

QUEST
Day 2 Summer 2026

Blackbody, Planck, Photoelectric, Molecules

A historical thread is used to link activities in this learning cycle. Starting with the premise that light is an electromagnetic wave, there is energy in light that cannot be seen, and the only way to understand why hot objects glow is to assume that light comes in fixed quanta where the energy is proportional to the frequency of the light. In describing blackbody, it does not mean that the “body is black” but rather all the radiation comes from the temperature and not from reflection.

Background:

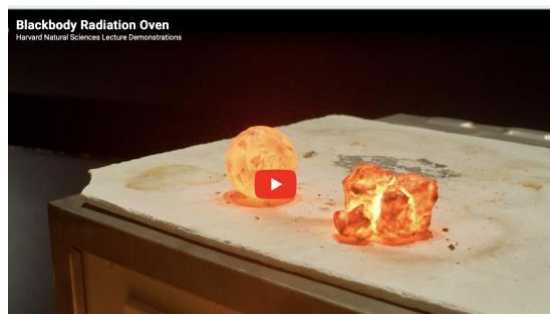
The Herschel experiment established that infrared radiation is a form of light invisible to the human eye, but transmits energy. His experiment was important in the quest to understand the nature of light and the spectrum and paved the way for future discoveries. One very significant result was that since hot objects glow, the glow was light energy being radiated from the object. Later in the 19th century, James Clerk Maxwell showed that light was electromagnetic waves and the frequency (or wavelength) of the wave was an indicator of the color of the light (if it was in the visible part of the spectrum). But why would hot objects produce electromagnetic waves? How did the color (frequency) of the light emitted by an object change with the temperature of the object? This radiation is called blackbody radiation, and a blackbody is something that absorbs all light, but like everything else, it emits light depending on its temperature.

ENGAGE

What would happen if two different objects were heated to the same temperature?

View

https://youtu.be/Psvo_XEc784?feature=shared



All objects glow with the same color when heated to the same temperature. The video demonstrates that iron and brick got to the same color when heated to the same temperature.

EXPLORE 1 Blackbody Radiation

Materials/Supplies: incandescent light on dimmer switch, iPhone Thermal Vision App (iTVC) app, diffraction glasses/slides

Objective:

Students will observe one example of blackbody radiation (i.e. incandescent light on dimmer switch) and correlate colors seen (via app or diffraction glasses) with heat energy. Students should notice how the visible portions of the spectrum change as the bulb dims or brightens and correlate to heat produced by the filament.

Overview of Lesson:

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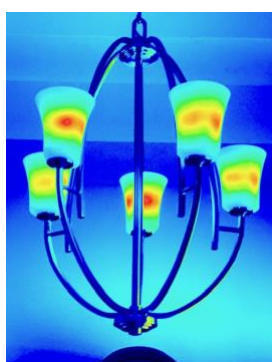
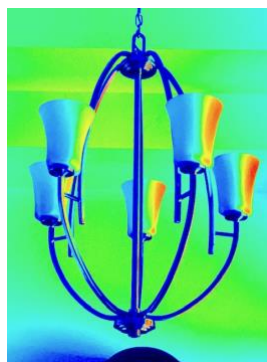
Blackbody: In the classical picture, all energies are equally probable because they can be pieces of arbitrary sizes. This is called equipartition of energy. Students view an incandescent bulb (with dimmer switch) to connect different parts of the spectrum to brightness (which is also heat from the filament). Hotter = more energy. Same glow = same temperature. Energy is being radiated in form of light (glow).

Observing a light on a dimmer switch using diffraction glasses allows students to *connect* different parts of the spectrum to brightness (which is also heat from the filament). Hotter = more energy. Same glow = same temperature. Energy is being radiated in form of light (glow).

A key factor that motivated the development of the quantum hypothesis by Planck was the failure of classical theory to account for glowing hot objects. The glow was clearly light, or electromagnetic radiation, but how to explain it? Objects could be modeled as a collection of electromagnetic resonators driven by thermal motions. Classical theory of equipartition of energy would spread the energy equally over an infinite number of frequencies, leading to the “ultraviolet catastrophe” where the amount of energy radiated at high frequencies grew so that the total energy radiated is infinite. Planck solved this problem by assuming that electromagnetic energy could not come in arbitrary amounts. Instead, he proposed that they come in “quanta” with each unit of energy equal to the frequency times a constant, h , which became known as “Planck’s constant”. With that assumption, the high frequency (high energy) emissions became much less probable and now the theory agreed with experimental results.¹

Teacher Notes:

The pictures below were taken using the Thermal Vision Camera (iOS iPhone app). The lights were on a room dimmer switch with the dimmest on the left and brightest on the right. The times are given on the screenshots which easily show the difference in less than 2 minutes.



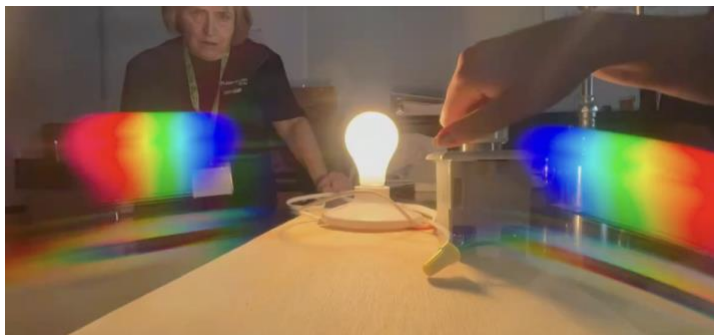
Set up an incandescent bulb (high wattage works best) connected to a dimmer switch (potentiometer). Set at a midway point for first viewing. Darken the room as much as possible. Ask students to view the light through the diffraction gratings and write down (or color) the parts of the visible spectrum seen. It is also useful to have them take a pic with their phone. After they make their prediction, change to higher or lower setting. Discuss their results

¹ The Quantum for All Students and Teachers Project: Sample Activities and the Historical Storyline Linking Them, The Physics Teacher Jan 2025 [TPT25](#)

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If available, use an app sensitive to IR for viewing. The colors will not be “visible” colors but there is a noticeable difference in the IR seen with the app. Have students discuss this difference. Do they come to the same conclusion?



Look at the incandescent light bulb with a diffraction glass or slide. Describe what you see. Predict if the colors would change if the light got dimmer or brighter. Justify your answer.

Students should say that they can see all the colors very brightly but as the dimmer switch is turned down, the blue/violet part of the spectrum gets dimmer before the red/orange side. It is important to point out that the greens/blues are not gone completely but have certainly become “less”.

EXPLORE 2 UV Catastrophe

Materials/Supplies:

Three different colors of Legos® (6 of each color)
Paper or poker chips for numbering
Student instructions and data table

Objective:

Students will use Legos® to help visualize the amount of energy in a parcel of light and learn to distinguish between high frequency and low frequency energy. This model helps students understand how Planck’s quantum hypothesis solved the black-body problem by limiting the amount of high-frequency light emitted by a hot object.

Teacher Notes:

A key factor that motivated the development of the quantum hypothesis by Planck was the failure of classical theory to account for glowing hot objects. The glow was clearly light, electromagnetic radiation, but how to explain it? Objects could be modeled as a collection of electromagnetic resonators driven by thermal motions. Classical theory of equipartition of energy would spread the energy out over an infinite number of frequencies, leading to the “ultraviolet catastrophe” where the amount of energy radiated at high frequencies grew so that the total energy radiated is infinite. Planck solved this problem by assuming that electromagnetic energy could not come in arbitrary amounts. Instead, he proposed that they come in “quanta” with each unit of energy equal to the frequency times a constant, h , which became known as “Planck’s constant”. With that assumption, the high frequency quanta became much less probable and now the theory agreed with experimental results.²

² The Quantum for All Students and Teachers Project: Sample Activities and the Historical Storyline Linking Them, The Physics Teacher Jan 2025 [TPT25](#)

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Let Go of My Lego

Part 1: Equipartition

Place the 18 single Legos® (6 of each color) in a container.
Grab a small handful of Legos® from the container or put in a cup and pour out about half.
Record the number of each photon (color) in the trial.
Return the Legos® to the container before repeating for 5 trials.



Determine the probability for each photon. Probability is the number of each color photon over the total number of all photons in the 5 trials.
Show calculations below the table.

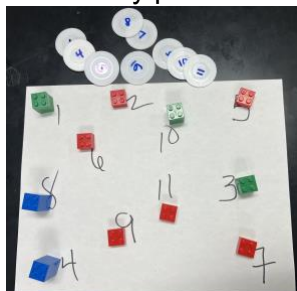
Trial	# Red Photons	# Green Photons	#Blue Photons
1			
2			
3			
4			
5			
Total			
Probability			

Calculations for probability:

Part 2: Quantum Hypothesis

Connect 3 of the blue color together and 2 of green color together. Leave the 3rd color (red) as singles.

Randomly place the 11 Legos® on a sheet of paper, number them (#1-11).



Cut 11 pieces of paper and number 1-11 or use poker chips with numbers.

One person will randomly select a number that corresponds to a Lego® location and another member will record the corresponding photon selected (i.e. color).

Repeat 15 times (i.e. this is trial 1) and tally the number for each color.
Repeat for 5 trials (each trial has 15 counts) and record data. Total the number of each photon and determine the probability for each photon.



Show calculations.

Probability is the number of each color photon over the total number of all photons in the 5 trials.

Trial	# Red Photons	# Green Photons	#Blue Photons
1			
2			
3			
4			
5			
Total			
Probability			

Calculations for probability:

Below are Teacher Notes and Sample Data:

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Part 1: Equipartition

SAMPLE DATA

Trial	# Red Photons	# Green Photons	#Blue Photons
1	14	12	9
2	6	9	10
3	10	11	13
4	16	13	16
5	14	17	14
Total	60	62	62
Probability	$(60/184)=0.33$	$(62/184)=0.34$	$(62/184)=0.34$

Students should get approximately the same number of each color. The sample data below was using more Legos® and students put blocks in one cup, used another cup for the lid, shook, and poured out about half. All blocks were returned to the cup between trials. Taking data from the whole class will yield better results.

Part 2: Quantum Hypothesis

NOTE: a triplet is tallied as 1

SAMPLE DATA

Trial	# Red Photons	# Green Photons	#Blue Photons
1	14	9	5
2	21	6	7
3	12	6	5
4	14	5	8
5	16	11	5
Total	77	37	30
Probability	$(77/144)=0.54$	$(37/144)=0.26$	$(30/144)=0.21$

Overview of Lesson:

Let Go of My Lego® or UV Catastrophe: The quantum hypothesis means that higher frequencies must have greater energies than low frequencies and so they are less probable. Students can see how this works out by looking at the probability of “selecting” different colored Legos® which represent the photons.

EXPLAIN**Blackbody Radiation**

Lord Rayleigh and Sir James Jeans worked on the problem of discovering why hot objects emit light. They decided that a theoretical object, called a blackbody, could absorb and emit any type of light and the light emitted was based on their temperature.

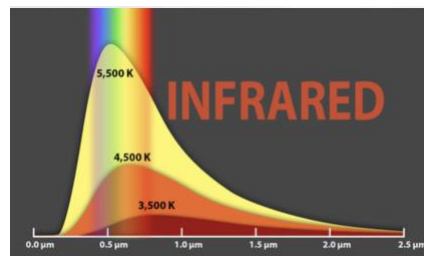
Hot objects glow due to thermal radiation, where the thermal energy of the object's particles is converted into electromagnetic radiation. Some of the radiation falls into the visible light spectrum and some does not (i.e. we cannot see it with our eyes). This is called Blackbody Radiation. The Sun is an object that glows and a large portion of the light from the Sun is in the visible spectrum.

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Atoms and molecules increase in their vibrations as they are heated which increases their random kinetic energy (otherwise known as thermal energy). The vibrations are vibrating electron distributions. Those distributions of electrons are what constitute the molecular bonds (i.e. molecular electronic states) in the material. Thus, those vibrating electron clouds can be thought of as little electromagnetic oscillators. But oscillating electric charges emit electromagnetic radiation. Hotter objects have more energy in the vibrations and so they have a greater probability of emitting short wavelength photons. That is why hotter objects emit light shifted toward the blue end of the spectrum.

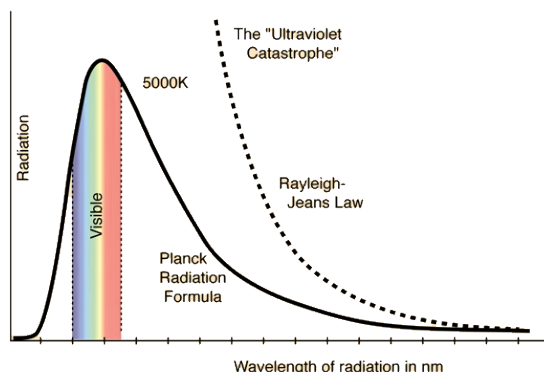
All objects have some type of thermal radiation, but an object will only glow visibly if the temperature is high enough (around 798°K). Cold objects emit radiation, but it is in the infrared portion of the spectrum so is not seen by the unaided human eye. (Picture Credit: The Visible Glow of Hot Things³)



UV Catastrophe

A calculation based on classical physics (Rayleigh-Jeans law) showed that a blackbody at thermal equilibrium will emit an infinite amount of energy with greater amounts of energy emitted at higher frequencies. However, it was obvious that objects did not glow with infinite energy. Experimental observations of black body radiation which showed that the energy of black body radiation decreased at higher frequencies. Something was deeply wrong with the classical physics approach, but the theoretical calculation made perfect sense and there were no errors.

The discrepancy between theory and experiment was termed the ultraviolet catastrophe in the 19th century by Rayleigh and Jeans. They stated that the ideal body currently at thermal equilibrium will emit radiation in all possible frequencies with equal probability. The amount of radiation energy will be directly proportional to the frequency squared (i.e., it will increase with the increase in frequency). Therefore, a black body should emit huge amounts of energy in the highest frequency (shortest wavelength) part of the spectrum, in the ultraviolet region and beyond.⁴



The ultraviolet catastrophe was resolved by Max Planck's introduction of quantum mechanics. Planck proposed that energy is **quantized**, meaning it can only take on discrete (quantized) values rather than a continuous range. In this model, light comes in little packets that Planck called "quanta" (we call them photons). Each little packet has a single value of energy that is proportional to its frequency. This revolutionary idea resolved the ultraviolet catastrophe and laid the foundation for the development of quantum mechanics. Because higher frequency had higher energy, higher energy photons were less likely to be emitted because there were fewer of them (as modeled with the Legos®). This limits the energy emitted at a higher frequency.

³ Picture: Visible Glow of Hot Things <https://coolcosmos.ipac.caltech.edu/images/193>

⁴ <https://physics.stackexchange.com/questions/309043/red-hot-objects-the-ultraviolet-catastrophe>

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Planck solved the UV Catastrophe and with his quantum theory and was able to calculate exactly the black body spectrum, even though at the time he did not know why this worked. He thought it was an accounting trick and did not believe quanta were real.

The Legos® are used to help students visualize the amount of energy in a parcel of light. In the first case, all the blocks are one unit in size, and they have an equal probability of being drawn out of the container. In the second case, the size of the blocks is related to the color (frequency), with higher frequencies quanta having more energy. Now the blue quanta are much less likely to be drawn than the red quanta. This illustrates how Planck's quantum hypothesis solved the black-body problem by limiting the amount of high-frequency light emitted by a hot object.

EXPLORE

Planck's Constant

A light-emitting diode (LED) is a device that produces light when a potential difference is applied across it. The potential difference allows electrons to move from high-energy states to lower-energy ones. Energy is released from the system as photons. The energy of each photon, hf , is equal to the change in energy of each electron $e\Delta V$.

$$hf = e\Delta V$$

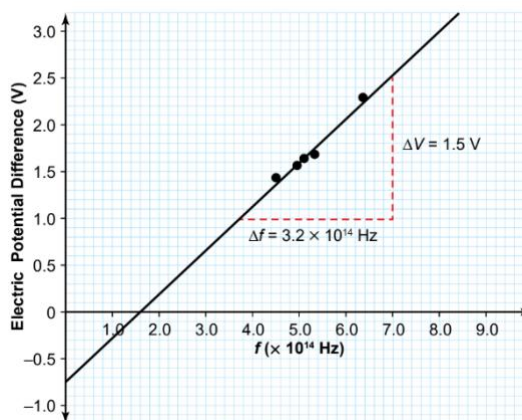
Where e is the elementary charge ($1.602 \times 10^{-19} \text{C}$), h is Planck's constant ($6.626 \times 10^{-34} \text{ J}\cdot\text{s}$) and f is the frequency of light. Planck's constant ($h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$) is a fundamental constant in nature, defining the scale at which quantum phenomena occur. It defines the size of energy quanta and plays a central role in describing the behavior of quantum systems. Each photon has energy ($E = hf$), where

- h is Planck's constant,
- f is the frequency of the light.

Sample Graph of Data Collected is shown here.

Essentially, the students are seeing the threshold voltage for the LEDs and should observe that not all LEDs are identical. It is possible for students to measure the voltage directly (see Perimeter

Institute Resources) to collect quantitative data. In this case, the threshold voltage, ΔV_T , is determined to be when the current can first pass through the LED. The voltage at which the LED first lights and threshold voltage are not the same, but by carefully observing the LED and connecting an ammeter in series with the LED, one will find the ammeter starts to register a current before the LED lights up. See <https://resources.perimeterinstitute.ca/> for more information and resources.



The amount of playdough in the procedure should be minimal in thickness since a longer length between the LED and battery will increase the resistance. It is suggested to give students a students will also discover that the long end of the LED must be connected to the +terminal of the battery to light.

For more instructions: Investigating Planck's Constant with LEDs, Perimeter Institute <https://youtu.be/np6oPTwYFFs?si=No0BvQfcK-n3tloe>

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Materials:

conductive playdough (bought or homemade)

LEDs

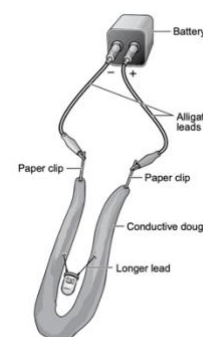
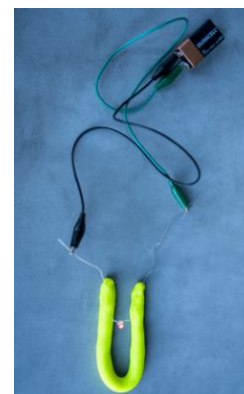
9V battery (clip optional)

Wires with alligator clips

Paperclip or conducting rods

Procedure:

1. Use a coin battery to light a LED. Notice and orientation of the LED with the + and – of the battery required to light.
2. Make a “U” shape with the dough being careful to not use too much which will increase resistance. The “U” shape should be close but not touching.
2. DO NOT connect the battery until your set up has been approved by the teacher. Paperclips can be used as connectors in the playdoh. When approved, connect the battery to playdoh as shown in the picture. To avoid draining the battery DISCONNECT when the circuit is not being tested.
3. Place the LED at the end closest to the battery and test for lighting. If the LED does not light, reverse the connection or the LED. Note the LED has one leg that is longer than the other. Which “leg” must be connected to the + end of the battery to light?
4. Move the LED closer and closer to the end (i.e. the U) of the playdough until it can no longer light. Note this distance. Compare the brightness of the LED as it is moved closer to the U.
6. Repeat the above procedure using different colored LEDs. Compare the distance at which they no longer light. Determine a sequence of LED colors starting with those that lit the longest (i.e. were closer to the U).
7. Compare your results to those of your colleagues.



PHOTOELECTRIC EFFECT

Objectives:

Students will recognize that light behaves as particles (photons). Teachers will need to help students use their evidence to explain wave-particle duality (WPD).

Students will understand that the kinetic energy of the electrons depends only on the frequency of the light, not the intensity. This means the energy transfer happens through individual photons, each delivering a quantized amount of energy

Students will understand the importance of discrete values (quantization or quanta).

TN: The threshold frequency shows that only photons with enough energy (as particles) can eject electrons, something classical wave theory could not explain. This is direct evidence that light has particle-like properties.

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Main ideas include:

- Electrons are ejected/removed when light of a given frequency/energy is shined on a metal surface if a threshold is exceeded.
- Different energies are associated with different colors of light (photons).
- Photoelectric effect: quantized values for energy transition in LEDs
- Planck's theory was the basis for Bohr's quantization of spectral lines in an atom
- Photons (light) comes in chunks
- Einstein was the one who said quanta were real, not Planck. Einstein convinced everyone. (Nobel Prize)

EXPLORE

Photoelectric Effect

Part A

TN: When using UV sources be sure students are careful about NOT looking directly at the light. This can cause eye damage.

Prepare the station as shown in the photograph by

1. Sand a soda can lightly on one side to remove the paint. This may have to be done again if not working or if it sits for a few days.
2. Attach to the bottom of a Styrofoam cup with tape, turn cup upside down so it is suspended by the cup and therefore insulated. Be sure the sanded part is on the top and not covered by masking tape. If sanded part is on the side, the students may accidentally shine the UVC in someone's eyes when testing.
3. Attach a thin metal rod (or large straightened paper clip that is uncoated) to the top of the can laying it over the sanded area. If necessary, sand the metal rod to remove any oxidation. The end needs to extend over the table and not be touching the table (i.e. short tinsel)
4. Attach tinsel to the rod with tape making sure it touches the rod.
5. A good way to charge the PVC is to rub with a dry paper towel (brown ones like used in schools, not commercial) or a balloon (be careful of latex allergies). Students can lightly touch the tinsel to transfer the charges via conduction.
6. Provide UV glass, UVA, UVB, UVC, or other light sources to try to remove electrons. Encourage students to use other objects such as opaque glass, clear glass, colored glass etc. between the can and the light to observe changes in tinsel. Blue Blocker glasses or prescription glasses with a blue blocker filter added can also be tested.



If available, a teacher can utilize any type of electroscope to demonstrate the photoelectric effect. The process outlined here simply allows students to make their own or for inexpensive multiple set ups.

Note: One can also positively charge the tinsel (use an electroscope or induction) and test again. *TN: nothing will happen, it will not discharge because the positive charge cannot be removed (protons are deep in nucleus and can't be removed easily) but electrons have low mass and can be removed easily. This is shown in the Arbor video.*

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Student Instructions:

1. Charge a rod (PVC) and then charge the tinsel. Discuss explanations for what is observed.
2. Predict what will happen if you touch the can. Test your prediction.
3. Predict what will happen if one shines UV, laser, or fluorescent light on the charged apparatus. Test your prediction by use various light sources (flashlight, red laser, UVB, UVC, etc.) to shine on the part of the can that has been sanded. Observe and record what happens to the tinsel.
4. Discuss with your group ideas of how to keep the tinsel from being discharged. Test your predictions. Observe and compare to prior results.
5. Explain results in terms of quantization, energy levels (of the light), and describe what the photons are doing during the process.
6. Watch one or more of the following videos <https://youtu.be/WO38qVDGgqw?feature=shared> or https://youtu.be/z-3XaXCvjZw?si=fnp_gQVnxwYVuMnv or <https://youtu.be/v-1zjdUTu0o?feature=shared> and revise your explanation if necessary.

**Sample Student Results/Observations:**

Negatively charging the can results in the leaves or tinsel repelling.

When one shines the UVC light on the can, the electrons are ejected and therefore are no longer repelled and the tinsel drops. Most other light sources will not affect the tinsel and it will remain spread out.

UV light can be blocked by a piece of UV glass which prevents the electrons from leaving the tinsel. As the UV light goes through the glass the energy of the UV light is diminished below the threshold energy needed to impact the tinsel.

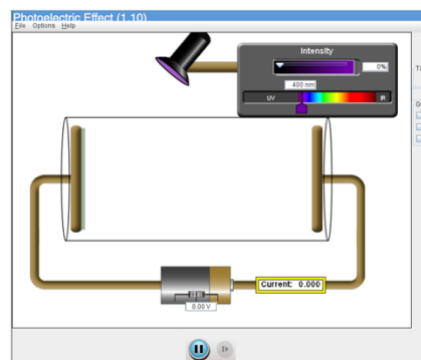
Blue Blocker glasses or prescription glasses with a blue blocker filter added.

Part B**PhET Simulation:**

<https://phet.colorado.edu/en/simulations/photoelectric>

Using the PhET Simulation "The Photoelectric Effect", students will:

1. Identify what factors affect the ability of light to free electrons from a metal surface.
2. Determine the energy of electrons emitted from different metal surfaces.
3. Find the threshold frequency for various metals.



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EXPLAIN

In the late 1800's to early 1900's experiments showed that shining light on certain metals caused electrons to be ejected. This phenomenon is known as the photoelectric effect. It challenged the classical wave theory of light based on Maxwell's equations which could not explain why no electrons were ejected below a certain frequency of light, no matter how intense the light was. Additionally, it could not explain why electrons were emitted immediately, without delay and the kinetic energy of ejected electrons depended on the frequency, not the intensity, of the light, but that the number of electrons ejected depended only on the intensity. The wave model of light could not explain this phenomenon.

Photoelectric Effect Explained by Perimeter Institute (5:30) gives good background information for teachers or students after the initial explore activities and help students make connections to relevance (camera in cell phone, semiconductors, danger of gamma rays, optimizing materials to see specific colors, etc.)

<https://youtu.be/jWbwDTPju-M?si=o-w9bmRXbtsk1WgT>



In the exploration regarding Planck's constant, students will learn that the minimum voltage (energy per charge) required to light LEDs will vary based on the LED since each LED requires a quantized voltage to emit light. This supports their understanding that energy levels in materials are quantized. Photons carry quantized energy. The energy of a photon is given by $E = hf$ where E is the photon energy, h is Planck's constant, and f is the frequency of the photon. Additionally, quantization means that there are no in-between states. Orbitals for the electron of hydrogen are also quantized. To go from one energy level to another the amount of energy required must be exactly the difference between the two energy levels. A photon is either absorbed by the electron causing the electron to transition between energy levels or the photon passes through the atom. Essentially, this process is quantized and an all or nothing process and means that electrons can't have energies between these levels they must transition from one level to another by absorbing or emitting the correct quantum of energy. A visual for this would be the steps of a ladder, the change is determined by stepping up or down using the rungs. For example, in the hydrogen atom the ground state for an electron is -13.6eV . If a photon equal to 13.6eV strikes the electron, the electron will leave the atom but have no kinetic energy. If the photon is greater than 13.6eV , the "photoelectron" will have kinetic energy once it leaves the atom.

The connection to photoelectric effect is that when a photon strikes an electron on the surface of a metal, there is a minimum energy (i.e. work function or ϕ) required to result in a photoelectron. If the energy is equal to the work function, the electron will be removed from the surface but will have no motion (i.e. kinetic energy). However, if the energy is greater than the work function, the photoelectron will leave the surface and have kinetic energy equal to the photon energy minus the work function, which is a fixed value ($KE = hf - \phi$).

While Albert Einstein is most famously known for his theory of relativity, it was his explanation of the photoelectric effect that earned him the Nobel Prize in Physics in 1921. In 1905, Einstein proposed that light delivered its energy in quanta (i.e. photons). If a photon's energy is above a certain threshold, it can remove an electron from a metal. The difference between the work function and the photon energy was the energy of the ejected electron—this explained the observations. Einstein's work challenged the prevailing view of light as purely a wave. It provided one of the first major pieces of evidence for quantum theory. Although initially controversial, his explanation was experimentally confirmed by Robert Millikan, who had initially set out to disprove Einstein's theory. In 1913 Millikan did experiments

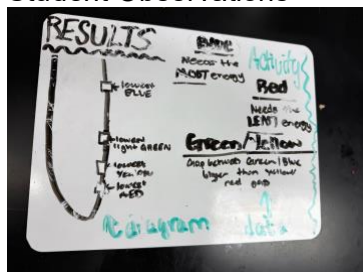
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involving the photoelectric effect which confirmed the photon theory. Einstein won the Nobel Prize for his work on the photoelectric effect in 1921. He did not receive the prize until 1922 because the Committee had already reserved the prize for a recipient in 1921. This work laid the foundation for quantum mechanics and revolutionized the way we understand the interaction between light and matter.

Planck's Constant

Student Observations

**EXTEND 1 (Optional)**

Objective: To measure the energy of electrons emitted from different metal surfaces.

Teacher Background: According to atomic theory, electrons are bound to the nucleus of the atom because of the electrostatic attraction with the positive nucleus of the atom. If an electron is given enough energy from the absorption of a photon, the electron will leave the atom, ionize the atom and cause a current. The work function for an atom is the minimum amount of energy needed to remove an electron to infinity from an atom (usually a metal) and is given by the Greek letter ϕ . The electrons that are freed from the surface of the metal have a specific amount of kinetic energy. Faster electrons have greater energies than slower ones. The energy of emitted electrons is measured by setting up an electrical field that opposes their motion, a stopping voltage. The voltage of the field is a measure of its strength. The potential difference, voltage, applied to stop the current is equivalent to the kinetic energy of the electron that was ejected by the light shining on the metal. The amount of energy or work needed to stop the electron is given by $W = Vq$ measured in eV electron volts. $1\text{eV} = 1.6 \times 10^{-19}\text{C}$. Recall that, the energy of a photon is $E = hf$ discovered by Planck, where $h = 6.63 \times 10^{-34}\text{J}\cdot\text{s}$ or $4.136 \times 10^{-15}\text{eV}\cdot\text{s}$ and f is the frequency of light.

Procedure:

Using the PhET simulation set the photon flux, intensity, to 100%.

<https://phet.colorado.edu/en/simulations/photoelectric>

Select the graph option: Electron vs Frequency.

Select several different metals and run the simulation noting where the electron energy increases from zero.

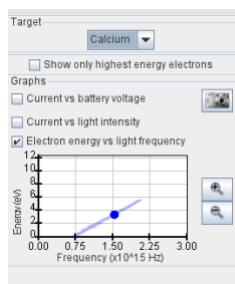
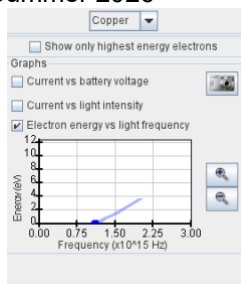
Compare data with peers and discuss any conclusions.

Compare the slope of the line for the different graphs.

ANS: Slope of the line is Planck's constant and is the same for all metals.



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EXTEND 2 Neon Bulb Ignition

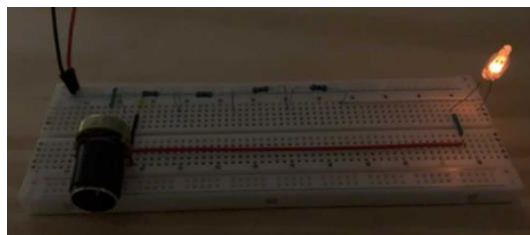
Quantization means that certain physical quantities—such as energy, angular momentum, or charge can only take on specific, discrete values rather than any value on a continuous scale. For example, energy comes in “packets” or “chunks” rather than being infinitely divisible.

Materials/Supplies:

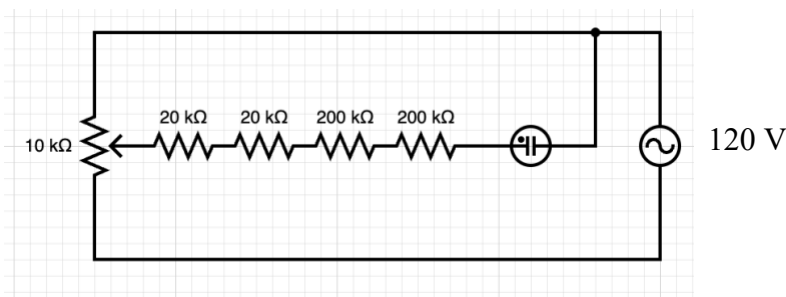
Breadboard, breadboard jumper wire, resistors (2-20 k Ω , 2-200 k Ω), 10 k Ω potentiometer, power cord connected to breadboard, UV light source or charged PVC rod.

Objective:

The purpose of the apparatus is to demonstrate the photoelectric effect. A neon lamp is a gas-discharge lamp. It creates artificial light via ionizing gas. When sufficient voltage is applied to the electrodes the lamp will start to produce an orange glow. If set up properly, then the potentiometer can control the voltage on the neon lamp. The higher the voltage, the brighter the lamp will glow. The potentiometer can be set below the ignition voltage. Then a UV light can be used to ignite the lamp.



The wiring diagram:

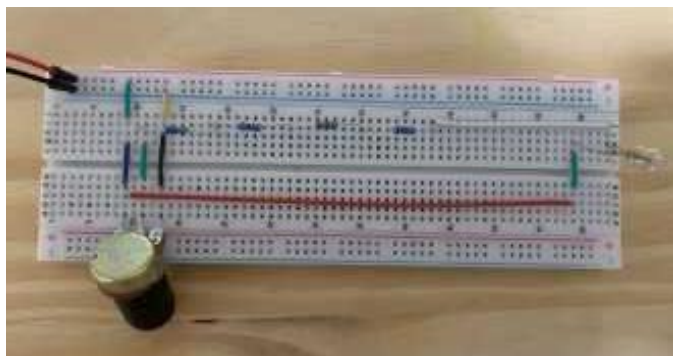


The power supply is plugged directly to the first and third prong of the potentiometer. The resistors and neon lamp are connected in series starting and ending with one of the power supply ends and the second (middle) prong of the potentiometer. Due to the power supply being AC, which end the inner series circuit is connected to doesn't matter. However, to stay organized, we will stick with the “positive” side of the power supply.

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Bread board setup:



The wiring set up is more complicated than necessary. However, it is set up in this orientation to keep things organized and to keep power supply as far away as possible. The breadboard has negative and positive power strips running along both sides of the board. As well as columns that are numbered 1 to 63, and rows ranging from a to j.

Below is a detailed explanation of the set up.

****Wire arrangement is not concrete. Changes can be made and simplified. Instructions below explain the picture above****

- “positive” line: positive power strip to j9, g9 to d9, c9 to c59, e59 to g59
- “negative” line: negative power strip to j13, h13 to d13
- 4 Resistors: e11 to g11, i11 to i19, i19 to i27, i27 to i35, i35 to i43
- Wire connecting resistors to lamp: j43 to j63
- Lamp: h63 to h59
- Wire connecting resistor to potentiometer: e11 to g11
- Potentiometer (3prong): a9, a11, a13

Teacher Notes:

Students should not handle the main power cord. There are full voltage and current passing through the wire which is roughly 120 V and 15 to 20 A.

After the resistors the voltage is varied, and the current reduces to 0.5 mA at maximum resistance.

The potentiometer is rated to handle a power supply of AC 220 V and 6A. However, the potentiometer tends to get hot. Handle it with care and keep demonstration times short. Unplug the power cord from the outlet before handling any breadboard wires. Ensure the breadboard is completely assembled before plugging in the main power supply to the outlet.

MOLECULES AND PHOTONS

Teacher Background: Planck proposed that light (electromagnetic energy) was a particle as well as a wave. He called his light particles “quanta”, from which we get “quantum mechanics”. We now call Planck’s quanta “photons”. The photoelectric effect showed that this was real things. Light did come in chunks when you looked on the very small scale (remember that Planck’s constant is a very small number).

By the end of the 19th century scientists knew that electrons were tiny particles with negative charge, and that this charge and the mass of the electrons were fixed, tiny values and that all electric charge was a multiple of this basic unit of charge. If light energy

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came in chunks (photons), electric charge came in chunks, and matter came in chunks (electrons, and later protons and neutrons), were there other things that were on the very small scale that were quantized?

Early quantum theory evolved from classical mechanics by invoking quantization, the principle that things on the tiny, quantum scale, came in irreducible chunks. One feature of late classical mechanics (Hamilton-Jacobi theory) was the special role played by periodic motion. A brilliant insight by Neils Bohr (and others) was that periodic motion could be quantized by using an angular form of Planck's constant h , where that constant would be $h/2\pi = \hbar$. This angular version of Planck's constant is read as "h-bar". Bohr used this approach to develop the first atomic model for hydrogen that could explain the absorption and emission of specific frequencies of light by hydrogen gas. This first application of the new quantum idea was a success, but it was only the beginning. More complete and comprehensive forms of quantum mechanics were developed to explain atomic structure, the periodic table, atomic and molecular bonds, and the behavior of materials, like semiconductors. The rapid progress in understanding led to equally rapid technological change, including the invention of the transistor, the integrated circuit, and much more.

Quantum theory for molecules relies on those early insights about periodic motion. Rotational and vibrational motion are quantized in molecules, and this has important implication of how molecules interact with light. If the angular momentum, L , is quantized so that $L = n\hbar$ (n is called the quantum number and it is equal to 0, 1, 2, ...). This means that the rotation energy is also quantized since for rotation, the energy is related to the momentum by $E = L^2/2I$, where I is the moment of inertia. The moment of inertia depends on the mass and the distribution of mass in a rotating object. This means that I will be different for different molecules, which have different atoms and arrangements of those atoms, and so the energy levels will be very specific to a single molecule. This is also true of vibrational energy states – they are different for different molecules (demonstrated by the PhET). Since these energy levels have specific values, only specific energy photons can be absorbed or emitted by molecules.

Understanding how light interacts with molecules in materials is an important area of research. It is also very important for identifying molecules. This is how, for example, one knows the composition of dust clouds in interstellar space. Scientists can see light passing through a cloud and identify frequencies of light that are being absorbed by the cloud. Since each molecule has its own "fingerprint", one can then determine the composition of the cloud.

EXPLORE

Molecular rotational and vibrational states

The simulation allows us to see for different molecules how light can excite vibrations and rotations in molecules, but only for specific energy photons. Not all photons can be absorbed, only those that match the energy need to put the molecule in a specific state can be absorbed. Once a molecule has absorbed a specific photon, it can't absorb another photon of the same energy because that state has already been excited, so those extra photons just pass by. The excited state can release its energy, but it will be the specific energy photon that it absorbed in the first place.

For example, in the water simulation, using microwaves, when the water absorbs a photon it begins to rotate, but other photons with same energy will pass by. Because they cannot be absorbed, (it has already absorbed all it can). Later it releases and stops rotating and can then absorb again.

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Lower energy photons, like microwaves, will tend to produce rotational motion, while higher energy, infrared photons produce more vibrational motion. But higher energies, like ultraviolet light, can split the molecule or cause transitions of electrons between energy levels in the atoms themselves. This is why microwaves heat food. The energy of the microwave causes water molecules to have more random motion, and heat is random motion at the molecular level.

EXPLORE

1. Open the PhET simulation
https://phet.colorado.edu/sims/html/molecules-and-light/latest/molecules-and-light_all.html
2. Select Carbon Monoxide (CO) and Microwave. Run the simulation.
3. Repeat using higher energy wavelengths of light.
4. Record observations
5. Select Carbon Dioxide (CO₂) and repeat steps 2-4.
6. Select water (H₂O) and 2 others and repeat steps 2-4.
7. Compare observations and conclusions with other members in your group.



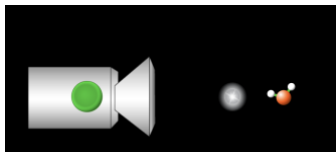
TN: Big Idea: The vibrational states are only for specific energy photons.

Observations may include the following:

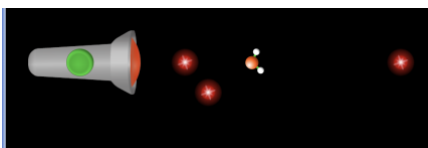
Some of the molecules vibrate when the photons interact, others do nothing.

Water will spin with microwaves and once spinning it does not absorb any more until it stops spinning. For infrared, it will just vibrate and for visible and UV does nothing.

Water and Microwave



Water and Infrared



Ozone will spin with microwaves, vibrate with infrared, visible and UV do nothing.

Carbon Dioxide will vibrate with infrared, but is not affected by the others.

Nitrogen Dioxide will split