might be a good thing to start with. The light rays are all real. At any point along the path, you can put your hand in the way and block the light. With a mirror you must extend the reflected rays behind the mirror and with a lens there is the difficulty of knowing how much each ray will bend.

1. **Refraction Walk: Grade 10/11/12**
* **Materials:** Lots of students and a large space.

Have the students link arms in three rows of at least four students. Have the rows about a metre apart and have them all step when you say step, making their steps about ½ m. After each step check to see that the lines are still straight and a metre apart. Practice until you can call ‘step’ at regular 1-second intervals. When they hit a different surface, have them slow down so that each step only takes them one foot.

* **Predict/Observe:** What will happen to the speed, wavelength and frequency when the rows of students enter the slower medium straight on? What will happen when they enter it at an angle?

They will notice that in the slower medium, the wavelength is decreased but nothing changes with the frequency. When the exercise is repeated at an angle to the surface, they will notice that they bend toward the normal when going into the slow medium and away when going out of the slow medium.

* **Analyse:** How could you model combined reflection and refraction? How could you model total internal reflection and thin film interference?

These will be harder to model and work best if you give this to groups of students to try and work out themselves. They may never get a good working model, but the process of trying to take their understanding and put it in another medium is where the learning takes place.

* Where do you see this as being most useful? Grades 10, 11 or 12?
1. **Varying Single Slit Diffraction: Grade 10/11/12**
* **Materials**: Laser pointers, pencils and elastics.

The elastics hold the pencils together and if you put one layer between the pencils it will hold them slightly apart. You must use round – not hexagonal – pencils for this.

* **Predict/Observe**: Look at a laser spot on a wall. What will you see when you look at it through the slit formed by the pencils held vertically? What will you see when you pass a laser beam through the slit?

Don’t give the pencils to the students until they have thought, discussed and written an answer. Confronting a prediction with the observation is only powerful if they have really committed to it. Most students will say that the spot will get narrow as light is blocked out because they have noticed how shadows form. Usually one or two will predict that it gets wider because they have noticed this effect when squeezing their eyelids close together when looking at an LED in a dark room or a street lamp at night. If you look very carefully you will also see the single-slit interference pattern. If you don’t want to deal with this, then do not shine the laser through the pencils, because it will be hard to miss!

* **Analyse**: How do you demonstrate diffraction of waves? How do you explain diffraction? How do you explain single slit interference? How do you explain diffraction of photons?
1. **Polarized Light: Grade 10/12**
* **Materials**: Many pairs of cardboard linearly polarized 2-D glasses. These are $0.50 each from <http://www.rainbowsymphonystore.com/pol3dglas.html>
* **Predict/Observe:** What do you see with one pair?

Look at clouds, glare, LCD screens.

Our eyes are not sensitive to polarized light. Wearing these glasses and closing one eye and then the other – or closing one eye and then tilting your head will shoe you many examples. This is a good opportunity to do an observation scavenger hunt. Reflection polarizes light parallel to the surface. One eye will see the glare and the other eye won’t. That is why polarized sunglasses are so useful. The sky is polarized by light scattering off molecules in the sky. The sky will look darker and this makes so the clouds stand out. (The clouds have so many particles that the repeated scatterings result in unpolarized light.) Photographers use polarizing lenses for effects like this. LCD screens on calculators, computers and some phones use polarized light. This is explained extremely well on the Physics 2000 site where they explain about polarization in general and laptop screens in particular. <http://www.colorado.edu/physics/2000/laptops/index.html>

What do you see with two pairs? What happens when you rotate them?

The second pair of filters can both look a little darker or one can be completely black and the other unchanged. The filter changes from black to unchanged every 90o. The lenses seem to be opposite in some sense – like vertical and horizontal.

What happens if you put a third in between?

If you have the lenses set up so no light gets through, then adding a third lense can let in more light. This seems like magic until you consider vectors and components.

* **Analyse**: How can you explain polarization with a Slinky?

You can show standing waves that are vertically polarized, diagonally polarized and circularly polarized really easily. Polarization is evidence

Why is interference of light emphasized much more than polarized light?
Polarizing filters used to be more expensive and the only common application was sunglasses. Now the filters are easily available and flat screens and 3-D movies are everywhere. The effects of polarization are even better than interference. Polarization is not only evidence of the wave nature of light – it shows that it must be a transverse wave. Our curriculum is behind the times.

1. **Measuring Planck’s Constant: Grade 12**
* **Materials**: voltmeter, leads, 1.5 V batteries, LED`s, diffraction gratings, resistor, variable resistor. LED`s can be purchased cheaply from <http://alan-parekh.vstore.ca/uv-led-5mm-3000mcd-p-16.html> and it is really worth while adding some uv and ir LED’s.
* **Predict/Observe**: Which LED`s will light with just one battery?

This is a simple qualitative start to the quantitative lab. The students will notice that they LED’s only work one way and that the red lights up but not the blue. This suggests that blue light needs more energy.

Measure the voltage drop across the LED and graph against frequency.

You will get a straight line, but it will not go through zero.

* **Analyse**: What will the slope be?

This is an example of conservation of energy. The energy provided to the electrons is eV and this energy is transferred to the photon – hf. Therefore the slope should be h/e = 6.626/1.602 x 10-34 + 19 = 4.136 x 10-15 eV s. This is also an example of a quantum effect. One electron produces one particle of light. Light is not a wave.

How is this similar to the photoelectric effect?

It is the reverse of the photoelectric effect where one photon gives energy to one electron. That experiment also yields a slope of Planck’s constant and an intercept caused by energy exchanges with the solid.

How do you explore the photoelectric effect with your class?

Most schools do not have the equipment or if they do it is some black box that generates a number. This experiment is cheaper and more relevant to students. The photoelectric effect is best explored with computer simulations like the one from PhET. <http://phet.colorado.edu/en/simulation/photoelectric>

Why is the photoelectric effect the key quantum experiment in the curriculum? What should be the central experiment?

The photoelectric effect is central because it was very important to the historical development of quantum physics and it is where Einstein got his Nobel Prize. However, it is a poor place to start pedagogically. The two-slit experiment shows the wave-particle duality much more concretely. Our curriculum needs changing!

1. **Quantum Eraser**
* **Materials**: double slits, polarizing filters, retort stands, laser pointers

For this to work clearly you need a very dark, long room. Each filter must completely cover one slit and be perpendicular in polarization to the other. The laser pointer is partially polarized, so it must be turned to that half the light goes through one slit and half goes through the other. If you don’t have a double slit, you can do this with a straight pin, but it won’t be as clear.

* **Predict/Observe:** What will you see if the laser beam is passed through a narrow double slit?

If the slits are narrow enough and close enough together you will get an interference pattern. You can also get this pattern by pointing the beam at a pin. Half of the light goes one way and half goes the other and they interfere.

* What if orthogonal polarizing filters are added over each slit?

The light from the two slits can no longer interfere. Vertically polarized light cannot cancel horizontally polarized light. You will only see a diffraction pattern. The two patterns are offset by only a fraction of a millimetre, so it looks like one pattern.

What if a third filter is added after the slits?

If the is vertical or horizontal it will just let the light from one slit through and you will still see a diffraction pattern – just fainter. However, if it is oriented in between the two, a component of each will get through and these components can interfere.

* **Analyse**: How do you explain the results with a classical wave model? How would you explain the results if they were done by many photons, but one at a time?

The classical explanation has been given above, but it won’t work for photons. The quantum explanation is that if you know which slit the object went through, then it behaves like a classical particle and there is no interference. The polarizing filters over the slit did just that. They allow us to identify which slit the photons came through. However, the third one can erase this knowledge. It is called a quantum eraser. For more information go to <http://www.oapt.ca/newsletter/2006_11_nl.pdf> or my website <http://roberta.tevlin.ca/>