

물질은 어디에서 왔을까?

- 수소 (hydrogen), 헬륨 (helium)
  - 대폭발 (Big Bang)에 의해 생성

PERIODIC TABLE

Atomic Properties of the Elements

**Primordial Nucleosynthesis**

**Group**

1A  
**H**  
Hydrogen  
1.008  
 $1s$   
13.5984

2A  
**He**  
Helium  
4.0026  
 $1s^2$   
24.5874

Hydrogen and helium were created during the Big Bang while the Universe was cooling from its initial hot, dense state.

About 10% of the lithium in the Universe today was also created in the Big Bang. We're still not sure where the rest comes from.

The first stars formed from this material.

18  
VIIIA  
**He**  
Helium  
4.0026  
 $1s^2$   
24.5874

**Period**

1  
**H**  
Hydrogen  
1.008  
 $1s$   
13.5984

2  
**Li**  
Lithium  
6.94  
 $1s^2 2s^1$   
5.3917

3  
**Na**  
Sodium  
22.990  
 $[Ne]3s^1$   
5.1391

4  
**K**  
Potassium  
39.098  
 $[Ar]4s^1$   
4.3407

5  
**Rb**  
Rubidium  
85.468  
 $[Kr]5s^1$   
4.1771

6  
**Cs**  
Cesium  
132.91  
 $[Xe]6s^1$   
3.8939

7  
**Fr**  
Francium  
(223)  
 $[Rn]7s^1$   
4.0727

**Atomic Number**

**Symbol**

**Name**

**Standard Atomic Weight**

**Ground-state Configuration**

**Ionization Energy (eV)**

**18**  
**Ar**  
Argon  
39.948  
 $[Ne]3s^2 3p^6$   
15.7598

**36**  
**Kr**  
Krypton  
83.798  
 $[Ar]3d^10 4s^2 4p^6$   
13.9999

**54**  
**Xe**  
Xenon  
131.29  
 $[Kr]4d^10 5s^2 5p^6$   
12.1298

**86**  
**Rn**  
Radon  
(222)  
 $[Rn]5d^10 6s^2 6p^6$   
10.7405

**118**  
**Og**  
Oganesson  
(294)

**71**  
**Lu**  
Lutetium  
174.97  
 $[Xe]4f^{14} 5d^1 6s^2$   
5.4259

**Actinides**

**89**  
**Ac**  
Actinium  
(227)  
 $[Rn]5f^7 6d^1 7s^2$   
5.3802

**90**  
**Th**  
Thorium  
232.04  
 $[Rn]6d^2 7s^2$   
6.3067

**91**  
**Pa**  
Protactinium  
231.04  
 $[Rn]5f^6 6d^1 7s^2$   
5.89

**92**  
**U**  
Uranium  
238.03  
 $[Rn]5f^3 6d^1 7s^2$   
6.1941

**93**  
**Np**  
Neptunium  
(237)  
 $[Rn]5f^6 6d^1 7s^2$   
6.2665

**94**  
**Pu**  
Plutonium  
(244)  
 $[Rn]5f^7 7s^2$   
6.0258

**95**  
**Am**  
Americium  
(243)  
 $[Rn]5f^7 7s^2$   
5.9738

**96**  
**Cm**  
Curium  
(247)  
 $[Rn]5f^7 6d^1 7s^2$   
5.9014

**97**  
**Bk**  
Berkelium  
(247)  
 $[Rn]5f^7 7s^2$   
6.1978

**98**  
**Cf**  
Californium  
(251)  
 $[Rn]5f^10 7s^2$   
6.2817

**99**  
**Es**  
Einsteinium  
(252)  
 $[Rn]5f^{11} 7s^2$   
6.3676

**100**  
**Fm**  
Fermium  
(257)  
 $[Rn]5f^{12} 7s^2$   
6.50

**101**  
**Md**  
Mendelevium  
(258)  
 $[Rn]5f^{13} 7s^2$   
6.58

**102**  
**No**  
Nobelium  
(259)  
 $[Rn]5f^{14} 7s^2$   
6.66

**103**  
**Lr**  
Lawrencium  
(260)  
 $[Rn]5f^{14} 7p^1$   
4.96

**18**  
**Ar**  
Argon  
39.948  
 $[Ne]3s^2 3p^6$   
15.7598

**36**  
**Kr**  
Krypton  
83.798  
 $[Ar]3d^10 4s^2 4p^6$   
13.9999

**54**  
**Xe**  
Xenon  
131.29  
 $[Kr]4d^10 5s^2 5p^6$   
12.1298

**86**  
**Rn**  
Radon  
(222)  
 $[Rn]5d^10 6s^2 6p^6$   
10.7405

<sup>†</sup>Based upon <sup>12</sup>C. ( ) indicates the mass number of the longest-lived isotope.

For the most precise values and uncertainties visit [ciaaw.org](http://ciaaw.org) and [pml.nist.gov/data](http://pml.nist.gov/data).  
NIST SP 966 (July 2018)

- 수소, 헬륨 이외의 다른 원자들의 탄생



"Just between you and me, where does it get enriched?"

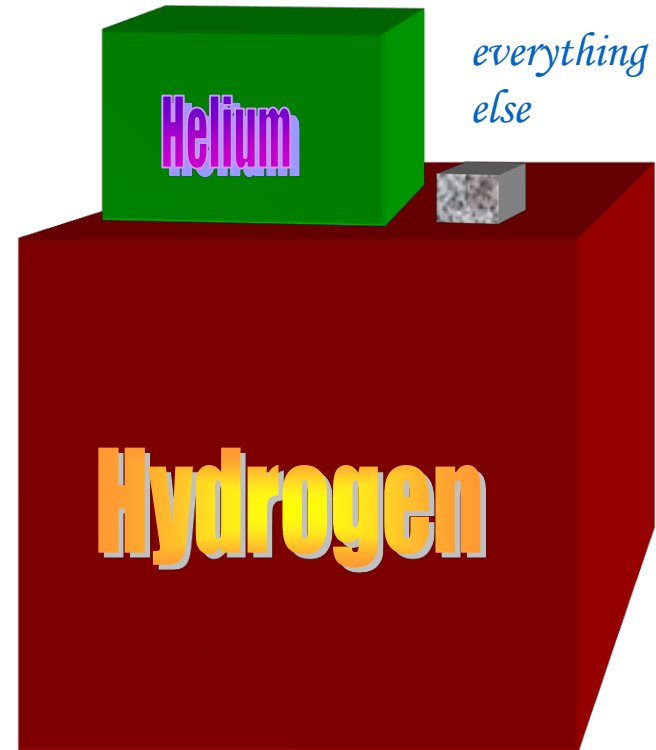
**STARS!**

- 별의 구성 성분

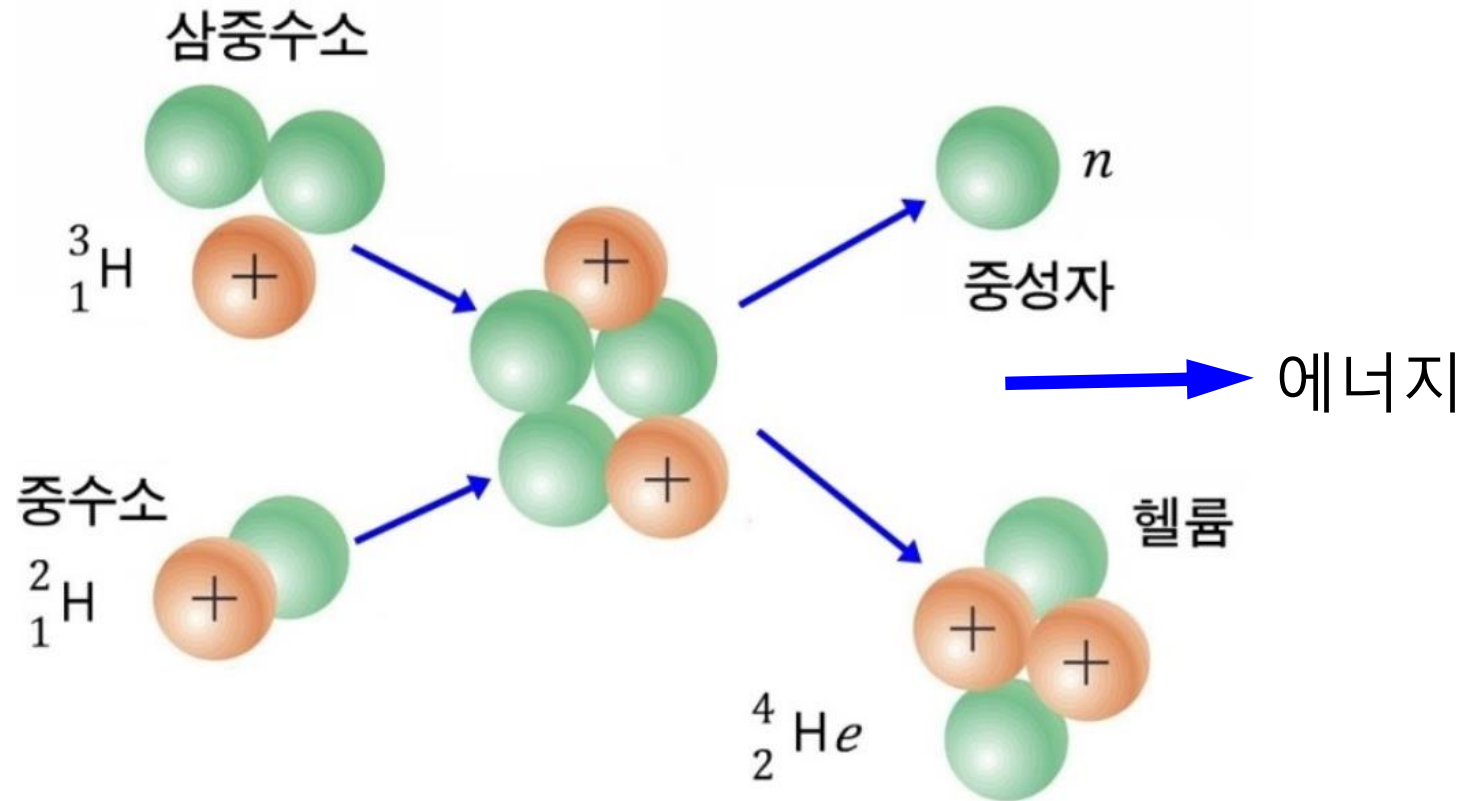
90% hydrogen atoms

10% helium atoms

Less than 1%  
everything else  
*(and everything  
else is made in stars!)*



- 태양의 핵융합 (nuclear fusion)





- Hydrogen burning

PERIODIC TABLE

Atomic Properties of the Elements

Group

1A  
1

<sup>1</sup>H  
Hydrogen  
1.008  
1s

2A  
2  
<sup>3</sup>Li  
Lithium  
6.94  
1s<sup>2</sup>2s

<sup>4</sup>Be  
Beryllium  
9.0122  
1s<sup>2</sup>2s<sup>2</sup>

FREQUENTLY USED FUNDAMENTAL PHYSICAL CONSTANTS<sup>1</sup>

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of <sup>133</sup>Cs

speed of light in vacuum  
 $c$  299 792 458 m s<sup>-1</sup> (exact)

Planck constant  
 $h$  6.626 070 × 10<sup>-34</sup> J s

elementary charge  
 $e$  1.602 177 × 10<sup>-19</sup> C

electron mass  
 $m_e$  9.109 384 × 10<sup>-31</sup> kg

proton mass  
 $m_p$  1.672 622 × 10<sup>-27</sup> kg

fine-structure constant  
 $\alpha$  1/137.035 999

Rydberg constant  
 $R_\infty$  10 973 731.569 m<sup>-1</sup>

$R_\infty c$  3.289 841 960 × 10<sup>15</sup> Hz

$R_\infty h c$  13.605 693 eV

$eV$  1.602 177 × 10<sup>-19</sup> J

Boltzmann constant  
 $k$  1.380 65 × 10<sup>-23</sup> J K<sup>-1</sup>

molar gas constant  
 $R$  8.314 5 J mol<sup>-1</sup> K<sup>-1</sup>

For the most accurate values of these and other constants, visit [nist.gov/constants](http://nist.gov/constants).

■ Solids  
■ Liquids  
■ Gases  
■ Artificially Prepared

NIST National Institute of Standards and Technology  
U.S. Department of Commerce

Physical Measurement Laboratory [www.nist.gov/pml](http://www.nist.gov/pml)

Standard Reference Data [www.nist.gov/srd](http://www.nist.gov/srd)

VIII A

<sup>2</sup>He  
Helium  
4.0026  
1s<sup>2</sup>

<sup>10</sup>Ne  
Neon  
20.180  
1s<sup>2</sup>2s<sup>2</sup>2p<sup>6</sup>

<sup>18</sup>Ar  
Argon  
39.948  
[Ne]3s<sup>2</sup>3p<sup>6</sup>

<sup>36</sup>Kr  
Krypton  
83.798  
[Ar]3d<sup>10</sup>4s<sup>2</sup>4p<sup>6</sup>

<sup>54</sup>Xe  
Xenon  
131.29  
[Kr]4d<sup>10</sup>5s<sup>2</sup>5p<sup>6</sup>

<sup>86</sup>Rn  
Radon  
222  
[Xe]4f<sup>14</sup>5d<sup>10</sup>6s<sup>2</sup>6p<sup>6</sup>

Period

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Stars burn hydrogen in their interiors to produce helium.

Hydrogen burning also rearranges carbon, nitrogen, and oxygen.

- Helium burning

# PERIODIC TABLE

## Atomic Properties of the Elements

### FREQUENTLY USED FUNDAMENTAL PHYSICAL CONSTANTS<sup>1</sup>

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proton mass  $m_p$  1.672 622 × 10<sup>-27</sup> kg

fine-structure constant  $\alpha$  1/137.035 999

Rydberg constant  $R_\infty$  10 973 731 568 m<sup>-1</sup>

$R_\infty hc$  3.289 841 960 × 10<sup>15</sup> Hz

$R_\infty hc$  13.605 693 eV

electron volt  $eV$  1.602 177 × 10<sup>-19</sup> J

Boltzmann constant  $k$  1.380 65 × 10<sup>-23</sup> J K<sup>-1</sup>

molar gas constant  $R$  8.314 5 J mol<sup>-1</sup> K<sup>-1</sup>

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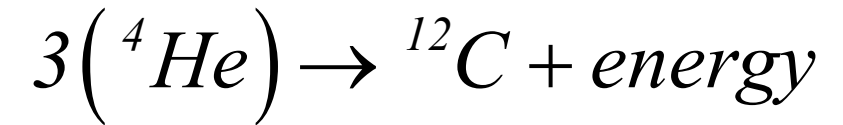
☒ Solids  
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Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IA	IIA	IIIB	IVB	VB	VIB	VII	VIII	IX	X	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	
Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu		
87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	
Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr		

<sup>1</sup>Based upon <sup>12</sup>C. ( ) indicates the mass number of the longest-lived isotope. For the most precise values and uncertainties visit [ciaw.org](http://ciaw.org) and [nist.gov/data](http://nist.gov/data). NIST SP 965 (July 2018)



Three helium atoms combine to form carbon



- Massive Stars (large stars)
  - Hydrogen → helium → carbon
  - 내부 온도가 높음 : carbon → 'alpha' elements (magnesium, etc.)

**PERIODIC TABLE**  
**Atomic Properties of the Elements**

**NIST** National Institute of Standards and Technology  
U.S. Department of Commerce  
Physical Measurement Laboratory [www.nist.gov/pml](http://www.nist.gov/pml)  
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electron mass  $m_e$  9.109 384 × 10<sup>-31</sup> kg  
proton mass  $m_p$  1.672 622 × 10<sup>-27</sup> kg  
fine-structure constant  $\alpha$  1/137.035 999  
Rydberg constant  $R_\infty$  10 973 731.569 m<sup>-1</sup>  
 $R_\infty c$  3.289 841 960 × 10<sup>15</sup> Hz  
 $R_\infty h c$  13.605 693 eV  
electron volt  $eV$  1.602 177 × 10<sup>-19</sup> J  
Boltzmann constant  $k$  1.380 65 × 10<sup>-23</sup> J K<sup>-1</sup>  
molar gas constant  $R$  8.314 5 J mol<sup>-1</sup> K<sup>-1</sup>

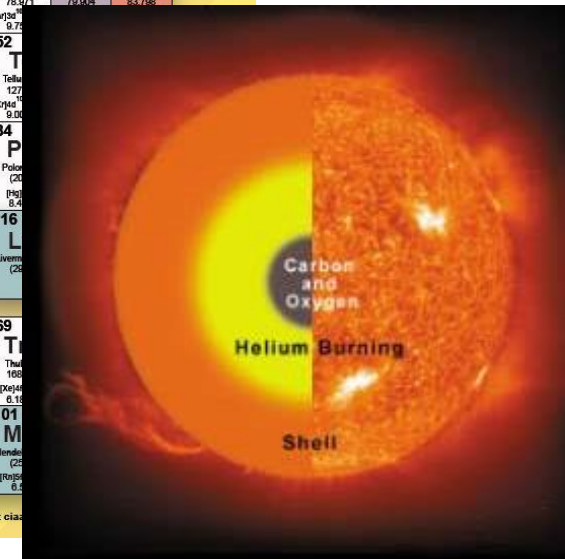
§ For the most accurate values of these and other constants, visit [nist.gov/constants](http://nist.gov/constants).

Legend: ■ Solids ■ Liquids ■ Gases ■ Artificially Prepared

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period	1 H 1.008 1s	2 He 4.0026 1s <sup>2</sup>																
2	3 Li 6.94 1s <sup>2</sup> 2s <sup>1</sup>	4 Be 9.0122 1s <sup>2</sup> 2s <sup>2</sup>																
3	11 Na 22.99 [Ne]3s <sup>1</sup>	12 Mg 24.305 [Ne]3s <sup>2</sup>																
4	19 K 39.098 [Ar]4s <sup>1</sup>	20 Ca 40.078 [Ar]4s <sup>2</sup>	21 Sc 44.956 [Ar]3d <sup>1</sup> 4s <sup>2</sup>	22 Ti 47.88 [Ar]3d <sup>2</sup> 4s <sup>2</sup>	23 V 50.942 [Ar]3d <sup>3</sup> 4s <sup>2</sup>	24 Cr 51.996 [Ar]3d <sup>5</sup> 4s <sup>1</sup>	25 Mn 54.938 [Ar]3d <sup>5</sup> 4s <sup>2</sup>	26 Fe 55.845 [Ar]3d <sup>6</sup> 4s <sup>2</sup>	27 Co 58.933 [Ar]3d <sup>7</sup> 4s <sup>2</sup>	28 Ni 58.693 [Ar]3d <sup>8</sup> 4s <sup>2</sup>	29 Cu 63.546 [Ar]3d <sup>10</sup> 4s <sup>1</sup>	30 Zn 65.38 [Ar]3d <sup>10</sup> 4s <sup>2</sup>	31 Ga 69.723 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>1</sup>	32 Ge 72.630 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup>	33 As 74.922 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup>	34 Se 78.96 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup>	35 Br 79.904 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup>	36 Kr 83.798 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup>
5	37 Rb 85.468 [Kr]5s <sup>1</sup>	38 Sr 87.62 [Kr]5s <sup>2</sup>	39 Y 88.906 [Kr]4d <sup>1</sup> 5s <sup>2</sup>	40 Zr 91.224 [Kr]4d <sup>2</sup> 5s <sup>2</sup>	41 Nb 92.906 [Kr]4d <sup>4</sup> 5s <sup>1</sup>	42 Mo 95.94 [Kr]4d <sup>5</sup> 5s <sup>1</sup>	43 Tc 98.906 [Kr]4d <sup>5</sup> 5s <sup>2</sup>	44 Ru 101.07 [Kr]4d <sup>7</sup> 5s <sup>1</sup>	45 Rh 102.91 [Kr]4d <sup>8</sup> 5s <sup>1</sup>	46 Pd 106.42 [Kr]4d <sup>10</sup>	47 Ag 107.87 [Kr]4d <sup>10</sup> 5s <sup>1</sup>	48 Cd 112.41 [Kr]4d <sup>10</sup> 5s <sup>2</sup>	49 In 114.82 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>1</sup>	50 Sn 118.71 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>2</sup>	51 Sb 121.76 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>3</sup>	52 Te 127.6 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>4</sup>	53 I 126.905 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>5</sup>	54 Xe 131.29 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>6</sup>
6	55 Cs 132.91 [Xe]6s <sup>1</sup>	56 Ba 137.33 [Xe]6s <sup>2</sup>	57-71 Lanthanides	72 Hf 178.49 [Xe]4f <sup>14</sup> 5d <sup>2</sup> 6s <sup>2</sup>	73 Ta 180.95 [Xe]4f <sup>14</sup> 5d <sup>3</sup> 6s <sup>2</sup>	74 W 183.84 [Xe]4f <sup>14</sup> 5d <sup>4</sup> 6s <sup>2</sup>	75 Re 186.21 [Xe]4f <sup>14</sup> 5d <sup>5</sup> 6s <sup>2</sup>	76 Os 190.23 [Xe]4f <sup>14</sup> 5d <sup>6</sup> 6s <sup>2</sup>	77 Ir 192.22 [Xe]4f <sup>14</sup> 5d <sup>7</sup> 6s <sup>2</sup>	78 Pt 195.08 [Xe]4f <sup>14</sup> 5d <sup>9</sup> 6s <sup>1</sup>	79 Au 196.97 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>1</sup>	80 Hg 200.59 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup>	81 Tl 204.38 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>1</sup>	82 Pb 207.2 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>2</sup>	83 Bi 208.98 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>3</sup>	84 Po 209 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>4</sup>	85 At 210 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>5</sup>	86 Rn 222 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>6</sup>
7	87 Fr 223 [Rn]7s <sup>1</sup>	88 Ra 226 [Rn]7s <sup>2</sup>	89-103 Actinides	104 Rf 261 [Rn]5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup>	105 Db 262 [Rn]5f <sup>14</sup> 6d <sup>3</sup> 7s <sup>2</sup>	106 Sg 266 [Rn]5f <sup>14</sup> 6d <sup>4</sup> 7s <sup>2</sup>	107 Bh 264 [Rn]5f <sup>14</sup> 6d <sup>5</sup> 7s <sup>2</sup>	108 Hs 277 [Rn]5f <sup>14</sup> 6d <sup>6</sup> 7s <sup>2</sup>	109 Mt 268 [Rn]5f <sup>14</sup> 6d <sup>7</sup> 7s <sup>2</sup>	110 Ds 271 [Rn]5f <sup>14</sup> 6d <sup>8</sup> 7s <sup>2</sup>	111 Rg 272 [Rn]5f <sup>14</sup> 6d <sup>9</sup> 7s <sup>2</sup>	112 Cn 285 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup>	113 Nh 284 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>1</sup>	114 Fl 289 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>2</sup>	115 Mc 288 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>3</sup>	116 Lv 293 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>4</sup>	117 Ts 294 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>5</sup>	118 Og 294 [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>6</sup>

<sup>§</sup>Based upon <sup>12</sup>C. ( ) indicates the mass number of the longest-lived isotope.

For the most precise values and uncertainties visit [nist.gov/constants](http://nist.gov/constants).





- Massive stars (supernova explosions 이전)
- Protons과 neutrons이 서로 교환 가능 → iron peak metals (transition metals) 생성

# PERIODIC TABLE

## Atomic Properties of the Elements

**NIST** National Institute of Standards and Technology  
U.S. Department of Commerce  
Physical Measurement Laboratory [www.nist.gov/pml](http://www.nist.gov/pml)  
Standard Reference Data [www.nist.gov/srd](http://www.nist.gov/srd)

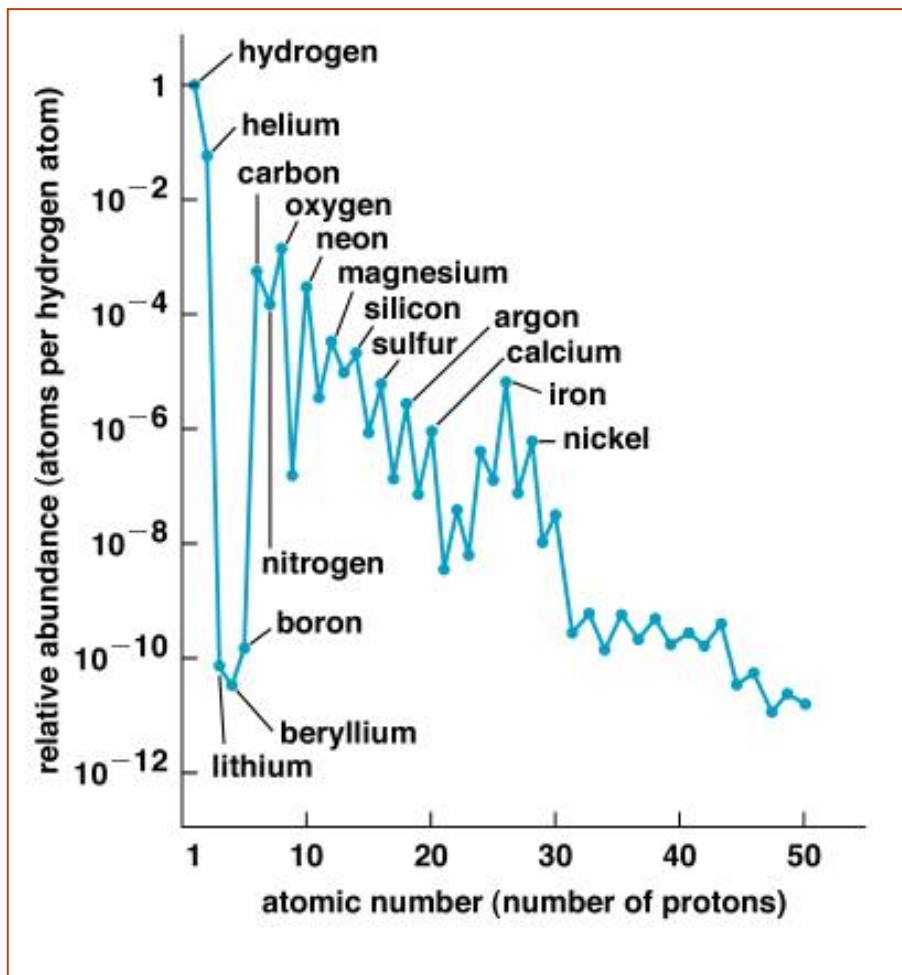
Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA	VIIIA
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
H 1.008 1s <sup>1</sup>	He 4.0026 1s <sup>2</sup>	Li 6.94 1s <sup>2</sup> 2s <sup>1</sup>	Be 9.0122 1s <sup>2</sup> 2s <sup>2</sup>	B 10.81 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>1</sup>	C 12.011 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>2</sup>	N 14.007 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>3</sup>	O 15.999 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>4</sup>	F 18.998 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>5</sup>	Ne 20.180 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup>	Na 22.990 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>1</sup>	Mg 24.305 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup>	Al 26.982 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>1</sup>	Si 28.086 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>2</sup>	P 30.974 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>3</sup>	S 32.06 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>4</sup>	Cl 35.45 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>5</sup>	Ar 39.948 1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup>	
K 39.098 [Ar] 4s <sup>1</sup>	Ca 40.078 [Ar] 4s <sup>2</sup>	Sc 44.956 [Ar] 3d <sup>1</sup> 4s <sup>2</sup>	Ti 47.87 [Ar] 3d <sup>2</sup> 4s <sup>2</sup>	V 50.942 [Ar] 3d <sup>3</sup> 4s <sup>2</sup>	Cr 51.996 [Ar] 3d <sup>5</sup> 4s <sup>1</sup>	Mn 54.938 [Ar] 3d <sup>5</sup> 4s <sup>2</sup>	Fe 55.845 [Ar] 3d <sup>6</sup> 4s <sup>2</sup>	Co 58.933 [Ar] 3d <sup>7</sup> 4s <sup>2</sup>	Ni 58.693 [Ar] 3d <sup>8</sup> 4s <sup>2</sup>	Cu 63.546 [Ar] 3d <sup>10</sup> 4s <sup>1</sup>	Zn 65.38 [Ar] 3d <sup>10</sup> 4s <sup>2</sup>	Ga 69.723 [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>1</sup>	Ge 72.630 [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup>	As 74.922 [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup>	Se 78.971 [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup>	Br 79.904 [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup>	Kr 83.798 [Ar] 3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup>	
Rb 85.468 [Kr] 5s <sup>1</sup>	Sr 87.62 [Kr] 5s <sup>2</sup>	Y 88.906 [Kr] 4d <sup>1</sup> 5s <sup>2</sup>	Zr 91.224 [Kr] 4d <sup>2</sup> 5s <sup>2</sup>	Nb 92.906 [Kr] 4d <sup>4</sup> 5s <sup>1</sup>	Mo 95.94 [Kr] 4d <sup>5</sup> 5s <sup>1</sup>	Tc 98.906 [Kr] 4d <sup>5</sup> 5s <sup>2</sup>	Ru 101.07 [Kr] 4d <sup>7</sup> 5s <sup>1</sup>	Rh 102.91 [Kr] 4d <sup>8</sup> 5s <sup>1</sup>	Pd 106.42 [Kr] 4d <sup>10</sup> 5s <sup>0</sup>	Ag 107.87 [Kr] 4d <sup>10</sup> 5s <sup>1</sup>	Cd 112.41 [Kr] 4d <sup>10</sup> 5s <sup>2</sup>	In 114.82 [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>1</sup>	Sn 118.71 [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>2</sup>	Sb 121.76 [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>3</sup>	Te 127.60 [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>4</sup>	I 126.90 [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>5</sup>	Xe 131.29 [Kr] 4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>6</sup>	
Cs 132.91 [Xe] 6s <sup>1</sup>	Ba 137.33 [Xe] 6s <sup>2</sup>	La 138.91 [Xe] 5d <sup>1</sup> 6s <sup>2</sup>	Hf 178.49 [Xe] 4f <sup>14</sup> 5d <sup>2</sup> 6s <sup>2</sup>	Ta 180.95 [Xe] 4f <sup>14</sup> 5d <sup>3</sup> 6s <sup>2</sup>	W 183.84 [Xe] 4f <sup>14</sup> 5d <sup>4</sup> 6s <sup>2</sup>	Re 186.21 [Xe] 4f <sup>14</sup> 5d <sup>5</sup> 6s <sup>2</sup>	Os 190.23 [Xe] 4f <sup>14</sup> 5d <sup>6</sup> 6s <sup>2</sup>	Ir 192.22 [Xe] 4f <sup>14</sup> 5d <sup>7</sup> 6s <sup>2</sup>	Pt 195.08 [Xe] 4f <sup>14</sup> 5d <sup>9</sup> 6s <sup>1</sup>	Au 196.97 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>1</sup>	Hg 200.59 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup>	Tl 204.38 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>1</sup>	Pb 207.2 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>2</sup>	Bi 208.98 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>3</sup>	Po 209 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>4</sup>	At 210 [Xe] 4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 6p <sup>5</sup>		
Fr 223 [Rn] 7s <sup>1</sup>	Ra 226 [Rn] 7s <sup>2</sup>	Ac 227 [Rn] 5f <sup>1</sup> 7s <sup>2</sup>	Rf 261 [Rn] 5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup>	Db 262 [Rn] 5f <sup>14</sup> 6d <sup>3</sup> 7s <sup>2</sup>	Sg 266 [Rn] 5f <sup>14</sup> 6d <sup>4</sup> 7s <sup>2</sup>	Bh 264 [Rn] 5f <sup>14</sup> 6d <sup>5</sup> 7s <sup>2</sup>	Hs 277 [Rn] 5f <sup>14</sup> 6d <sup>6</sup> 7s <sup>2</sup>	Mt 268 [Rn] 5f <sup>14</sup> 6d <sup>7</sup> 7s <sup>2</sup>	Ds 271 [Rn] 5f <sup>14</sup> 6d <sup>8</sup> 7s <sup>2</sup>	Rg 272 [Rn] 5f <sup>14</sup> 6d <sup>9</sup> 7s <sup>2</sup>	Cn 285 [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>1</sup>	Nh 286 [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>2</sup>	Fl 289 [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>3</sup>	Mc 288 [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>4</sup>	Lv 293 [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>5</sup>	Ts 294 [Rn] 5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>6</sup>		
		La 138.91 [Xe] 5d <sup>1</sup> 6s <sup>2</sup>	Ce 140.12 [Xe] 4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup>	Pr 140.91 [Xe] 4f <sup>3</sup> 6s <sup>2</sup>	Nd 144.24 [Xe] 4f <sup>4</sup> 6s <sup>2</sup>	Pm 144.91 [Xe] 4f <sup>5</sup> 6s <sup>2</sup>	Sm 150.36 [Xe] 4f <sup>6</sup> 6s <sup>2</sup>	Eu 151.96 [Xe] 4f <sup>7</sup> 6s <sup>2</sup>	Gd 157.25 [Xe] 4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	Tb 158.93 [Xe] 4f <sup>9</sup> 6s <sup>2</sup>	Dy 162.50 [Xe] 4f <sup>10</sup> 6s <sup>2</sup>	Ho 164.93 [Xe] 4f <sup>11</sup> 6s <sup>2</sup>	Er 167.26 [Xe] 4f <sup>12</sup> 6s <sup>2</sup>	Tm 168.93 [Xe] 4f <sup>13</sup> 6s <sup>2</sup>	Yb 173.05 [Xe] 4f <sup>14</sup> 6s <sup>2</sup>			
		Ac 227 [Rn] 5f <sup>1</sup> 7s <sup>2</sup>	Th 232.04 [Rn] 6d <sup>2</sup> 7s <sup>2</sup>	Pa 231.04 [Rn] 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	U 238.03 [Rn] 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Np 237 [Rn] 5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Pu 244 [Rn] 5f <sup>6</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Am 243 [Rn] 5f <sup>7</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Cm 247 [Rn] 5f <sup>7</sup> 6d <sup>2</sup> 7s <sup>2</sup>	Bk 247 [Rn] 5f <sup>9</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Cf 251 [Rn] 5f <sup>10</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Es 252 [Rn] 5f <sup>11</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Fm 257 [Rn] 5f <sup>12</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Md 258 [Rn] 5f <sup>13</sup> 6d <sup>1</sup> 7s <sup>2</sup>	No 259 [Rn] 5f <sup>14</sup> 6d <sup>1</sup> 7s <sup>2</sup>	Lr 262 [Rn] 5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup>		

<sup>1</sup>Based upon <sup>12</sup>C. () indicates the mass number of the longest-lived isotope.

For the most precise values and uncertainties visit [ciaaw.org](http://ciaaw.org) and [pml.nist.gov/data](http://pml.nist.gov/data).  
NIST SP 966 (July 2018)

In the cores of massive stars just before supernova explosions, atomic nuclei exchange protons and neutrons to form the iron peak metals.

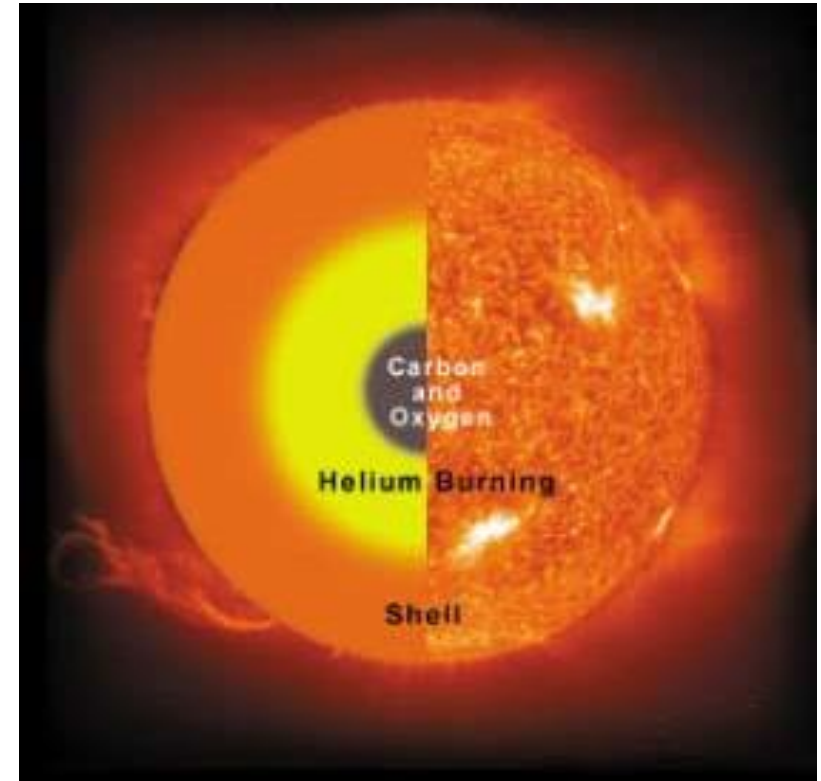
- 원소들의 개수분포 비율
  - 수소 원자의 개수를 1로 놓는다.
  - Odd-even effect



- 정리

- Hydrogen
  - from big bang nucleosynthesis
- Helium
  - from big bang and from hydrogen burning
- Nitrogen
  - from CNO cycle
- Carbon, Oxygen
  - from helium burning
- Light elements (Neon, Magnesium, Calcium)
  - from carbon and oxygen burning
- Iron metals
  - from the final burning

## Making Elements Up to Iron



- 핵자의 결합 에너지 nuclear binding energy

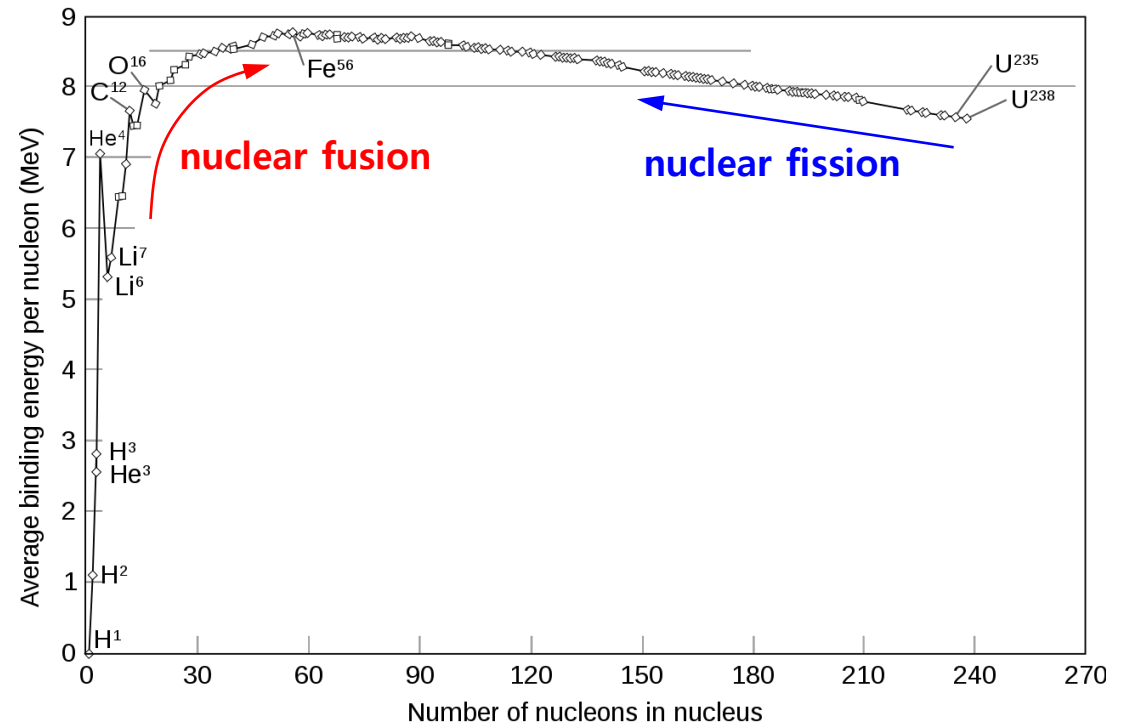
- 수평축 : 원자의 질량수  $A$
- 수직축 : 핵자의 결합에너지

- 핵융합 nuclear fusion

- 예) K-STAR

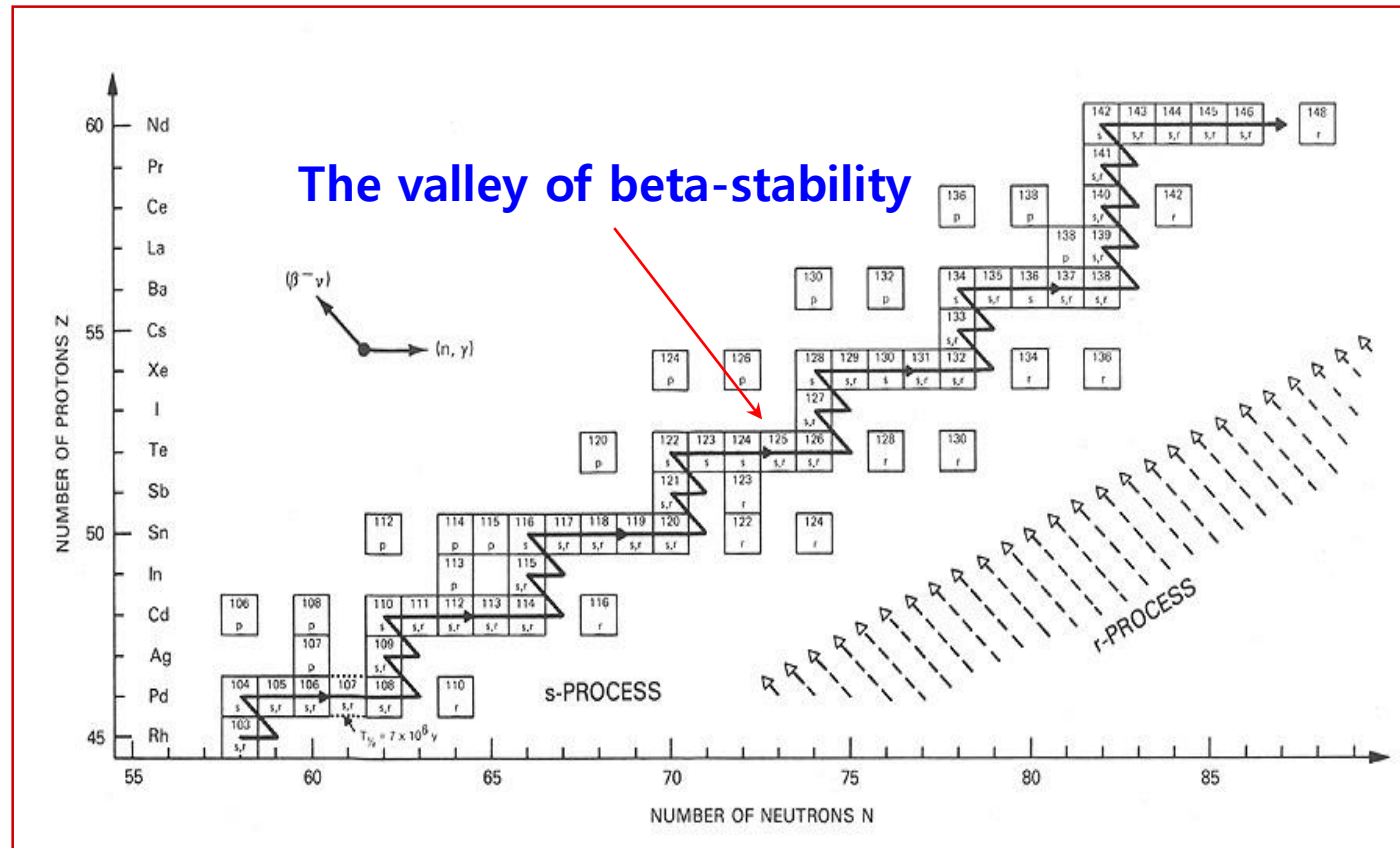
- 핵분열 nuclear fission

- 예) 핵폭탄, 원자력발전





- 철 Fe 보다 무거운 원자 생성
  - Ion peak metals에 중성자 포획 (neutron capture)
  - ${}_{26}\text{Fe} + \text{neutron} + \text{energy} \rightarrow {}_{26}\text{Fe} + \text{proton} \rightarrow {}_{27}\text{Co}$
  - ...





- 주기율표의 원자 생성 분류

1 H																	2 He				
3 Li	4 Be															5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg															13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr				
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe				
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn				
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	--	--	--	114 --		116 --		118 --					
		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu						
		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr						

White - Big Bang

Yellow - Small Stars

Pink - Cosmic Rays

Green - Large Stars

Blue - Supernovae



- Your Cosmic Origin

