"Does God play dice?"

– Albert Einstein

Introduction & The Fall of Classical Thermodynamics - The Quantization of Light

In the 1900s there was a puzzle concerning the emission of blackbody radiation. The traditional method of calculating the wavelength and the corresponding temperature of a blackbody then was to use the Wien's law at short wavelengths and the Rayleigh-Jeans law for longer wavelengths. One of the clearest indications that something obviously and terribly wrong with the framework of thermodynamics of 1900s was the so-called "Ultraviolet Catastrophe." This in turn led to Planck's formulation of his law of blackbody radiation, from which the Stefan-Boltzmann law is now derived. Planck also published another equation:

$$E = hf \quad (1)$$

This equation relates the energy to the frequency of the wave. This in turn led to the full-fledged development of Quantum Mechanics, after Einstein quantized light, given by Einstein's Photoelectric Equation:

$$hf = W + \tfrac{1}{2}mv^2 \quad (2)$$

This equation (which brought Einstein the Nobel Prize) successfully accounted for the existence of a threshold electron emission frequency ($hf_0 = W$) and the dependence of the electrons' kinetic energies on the frequency of the incident wave packets. Indeed, after this many others came into the picture, such as Heisenberg, Schrödinger, Dirac, Pauli and, of course, many others.

Heisenberg's Uncertainty Principle

Quantum Mechanics is primarily the study of the microcosm. At this range of sizes ($\approx 10^{-6} cm$), no event can be predicted with a 100% certainty that it ***will*** happen, only that its happening is a possibility, but even then that event can never occur with a 100% certainty. This occurs as a consequence of Heisenberg's celebrated Uncertainty Principle, in short, it is:

$$\Delta x_{(x,y,z)} \Delta p_{(x,y,z)} \geq h$$

This means that there will always be uncertainty in the "exact" values of *x*, which is the position, and *p*, which is the momentum value (there is also another uncertainty relation $\Delta E \Delta t \geq h$, *E* for energy and *t* for time). For greater certainty in the measurement(s) of a particle's *x* value (which is achieved by using probing radiation with shorter wavelengths), there would inevitably be greater uncertainty in the particle's *p* value. The inverse also proves true, for in this case probing radiation of longer wavelengths are preferred since lesser energy is imparted to the particle as compared to shorter wavelengths, and hence the particle's *p* value will not deviate from the value before the disturbance too much. In either case the law of Uncertainty still holds, since both values will deviate, by varying amounts, but the deviation is always greater than 6.63×10^{-43} erg per sec divided by 2 π, $\hbar$. This law is the foundation on which much of Quantum Mechanics was built on. Another point to note would be that there is still uncertainty in the values *x* and *p*, even when no one's watching them. The simple reason is due to the wave-particle duality, expressed simply by:

$$\lambda = \frac{h}{p}. \quad (3)$$

Henceforth the two main principle of Quantum Mechanics that one ***must, at all times***, remember are that there is an irreducible "amount" of uncertainty in Nature, but that the effects of uncertainty is more easily measured in the microcosm, and that energy and matter are always quantized (a wave packet is the quantized form for a smallest unit of a wave, e.g. a photon). Although these two principles are important, one must also not leave the other postulates, and an excellent description of them can be found at:
http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/qm.html#c2

The Photoelectric Effect

The photoelectric effect is, as its name suggests, the effect of electron emission(s) when irradiated with light of a particular frequency. Let's take a look at some of the observations of this phenomenon.

1. The kinetic energies of the emitted electrons is dependent on the frequency of the incident radiation, not the intensity
2. The number of electrons emitted is directly proportional on the intensity of the incident radiation, not the frequency
3. Instantaneous emission occurs as the surface is irradiated
4. There is a threshold frequency for electron emission

All of these observations could be explained by the postulation that light is quantized and that a photon can only be absorbed by an electron at a time. This postulate explains why there is an increased number of electrons emitted as the intensity of the incident radiation increases (there are more photons incoming), and also why the kinetic energies of the emitted electrons is frequency dependent; the frequency of the incoming wave packet increases the corresponding energy and hence momentum increases. In fact, this also directly explains why there is a threshold frequency for electron emission: different amounts of energy (reflected in the frequency, and of course, wavelength) is needed to kick the electron to the ionization energy level in the electron orbitals (shells), and this is exactly what $W = hf_0$ means, and all of this simplicity expressed neatly in $hf = W + \frac{1}{2}mv^2$.