Earth and Planetary Sciences (ES1101)

Autumn 2024

Origin of Elements

During Big Bang Nucleosynthesis

a. At the initial stage of expansion, universe consisted of neutrons
b. Beta decay produces electrons and proton
c. Capture of neutron by H to produce ^{2}H
d. Collision of two ^{2}H to form $^{3}H + H$
e. Collision between ^{3}H & ^{2}H to form He + H

Some He-3 and much of Li were probably produced https://www.youtube.com/watch?v=lInXZ6I3u_I

https://www.youtube.com/watch?v=IoWdgU_QYxA&t=0s

Red Shift

(c) The atoms in a star absorb certain specic wavelengths of light. We see these wavelengths as dark lines on a light spectrum. Note that the lines from a galaxy a billion light-years away are shifted toward the red end of the spectrum (i.e., to the right), relative to the lines from our own Sun.

Solar Abundance of Elements

TABLE 1.1 Top 10 Elements in the Milky Way (out of 1 Million Atoms)

Hydrogen	739,000
Helium	240,000
Oxygen	10,400
Carbon	4,600
Neon	1,340
Iron	1,090
Nitrogen	960
Silicon	650
Magnesium	580
Sulfur	440
Other (approx.)	940

Solar Abundance of Elements

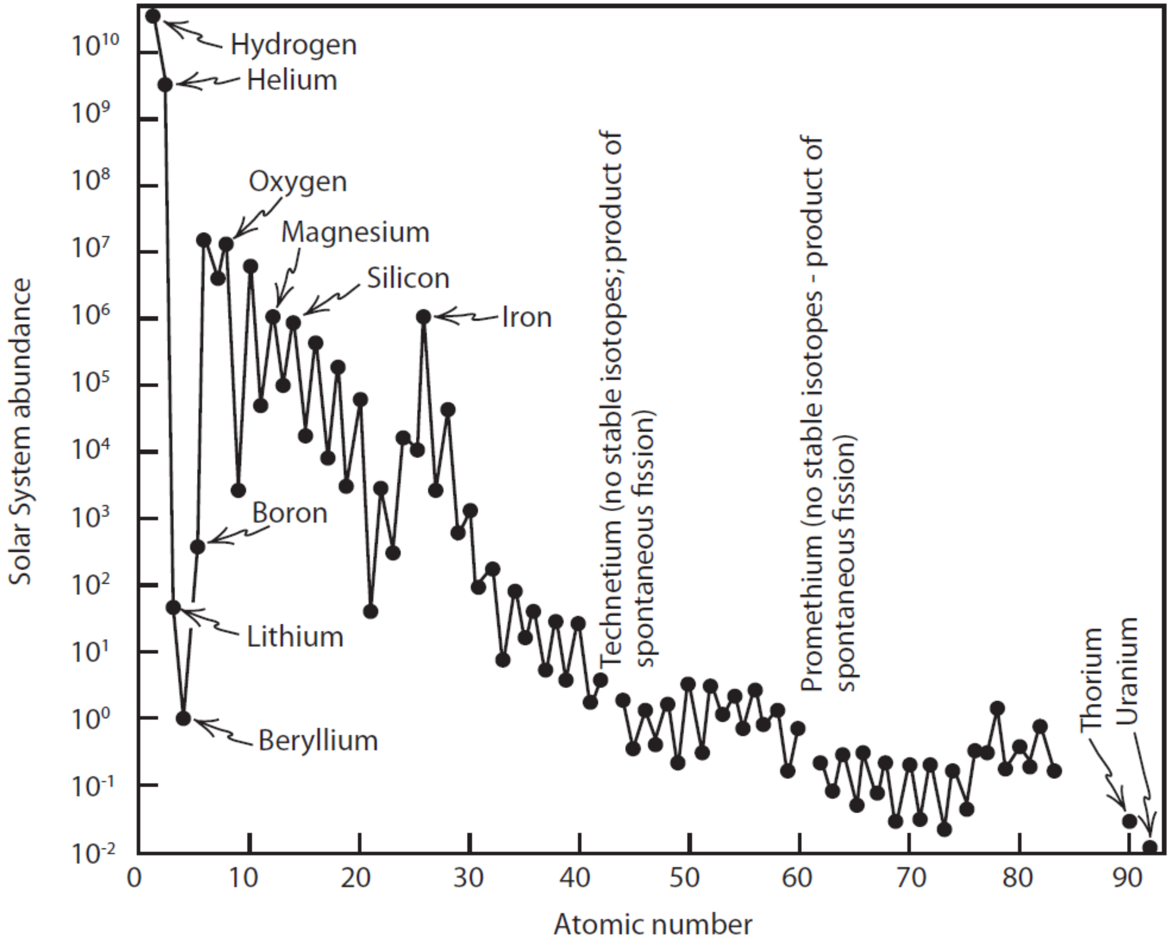


Fig. 3-1: Relative abundances of the elements in our sun: as the abundances range over 13 orders of magnitude, they must be displayed on a power of 10 (logarithmic) scale. The abundance of each element is expressed as the number of atoms per million (i.e., 10^6) atoms of the element silicon. The gaps in the sequence of technetium and promethium represent elements that have only radioactive isotopes and are, therefore, absent in a relatively low temperature star such as the sun.

Solar Abundance of Elements

Relation with mass number

a) Rapid exponential decrease for elements 1-40

b) Pronounced peak for Fe26

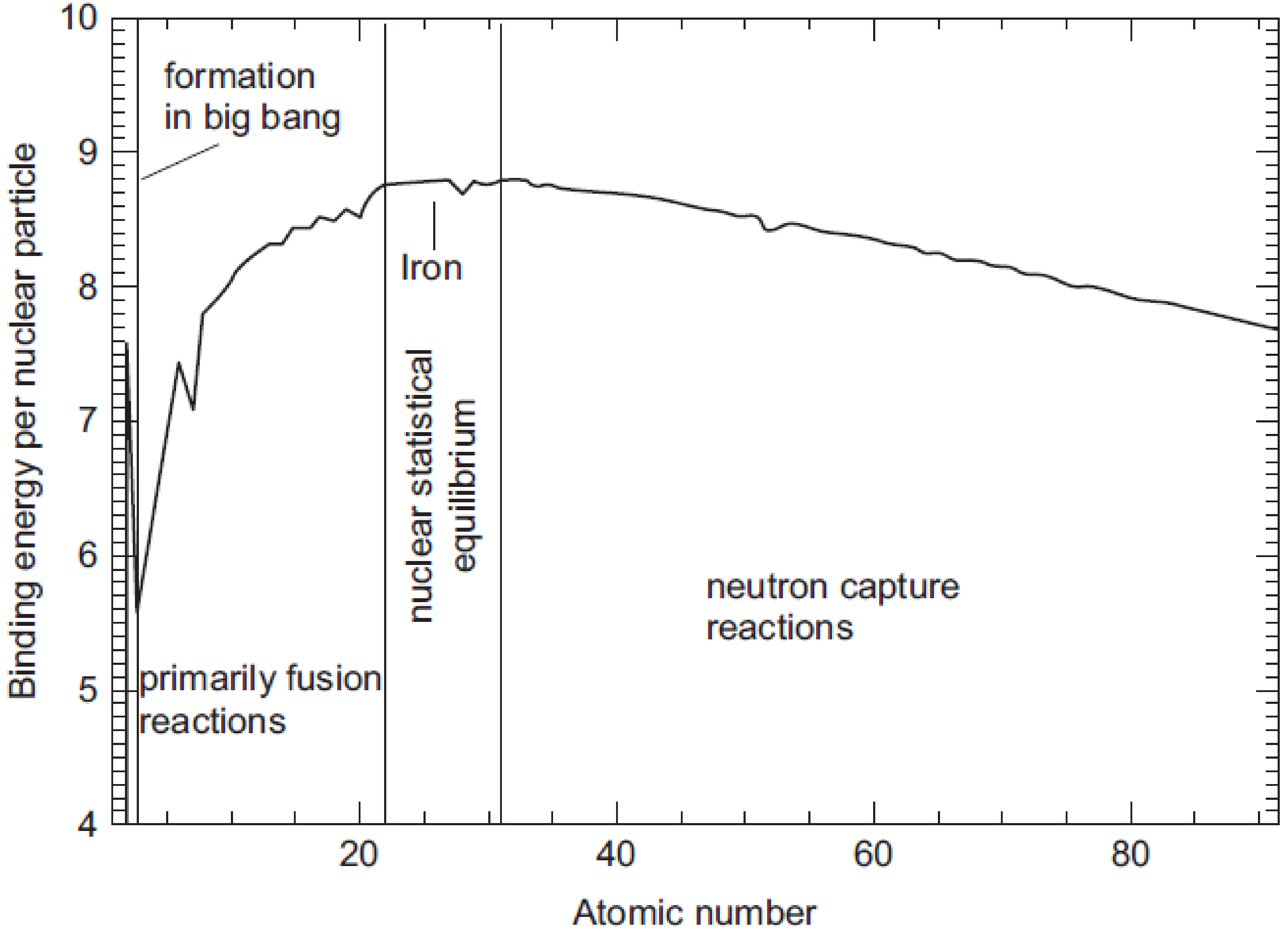
c) Even atomic number more common than odd numbers on both sides Oddo–Harkins rule

d) 10 elements with atomic number <27 are most abundant: H, He, C,N,O Ne,Mg,Si,S,Fe

Nucleii with even N + even Z most abundant

Nucleii with odd N-even Z & even N-odd Z are equally abundant

Nucleii with odd N and odd Z least abundant- exception N(14)



Binding energy per nuclear particle
Atomic number
formation
in big bang
primarily fusion
reactions
nuclear statistical
equilibrium
Iron
neutron capture
reactions
10
9
8
7
6
5
4
20
40
60
80

Nuclear fusion in Sun and Older stars

- Starting from primordial H, He was produced by fusion via p-p or proton-proton process
  - Should take ~ 12 billion years to burn all H
- CNO cycle in older stars to produce more He
  - Fusion of He(4) at higher temperature

  He(4)+He(4)=Be(8) unstable, Be(8)+He(4)=C(12), C(12)+He(4)=O(16), He(4)+O(16)=Ne(20), He(4)+Ne(20)=Mg(24)…………………………
  - Fusion of C at further high temperature- C(12)+C(12)=Ne(20)+He(4)
  - Fusion of O to produce Si, S, P, Al……
  - Fusion of Si to produce Fe

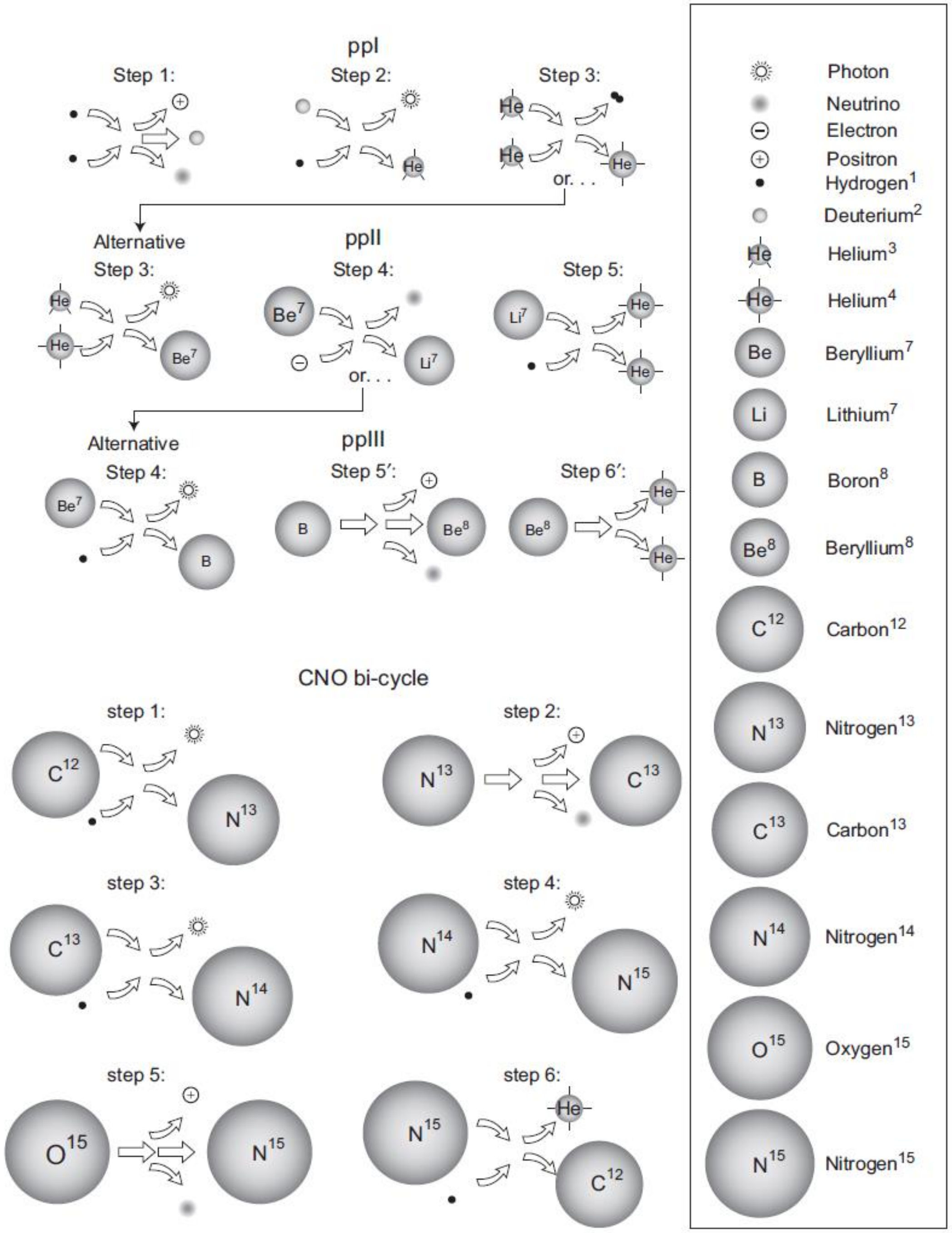
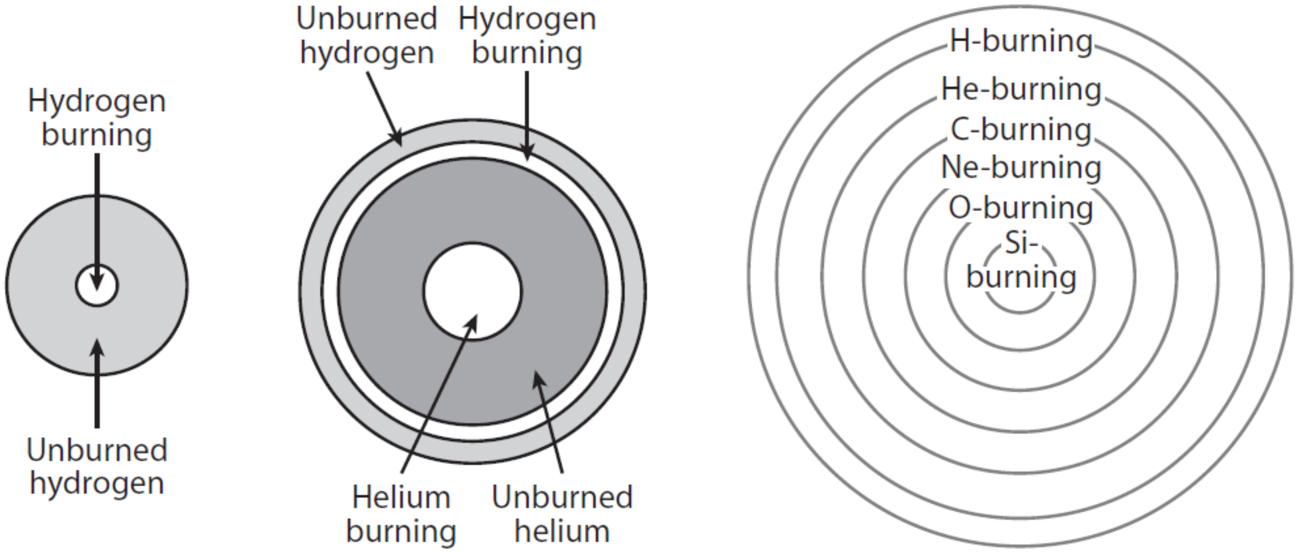


Figure 4.2 Steps involved in four kinds of fusion reactions in stars, all of which convert hydrogen to helium.



Name of process	Fuel	Products	Temperature
Hydrogen-burning	H	He	60×10^6 °K
Helium-burning	He	C, O	200×10^6 °K
Carbon-burning	C	O, Ne, Na, Mg	800×10^6 °K
Neon-burning	Ne	O, Mg	1500×10^6 °K
Oxygen-burning	O	Mg to S	2000×10^6 °K
Silicon-burning	Mg to S	Elements near Fe	3000×10^6 °K

Fig. 3-5: Three stars with progressively hotter nuclear fires. Like our sun, the star at the left burns hydrogen to form helium in its core; this core is surrounded by unburned fuel. The middle star is burning helium to form carbon and oxygen in its core. This core is surrounded by a layer of unburned helium. Outside of this is a layer in which hydrogen burns to produce helium. Finally, there is an outer layer of unburned hydrogen. The star on the right has a multilayered fire all the way up to Si-burning to create ^{56}Fe. The approximate temperatures required to ignite the successive fuels are also given.

Production of heavier elements is by capture of neutron and proton by nuclei
Slow process upto Bi(209), Rapid process, Proton capture process

Non-stellar production: Li, Be and B (l-process)- nuclei ejected in the space by supernova explosion collide with interstellar H to produce these elements

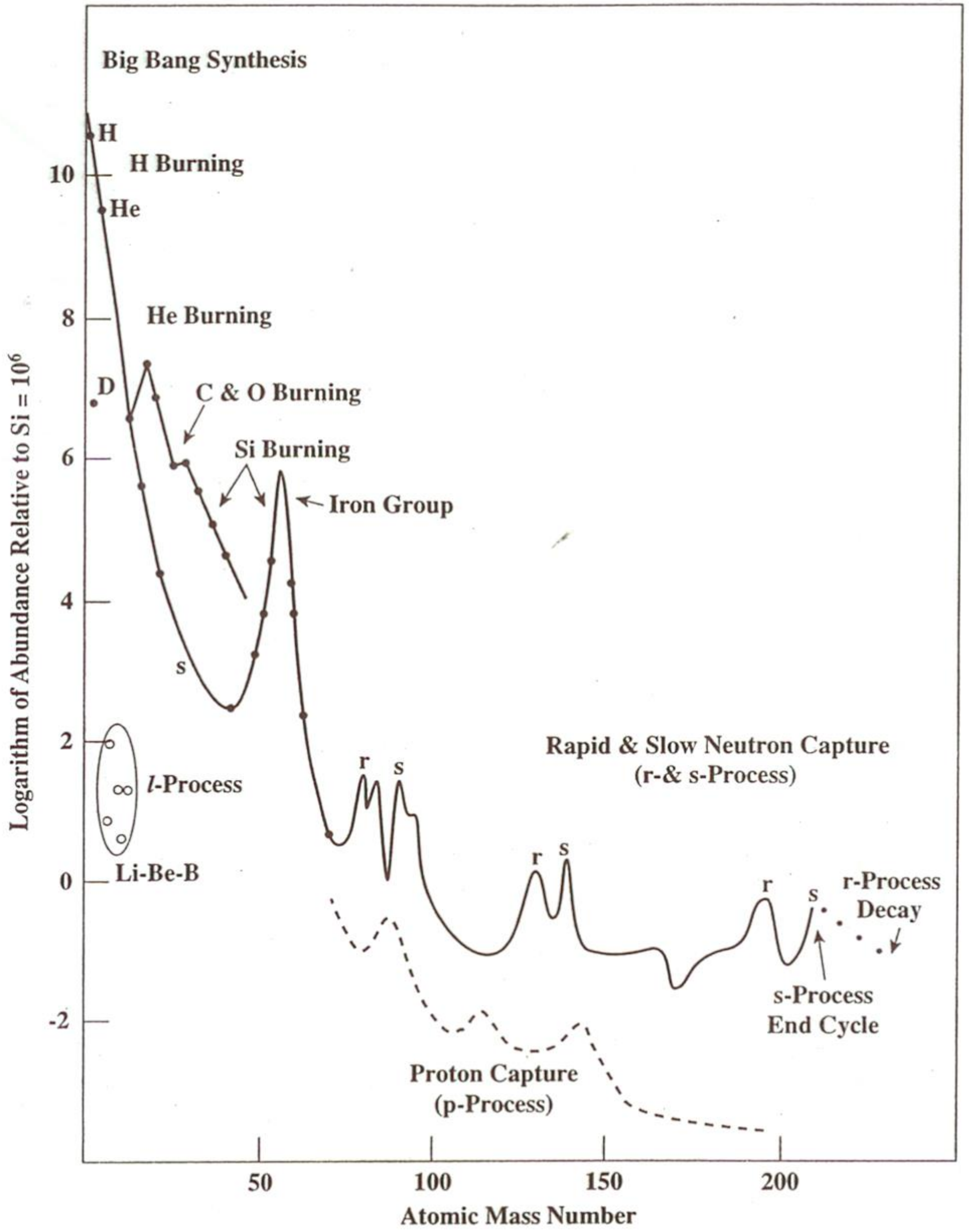


Figure 4.5. Summary of mechanisms by which elements are produced, plotted as the logarithm of the element's abundance versus the element's atomic weight. On the vertical scale $2 = 10^2$, $4 = 10^4$, etc. The mechanisms themselves are discussed in this chapter. Modified from Mason (1991) by permission of Clarendon Press.