Photoelectric Effect

Introduction

In the 17th century, two major theories about the structure of light submerged. One was from mathematician Isaac Newton, who believed that light traveled in particles. The other theory belonged to Robert Hooke, who believed that light traveled in waves. As technology developed, experiments showed strong evidence supporting Hooke's wave theory, and light was known as a wave for the next several hundred centuries. In fact, it wasn't until the early 20th century when Albert Einstein discovered the photoelectric effect, which proved both Newton and Hooke to be correct. The photoelectric effect was discovered through an experiment Einstein developed where you shine different frequencies of light on certain metals. He found that when you have the right combination of frequency and metal, electrons are emitted off the surface and into space. This showed that light can behave as a wave, a particle, or both, which is more commonly known as wave-particle duality. While he could never exactly run a perfect scenario experiment, scientist Robert A. Millikan had the resources, 2 years later, to run the experiment, proving Einstein correct in the process. Both scientists won Nobel prizes for their efforts. After finalizing the photoelectric effect, Einstein worked with Max Planck to conceive formulas that relate the energy of a photon (E), the work constant (Φ), kinetic energy (1/2mv^2), frequency (v), and Planck's constant (6.626x10^-34 m^2(kg/s)). These equations are the birth of quantum mechanics as we know today.

Hypothesis

We set out to demonstrate the correlation between the work constant and frequency, and show that this phenomenon of electrons discharging due to light, only works with specific metals and specific frequencies.

Materials

- Homemade electroscope
  - Copper wire straightened out
  - Thin Straw cut to 2 inches long
  - Mason Jar
  - Electrical tape
  - Aluminum foil
- Metals
  - Magnesium sheet
  - Aluminum foil
  - Strip of cut out soda can (zinc and aluminum)
- Stand for metals
- Light sources
  - Visible light
  - UVA light (400nm to 315nm)
  - UVB light (315nm to 280nm)
  - UVC light (280nm to 100nm)

Procedure

1. Making the Electroscope
   1. Cut out cardboard in the shape of the lid of a large jar
   2. Cut a hole in the middle of the cardboard lid
   3. Cut a strand of copper wire roughly the height of the jar
   4. Make a fishhook at the end of the copper wire
   5. Cut out two teardrop shaped aluminum foil pieces
   6. Attach the foil to the end of the hook
   7. String the copper wire through a straw cut one inch shorter than the wire
   8. Put the straw containing the wire through the cardboard and tape it down
   9. Create a foil ball roughly 1 inch in diameter and attach it to the top of the exposed wire
2. Use a stand to hold the metal you are testing and place it adjacent to the foil ball
3. Using a balloon and cotton, generate static electricity on the balloon
4. Hold the balloon close to (but not touching) the foil ball
5. Using another hand, poke the foil ball, and move the balloon away from the device
6. If done correctly, the foil teardrops should stay repelled from each other without any interference

Shine visible light at the metal sheet in a way that it reflects onto the foil ball

ct the two foil strips to see if they closed on one another

d the experiment is complete

repeat step 7 with increasingly higher frequencies of light

Calculations

Φ for Aluminum is 4.2E_v

$f = \dfrac{\Phi \text{ (in } E_v)}{h \text{ (Planck's constant)}}$

$\lambda = \dfrac{c}{f}$ ← speed of light

$\Phi = hf$

$\lambda = \dfrac{2.998\times10^{17}\,\text{nm/s}}{f}$

$f = \dfrac{4.2(1.6\times10^{-19})}{6.626\times10^{-34}\,\text{mk/s}} = 1.014\times10^{15}\,\text{hz}$

$\lambda = \dfrac{2.998\times10^{17}\,\text{nm/s}}{1.014\times10^{15}\,\text{hz}} \approx \boxed{294.817\,\text{nm}}$

$\boxed{\text{UV-B radiation}}$

$\frac{1}{2}m_e v^2 = hf - \Phi = h(f_1 - f_2)$

$\frac{1}{2}m_e v^2 = h\left(\frac{c}{\lambda_1} - \frac{c}{\lambda_2}\right)$

$\frac{1}{2}m_e v^2 = (6.626\times10^{-34}\,\text{mks}) \times \left[\left(\dfrac{2.998\times10^{17}\,\text{nm/s}}{185\,\text{nm}}\right) - \left(\dfrac{2.998\times10^{17}\,\text{nm/s}}{294.817\,\text{nm}}\right)\right]$

$\frac{1}{2}m_e v^2 = 3.999\times10^{-19}$

$m_e = 9.109\times10^{-31}\,\text{kg}$

$v = \boxed{937{,}117.05\,\text{m/s}}$

Φ for Zinc is 4.33E_v

$\lambda = \dfrac{2.998\times10^{17}\,\text{nm/s}}{f}$

$f = \dfrac{\Phi}{h}$

$f = \dfrac{4.33(1.6\times10^{-19})}{6.626\times10^{-34}\,\text{mk/s}} = 1.045\times10^{15}\,\text{hz}$

$\lambda = \dfrac{2.998\times10^{17}\,\text{nm/s}}{1.045\times10^{15}\,\text{hz}} \approx \boxed{286.731\,\text{nm}}$

UV-B radiation, very close to UV-C

$\frac{1}{2}m_e v^2 = h(f_1 - f_2)$

$\frac{1}{2}m_e v^2 = h\left(\frac{c}{\lambda_1} - \frac{c}{\lambda_2}\right)$

$\frac{1}{2}m_e v^2 = (6.626\times10^{-34}\,\text{mk/s}) \times \left[\left(\dfrac{2.998\times10^{17}\,\text{nm/s}}{185\,\text{nm}}\right) - \left(\dfrac{2.998\times10^{17}\,\text{nm/s}}{286.731\,\text{nm}}\right)\right]$

$\frac{1}{2}m_e v^2 = 3.809\times10^{-19}$

$m_e = 9.109\times10^{-31}\,\text{kg}$

$v = \boxed{914{,}586.2\,\text{m/s}}$

Φ for magnesium is 3.68E_v

$\lambda = \dfrac{2.998\times10^{17}\,\text{nm/s}}{f}$

$f = \dfrac{3.68E_v(1.6\times10^{-19})}{6.626\times10^{-34}\,\text{mk/s}} = 8.886\times10^{14}\,\text{hz}$

$\lambda = \dfrac{2.998\times10^{17}\,\text{nm/s}}{8.886\times10^{4}\,\text{hz}} = \boxed{337.376\,\text{nm}}$

UV-A radiation, but close to UV-B

$\frac{1}{2}m_e v^2 = hf - \Phi = h(f_1 - f_2)$

$\frac{1}{2}m_e v^2 = h\left(\frac{c}{\lambda_1} - \frac{c}{\lambda_2}\right)$

$\frac{1}{2}m_e v^2 = (6.626\times10^{-34}\,\text{mk/s}) \times \left[\left(\dfrac{2.998\times10^{17}\,\text{nm/s}}{185\,\text{nm}}\right) - \left(\dfrac{2.998\times10^{17}\,\text{nm/s}}{337.376\,\text{nm}}\right)\right]$

$\frac{1}{2}m_e v^2 = 4.849\times10^{-19}$

$m_e = 9.109\times10^{-31}\,\text{kg}$

$v = \boxed{1{,}031{,}898\,\text{m/s}}$

Data

Test 1

The first test was our control to make sure that the photoelectric effect was actually taking place and that the aluminum teardrops weren't just closing together due to gravity. After charging up the teardrops with static electricity, we let it sit for 30 seconds. We then used all the light sources we had available to shine directly onto the static electricity collector directly. Nothing happened with the visible, UVA, and UVB lights. However, with the UVC light we noticed the teardrops started coming closer together very slowly.

Test 2

The next test we ran used the strip of soda can we cut out, which contains aluminum and zinc. Unlike the control, we aimed the light sources directly at the metal, which was propped up adjacent to the electroscope. Since we knew the electroscope would stay charged up unless acted on by another force, we skipped the precaution where we let it set for 30 seconds. We then used all the light like we did in the control. The first 3 light sources had no effect, similar to the control test. The final light source, UVC, worked and made the electroscope discharge, also similar to the control test. The obvious difference we noticed between the control and this test was that the teardrops closed much faster in this test compared to the control.

Test 3

The third test was completed using aluminum foil as the metal sheet. Similar to the previous test, we used the four sources of light after charging up the electroscope with static electricity. The first three lights had no effect, but the final source, UV-C made a very obvious impact. As soon as the UV-C light turned on and was put above the electroscope, the teardrops came together very quickly. It's worth noting that they closed together much quicker than both of the previous experiments.

Test 4

The final test was probably the most important one, as we were using a metal with a work constant far different from the other 2 (The previous two metals had a predicted wavelength value of around 285 nm, whereas magnesium had 337 nm). Because of this we only had 2 light sources that showed no effect, visible light and UV-A. The UV-B light, which had shown zero effect for all the previous tests, worked on this test, and the teardrops closed together as it shined on the magnesium.

Analysis

Before we conducted our experiment we were unsure about some of the results we extracted from our calculations. For example, when we calculated the wavelength value for Aluminum (294.817 nm), it technically fell within the parameters of what is considered UV-B (280-315 nm). Similarly, the calculations we did for magnesium placed it within UV-A territory, with 337 nm. It wasn't until we ran every test multiple times, that we fully understood the specifics of what was going on.

In our control experiment, (where we did not reflect light onto the electroscope but rather shone the light directly onto it), we were surprised by the results. We expected to see the aluminum strips charged throughout the entirety of the control test. This did not happen, however, as when we shone UV-C light onto the electroscope, the aluminum strips slowly lost their charge. It wasn't until test 3 that we understood that, because the electroscopes collector and the metal we tested were the same material, they would have similar results.

Test two was the first test in which we used one of the metals to demonstrate the photoelectric effect. This test was similar to the control in that the first three light sources had no effect, and the UV-C source closed the aluminum strips. Contrary to the control, the strips lost their charge at a much faster rate. Even though the soda can contained aluminum, which is the same material that affected the control, the surface area was much larger, which we figured was the main reason why the teardrops lost charge quicker.

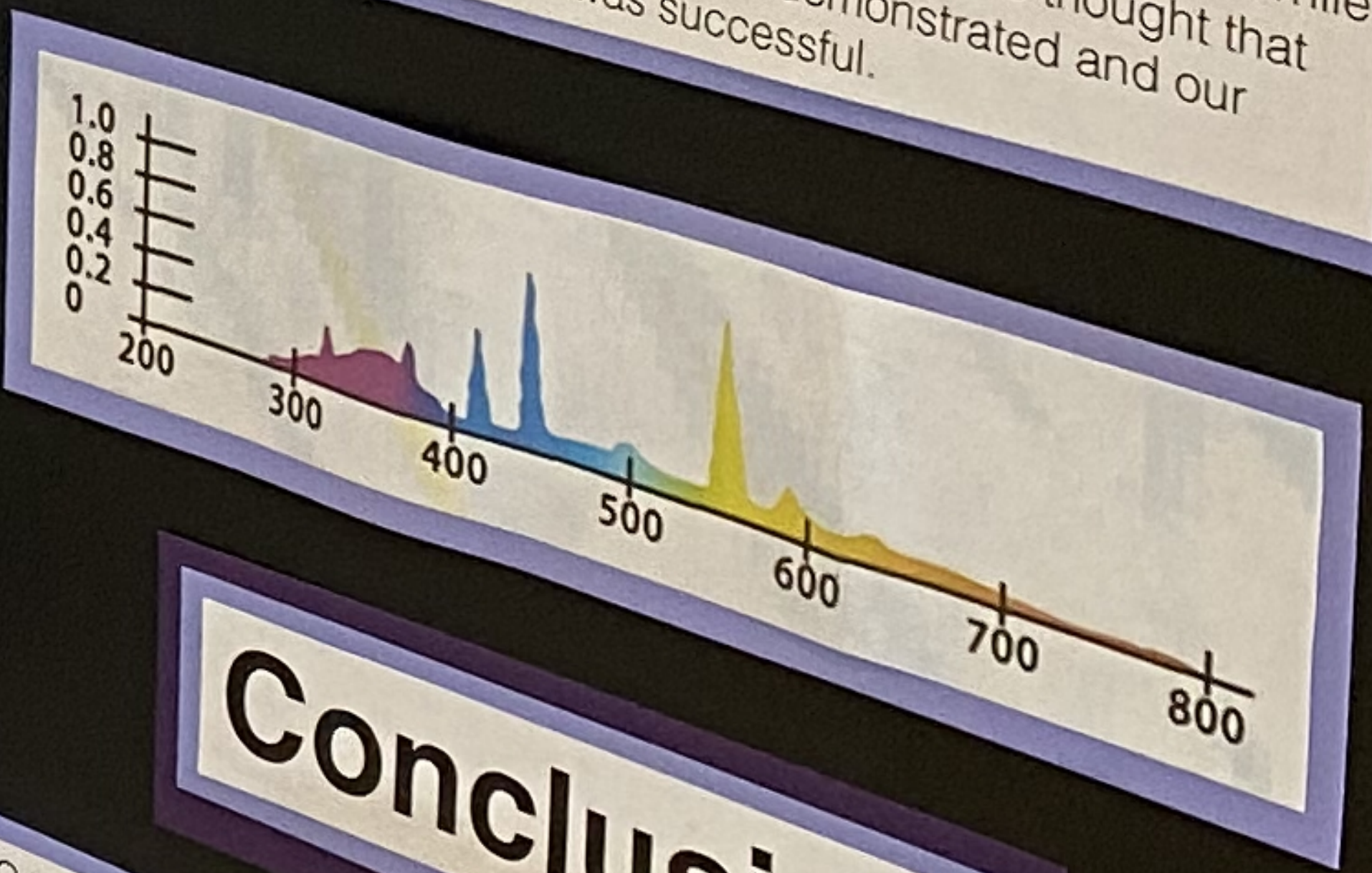
The third test used a plate of aluminum foil. Similar to the second test, this aluminum sheet had a much larger surface than the control. The teardrops closed at a rate much faster than both previous experiments. We believed that, like test 2, this test closed faster than the control because of the larger surface area, and the ability to absorb more light than the device attached to the electroscope. As for the comparison to test 2, we believe that the presence of zinc in the soda can gave the light a harder time to discharge electrons. We calculated earlier in our experiment that the required frequency for zinc is slightly higher than aluminum's, meaning that in theory, a combination of aluminum and zinc should be harder to discharge then just aluminum.

The final test we ran was with a magnesium sheet, and the results from this test were the most interesting. While all the tests before this had worked with UV-C light, none of them showed any effect when using UV-B light. This test, however, did show results with UV-B, and the teardrops discharged at a similar rate to test 2. The reason this test's success was so vital to our experiment was because we wanted to show that different metals each had a unique minimum frequency needed to discharge electrons. Even though zinc and aluminum's minimum frequencies are technically different, it would require very precise measurements and access to equipment we didn't have.

One important point that we didn't realize until after the testing was over was that the discharged electrons weren't actually triggering the electroscope and discharging it. While electrons were flying off the metal, the main result of this would be to make the metal positively charged. This influx of positive charge would counteract the static electricity put onto the electroscope by our balloon. In chemistry this is known as the inductive effect, where bonds are polarized, causing molecules to either repel or attract each other. This theory was confirmed when we found that a balloon and the type of clothing we were using to charge it (cotton) creates a negative charge, charging the electroscope negatively. Though this is different from what we originally thought happened, our experiment still worked, and the photoelectric effect was still clearly demonstrated.

Possible Source of Error

While our homemade electroscope worked fairly well for our purposes, charging it up proved to be slightly inconsistent. While we could consistently get a good charge that would keep the teardrops repelled, the amount of charge in them varied a lot. Sometimes they would be about 45 degrees apart and other times they would only get to around 25. Creating a consistent way to create the same magnitude of charge every time was too difficult with the tools we had, so rather than time the tests, or measure how much the angle changed, we resorted to comparisons and observational data. In other words, the actual data we found was based on comparison between tests and what we saw. While this isn't as ideal as data with numbers and charts, we thought that despite this setback the effect was still demonstrated and our experiment was successful.



Conclusion

Originally, our equations showed us that UV-B and UV-A would work for
aluminum and magnesium respectively. What we ended up finding was
that the UV lights we had access too weren't exactly pure ultraviole
frequency, but rather a combination of ultraviolet light and visible ligh
Because of this, the effect only became visually clear when we went
about one step ahead in frequency for each light. In other words the
B tests turned into UV-C and the UV-A test turned into UV-B. D
this, we still accept our hypothesis, as we felt that we su
demonstrated the photoelectric effect using our home