TOWARDS QUANTUM MECHANICS

"Quantum mechanics" is the description of the behaviour of matter and light in all its details and, in particular, of the happenings on an atomic scale. Things on a very small scale behave like nothing that you have any direct experience about. They do not behave like waves, they do not behave like particles, they do not behave like anything that you have ever seen.

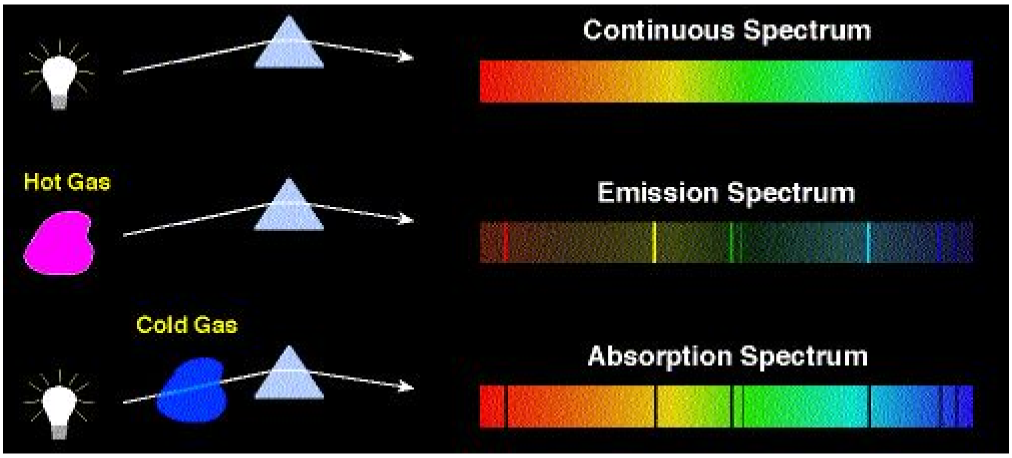
THE POTTER'S GUIDE

TEMPERATURE (° C)	COLOUR
550	DARK RED
750	CHERRY RED
900	ORANGE
1000	YELLOW
1200	WHITE

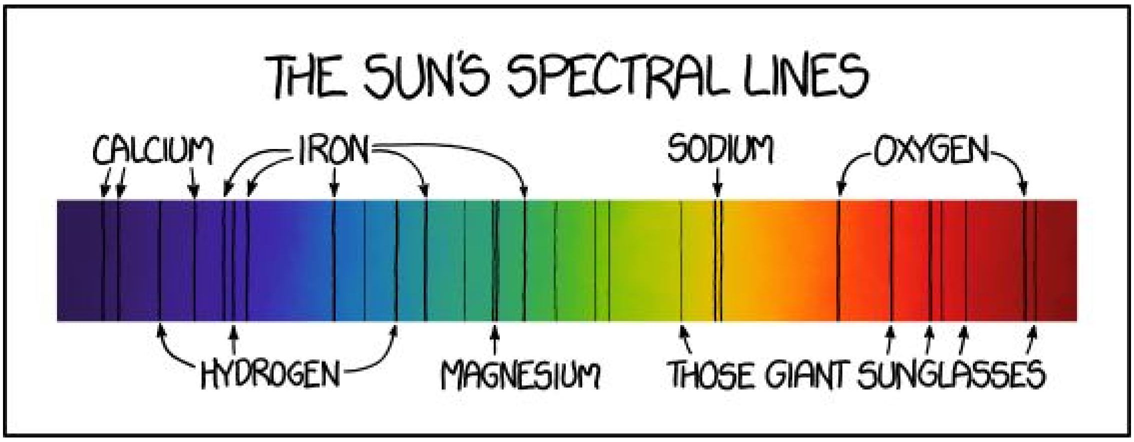
A potter named JOSIAH WEDGEWOOD in 1792 noted that all bodies become red at same temperature . From his observations it was clear that each colour is associated with a particular temperature or vice versa.

SCOTTISH PHYSICIST THOMAS MELVILL FOUND THAT SPECTRUM OF LIGHT FROM HOT GASES WHEN PASSED

THROUGH A PRISM WAS COMPLETELY DIFFERENT FROM RAINBOW LIKE SPECTRUM.



WHITE LIGHT PASSING THROUGH PRISM PRODUCES CONTINUOUS SPECTRUM WHILE A LINE SPECTRUM IS OBSERVED WHEN HOT GAS IS USED AS SOURCE. IF WE USE COLD GAS WE GET DARK LINE SPECTRUM. THE COOL GAS ABSORBS LIGHT PRECISELY AT SAME FREQUENCIES AT WHICH IT EMITS LIGHT WHEN HEATED.



JOSEPH VON FRAUNHOFER IN 1814, RECORDED SOLAR SPECTRUM WHICH CONSISTS OF 746 LINES. LATER ON

GUSTAV KIRCHHOFF STUDIED THESE DARK LINES. THIS WAS ONE OF MANY PHENOMENA THAT CLASSICAL PHYSICISTS COULDN'T EXPLAIN PROPERLY.

The Birth of Quantum Physics.. watch it……..
https://www.youtube.com/watch?v=i1TVZIBj7UA

(a) BLACK BODY RADIATION

A black body is one which absorbs all the radiation falling on it. The spectral distribution of the radiation emitted by a black body can be derived from the general laws of interaction between matter and radiation.The expressions deduced from the classical theory are known as Wien's law and Rayleigh's law. The former is in good agreement with experiment in the short wavelength end of the spectrum only, while the latter is in good agreement with the long wavelength results but leads to divergency in total energy. According to classical statistics the energy distribution in black body radiation is given by

$$E_\nu \, d\nu = \frac{8\pi V}{c^3} KT\nu^2 d\nu$$

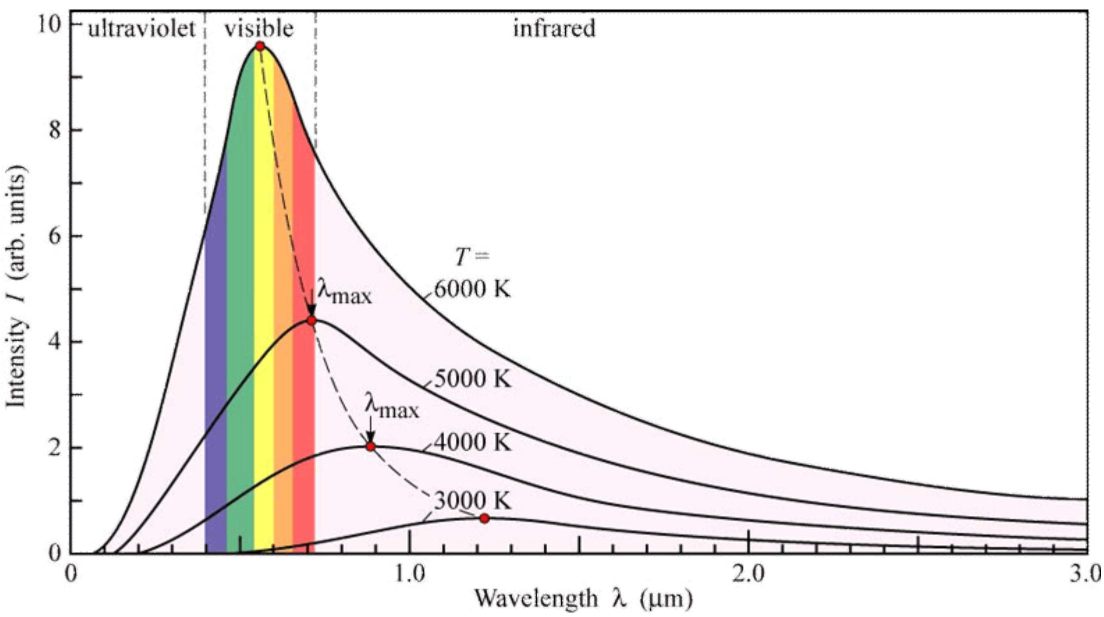
Conclusions

1. There is an infinite total energy in the cavity. This cannot be immediately disproved because total energy is not an observable quantity directly, but is an unpleasant result.
2. The radiation in a cavity has infinite specific heat. This cannot be true because temperature can be raised with finite amount of energy.
3. The specific heat is independent of temperature and total energy is proportional to temperature. This cannot be true since it can be shown

thermodynamically and also experimentally that the total enegy in the cavity is proportional to T^4.

4. The energy is concentrated at high frequencies and energy per unit frequency range is proportional to the square of the frequency. This is not true since experiments show that the energy is a function of frequency, has a definite maximum at a frequency which is a function of temperature.

These contradictions to the experimental results provided a paradox whose solution was found with introduction of Planck's constant h.



Planck in 1900 succeeded in removing the difficulties encountered by classical physics in black body radiation by postulating that energy exchanges between matter and radiation do not take place in a continous manner but by discrete and indivisible quantities, or quanta of energy. He assumed quite arbitrarily for the purpose of obtaining result as: Each normal co-ordinate can vibrate with only such amplitudes which will give it an energy **nhν**. He showed that by assuming that the quantum of energy was proportional to the frequency, **E= hν** ,he was able to obtain an expression for the spectrum which is in complete agreement with experiment:

$$E_\nu = 8\pi h \frac{\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Where h is known as Planck's constant.

(b) PHOTOELECTRIC EFFECT

This refers to the emission of electrons observed when one irradiates a metal under vaccum with ultraviolet light. It was found that the magnitude of the electric current thus produced is proportional to the intensity of the striking radiation provided that the frequency of the light is greater than a minimum value characteristic of the metal, while the speed of the electrons does not depend on the the light intensity, but on its frequency. These results could not be explained by classical physics.

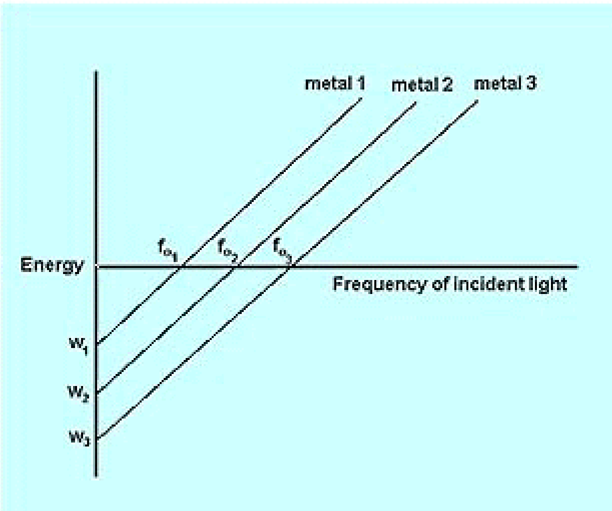
Einstein in 1905 explained these results by assuming light, in its interaction with matter, consisted of corpuscles of energy $h\nu$, called photons. When a photon encounters an electron of the metal it is entirely absorbed, and the electron after receiving the energy $h\nu$, spends an amount of work W equal to its binding energy in the metal, and leaves with a kinetic enrgy

$$\frac{1}{2}mv^2 = h\nu - W$$

Millikan verified Einstein's explanation during years 1912-1917. He obtained linear results so accurate that Einstein's predictions are proved.

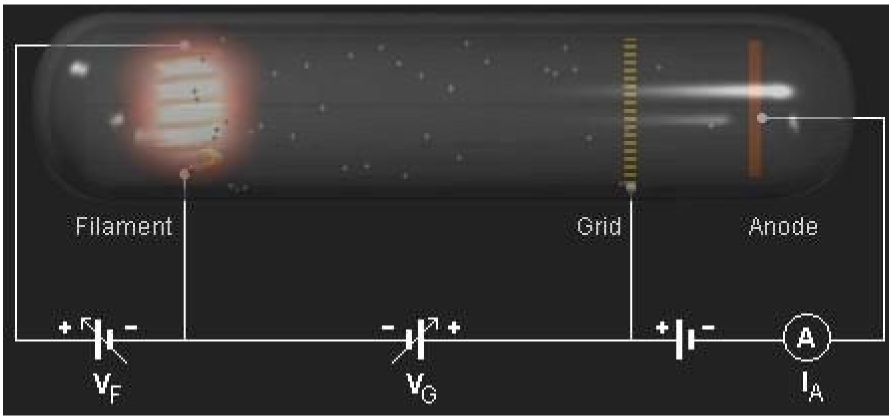
"contrary to all my expectations I am compelled to assert its unambiguous experimental verification inspite of its unreasonableness. The hypothesis was made solely because it furnished ready explanation of the fact that the energy of an ejected electron is independent of the intensity of light but depends on the frequency. I understand that even Einstein himself no longer accepts it."

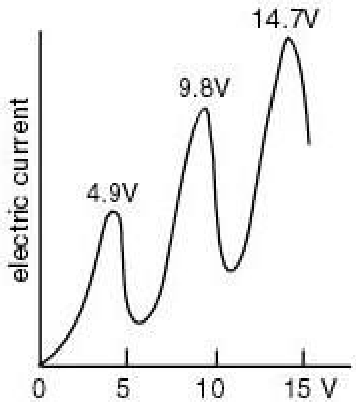
This quantitive theory of photoelectricity has been completely verified by experiment, thus establishing the corpuscular nature of light.



(c) FRANCK-HERTZ EXPERIMENT

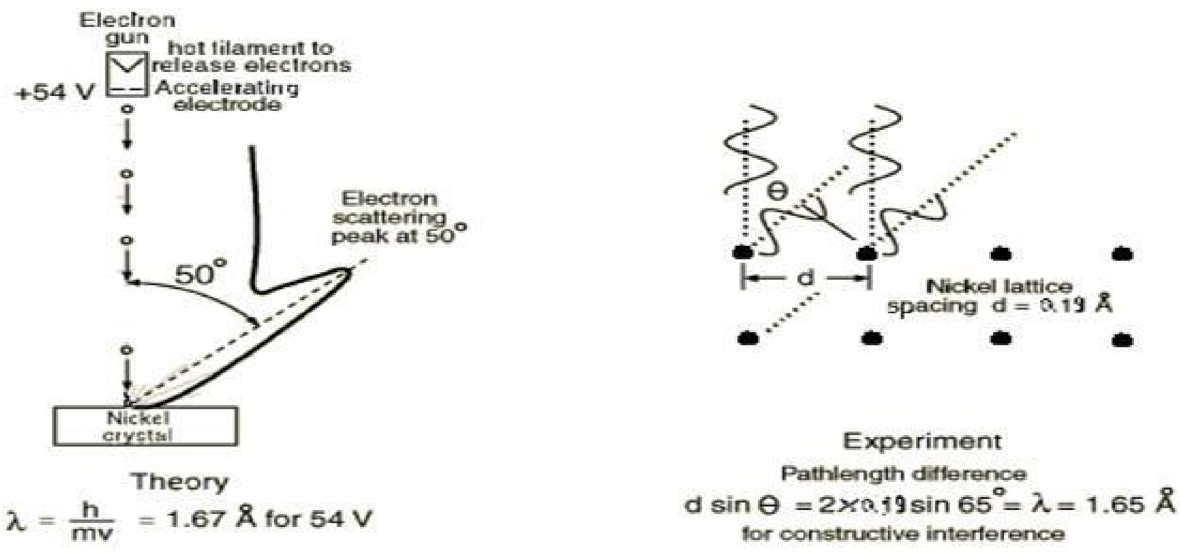
The experiment of Franck and Hertz consisted of bombarding atoms with monoenergetic electrons and measuring the kinetic energy of the scattered electrons, from which one deduced by subtraction the quantity of energy absorbed in the collisions by the atoms. Suppose E_0, E_1, E_2 etc are the sequence of quantized energy levels of the atoms and T is the kinetic energy of the incident electrons. As long as T is below $\Delta= E_1- E_0$, the atoms cannot absorb the energy and all collisions are elastic. As soon as $T> E_1- E_0$, inelastic collisions occur and some atoms go into their first excited states. Similarly, atoms can be excited into the second excited state as soon as $T> E_2- E_0$, etc. This was exactly what was found experimentally. Thus the Franck-Hertz experiment established the quantization of atomic energy levels.





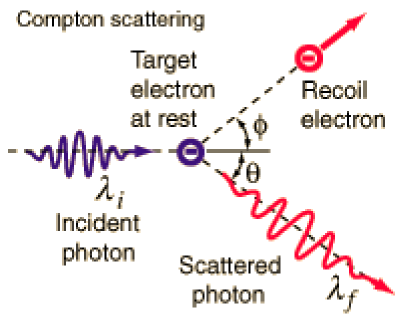
(d) DAVISSON-GERMER EXPERIMENT

The first diffraction experiments with matter waves were performed with electrons by Davisson and Germer(1927). The incident beam was obtained by accelerating electrons through an electrical potential. Knowing the parameters of the crystal lattice it was possible to deduce an experimental value for the electron wavelength and the results were in perfect accord with the de Broglie relation $\lambda = \frac{h}{p}$, where h is Planck's constant and p is the momentum of the electrons.



Davisson and Germer Experiment

(e) COMPTON SCATTERING



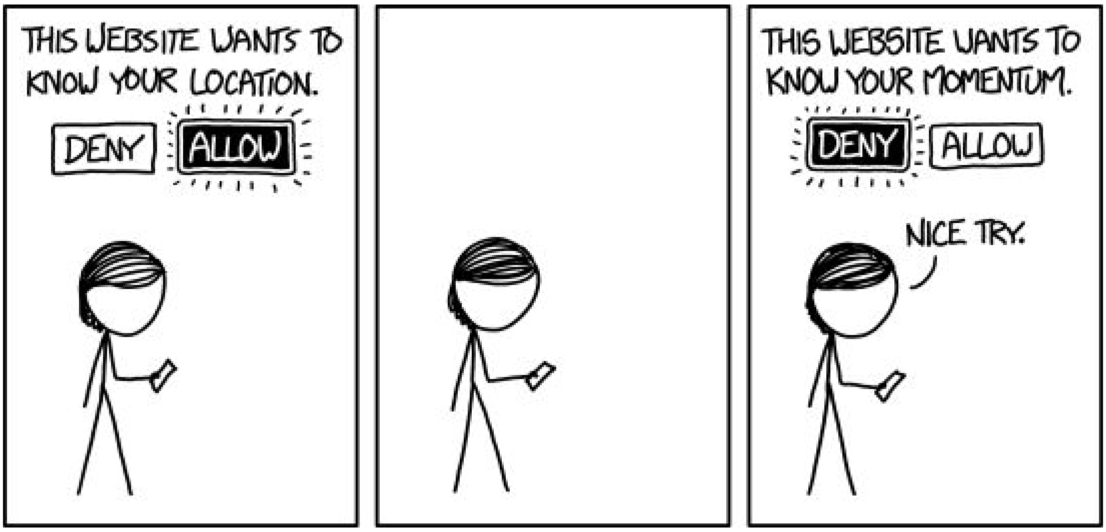
Compton observed the scattering of X-rays by free electrons and found the wavelength of the scattered radiation exceeded that of the incident radiation. The difference Δ λ varied as a function of the angle θ between the incident and scattered directions:

$$\Delta\lambda = 2\frac{h}{mc}\sin^2\frac{\theta}{2} \;,$$

where h is Planck's constant and m is the rest mass of the electron. $\Delta \lambda$ is independent of the incident wavelength. The Compton effect cannot be explained by any classical wave theory of light and is therefore a confirmation of the photon theory of light.

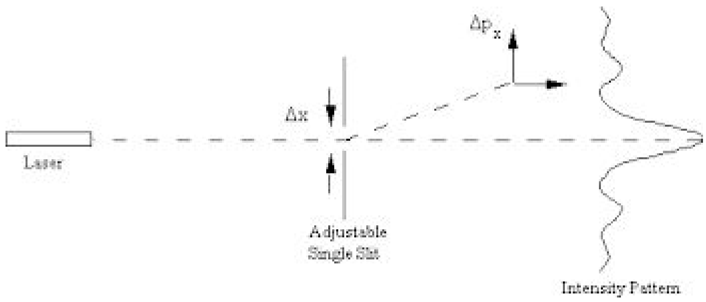
THE UNCERTAINTY PRINCIPLE

This is the way Heisenberg stated the uncertainty principle originally: If you make the measurement on any object, and you can determine the x-component of its momentum with an uncertainty Δp, you cannot, at the same time, know its x- position more accurately than $\Delta x \geq \frac{\hbar}{2\Delta p}$, where ħ is a definite fixed number given by nature. It is called the "reduced Planck constant", and is approximately 1.05×10^{-34} J-s. The uncertainties in the position and momentum of a particle at any instant must have their product greater than half the reduced Planck constant.



The uncertainty principle 'protects' quantum mechanics. Heisenberg recognized that if it were possible to measure the momentum and the position simultaneously with a greater accuracy, the quantum mechanics would collapse. So he proposed that it must be impossible. Then people sat down and tried to figure out ways of doing it, and nobody could figure out a way to measure the position and momentum of anything with any greater accuracy.

$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$



There is an uncertainty principle for every pair of observables whose operators do not commute known as incompatible observables. Incompatible observables do not have shared eigen functions, ie. they cannot have a complete set of common eigen functions. For further information on expectations, momentum and uncertainty see (https://ocw.mit.edu/courses/physics/8-04-quantum-physics-i-spring-2013/lecture-notes/MIT8_04S13_Lec04.pdf)

References:

1. The Feynman LECTURES ON PHYSICS, Feynman, Leighton, Sands.
2. Poblems and Solutions on Quantum Mechanics, The physics coaching class, University of Science and Technology of China.