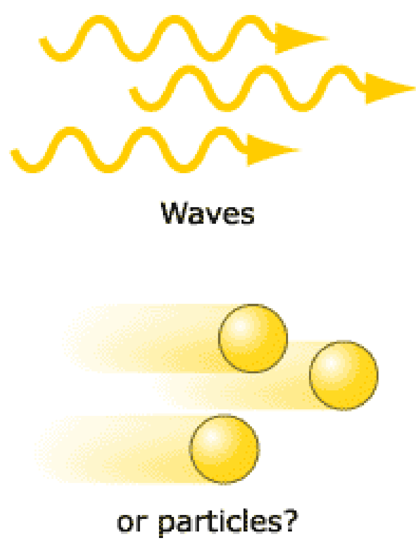
Lab 3 Part 2

Is light

a *wave* or

a *particle?*

(Part 2)



You may have heard that light is both a particle and a wave, and that this is paradoxical. This week, we'll continue our investigation of why physicists have come to this wild conclusion, and continue to practice working with the scientific cycle that we have presented.

Learning Goals:

- EM spectrum familiar, cause of discrete vs continuous sources
- Make careful predictions based on hypotheses and a given experimental setup
- Make a judgment about hypotheses based on the result of an experiment.

The mystery - light causing electrons to flee a metal

Gather around and watch the TA demonstrate this strange phenomenon - first they charge the electroscope (device for detecting electric charge), loading up extra electrons onto it, causing the thin metal foil to rise as it is repelled by the vertical post. Then they shine various light sources on the metal, to see if any will liberate the electrons and thereby discharge the 'scope. They try a lightbulb, red and green lasers, and a mercury lamp (which is tested both with its acrylic shield in place, and without it). At least one of these light sources causes the electrons to gain enough energy to jump of the plate.

Curious about the process of charging the electroscope?

Here are the steps, with explanation:

1. The TA rubs the acrylic rod with a silk cloth. This causes electrons to move from the rod to the cloth, leaving the rod with more protons than electrons, thus charging it positively.

2. The TA brings the positively charged rod close to the electroscope's plate. The foil rises as electrons move to the plate to get closer to the positively charged rod)

3. With their other hand, they touch the plate. The foil falls as it pulls electrons from the person to the plate (so the plate is negatively charged, while the foil is neutral).

4. They stop touching the plate, which ends the charge transfer, leaving the electroscope with excess electrons.

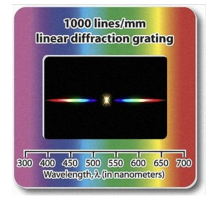
5. They move the rod away from the plate. The foil rises as the excess electrons spread evenly through the electroscope.

Investigating the mystery - what are these lights?

Goal: Observe the spectra of the light sources that were used by the TA and determine what is different about the source(s) that succeeded in discharging the electroscope.

Light can be made of many different wavelengths at the same time. It combines to form a color that we perceive. To see what colors make up light, we can split them up with a triangular prism, or with a diffraction grating.

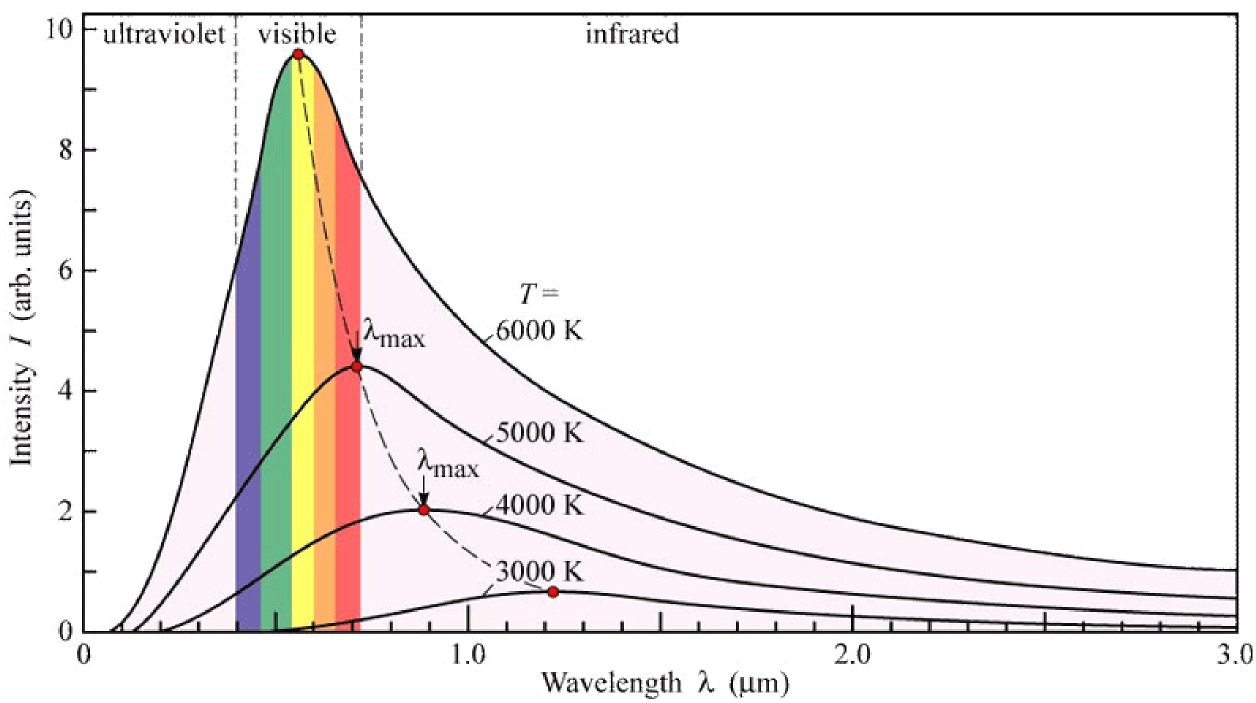
▶️ **Use the diffraction grating** to view the **lightbulb** while the lightbulb is at full voltage (120 V). Hold up the grating in front of your eye, with the text on the frame upright. Start by looking at the lightbulb through it, then turn your feet to the left or right about 30 degrees, letting your whole body-arm-grating system rotate with your feet. You should see a rainbow. **This is all the colors that make up the light coming from the lightbulb, split into different wavelengths.**



▶️ **Looking directly** at the lightbulb without the diffraction grating, **what color is it**❓ Looking **through the diffraction grating** as described above, **what colors** make up the lightbulb's spectrum❓

Why the lightbulb rainbow? Thermal radiation!

Everything with a temperature emits electromagnetic radiation with a characteristic distribution of wavelengths, called *thermal radiation.*[1] If the matter is hot enough, then it even glows in the visible spectrum. Common examples of this include glowing electric heating elements, incandescent lightbulbs, and the Sun.



Everything with the same temperature gives off that same distribution of wavelengths. This is how infrared thermometers are used to take someone's temperature without touching them,

[1] This is also called blackbody radiation, because it is the total radiation emitted by an object ("body") that is not reflecting any light from outside itself (meaning that its color is black for objects that are too cold to detectably emit in the visible range of the spectrum).

and how astronomers tell the temperature of distant stars.

Yes, this means that since you have a temperature, you also glow! You can check out what shape of radiation you emit using this simulation.

Examining in more detail using the digital spectrometer

A digital spectrometer also uses a diffraction grating, but instead of collecting the dispersed light on a screen to be viewed by people, it collects the light with a charge-coupled device (CCD), an array of light-sensitive pixels much like a digital camera. It then translates the position on the CCD to individual wavelengths and displays a plot of intensity vs. wavelength on a computer. Another difference is that we use an optical fiber to collect the light.

⚠️ **Safety Warning!** Do not observe lasers directly — shine them onto a white surface, and then observe the spot that reflects from it.

▶️ For each of the light sources at your station — lightbulb, red laser, and green laser — examine first with the diffraction grating, then with the digital spectrometer. **Save the data for each of your observations.**

Tips for using the digital spectrometer

Warning! Fragile Equipment! If the fiber optic cable is bent into a circle of less than 9 cm (6 inch) diameter, then the fiber inside may break. Also, the blue end cap should be replaced on the end of the fiber optic cable when you are done using it, to protect from dust and debris entering.

Background subtraction. When you are observing the spectrum of something, there may be stray light entering that is not coming from the thing you are studying. To remove this *background* from the plot, select the gray lightbulb icon in the toolbar. This records the current plot as the background. To display the plot while subtracting the background, select the icon with the minus-lightbulb. To go back to viewing the full spectrum including the background, select the blue S icon.

Oversaturation. If, when you zoom out all the way, the plot includes a **flat line** near the top of the plot, this means that the pixels of the image sensor are recording their maximum value, and they cannot tell you the actual intensity. Reduce the intensity by either reducing the integration time (upper-left corner) or moving the fiber optic cable off-center, so that it receives less light. Note that if you change either of these, then the background frame is no longer correct and must be remeasured.

Overlays. To compare spectra, it can be helpful to freeze one measurement on the plot, and then observe a different one. You can do this by converting the current measurement into an *overlay* by pressing the green curvy line icon on the toolbar.

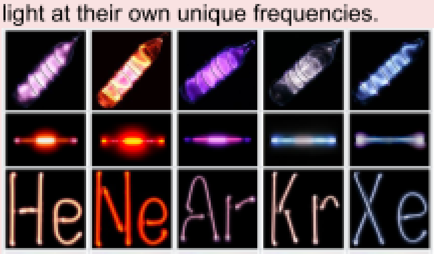
Saving data. To **save an image** of your graph, click on the fourth icon from the left in the Spectrum IO controls. This will copy an image of the graph to the clipboard. Then in your word processor, paste the image by pressing Ctrl-V. **To save the numerical data**, click on the third from the left icon in Spectrum IO controls (to the right of print icon). This copies it to the clipboard. In Excel file make sure you are in a new sheet and press Ctrl-V.

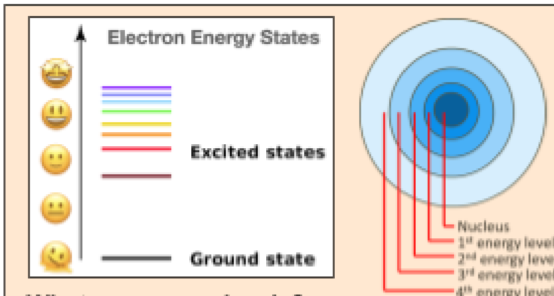
▶️ **Ask the TA** to show you the spectrum of the **mercury lamp** with and without the acrylic shield. **Take a photo** of these spectra with your phone. The TA will also share the data with you electronically.

❓ **What do the different spectra look like, and how do they differ from each other?**

Did you know?

Running electricity through different elements is how "neon" signs glow. Originally, these signs contained only the element neon, which is how they got their name, though the composition has since changed. While neon glows red, other elements can be used to create different colors because each element releases light at their own unique frequencies.





What are energy levels?

Electrons orbit atoms in *shells*. The lowest-energy shell is called the *ground state*. Electrons can get bumped up into higher-energy states, or *excited states*, e.g. when we run electricity through a gas of that element in lamps. Every element has its own unique energy levels that are determined by properties of the element's nucleus. We can see this through the color signature of elements like the three elements below.

❓Looking at your data, **what about the light source that discharged the electroscope is different from the other light sources?** Is there a difference in certain wavelengths or certain intensities/brightnesses of light overall?

Back to the hypotheses — what is light?

❓Given your prior investigation about how waves and particles **transfer energy**, for **each hypothesis** (“Light is a particle” and “Light is a wave”), what does the hypothesis predict in this situation?

Tips:

- Light with a shorter wavelength (higher frequency) carries more energy.
- Metals have electrons in them that can absorb energy from light. Once an electron absorbs a certain amount of energy, it is emitted from the metal and gains kinetic energy.

So what is the conclusion?

You now have a set of predictions and outcomes from the first situation (laser on slits) and the second situation (light on charged metal).

❓Given your predictions and outcomes for these situations, what can you conclude about the answer to the question: “Is light a particle or a wave?”

❓Write a 100–200 word paragraph reporting back from each of the four roles: facilitator, scribe, technician, skeptic. Where did you see each function happening during this lab, and where did you see gaps? What successes and challenges in group functioning did you have? What do you want to do differently next time?

Report checklist and grading

The lab grade consists of 3 points for each of seven scientific ability rubric rows (the 5 listed above, as well as F1 and F2, applied to the entire report), 3 points for attendance and participation, and 6 points for providing evidence in the lab report of completing all steps of the lab, including answering every question, for a total of 30 points.