Note: If you cannot access the simulation hyperlinked below, the reading and annotations are still relevant…

Before reading this passage, go to the website: http://jersey.uoregon.edu/vlab/elements/Elements.html. (need Java…) **When the colored periodic table appears, select the button for "Emission". Click on Hydrogen to see the emission lines that are mentioned below. Now click on a variety of other elements to see each one's unique emission spectrum. Then read the passage. Annotations are included to help you follow the explanation for these spectral lines and why a "new" kind of physics was needed to explain atomic structure. Make an effort to read between the notes!**

Niels Bohr (1885-1962)

On the Spectrum of Hydrogen* (address to the Physical Society of Copenhagen, **December 20, 1913**

Hydrogen possesses not only the smallest atomic weight of all the elements, but it also occupies a peculiar position both with regard to its physical and its chemical properties. One of the points where this becomes particularly apparent is the hydrogen line spectrum.

The spectrum of hydrogen observed in an ordinary Geissler tube consists of a series of lines, the strongest of which lies at the red end of the spectrum, while the others extend out into the ultra-violet, the distance between the various lines, as well as their intensities, constantly decreasing. In the ultraviolet the series converges to a limit. ...

We shall now consider the second part of the foundation on which we shall build, namely, the conclusions arrived at from experiments with the rays emitted by radioactive substances. I have previously here in the Physical Society had the opportunity of speaking of the scattering of α rays in passing through thin plates, and to mention how Rutherford (1911) has proposed a theory for the structure of the atom in order to explain the remarkable and unexpected results of these experiments. I shall, therefore, only remind you that the characteristic feature of Rutherford's theory is the assumption of the existence of a positively charged nucleus inside the atom. A number of electrons are supposed to revolve in closed orbits around the nucleus, the number of these electrons being sufficient to neutralize the positive charge of the nucleus. The dimensions of the nucleus are supposed to be very small in comparison with the dimensions of the orbits of the electrons, and almost the entire mass of the atom is supposed to be concentrated in the nucleus. ...

Let us now assume that a hydrogen atom simply consists of an electron revolving around a nucleus of equal and opposite charge, and of a mass which is very large in comparison with that of the electron. It is evident that this assumption may explain the peculiar position already referred to which hydrogen occupies among the elements, but it appears at the outset completely hopeless to attempt to explain anything at all of the special properties of hydrogen, still less its line spectrum, on the basis of considerations relating to such a simple system.

Let us imagine for the sake of brevity that the mass of the nucleus is infinitely large in proportion to that of the electron, and that the velocity of the electron is very small in comparison with that of light. If we now temporarily disregard the energy radiation, which, according to the ordinary electrodynamics, will accompany the accelerated motion of the electron, the latter in accordance with Kepler's first law will describe an ellipse with the nucleus at one of the foci. These expressions are extremely simple and they show that the magnitude of the frequency of revolution as well as the length of the major axis depend only on W, the work which must be added to the system in order to remove the electron to an infinite distance from the nucleus; and are independent of the eccentricity of the orbit. By varying W we may obtain all possible values for the frequency of revolution and the major axis of the ellipse. This condition shows, however, that it is not possible to employ Kepler's formula directly in calculating the orbit of the electron in a hydrogen atom. For this it will be necessary to assume that the orbit of the electron cannot take on all values, and in any event the line spectrum clearly indicates that the oscillations of the electron cannot vary continuously between limits. The impossibility of making any progress with a simple system like the one considered here might have been foretold from a consideration of the dimensions involved.

It can be seen that it is impossible to employ Rutherford's atomic model so long as we confine ourselves exclusively to the ordinary electrodynamics. But this is nothing more than might have been expected. As I have mentioned, we may consider it to be an established fact that it is impossible to obtain a satisfactory explanation of the experiments on temperature radiation with the aid of electrodynamics, no matter what atomic model be employed. The fact that the deficiencies of the atomic model we are considering stand out so plainly is therefore perhaps no serious drawback; even though the defects of other atomic models are much better concealed they must nevertheless be present and will be just as serious.

Quantum theory of Spectra

Let us now try to overcome these difficulties by applying Planck's theory to the problem.

In assuming Planck's theory we have manifestly acknowledged the inadequacy of the ordinary electrodynamics and have definitely parted with the coherent group of ideas on which the latter theory is based. In fact in taking such a step we cannot expect that all cases of disagreement between the theoretical conceptions hitherto employed and experiment will be removed by the use of Planck's assumption regarding the quantum of the energy momentarily present in an oscillating system. We stand here almost entirely on virgin ground, and upon introducing new assumptions we need only take care not to get into contradiction with experiment. Time will have to show to what extent this can be avoided; but the safest way is, of course, to make as few assumptions as possible.

With this in mind let us first examine the experiments on temperature radiation. The subject of direct observation is the distribution of radiant energy over oscillations of the various wave lengths. Even though we may assume that this energy comes from systems of oscillating particles, we know little or nothing about these systems. No one has ever seen a Planck's resonator, nor indeed even measured its frequency of oscillation; we can observe only the period of oscillation of the radiation which is emitted. It is therefore very convenient that it is possible to show that to obtain the laws of temperature radiation it is not necessary to make any assumptions about the systems which emit the radiation except that the amount of energy emitted each time shall be equal to $h\nu$, where h is Planck's constant and ν is the frequency of the radiation. During the emission of the radiation the system may be regarded as passing from one state to another; in order to introduce a name for these states we shall call them "stationary" states, simply indicating thereby that they form some kind of waiting places between which occurs the emission of the energy corresponding to the various spectral lines. ...

Under ordinary circumstances a hydrogen atom will probably exist only in the state corresponding to $n = 1$. For this state W will have its greatest value and, consequently, the atom will have emitted the largest amount of energy possible; this will therefore represent the most stable state of the atom from which the system cannot be transferred except by adding energy to it from without. I shall not tire you any further with more details; I hope to return to these questions here in the Physical Society, and to show how, on the basis of the underlying ideas, it is possible to develop a theory for the structure of atoms and molecules.

*[Fysisk Tidsskrift 12, 97 (1914) translated by A. D. Udden ("The Theory of Spectra and Atomic Constitution--Three Essays", 1922) from Forest Ray Moulton and Justus J. Schifferes, Eds., Autobiography of Science (New York: Doubleday, 1950)]