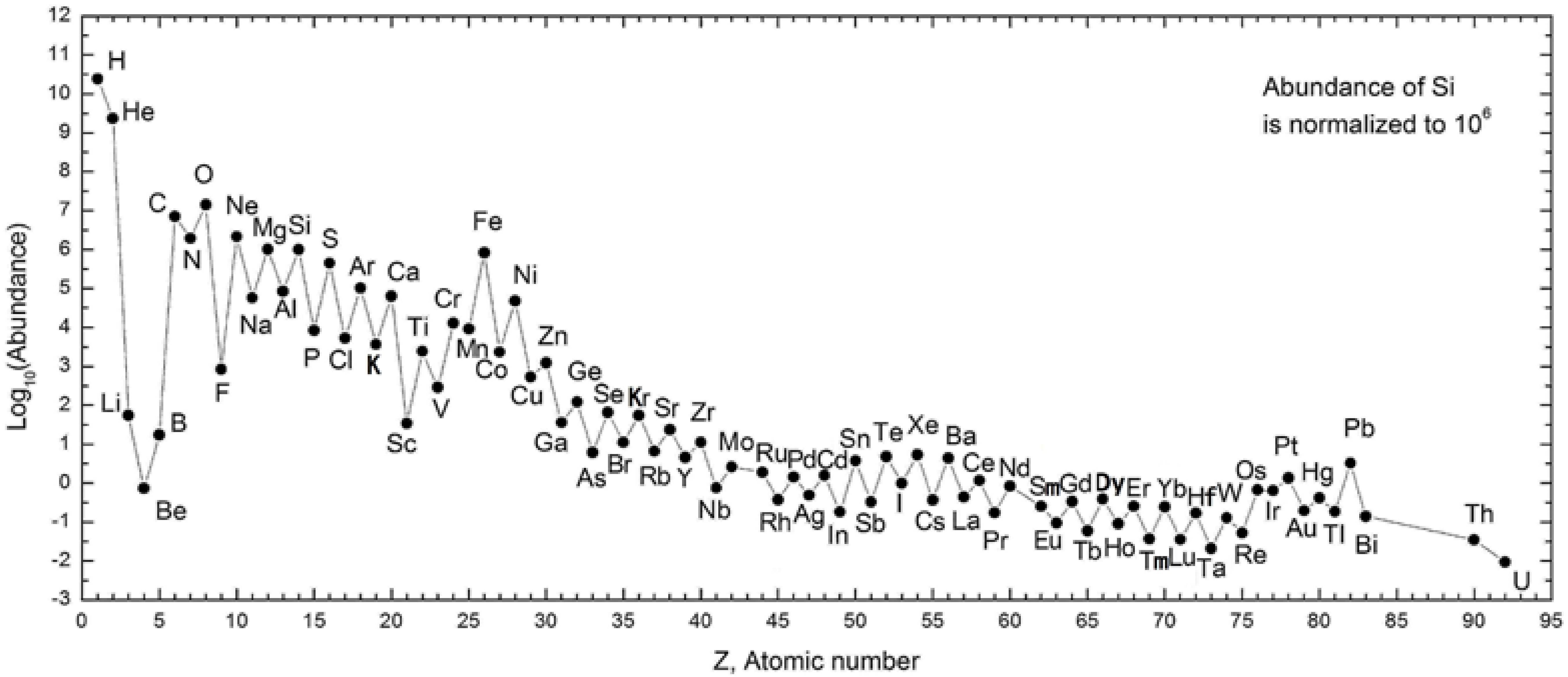
Lecture 2: Making the elements

1. Chemical composition of the solar system
    A. Making the elements
2. Condensation from the nebula
    A. Thermodynamics

We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.



Abundance of Si
is normalized to 10^6
Log_{10}(Abundance)
Z, Atomic number
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Th
U

Why is a nucleus stable?

Mass of:

(P) Proton: 1.007276u

(N) Neutron: 1.008664u

(e) Electron: 0.00054858u

u is unified atomic mass unit $\sim 10^{-27}$ kg

Consider:

$$^{2}H + {}^{2}H \rightarrow {}^{4}He$$

$$2(P+N+e) \neq 2(P+N+e)$$

Mass ^{4}He < Mass $2\times(P+N+e)$

mass decrement, δ, related to energy

$$e = \delta c^2$$

the **strong** force

10^2 times stronger than electromagnetic

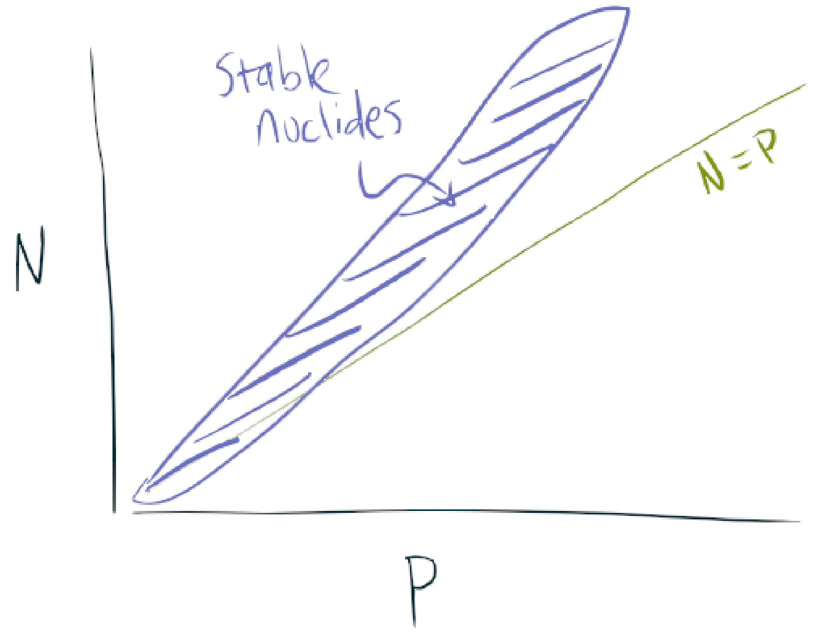
10^{39} times stronger than gravity

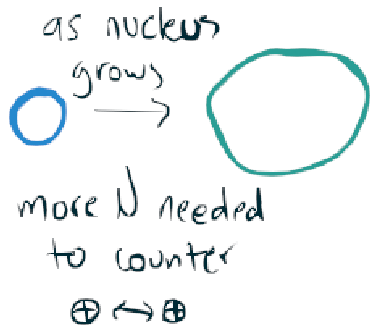
- falls off w/ distance rapidly

at > 10^{-14} m weaker than electromagnetic

$$E_b = \frac{\delta}{A} c^2$$

binding energy per nucleon



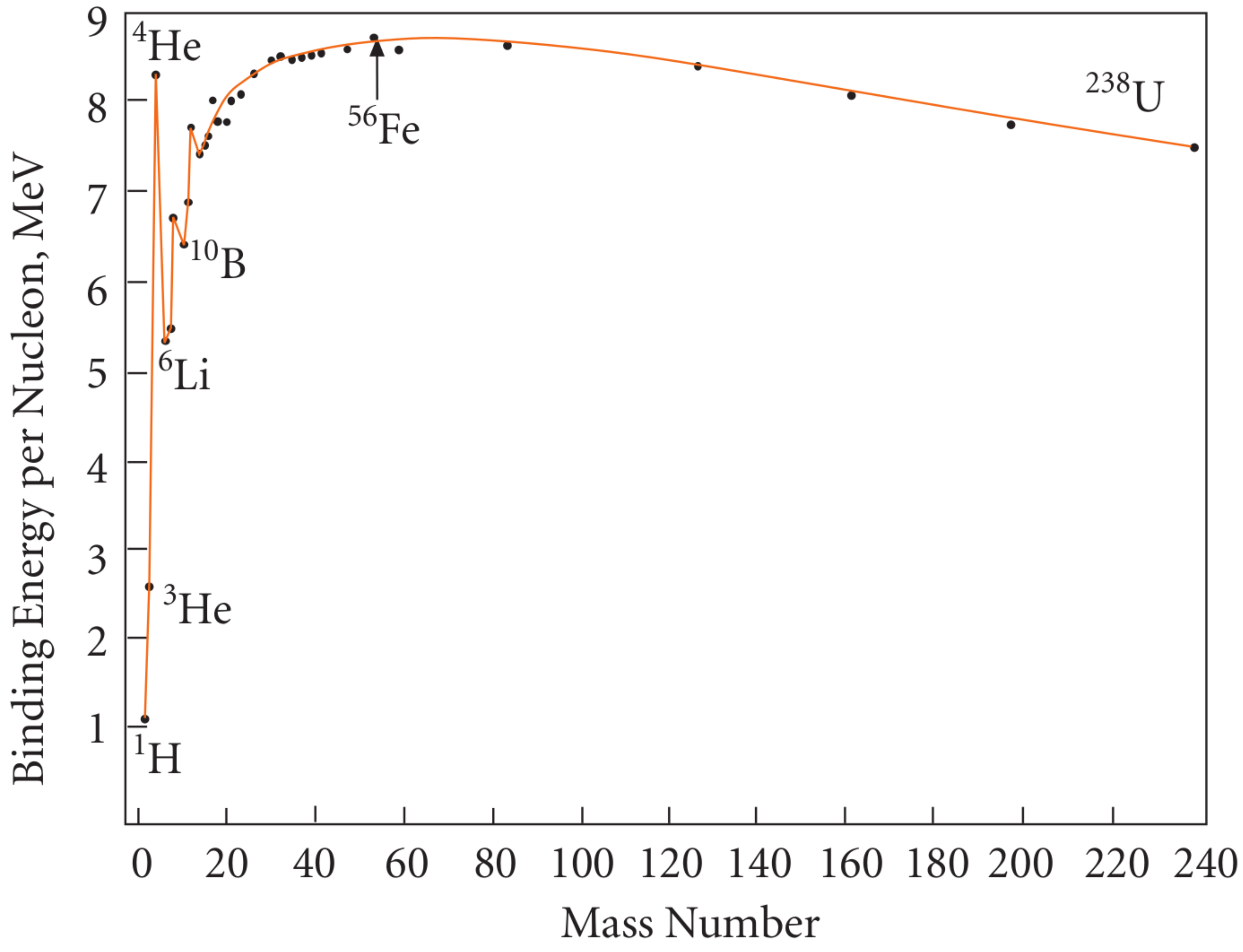


(A = P + N)

More stable nuclei with even A

even : 169

odd : 105



Binding Energy per Nucleon, MeV
Mass Number
0
20
40
60
80
100
120
140
160
180
200
220
240
1
2
3
4
5
6
7
8
9
^{4}He
^{56}Fe
^{238}U
^{10}B
^{6}Li
^{3}He
^{1}H

$$E_b = \frac{\delta}{A} c^2$$

binding energy per nucleon

^{56}Fe most stable

$$H + H \rightarrow He + \text{energy}$$

Fusion to a more stable nucleus releases energy

Favorable*

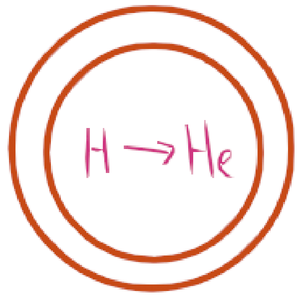
*Why doesn't it always happen?

activation E needed to overcome $\ominus \leftrightarrow \ominus$

H and He produced in Big Bang ~ $\overset{H}{75} : \overset{He}{25}$

heavier elements form in stars

the sun



fusion

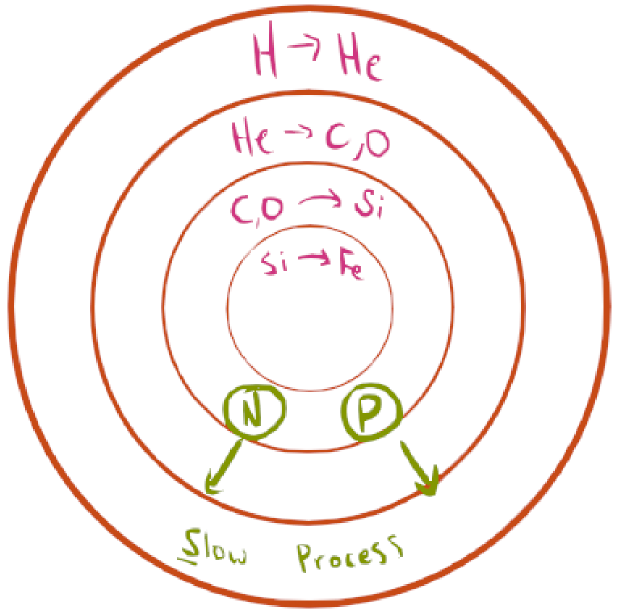
S process

→ if unstable will decay* before another capture

We will learn more about

β- decay later N → P

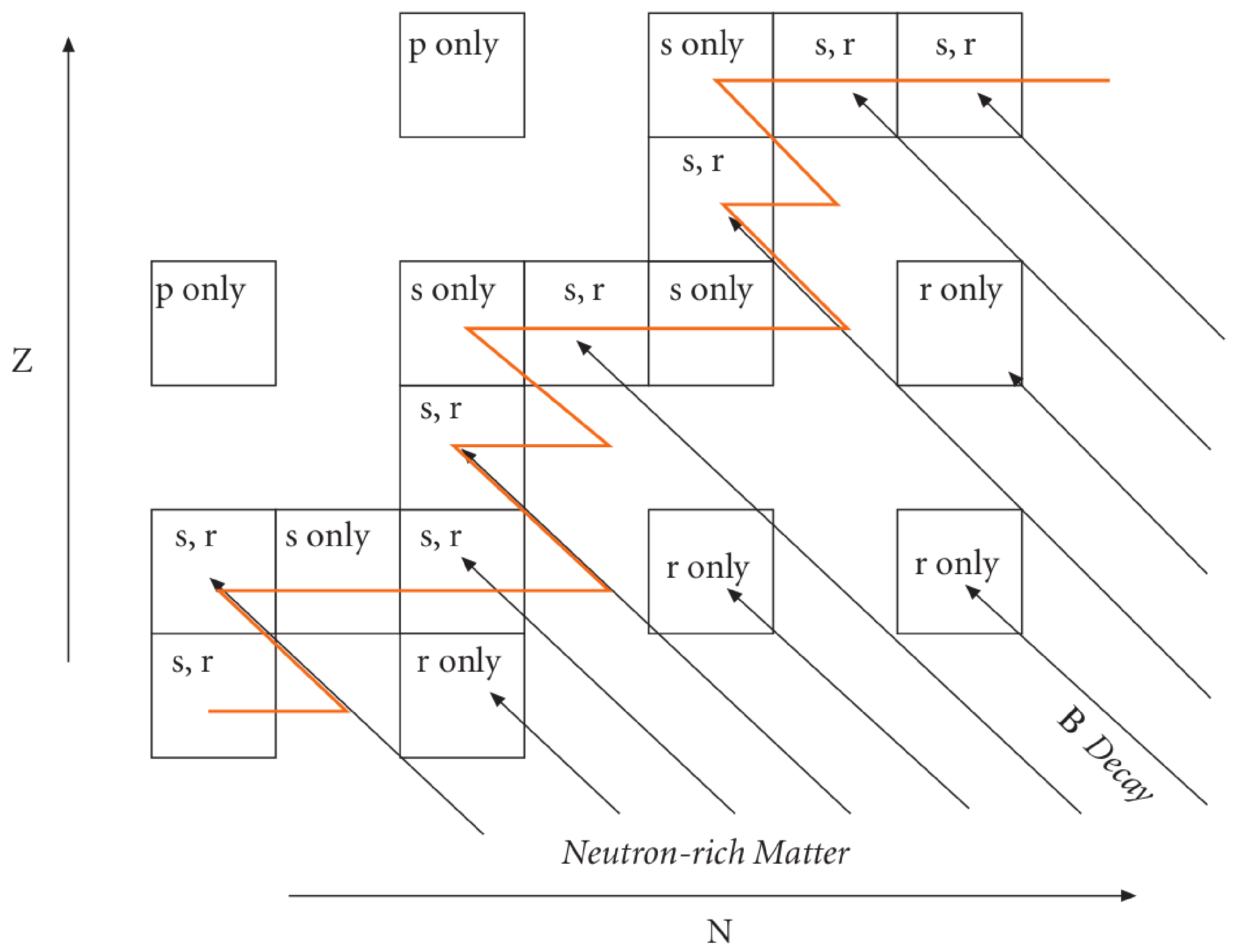
late stage star

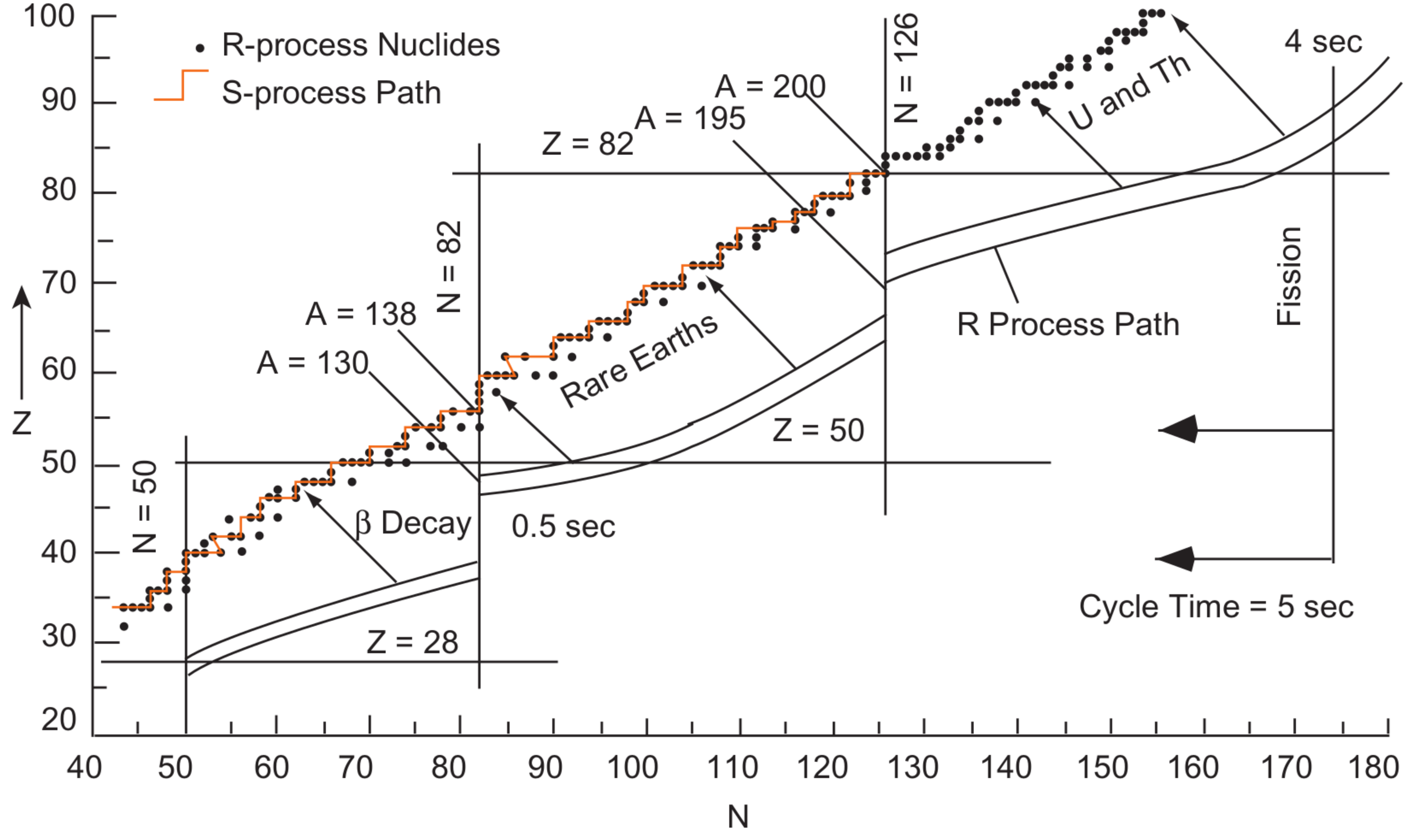


What happens when there's no fuel left for fusion?

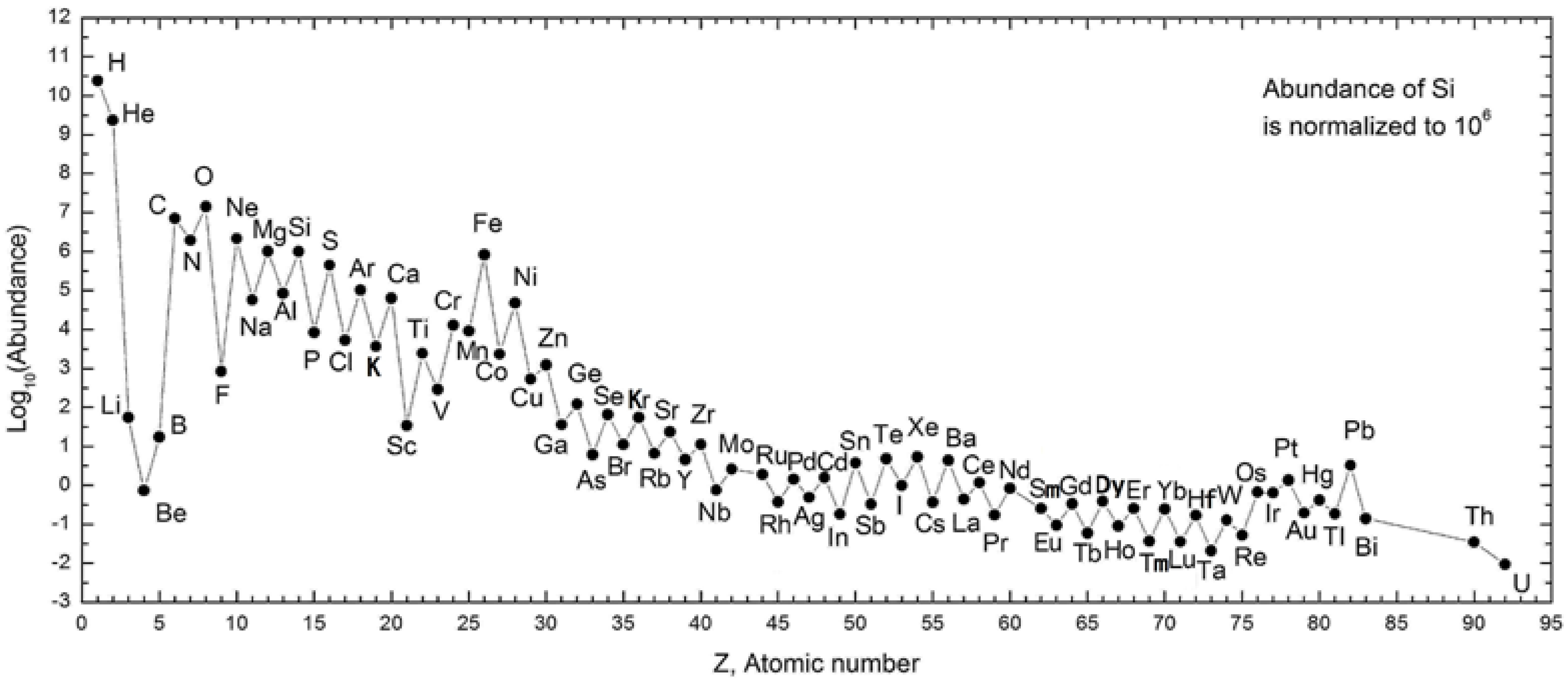
thermal expansion < gravity

rapid process: N capture faster than β decay


p only
s only
s, r
s, r
s, r
p only
s only
s, r
s only
r only
Z
s, r
s, r
s only
s, r
r only
r only
s, r
r only
B Decay
Neutron-rich Matter
N

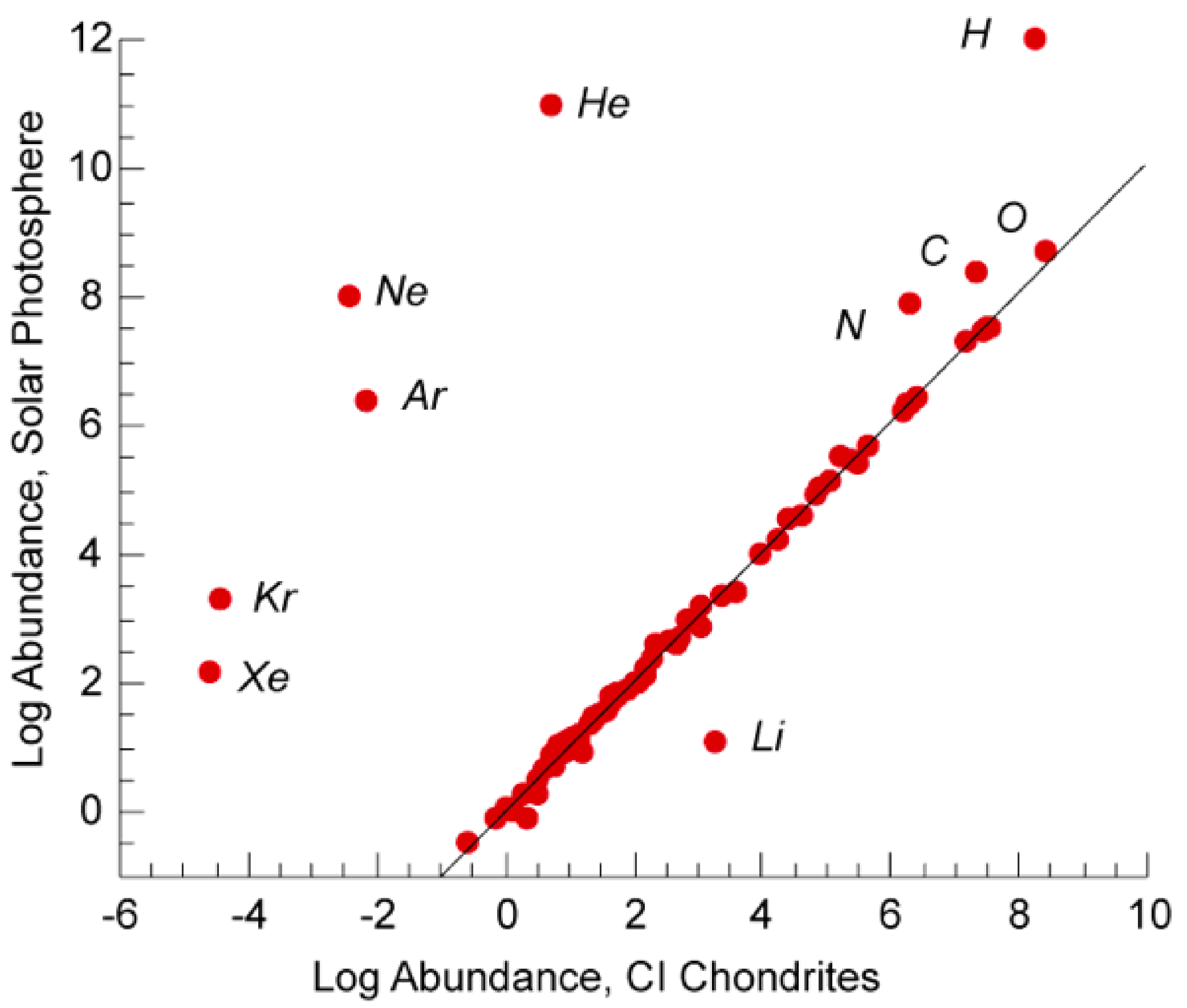


R-process Nuclides
S-process Path
Z
N
Z = 82
Z = 50
Z = 28
N = 50
N = 82
N = 126
A = 200
A = 195
A = 138
A = 130
Rare Earths
U and Th
β Decay
0.5 sec
4 sec
R Process Path
Fission
Cycle Time = 5 sec



Should the Sun and Earth have the same chemistry? What about Earth and Jupiter?

Do the planets share a common origin with the Sun?



Condensation sequence

Condensation sequence

- Condensation: as a gaseous material cools, it will condense into solid or liquid form
- Some questions we will consider:
    - Starting with a hot gas with the composition of the sun/nebula, what solids condense first? (These solids are the building blocks of planets)
    - When does all of a specific element finish condensing?

Condensation sequence

- Condensation: as a gaseous material cools, it will condense into solid or liquid form
- Some questions we will consider:
  - Starting with a hot gas with the composition of the sun/nebula, what solids condense first? (These solids are the building blocks of planets)
  - When does all of a specific element finish condensing?
- To answer these questions, will need to use **thermodynamics**

What is energy?

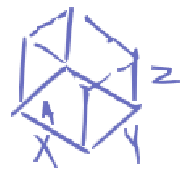
- capacity to produce $\boxed{\text{change}}$

What forms does it take? work, thermal, chemical, etc

equilibrium: no more change, So energy minimized

1st Law of Thermodynamics: $\Delta U = Q + W$

Δ energy = heat + work



$A = xy$

$V = xyz$

Work $W = \int_{x_0}^{x} F\,dx$ $\quad F = m \cdot \frac{dv}{dt}$ $\quad P = \frac{F}{A}$

P-V work

$$W = \int_{z_0}^{z} \frac{F}{A} A\,dz = -\int_{V_0}^{V} P\,dV$$

convention defines work the system does as negative

Q or heat: related to T but must also capture that there is a natural direction which reactions proceed