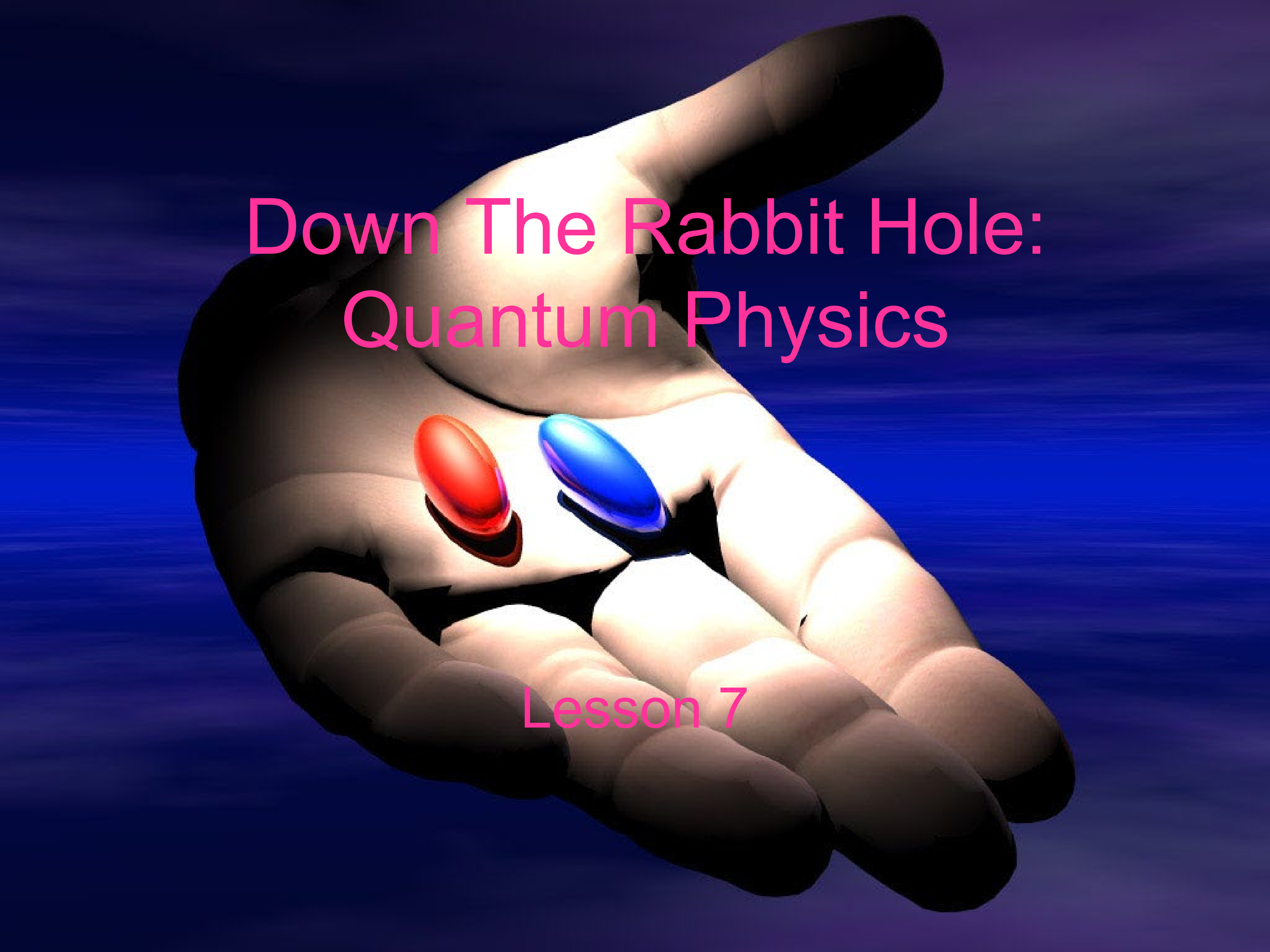
Down The Rabbit Hole: Quantum Physics



Lesson 7

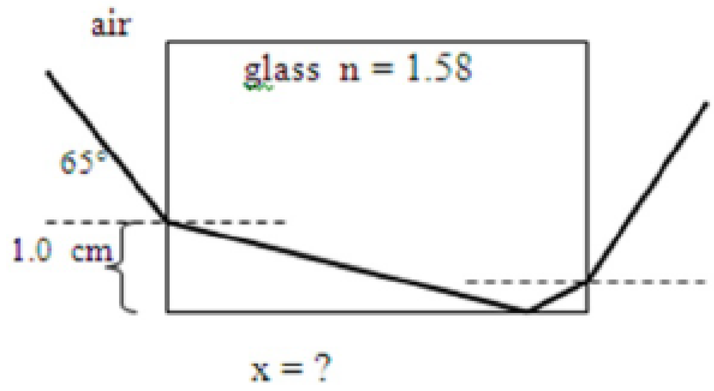
Objectives

- Define a quantum
- Calculate the energy of a photon
- Relate photon energy to wavelength and frequency of EMR

NR In a Michelson-type experiment, an eight-sided mirror makes $2/8^{th}$ of a revolution while rotating at 1.20×10^3 rps. The calculated speed of light for fixed mirror placed 30.0 km away is $a.bc \times 10^d$ m/s. The values of a, b, c and d, respectively, are ___________.

(Record your 4 digit answer on the answer sheet provided.)

Use the following diagram to answer the next question.



NR

The value of x in the diagram is ______ cm.

(Record your 2 digit answer on the answer sheet provided.)

NR

A light ray passes through a piece of plastic with a 38° angle to the normal. It emerges in the air at 85° to the normal. The critical angle for this plastic is ____ degrees.

(Record your 2 digit answer on the answer sheet provided.)

NR Monochromatic light is shone through a pair of slits which are 0.100 mm apart; an interference pattern is observed on a screen 4.00 m away. The distance from the central bright spot to the third **dark** region is 5.00 cm. The wavelength of the light is _______ nm.

(Record your 3 digit answer on the answer sheet provided.)

Use the following diagram to answer the next question.

A group of students conducted an experiment with a converging lens of focal length 6.50 cm. They placed an object at a distance of 17.0 cm from the lens. A list of their possible findings is shown below.

1. Image is errect
2. Image is inverted
3. Image is real
4. Image is virtual
5. Image is dimisnished
6. Image is enlarged

NR The findings the students should have observed, in order from smallest number to largest number, are ___, ___ and ___.

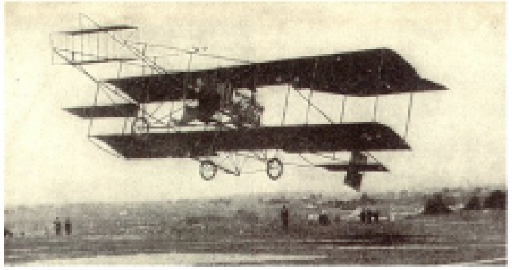
The Story so Far:

In the big picture of this thing we call physics, we have two distinct eras.

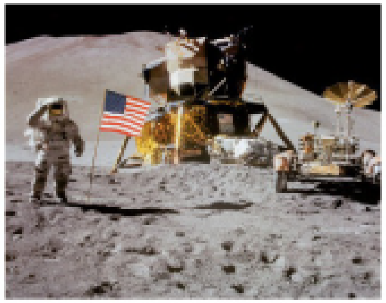
From early Greek philosophers up until about 1850, all of the physics done can be thought of as *classical physics*.

Classical physics was good. It allowed us to:

Build sweet cannons.



Take to the air.



Golf on the moon.

In fact, it lead some pretty famous physicists to make some pretty cocky statements:

Lord Kelvin (1824 - 1907) has a number of good quotes, such as:

"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement." (1900)

NICE.

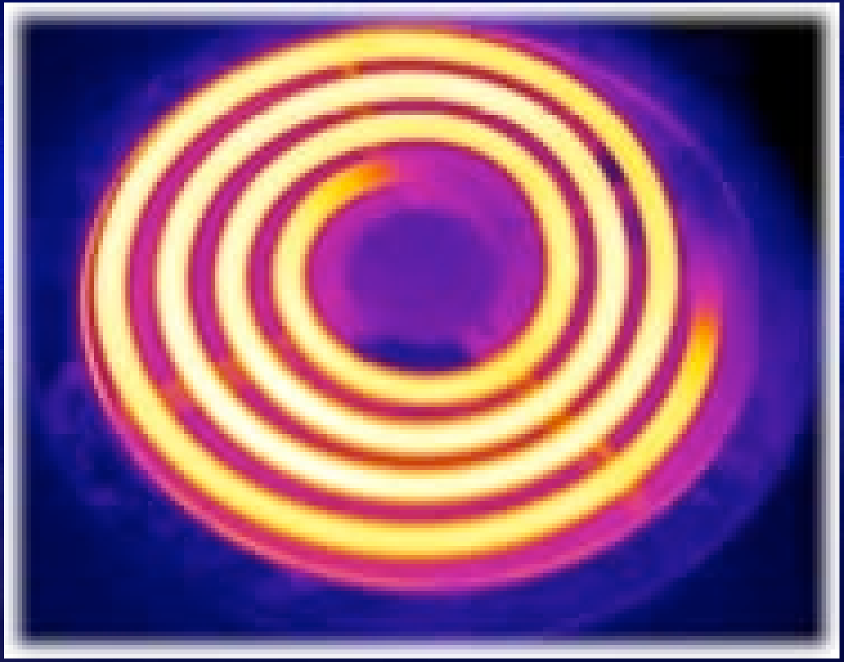
However, there were a few odd phenomenon kicking around that Kelvin (or anyone else) could not explain…

One, for example, was hot objects.

Why exactly do hot objects emit light? And why does that light change colour (wavelength)?

Blackbody Radiation

- Stove burner



Blackbody Radiation

- It was known that as one heats an object it changes color. What colors can you name as objects heat up?
- The color corresponds to the emission of EMR. As the object gets hotter it should emit greater and greater frequencies of EMR.

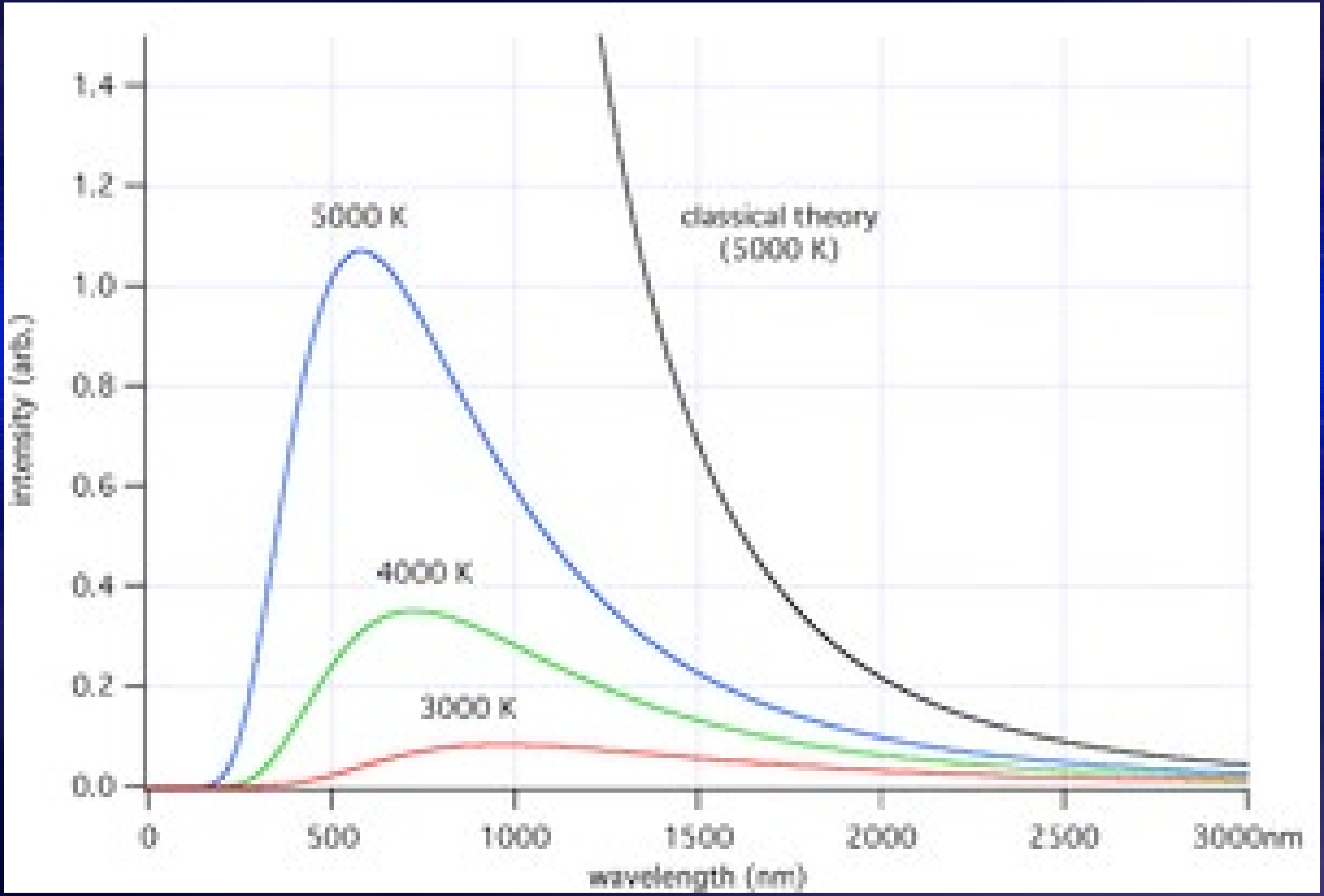
One physicist who had a crack at this question was Gustav Kirchhoff. He proposed that objects that absorb all EMR energy and emit light are called blackbodies.

Blackbodies absorb all EMR that falls on them. No light is reflected, hence they are black when cold. However, when they are heated to specific temperatures, they start to emit light of a certain wavelength (colour).

Predicted Wavelengths

- It was predicted that an ideal blackbody at thermal equilibrium will emit EMR with infinite power under classical physics
- However, blackbodies only emit wavelengths of certain color when at certain temperatures as shown by the graph on the next page

Predicted vs. Actual Blackbody Radiation



Ultraviolet Catastrophe

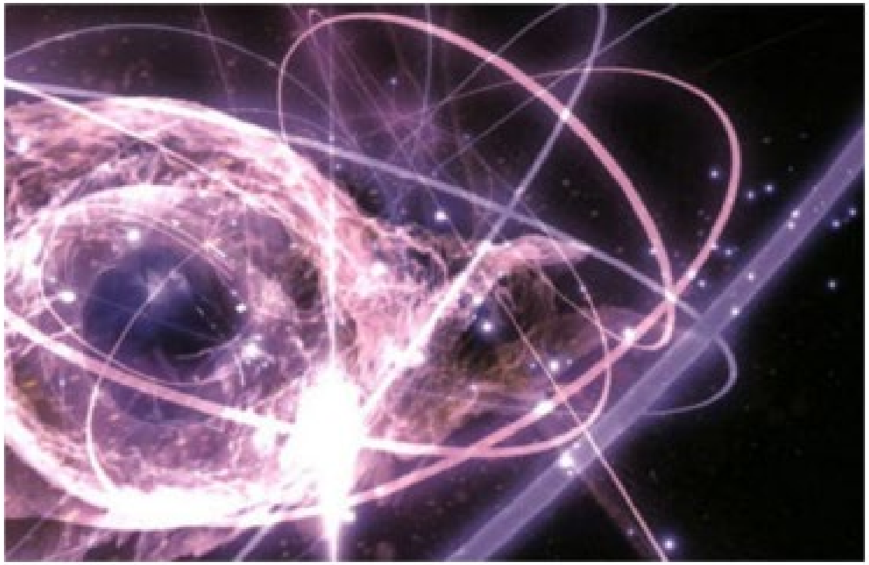
- **Since values above the visible light region did not occur in increasing amounts as predicted, scientists were at a loss to explain the results and called this the Ultraviolet Catastrophe.**

Max Planck

- **Max Planck resolved this issue by postulating that electromagnetic energy did <u>not</u> follow the classical description**
- **Planck assumed that the energy given off by these objects had to occur in discreet units (bundles) of energy. Each of these bundles had a specific quantity of energy associated with it. He called these units Quanta.**

Enter: The Quantum

A quantum is the smallest amount of energy a particular wavelength of light can produce.



This idea that energy was "quantized", or discontinuous, was a huge departure from the old rules.

The quanta of energy is related to the frequency of the light produced, an idea summarized in Planck's formula:

$$\Delta E = hf$$

Planck's Formula

where:

E = energy (J)

h = Planck's Constant (6.63×10^{-34} Js)*

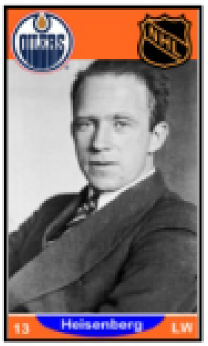
f = frequency (s^{-1})

*Note: Planck's constant can be expressed another way, 4.14×10^{-15} eVs.

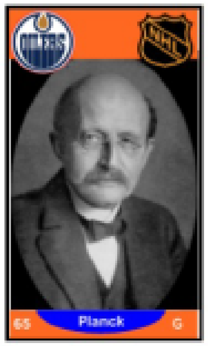
Enter: Quantum Physics

In the first half of the rockingest centry of all (the 20th century), an All Star Team of Physicists came up with a more precise model of the atom.

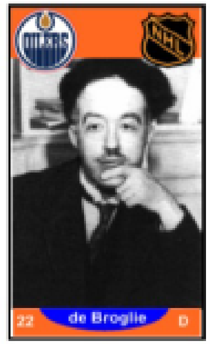
The Team Included:



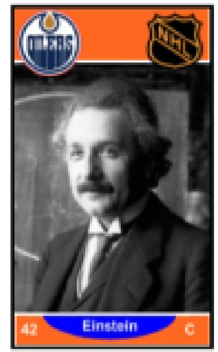
Werner Heisenberg



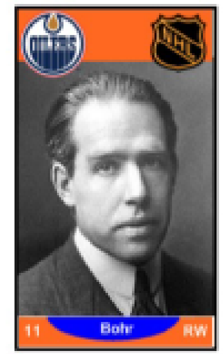
Max Planck



Louis de Broglie



Albert Einstein



Neils Bohr

Erwin Schrodinger

This theory could explain why certain blackbodies produced certain frequencies of light: perhaps different elements released different amounts of energy when heated. But why?

$$\Delta E = hf$$

To fully answer what was happening inside atoms that become blackbodies, another physicist had to come onto the scene…

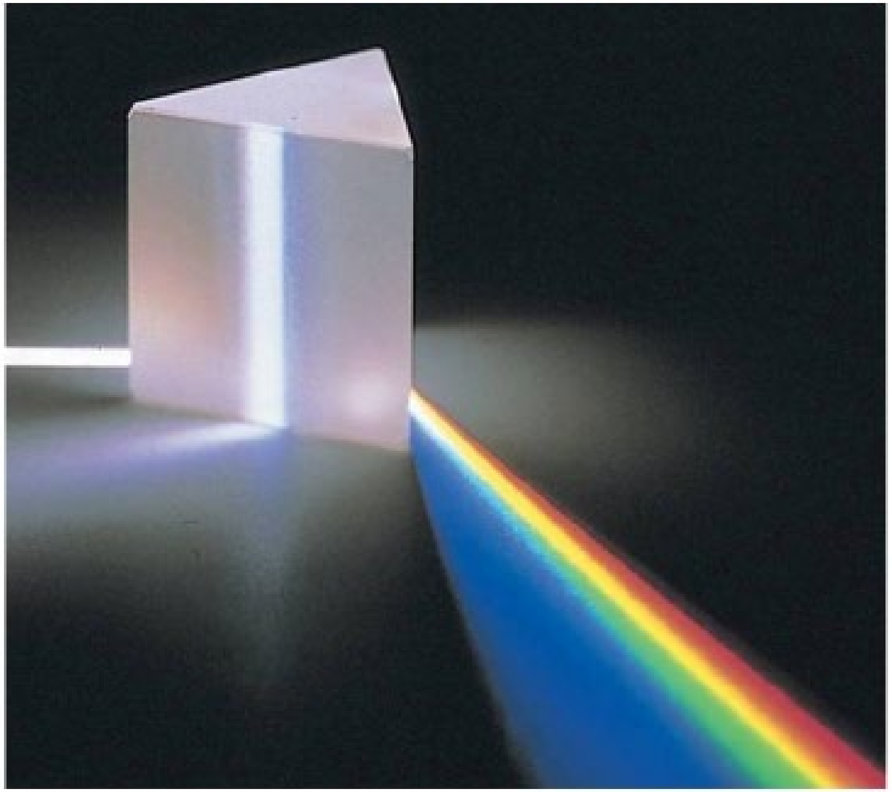
In 1905, a young Albert Einstein took Planck's idea of quantization of energy and stretched it a little further.

Einstein proposed that energy was not the only matter that was quantized: he proposed that light was also quantized.

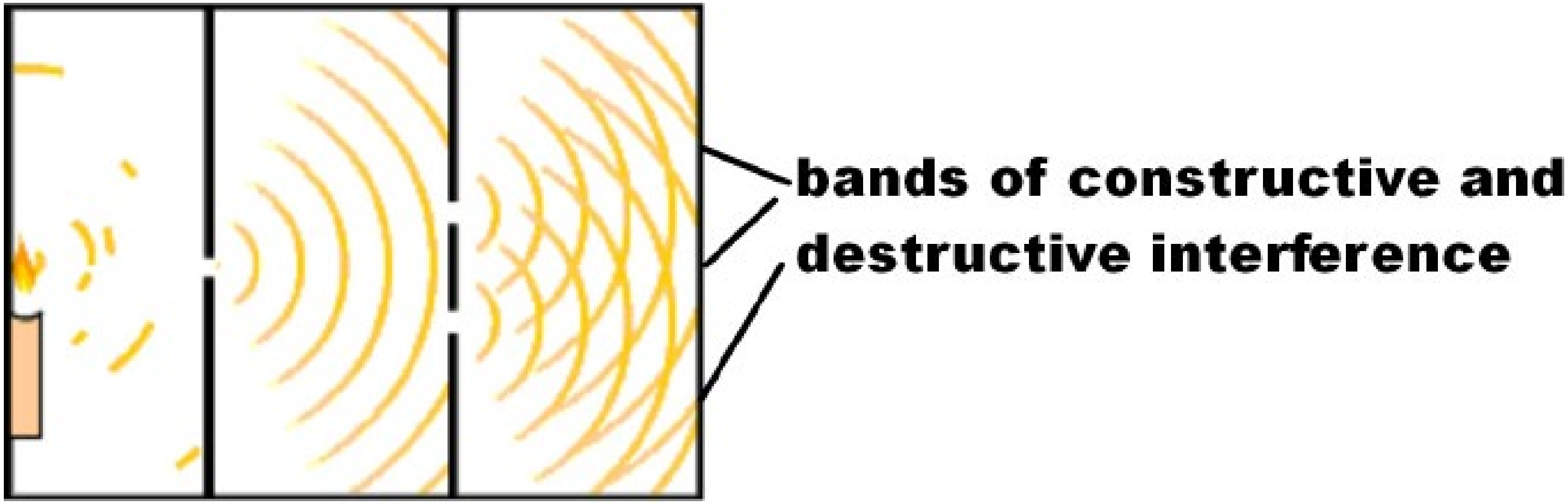
Einstein's little quantums of light were later called (by chemist Gilbert Lewis (LDD)) *photons*.

This was a bold statement because at the time, there was a lot of evidence that light was a wave, not a particle.

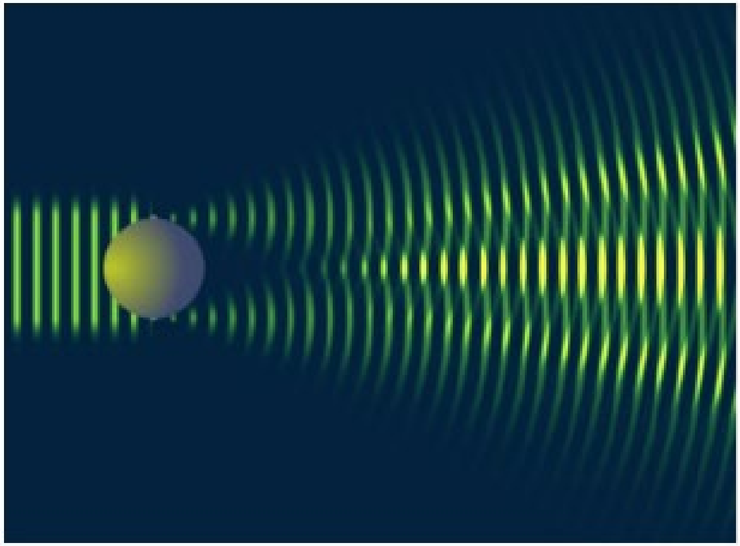
Wave Evidence: Refraction



Wave Evidence: Young's Double Slit



Wave Evidence: Diffraction



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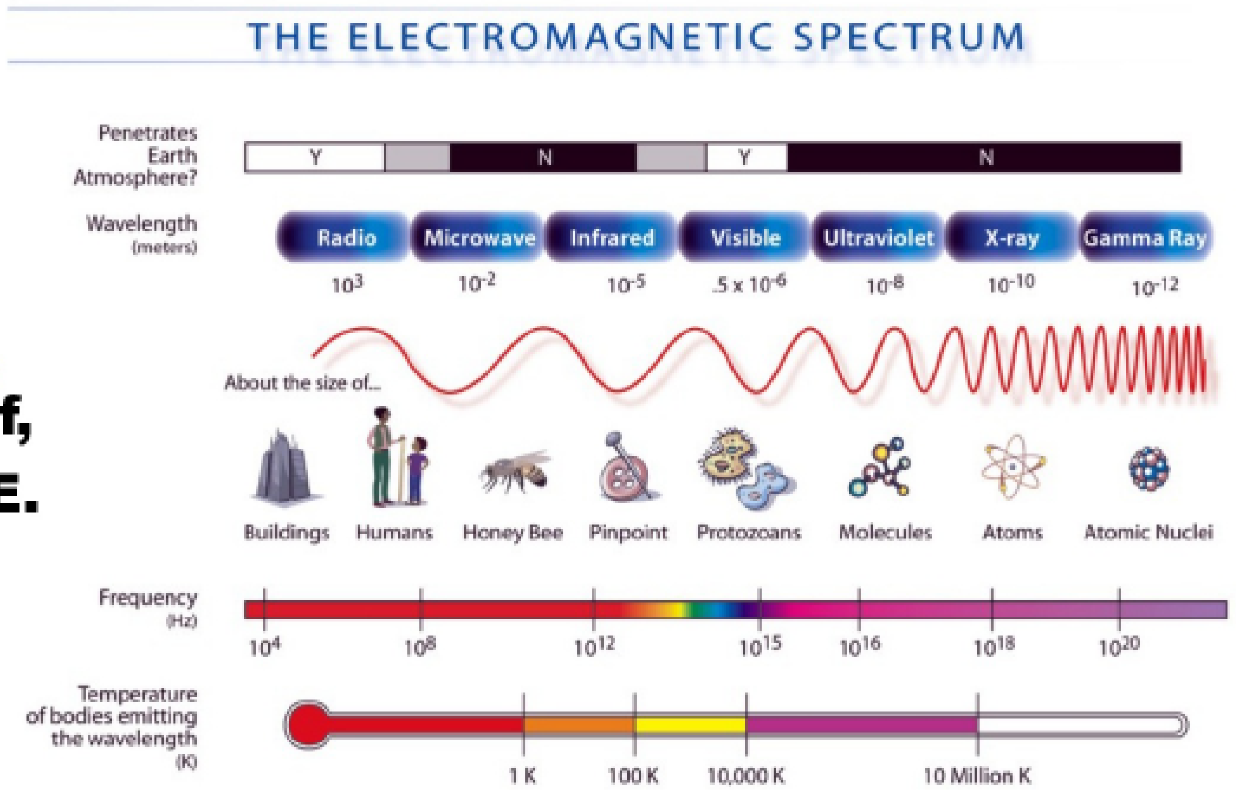
Plank's equation makes understanding the EMR spectrum easier as well:

$$E = hf$$

The higher the f, the higher the E.



So, is light a wave, or a particle?

The answer to that question is for another day, right now, let's try some calculations:

ex) What is the energy of a cute green photon of frequency 4.00 x 10^{14} Hz?

ex) How many photons of red light (600 nm) are required to deliver 10 J of energy?

ex) How many green-photons (550 nm) are emitted every second by a laser of output 0.500 mW?

Examples

- **1. How much energy does a photon (quantum) with a frequency of 2.00×10^{14} Hz have in J and eV?**
- **2. What is the wavelength of a photon having 5.97×10^{-15} J of energy? What part of the EMR spectrum is this?**
- **3. How many photons are given off each second by a green (λ = 555 nm) 60.0 Watt light bulb?**