A. Vibert Douglas "Hydrogen"

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Loc 2303.9
Box 4
File 14

Hydrogen

Hydrogen is by far the most abundant element in the universe. Next to hydrogen in cosmic importance is helium. All the heavier elements of the chemists' table—lithium, beryllium, boron, carbon, nitrogen, oxygen and soon up to uranium which is number 92 at the end of the list of natural elements—comprise perhaps not more than one percent of the material content of the universe.

Cosmologists have good reasons for believing that this is true for stars in general, not only the hundred thousand million stars in our own galaxy or Milky Way system but for the stars in the millions of other galaxies comparable to our own; and true also for the vast quantities of matter thinly distributed in interstellar space within each galaxy.

Obviously the Earth and other planets, the satellites, comets and meteors are exceptions in that they have lost most of their hydrogen and helium into interstellar space, not being sufficiently massive bodies to be able to retain these light gases by gravitational attraction. It should be remembered however, that all these non-selfluminous bodies of the solar system do not add up in total mass to one seven hundredth of the mass of the sun, and the sun is a very average star. Many stars are of masses down to one fifth that of the sun, a few as low as one tenth, but many are two or three times more massive than the sun and some are up to ten times, while others (though a relatively small proportion) appear to exceed this.

The evidence for the overwhleming predominance of hydrogen in the universe is both spectroscopic and theoretical. It came to a head in 1932 when Sir Arthur Eddington in Cambridge and Professor Stromgren in Sweden reached this conclusion independently. Eddington, in the course of his pioneering investigations on the internal constitution of the stars, had assumed for his

theoretical model a rotating sphere of gas of composition not unlike the relative abundance of the various elements in the earth. He had run into persistent difficulties in calculating the opacity of such a star to outward flowing radiation. He knew that agreement with laboratory data on opacity could be obtained if the proportion of hydrogen in the model star were drastically increased, but neither he nor his contemporaries thought this justifiable in the 1920's. Gradually the relative abundance of elements in the photosphere of a star was determined spectroscopically and hydrogen was discovered to be the chief constituent of stellar atmospheres with helium a far off second and all the heavier elements forming but a small fraction of the whole. By 1932 the existence of powerful convection currents beneath the surface layers of a star appeared to have been established theoretically. The deduction that hydrogen atoms far outnumber all others as the stuff of which stars are made could then be drawn, whereupon stellar theory and cosmology entered on a new era.

Granted that hydrogen is the basic substance of the universe, how, when and where have the quite significant quantities of helium come into existence and the relatively minute quantities of all the other ninety elements? Two types of answer may be given. One line of argument depends on the theory of the expanding universe proposed by Professor G. Lemaître of Louvain in 1927. If, "in the beginning" about seven thousand million years ago, all the matter of the universe was concentrated in the form of protons, neutrons and electrons in "a primeval atom" or small volume of immense energy density, the temperature would have been tremendously high and cataclysmic explosion would have taken place with thermonuclear synthesis of atomic nuclei and decay of neutrons until, in some thrity minutes, according to their respective probabilities of

formation and of nuclear stability, approximately the present relative abundances of the different elements would have come into being. The names of Fermi and Turkevich are associated with the calculations of these probabilities and times. With expansion the temperature would fall rapidly and further synthesis of heavy elements would cease, leaving the great surplus of hydrogen and helium which has continued to exist through the thousands of millions of years during which gradual condensation of matter into vast galactic units took place. In each galactic volume out of the hydrogen, helium and heavier dust particles condensation into individual stars gradually proceeded and is still taking place at the present time.

The second type of argument presupposes only hydrogen and then proceeds to consider the synthesis of other elements in the deep hot interiors of stars. At central temperatures of the order of 15 million degrees helium is synthesized by proton - proton collisions and by the carbon - nitrogen cycle propounded by Bethe at Cornell. In the former, two hydrogen nuclei (protons) collide with such force that they form a new heavier nucleus of hydrogen, this in turn collides with a proton to form a light helium nucleus, and this in collision with a proton and attracting to itself two electrons forms a normal helium atom. Other sequences of proton collisions can produce small amounts of the lighter elements up to carbon, nitrogen and oxygen. Bethe's cycle involves atoms of those three elements in a sequence of collisions with protons and of nuclear fission resulting in four hydrogen atoms becoming one helium atom with a total liberation of enough radiant energy to explain the output of light and heat from a star like our own sun. The central temperature of the star will slowly mount to heights approaching 100 million degrees. This range of temperature, incidentally, has been produced artificially over brief instants of time by heavy hydrogen collision with resulting nuclear fission and this represents an advance of knowledge which, like all knowledge whether scientific or non-scientific, can be used either for good or for evil purposes.

When the central temperature rises beyond 100 million degrees, in the early old age of a star, the thermonuclear reactions, as recently described by Hoyle,

~~reactions~~ will have transmuted so much of its helium into the elements up to neon that contraction and rise of internal temperature will rapidly follow. At 600 million degrees, sodium and magnesium will be formed; at 1500 million aluminium, silicon, sulphur, phospherus, chlorine, argon, potassium and calcium. If the star began with enough mass (at least 30% more than our sun) its central temperature could attain 2000 million degrees and the formation of iron and to a leaser extent of titanium, chromium, manganese, cobalt, nickel, copper and zinc would proceed.

With continued reduction of its hydrogen and helium content in this vast process (where for example 56 hydrogens are lost for every ordinary iron atom that is formed) the rapidly ageing star may become so unstable that it suffers a "nova" explosion, hurling its own substance, including many of its heavier atoms, into interstellar space. Thus with the passage of aeons of time the interstellar gases have become enriched with more and more heavy atoms, these form molecules and aggregations as dust and frozen crystals capable of producing polarization of starlight.

In these regions of dust clouds and much free hydrogen the youngest stars are being born--born with a head start by having a generous 1% of the heavier atoms including 0.25% of metallic elements, and also 10% of helium in their original make up. Such stars form a distinct contrast to the mature stars which were born when the universe was younger and have perhaps no more than 0.01% of the metallic elements in their composition even after 6000 million years or more.

The globular clusters and the central portions both of our own and other spiral galaxies, and the elliptical galaxies appear to be made up of these older stars and their interstellar spaces are extraordinarily free of dust and

absorbing gases. But the arms of the spiral galaxies appear to be rich in hydrogen and dust clouds, and here are found the young very hot, massive blue giant stars and the young stars of lesser mass and surface temperature, all testifying by their spectra to their greater content of metallic atoms. That our sun is a mature member of this younger group of stars, not massive enough to have evolved rapidly in converting its hydrogen into helium beyond the safety limit, is now very generally accepted.

By observation it is clear that the sun is not near the centre of our galaxy, our Milky Way system. Are we out in a spiral arm? Can we trace the extent of our particular arm and the other arms seen in overlapping perspective between the obscuring dust clouds around the plane of the Milky Way? The affirmative answer has only come in the last four or five years.

The new tool in astronomy is radio and in Professor A.C.B. Lovell's words it has opened a new window on space. Jansky in the United States had found that radio waves are reaching the earth from outer space. Then Reber found a higher intensity, on the average, from the great circle of the Milky Way. Later van de Hulst of Leiden found theoretically that hydrogen under the conditions prevailing in interstellar space should emit a 21cm. radar wave. This was first detected in 1951 at Harvard and now its intensity is being mapped in various directions by astronomers in many countries. Not only does it locate the great concentrations of diffuse hydrogen in direction, and in spite of any intervening dust clouds which are opaque or semi-opaque to visible light, but it makes possible distance measurements so that the spiral arms of our galaxy can be mapped in three dimensions. The well known Doppler relation between the velocity of the source relative to the receiver and the position of the radiation in the spectrum--its wavelength being lengthened with recession and shortened

with approach--is as applicable in the radio spectrum as in the optical or ultra violet range. Because every star and nebula in our galaxy is revolving about the centre of gravity of the galaxy, and because these velocities are greatest near the centre in accordance with Kepler's law of orbital velocities, it is possible to calculate the velocities which nebulae or stars would have at different distances. This together with the knowledge of our solar system's distance from the centre(26,000 light years where the distance unit one light year is approximately six million/miles) and the information given us by the Doppler shifts of the 21cm hydrogen line enable us to determine the distance of the atoms emitting the radiation.

A beautiful example of the ability of this method to differentiate between three distinct concentrations of hydrogen in the same direction is shown on a radio record recently obtained with the Harvard radio telescope. Instead of one line agreeing exactly with the 21cm position on the spectrum, or in other words corresponding to a radio pulse of frequency 1420 megacycles, the record shows three lines, one relatively weak and two very strong, with Doppler displacements which indicate that the weakest originates in a very remote hydrogen cloud, while a much greater concentration lies at an intermediate distance between the remote cloud and an almost equally extensive hydrogen region which lies relatively near to us.

At the meeting of the International Astronomical Union in Dublin in early September 1955 a three dimensional model was shown of the arms of the Milky Way in a wide sector surveyed by the Leiden observers. A few years ago such an achievement would have seemed a visionary unattainable hope.

If one meditates on the significance of hydrogen in the universe, ponders the problem of its origin, and speculates about the far off future when the

original amount of hydrogen has been largely transformed into other elements, many problems present themselves. We may ask, Why is hydrogen the basic substance? Very few, if any, living cosmologists will attempt an answer. An effort to supply a fundamental answer was made in 1931 by Eddington, but in the form in which the argument was left at the time of his death in 1944, it had still not carried conviction; and yet it is suggestive of a mode of approach worthy of further study. Eddington formulated a quadratic equation the coefficients of whose terms were 10 and 136, the latter being the number of degrees of freedom (omitting one for interchange) of two charged particles and the former being associated with the momentum of a particle. The roots of this equation are in the ratio of the mass of the proton to the mass of the electron and suggest that these two basic particles of matter are of necessity the ultimate units of matter. One of each of these, carrying equal and opposite electric charge in spite of a mass ratio of about 1836, constitute a hydrogen atom.

Some cosmologists dislike the idea of a finite time since the instant of creation of the universe, and have sought an alternative theory. Jordan in Germany and Bondi, Gold and Hoyle in Great Britain have investigated the implications of assuming a large scale uniformity of the universe not only in space but in time. This means neither a beginning nor an end; and it assumes continuous creation of matter throughout space to maintain the density which would otherwise become progressively lower with the expansion of space. From the actual rate of recession of the distant galaxies, it is found that the rate of appearance of matter ex nihilo would have to be one atom of hydrogen per cubic mile of space per hour. This is much too small for observational detection even if it is taking place. Assumptions about creation from which various

cosmologies are developed must be selected at present on a basis of intellectual or aesthetic preference. As far as religious feeling is concerned there is no less mystery and sublimity about one of the following statements than about the other: "In the beginning God created ....." "From eternity God has been creating ....." On the latter assumption galaxies are formed and their individual stars run their evolutionary courses and eventually become extinct but the supply of new hydrogen from which yet other stars and clusters and galaxies are formed is never exhausted.

If, as most astronomers seem inclined to do, we reject the theory of continuous creation of hydrogen, is there any process at work in the universe renewing the stores of hydrogen to some extent at least by the disintegration of helium and heavier atoms? Possibly an agent of this sort is to be found in the extraordinarily high energy particles known as cosmic rays, some of which appear to attain energies corresponding to a thousand million million volts. Recently the swedish physicist, Alfven has investigated the remarkable properties of what are called "magneto hydro dynamic" waves in a deep bowl of mercury subjected to a magnetic field. By analogy the results are applied to a large ionized gaseous body like a star and to the far vaster regions of hydrogen and ionized hydrogen in the spiral galaxies, where these waves may be surging through interstellar space with its wide spread magnetic fields, generating weak electric fields which because of their vast extent can accelerate charged particles to velocities that are capable of disrupting any nucleus and releasing its imprisoned protons. Here is an almost unexplored field. Truly it may be said that eye hath not seen nor ear heard and scarcely hath it entered into the mind of man to conceive the things which Nature may still be holding in store for them that seek.