

Determination of Planck's Constant Using the Photoelectric Effect

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Subject: Physics

Grade Level: 9-12

Standards: Next Generation Science Standards (www.nextgenscience.org)

HS-PS4-3 Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model (quantum theory), and that for some situations one model is more useful than the other.

HS-PS4-5 Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Schedule: 1.5 hour

CCMR Lending Library Connected Activities:



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<u>Objectives:</u> Students will learn about the photoelectric effect and its applications. They will use the effect to attempt to calculate Planck's constant.	<u>Vocabulary:</u> Photon Electron Photoelectric Planck's Constant Quantum Physics
<u>Students Will:</u> - Students will observe and understand that when a photon hits an electron on a metal surface, the electron can be emitted. - Students will plot data, make a line of best fit, and calculate the slope of the line. - Students will use the photoelectric effect to measure and calculate Planck's constant. - Students will calculate their percent error and try to identify sources of error.	<u>Materials:</u> For Each Group (3-4 students) ___ Flashlight ___ 2 Wire w/alligator clips ___ LED's (Red, Orange, Yellow, Green, and Blue) ___ Breadboard ___ 9V battery w/leads ___ 10k Potentiometer Teacher Will Need to Provide ___ Graph Paper ___ Ruler
Safety	There are no safety concerns

Science Content for the Teacher:

When we think of the evaluation of fundamental physical constants, such as the speed of light or the force of gravity, we probably think of famous, large-scale experiments – but classroom equipment can also be used to calculate these unvarying values.

The Planck constant may seem a rather rarefied concept unlike, say, the speed of light, but it plays an absolutely central role in understanding the behaviour of matter at the subatomic level. It is a cornerstone of the theory of quantum mechanics, which describes the strange behavior of particles at this level. Here energy, as well as matter, is made up of particles. Light and other electromagnetic radiation^{w1}, for example, consists of particles called photons.

Named after German physicist Max Karl Planck (1858–1947), the Planck constant tells



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us how the energy of individual photons relates to the wavelength of their radiation, as this key equation shows:

$$E_p = hc/\lambda$$

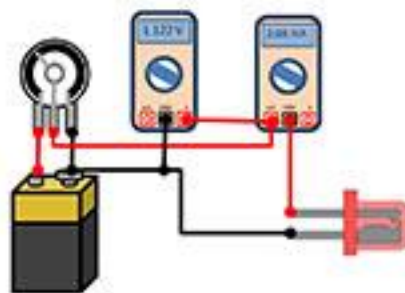
Where E_p is the energy of a single photon (in joules), h is the Planck constant, c is the speed of light in a vacuum, and λ is the radiation's wavelength.

Perhaps surprisingly, even though the value of the Planck constant is extraordinarily small, we have developed a method of determining this value in a classroom experiment. The activity needs no special equipment – just a few coloured light-emitting diodes (LEDs) and standard electrical apparatus. This activity is suitable for a wide range of students, from the age of about 16 up to postgraduate level.

How LEDs work

LEDs are produced by the junction of two 'doped' semiconductor materials, one of which has an excess of electrons (n-type) and the other a lack of electrons – also designated as holes (p-type). When an electrical current is injected through this so-called 'p-n' junction, the recombination of electrons and holes releases energy in the form of photons.

Electric circuit for measuring the voltage-current response of each LED. From left to right: battery, potentiometer or rheostat, voltmeter, ammeter, LED.



The colour of the light emitted from an LED is determined by the energy of the photons, which can be tailored by changing the chemical composition of the semiconductor materials. LEDs are most commonly made from alloys of gallium, arsenic and aluminium, and changing the proportion of these constituents can produce LEDs that emit light in specific colours – such as red and green in the visible region of the electromagnetic spectrum, or beyond into the ultraviolet and infrared regions.

As with any light, it is the wavelength that determines its colour. The human eye is sensitive to light with wavelengths from about 390 to 700 nanometres (0.00039–0.0007 mm). We see the shortest wavelengths as violet and the longest as red, and each in between corresponds to a particular colour in the spectrum. For example, green-emitting LEDs typically produce light with a wavelength of around 567 nanometres.

We use LEDs in this experiment because each colour of LED has a different threshold



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voltage at which electrons start being produced. Measuring this voltage, together with known values for the emission wavelengths, provides a path to finding a value for the Planck constant.

Resources:

YouTube. (2019). *Planck's Constant and The Origin of Quantum Mechanics* | *Space Time PBS Digital Studios*. [online] Available at:

https://www.youtube.com/watch?time_continue=2&v=tQSbms5MDvY

“Photoelectric Effect.” *KidzSearch.com*, wiki.kidzsearch.com/wiki/Photoelectric_effect.

Einstein. “Einstein's Legacy: The Photoelectric Effect.” *Quick and Dirty Tips*, Everyday Einstein, 12 Feb. 2016,

www.quickanddirtytips.com/education/science/einsteins-legacy-the-photoelectric-effect.

Classroom Procedure:

Explore (15 minutes):

Have students perform intro lab on the photoelectric effect and make observations and inferences. Discuss photoelectric effect with class.

Experiment (45 minutes):

Have students perform lab to determine Planck’s constant. Compare numbers and discuss with class possible sources of error.

Explain (15 minutes):

Discuss applications of the Photoelectric Effect and Planck’s constant. Have students read handout (this can also be given before the experiments).



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Assessment:

The following rubric can be used to assess students during each part of the activity. The term “expectations” here refers to the content, process and attitudinal goals for this activity. Evidence for understanding may be in the form of oral as well as written communication, both with the teacher as well as observed communication with other students. Specifics are listed in the table below.

4= exceeds expectations

3= meets expectations consistently

2= meets expectations occasionally

1= not meeting expectations

	Engage	Explore	Explain	Expand
4	Shows leadership in the discussion and a good understanding of the photoelectric effect and how to calculate Planck's Constant.	Works very well with others and shows excellent understanding of correlation between activity and real life.	Provides an in-depth explanation of findings. Makes excellent and thoughtful comparisons to demos/real life. Fills out worksheet clearly.	Synthesizes analysis of flammability based upon particle-sized and surface area.
3	Participates in the discussion and shows an understanding of the photoelectric effect and how to calculate Planck's Constant.	Works cooperatively with others, shows some understanding of correlation between activity and science.	Provides clear explanation of findings. Notes good correlations to demos/everyday life. Fills out worksheet clearly.	Provides a clear understanding that flammability of flour is based upon particle-sized and surface area.
2	Contributes to the discussion, but shows little understanding of the photoelectric effect and how to calculate Planck's Constant.	Works cooperatively, but makes a few mistakes. Tries to understand the relationship between the activity and real life.	Provides a limited explanation of findings. Struggles to make comparisons to demos/everyday life. Fills out some of the worksheet.	Has difficulty seeing that flammability of flour is based upon particle-sized and surface area but observes a size/surface area dependence
1	Does not participate in discussion. Shows no understanding of the photoelectric effect and how to calculate Planck's Constant.	Has trouble working with others, does not try to understand activity's relationship to science.	Is not clear in explanation of findings. Does not fill out the worksheet.	Does not observe flammability particle-sized and surface area.



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