member of the academic council and the senate for many years and also of its syndicate for a time. As chairman of the Board of Studies in Chemistry of Madras University, he played an important part in improving standards of teaching and examination in the university. Many of the leading universities in India had the privilege of receiving his advice and help. He served as a member of the enquiry committee of Calcutta University in 1954 and also as chairman of the Secondary Education Commission of the West Bengal Government in the same year. He was a founder-member and president of the Bengali Association of Madras, and also president of the South Indian Brahmo Samaj over a period of many years. He was elected president of the Indian Chemical Society during 1943–1944 and took a keen interest in its activities throughout his life.

Dey passed away peacefully on the night of 18 January 1959, deeply mourned by all who had the privilege of knowing him. No one can deny that he had made a profound impact on chemistry in India. He was one of the great pioneers who established and cultivated the tradition of research in Indian universities. He ranks high among the great builders of modern India by his inspiring work as a teacher and his contributions as a research scientist of the highest calibre.

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RESEARCH NEWS

Large atoms in interstellar space

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In interstellar space atoms spend most of their time in the ground state. However, under suitable conditions it is possible to find some atoms in highly excited states with large principal quantum numbers ($n > 500$). During a recent visit to the Raman Research Institute, A. A. Konovalenko described his observations of carbon atoms in interstellar space with principal quantum numbers as large as 768! The 'classical radius' of such atoms is $\sim 5\,\mu m$ and they can be considered as the largest atoms yet observed in either a terrestrial laboratory or an astronomical object. These atoms are observed through their characteristic absorption spectrum when the atom jumps from the excited state $n = 768$ to $n = 769$ by absorbing radiation from a background astronomical source. The frequency of this absorption line is near 14.5 MHz (wavelength ~20 metres!) and requires, for its measurement, a radio telescope operating at this frequency. Such a radio telescope, known as UTR-2, is located near Kharkov in the USSR and is operated by the Institute of Radio Astronomy of the Ukrainian Academy of Sciences where Konovalenko works. The first observations of an absorption line at 26.13 MHz, in the direction of the strong radio source Cassiopeia A, was made using this telescope by Konovalenko and Sodin in 1980 (ref. 1). This absorption line was correctly identified by Blake, Crutcher and Watson[2] as due to excited carbon atoms with principal quantum number of 631. The UTR-2 radio telescope used for these observations is a 'T'-shaped array of 'fat' dipoles stretching about 2 km along the north–south direction and 1 km along the east–west and operates over a frequency range of 12 to 30 MHz. In this frequency range the telescope can be used to observe excited carbon atoms with principal quantum numbers ranging from 600 to 800 or so. The 'T'-shaped radio telescope at Gauribidanur near Bangalore, which was constructed jointly by the Raman Research Institute and the Indian Institute of Astrophysics, is somewhat similar to the UTR-2 telescope, but operates over a narrow band of frequencies around 34.5 MHz (see accompanying article on 34.5-MHz sky survey, p. 144). This telescope has also been used recently to observe carbon atoms excited to $n = 579$ in the direction of Cassiopeia A (ref. 3).

In the decade since their first discovery, Konovalenko and collaborators have observed excited carbon atoms in several regions of interstellar space using the UTR-2 radio telescope[4]. In the direction of Cassiopeia A, carbon atoms with principal quantum numbers ranging from 600 to 768 have been observed. These are difficult observations requiring anywhere from ten to several hundred hours of integration per detection since the lines are extremely weak ($\sim 10^{-3}$ of the sky background at these frequencies). In addition man-made interference is severe in these bands, which means even longer observations to obtain the required integration after careful editing of the data. Observations of these lines, apart from the novelty of being the lowest frequency spectral lines, tell us something about the nature of the interstellar medium. Carbon atoms in these highly excited states are produced through the process of ionization and recombination. These atoms reside in gaseous clouds containing mostly neutral hydrogen. There is approximately one carbon atom for every 2500 hydrogen atoms in these clouds. The carbon atoms are ionized by the background ultraviolet photons with energies greater than 11.26 eV, which is the ionization potential of carbon. Hydrogen in these clouds is mostly neutral since there are not many background UV photons with energies greater than the 13.6 eV required to ionize hydrogen. The process of ionization is balanced by an equal number of recombinations in which a carbon ion captures a free electron to become neutral again. The process of recombination can leave the electron in a highly excited state. It is these excited atoms that give rise to the low-frequency lines. In radio astronomy parlance these spectral lines are known as radio recombination lines.

Until the discovery by Konovalenko and Sodin[1], recombination lines at radio frequencies were observed only from objects known as HII regions, which are hot clouds of ionized gas surrounding young bright stars in the Galaxy. These stars can emit UV photons with energies sufficient to completely ionize hydrogen and to some extent helium, and heat the HII regions to temperatures of about 10,000 K. Radio recombination lines from HII regions are observed from much lower principal quantum numbers ($n = 70$–200) and are always found in emission. On the other hand, recombination lines of carbon with high principal quantum numbers ($n > 500$) described above are observed in absorption and come from cold clouds with temperatures of about 100 K. Since there are no stars in them, the ionizing and heating sources for these clouds are the background UV radiation and cosmic rays in the Galaxy. Such cold clouds are more numerous than HII regions in the Galaxy and they constitute an important component of the interstellar medium. Observation of excited carbon atoms in these clouds can lead to a determination of their density and temperature, which are important parameters for an overall understanding of the interstellar medium.

Whether a recombination line is observed in emission or absorption depends on the relative population of atoms in the adjacent quantum levels between which the transition takes place. This relative population can be characterized by the excitation temperature (T_{ex}) of the quantum levels using the Boltzmann equation

$$\frac{N_n}{N_m} = \frac{g_n}{g_m} \exp\left(-h\nu_{nm}/kT_{ex}\right)$$

where N_n is the number of atoms with electrons in the upper quantum level n and g_n is the statistical weight of the level, and ν_{nm} is the frequency corresponding to the energy difference between the levels n and m. In general, at very high quantum levels, upper levels are less populated than the lower levels, leading to a positive excitation temperature which is nearly equal to the kinetic temperature of the clouds (20–100 K). This happens because collision-induced transitions (mainly due to free electrons in the cloud) between the high quantum levels dominate over radiative transitions and the populations in these levels approach thermodynamic equilibrium values. At frequencies corresponding to the transitions between these high quantum levels (< 100 MHz or so), the brightness temperature of astronomical radio sources is extremely high. For example, at 26 MHz, the brightness temperature of Cas A is $\sim 10^9$ K. In other words at 26 MHz, Cas A emits as much radiation per unit solid angle as a black body heated to 10^9 K. The brightness temperature of the synchrotron radiation, which is seen everywhere in the Galactic plane, is $\sim 10^5$ K at 26 MHz. It is therefore to be expected that the recombination lines from high quantum levels of carbon in the cold clouds appear in absorption against the 'hot' radiation from the background sources at these frequencies. However, at lower quantum levels, collision-induced transitions are less important than radiative transitions, which tend to make upper levels more populated than lower levels, resulting in a negative excitation temperature or inverted population as in the case of a maser. The recombination lines from these levels will therefore always appear in emission regardless of the brightness temperature of the background source. The background radiation will then enhance the line strength through stimulated emission. This reversal from absorption to emission of recombination lines from high quantum numbers of carbon has in fact been observed to occur near a frequency of 150 MHz (or quantum number $n \sim 380$) in the direction of Cas A (ref. 5). The frequency at which this reversal occurs, as well as the variation of the line strength and line width with quantum number, is an indicator of the density and temperature of the clouds. The observations have indicated that the product of density and temperature (which is an indicator of the pressure nkT) in these clouds is about 20,000 K cm^{-3}, whereas the value for the general interstellar medium is believed to be about 3000 K cm^{-3}. Therefore, unless the clouds that contain highly excited carbon atoms are not in pressure equilibrium with the interstellar medium, the observations of these large atoms suggest a need to revise the generally believed value for interstellar pressure.

It has been possible to observe these highly excited carbon atoms because they reside in cold (100 K) interstellar clouds with very low electron densities ($n_e \sim 0.1$ cm^{-3}). Although hydrogen atoms with such high principal quantum numbers may exist in hot HII regions, it is not possible to observe them because the electron density in these regions is relatively large ($n_e \sim 10$–10^4 cm^{-3}). At such densities, and also the high temperature (10,000 K) characteristic of regions where hydrogen is completely ionized, recombination lines from atoms with high principal quantum numbers become extremely weak and are undetectable with present-day radio telescopes. The highest principal quantum number at which hydrogen atoms have been observed in HII regions is ~ 355 (ref. 6). The radio telescope at Ooty operated by the Tata Institute of Fundamental Research is capable of observing hydrogen and carbon atoms in interstellar space excited to principal quantum numbers of ~ 272. Such observations have in fact been carried out in a number of directions in the Galaxy[7].

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