Lecture 4 :Energy generation in stars

At a time when the discovery of neutrons was ten years in the future, when the physics of nuclear transmutation was yet to be developed, Sir Arthur Eddington boldly proclaimed that the Sun's source of energy came from the fusion of Hydrogen into Helium. When skeptics raised doubts about the temperature in the interior of the Sun being adequate for such reactions to take place, Eddington retorted - "..we ask them to go and find a hotter place". Thus was born the field of 'nuclear astrophysics' which would later be shaped by the likes of Hans Bethe, Carl von Weizsacker, George Gammow and finally by the quartet of Margaret Burbidge, Geoffrey Burbidge, William Fowler and Fred Hoyle in the mid-1900s.

Why do the stars shine? How do they generate the energy they radiate? This lecture will explain Eddington's brilliant conjecture that stars generate enormous amount of energy by converting hydrogen to helium. This transmutation of hydrogen requires quantum mechanical tunneling. This notion, as well as the various steps involved in converting hydrogen to helium, are explained in this lecture.

Suggested Reading -

Donald. D. Clayton, 1984, Principles of Stellar Evolution & Nucleosynthesis, University of Chicago Press

For the curious and the advanced -

H. A. Bethe, 1939, Physical Review, **55**, 434

E. M. Burbidge, G R. Burbidge, W A. Fowler & F. Hoyle, 1957, Reviews of Modern Physics, **29**, 547

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Astronomy & Astrophysics : An Introductory Survey

A lecture series by Prof. G. Srinivasan

A 'Golden Jubilee Celebration' Event of the Astronomical Society of India

Lecture 4 : Energy generation in stars

[Supplementary Material : Dr. Sushan Konar]

Suggested Problems

1. Show that a self-gravitating system has negative specific heat.

2. (a) Given the mass and the radius of the Sun (you must derive the central temperature from these quantities) find the expected life-time of the Sun, from the known value of solar luminosity ($L_\odot \simeq 4 \times 10^{33}$ erg.s^{-1}), assuming that the source of solar energy is entirely thermal.

   (b) We know that the source of solar energy is not thermal but nuclear. Calculate the rate of Hydrogen transmutation per unit time (in units of gm.s^{-1}) to sustain the observed value of $L_\odot$.

3. The nucleon-nucleon interaction potential can be approximated by a hard-sphere part for distances $< r_n$ (radius of a nucleus) and a Coulomb repulsion part beyond r_n. Write down the effective interaction potential $V(r)$ as a function of r, the distance between the two nucleon.

4. Show that (using the above interaction potential), without quantum tunneling, transmutation of Hydrogen to Helium would not be possible in the interior of the Sun. Use the central temperature estimated above and the standard proton radius.

5. Mathematically establish that higher temperatures are required for transmutation of heavier nuclei.

6. Carl Sagan once said "..We are made of star-stuff..." Star-stuff, yes. But quite a number of elements in our body can only be created when a star ends its active life in Supernova explosion (or, when two neutron stars merge). Explain why that should be so.

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