The Atom Down the Ages: The Atom as Radiations

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One of the many achievements to the credit of 19th century Physics was the development by Maxwell, Boltzmann and others of the kinetic theory of matter. Attributing the thermal energy of matter to the random or chaotic movements of its ultimate particles, namely its molecules, many of the physical properties of matter in bulk are explained in a simple manner. Taking for example a gas, even the smallest quantity of it that one can handle in the laboratory contains billions of billions of molecules. Since all of them are alike and behave in the same manner, we have here an ideal field for the application of statistical laws. The conditions are so favourable that probablities become almost certainties. One even wishes the exceptional did occasionally happen, one of those exceptions that are supposed to be requisite to prove the rule. Actually it is one of the few fields where statistics is given no change to tell any of its proverbial lies.

If the gaseous state of matter is amenable to theoretical treatment because of the perfectly chaotic state of the thermal movements of its molecules, the solid state is equally well amenable, because of the perfectly regular arrangement of the (mean positions of the) atoms, about which the thermal movements take place.

One important result that emerges is that our old idealized pictures of a well-developed crystal having perfectly plane boundaries and sharp edges, or of the free, i.e. the undisturbed, surface of a liquid being a perfectly smooth surface ,etc, are no more correct . The pictures get blurred. If we could view these surfaces with a microscope of sufficiently high resolving power, we should see them no smoother than the surface of a sea in a storm; though for all practical purposes, where only macroscopic imperfections count, the surfaces may still be regarded as smooth.

We know today that this blurring is typical of our pictures not only of an assembly of molecules, but of even individual particles, whether they be molecules or atoms , or the more fundamental particles like the electron or the proton. There is an inherent fussiness about our pictures of them, which cannot be avoided and which suggests their resemblence more to a packet of waves, than to localised particles. Indeed the wave and the particle aspects are complementary aspects, both existing at the same time and intimately related to each other. One is reminded of the pre-established harmony between bodies and souls which Leibnitz used to expound, according wo which " Bodies act as though there were no souls, and souls act as though there were no bodies, and both act as though each influenced the other. I shall illustrate these complementary aspects with special reference to the atom, particularly the parts outside the kernel or the nucleus of the atom, and show how they behave as though they resemble a set of standing waves or wave packets rather than localized particles.

One of the cherished concepts of 19th century physics was the permanance and the indivisibility of the atom. With the discovery of the radio activity of some of the heavy elements and the recognition by Rutherpord that the atoms of these elements were disintergrading this concept received a rude shock. The atom which literally means the uncut, and by implication the uncuttable, was splitting into other atoms. The dream of the alchemist, namely the tranmutation of elements, which the 19th century scientist had been at great pains to demonstrate was just a dream, was being enacted before his very eyes. The apparently impossible was being accomplished. Further, in the course of the disintegration enormous amounts of energy, out of all proportion to the quantities involved, were being released.

I I remember a Punch cartoon depicting a boy who ~~afta~~ had just joined a research laboratory, who and after making a few experiments in a test tube, anounces ing to the Professor. " I think, Sir, I have split the atom" and the cartoon depict the look of grave concern-- Evidently for the boy's future- with which the professor reacts to the announcement.

Even the grand old man of science, Lord Kelvin took considerable time to be convinced, especially regarding the internal or atomic origin of the large energies evolved in the course of radio active disintegration. After a strong opposition, Professor Eve records, that "Kelvin, with considerable courage, abandoned his theory ~~publicly~~ publicly at the 1904 British Association Meeting. He also paid a bet of five shillings to R.S.Strutt, the present Lord Rayleigh, who had a few months previously backed the view that Kelvin would shortly ~~xix~~ fall in line with Rutherford's ideas.

There is an unconscious irony in Kelvin's opposition to the internal or the atomic origin of the energies evolved in the course of the radi active disintegration, since precisely such a source of large energy is needed to reconcile the very low estimates made by Kelvin, from certain obvious physical considerations, regarding the age of the earth with the much large age adopted by the geologists then, and generally accepted today. Knowing the rate at which the temparature of the earth increases as we go deeper and deeper below the surface of the earch, and knowing also the thermal conductivity of the material of the earth, it is easy to calculate the epoch when the earth's crust should have solidified. Making such a calculation, Kelvin found that it must have happened some 50 million years ago. This age however, appeared, even to the most accommodating among the geologists to be far too short a span, within which to compress the various known geological epochs. The geologists would have preferred a period of two to three thousand million years, i.e. nearly 50 times that allotted by Kelvin.

Some independent calculations made by Helmholtz on the age of the sun, which gave about 20 million years, seemedto len suppogt to Kelvin's low estimates, since the earth can not be older than the parentx namely the sun. Helmholtz's estimate is based upon cetain very simple, and convincing considerations We know the rate at which we receiving evergy from the sun, from which we one can estimate correctly the rate at which energy is being poured out into space by the sn. Assuming that the sun had been shining all along at the present rate- we have some evidence that thisassumption can not be far wrong- and knowing all the available sources of energy we can set a maximum limit to the age of the sun. Even if the sun had been originally of infinitely large size, and had contracted to its present size, the energy so released- which was the main source known then- could not have lasted more than 20 million years.

We now know the answer. The Earth isnot coolint as rapidly as Kelvin assumed. Indeed the amount of radi active material present is more than sufficient to prevent it from fol cooling at all. As Rutherford said " the Geologist xxxx can fill in a blank cheque as he will, and can postulate xxxxxxx succes ive heatings and collings such as the series of ice ages and mountain building and vulcanic activity require". At any rate the earth can be very much older than Kelvin estimated. Indeed other estimates from the observed uranium-lead ratios in some of the oldest rocks, do confirm the geologist's claims.

We know also today that the main source of the energy in the sun is atomic due ultimately to the conversion of Hydrogen to helium, in which process a small part of the mass is converted into energy, so that the sun also may be much older than Helmoltz estimated-

Incidentally it is interesting to know when we talk so fre- quently nowadays about atomic energies, that practically the whole of energy output of the sun is atomic, and since all the energy we use on the surface of the earth, whether it is from fuel or coal or patroleum or natural gas, or from a hydro-electric plant is ultimately derived from the sun, all the energy we use today is in sense atomic energy.

the problem is naturally more complicated. But even for complicated atoms the shape and the size of the various orbits the velocities, momenta and energies of the electrons moving in them, can all be calculated in detail on the basis of the Bohr theory, and the spectral characteristics predicted.

In spite of the elegant and almost uncanny way in which the Bohr theory explained the spectral facts, thefundamental assumptions on which the theory was based, were so unconventional, and so radically at variance with classical ideas that even the late Lord Rayleigh who was very receptive to new ideas, did not enthusiastically accept them. How unconventional the fundamental bases were will be realised from a letter from Hevesy to Rutherford in which he reports a conversation with Einstein.in 1914 soon after Bohr published his theory. "Speaking with Einstein on different topics writes Hevesy, "we came to speak on Bohr's theory; he told me that he had once similar ideas, but he did not dare to publish them". That from the most original and unconventional of our thinkers.

But the theory works. Indeed its only drawback is that it explains a little too much. Though the spectral characteristics in which energy changes taking place in the atom are alone involved, are beautifully explained, attempts at verifying the detailed orbital structures, the instaneous positions of the electrons in these orbits, etc., have always proved uninformative. It reminds one of the various negative experiments that preceded the postulate of the theory of relativity, and suggests, like absolute motion in space, these details regarding the electrons in the atom, are unobservables.

Nature has a curious way of hiding her secrets. All the physical quantities in Nature are paired off in such a manner that any attempt to measure precisely one of the ~~complain~~/ components of the pair, is such as to spoil complete

Coming back to the atom, experiments by Rutherford on the scattering of positively charged fast particles, like the X-rays, by matter, showed that the number of such scattered particles even along the backward direction was quite large -- which revealed that the massive and positively charged part of the atom was concentrated in an extremely small region, much smaller than a million millionth part of the whole atom, which we might call the nucleus, and the rest of the atom is just a padding by negatively charged light particles, namely the electrons. Their number is the same as the number of positive charges in the nucleus, which is also the number assigned to the atom in the Periodic Table of elements.

The nucleus in which almost the whole mass of the atom is concentrated has itself a compositive structure, as is revealed by radioactive disintegration. Its detailed structure, as built of two kinds of heavy particles namely the proton which is positively charged, and the neutron which is not charged at all, is a fascinating study. It is not, however, quite relevant to the subject of my talk, and I shall confine myself to the external padding or cloud of electrons, which forms the extensive atom as we know it.

The greatest advance in our understanding of the structure of this exterior padding or electronic cloud came from Niels Bohr Jaking the simplest atom, namely the hydrogen atom, with a single positive charge forming the nucleus, and a single electron outside it, he investigated the shape, the size and the energies of the orbits in which this electron can revolve round the central nucleus. Attributing the emission and absorption of light by the atom to transitions from one orbit to another, Bohr was able to explain quantitatively all the known spectral characteristics of the hydrogen atom.

With other atoms, with a larger number of electrons, all chances of measuring the other component or the conjugate quantity. This is not due to imperfections in our experimental technique, but is inherent to the experiments themselves and will apply even to idealized experiments in thought. Position and momemtum of the electron are two such conjugate quantities, and so are time and energy. The two conjugates are connected respectively with the particle and the wave aspects, so that any attem t at determining the instantaneous positions of the electrons reduces to one of calculating the probabilities. Since the distribution of probability has a wave-form the resemblance of the external electrons in an atom to a set of standing waves or wave-packets follows as a natural consequence. The waves defining the probabilities have been called the waves of knowledge, and quite appropriately since they contain all the knowledge we can hope to obtain regarding the cloud of electrons revolving round the nuclars of the atom.