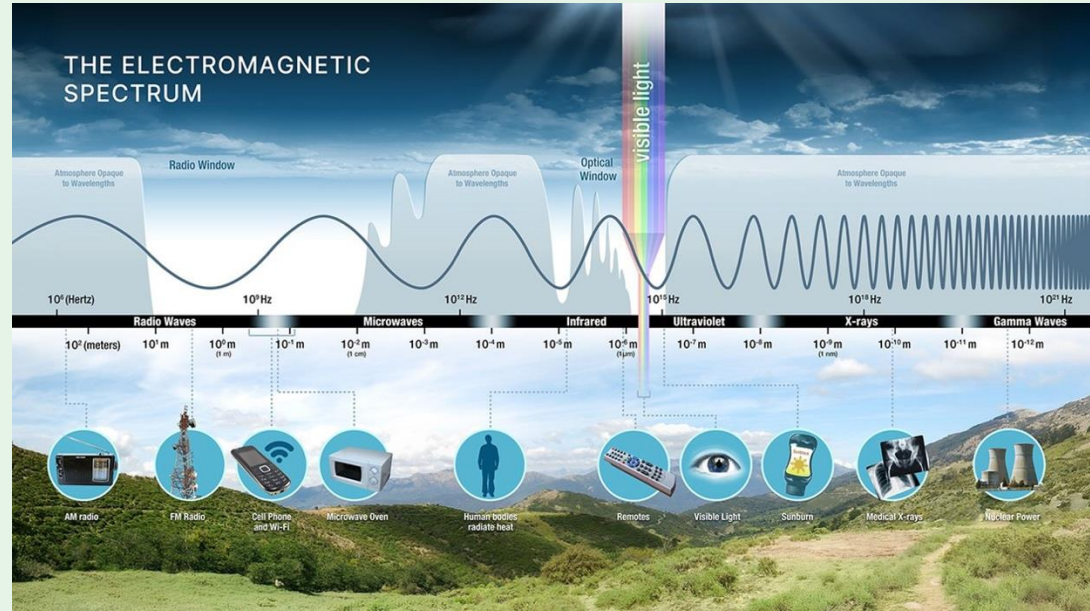


Planck's Constant

Main Ideas

Light is an electromagnetic wave and the wavelength is an indicator of the color of light.

Planck proposed that each unit of energy (quanta or photons) is proportional to the frequency times a constant so high (high frequency would be less probable). $E = hf$



Credit: NASA

LEDs

Practice lighting the LED using one LED and one coin battery. Discuss with your peers the variations tried and which ones were successful. What conclusions can be made regarding the structure of the LED?

If available, try lighting different colors of LEDs and compare the brightness of the bulbs across the same voltage (i.e. use a coin battery).

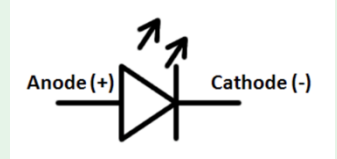


Structure of LED

- Semiconductor chip, anode, cathode
- Anode (positive) longer lead
- Cathode (negative) shorter lead, has flat side next to cathode pin, larger metal anvil plate is usually attached to cathode.
- 1962 first visible light LED, red light (cost \$200)
- Current flows from anode (P) to cathode (N).
- Electron at P-N junction falls to lower energy state. Difference is “band gap” which determined color of light.
- Excess energy is released as a photon.
- Larger band gap = higher energy difference and shorter wavelengths of emitted light.
- Important for energy efficiency and precise beam control



Image credit: Wikimedia Commons



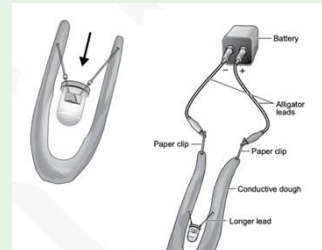
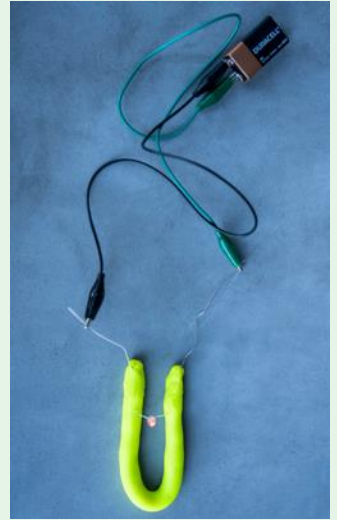
Blue LED

- Developed in 1990s and won Nobel Prize in 2014 (enabled energy efficient white light)
- Blue light required larger energy gap
- Gallium nitride (GaN) was challenging due to lack of proper substrate (structural defects). Needed positive (p-type doping) layer of GaN
- <https://youtu.be/idwKHQEw78g?si=6PlrgwWuXzLsjVYp> How Blue LEDs changed the world
- Why it was almost impossible to make a blue LED (Veritasium)
<https://youtu.be/AF8d72mA41M?si=nzIBaawXXFv6F2MO>

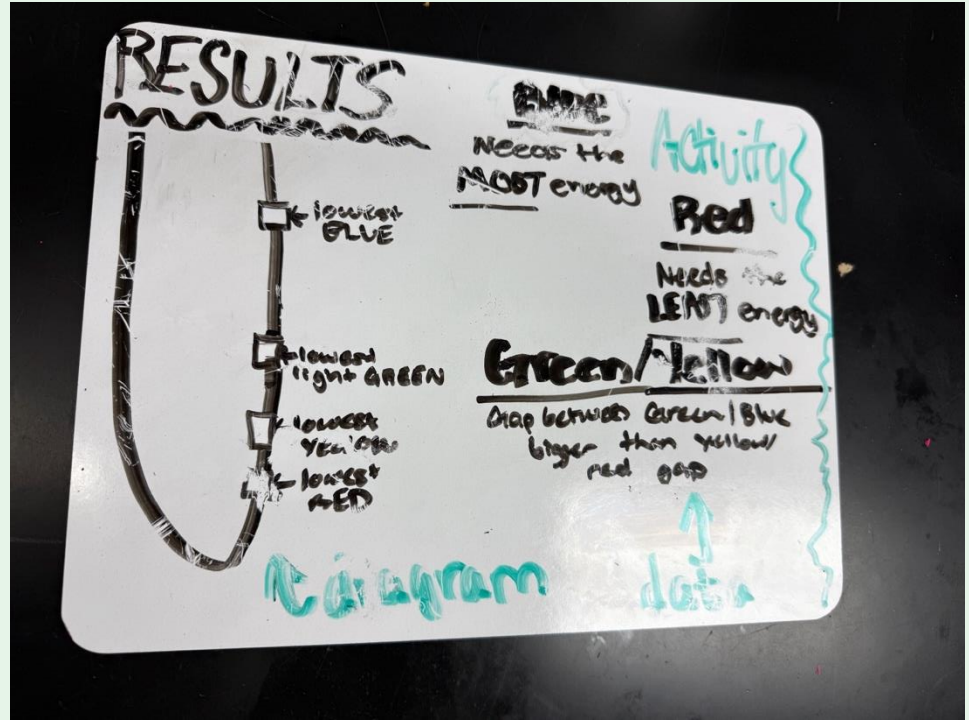
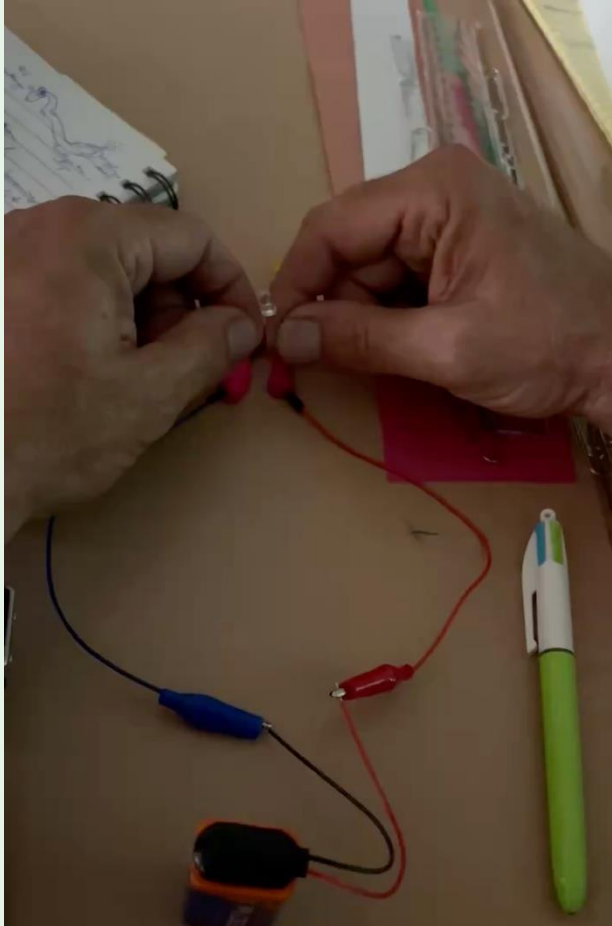
Explore: Planck's Constant

Procedure:

1. 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.
4. Move the LED closer and closer to the end (i.e. the U) of the playdoh until it can no longer light. Note this distance. Compare the brightness of the LED as it is moved closer to the U.
5. 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).



TN: Sample Results



EXPLAIN: Planck's Equation

$$E = h\nu \quad \text{or} \quad E = hf$$

E = energy (J)

ν or f = frequency (either symbol can be used)

h = Planck's Constant = 6.626×10^{-34} J s

This relationship led to a model that matched the experiment for **black-body radiation**.

Until then scientists were unable to explain why the higher frequencies of radiation diverged from predictions.

EXPLAIN

- Max Planck tried looking at light in terms of small "packets" of energy rather than as a continuous wave.
- This "quantization" of light explained how hot objects glow.
- At the time, Max Planck did not know why this worked! He thought it was an accounting trick, he did not believe that quanta were real.



<https://www.britannica.com/biography/Max-Planck>

Wrap Up

- Photons are information carriers and fiber optics allow photons to be transmitted without disturbing their quantum states.
- Entangled photon pairs can be created and sent through fiber optic cables for quantum networks.
- Biosensors, chemical sensors, and environmental detectors use optical fibers for transmission of information.
- Light refraction is explained at the quantum level by Quantum Electrodynamics (QED). Instead of light physically "slowing down", photons continuously interact with the electrons of the medium. This creates secondary waves that interfere with the original photon, generating a phase shift that appears as a bent trajectory and a reduced effective speed.