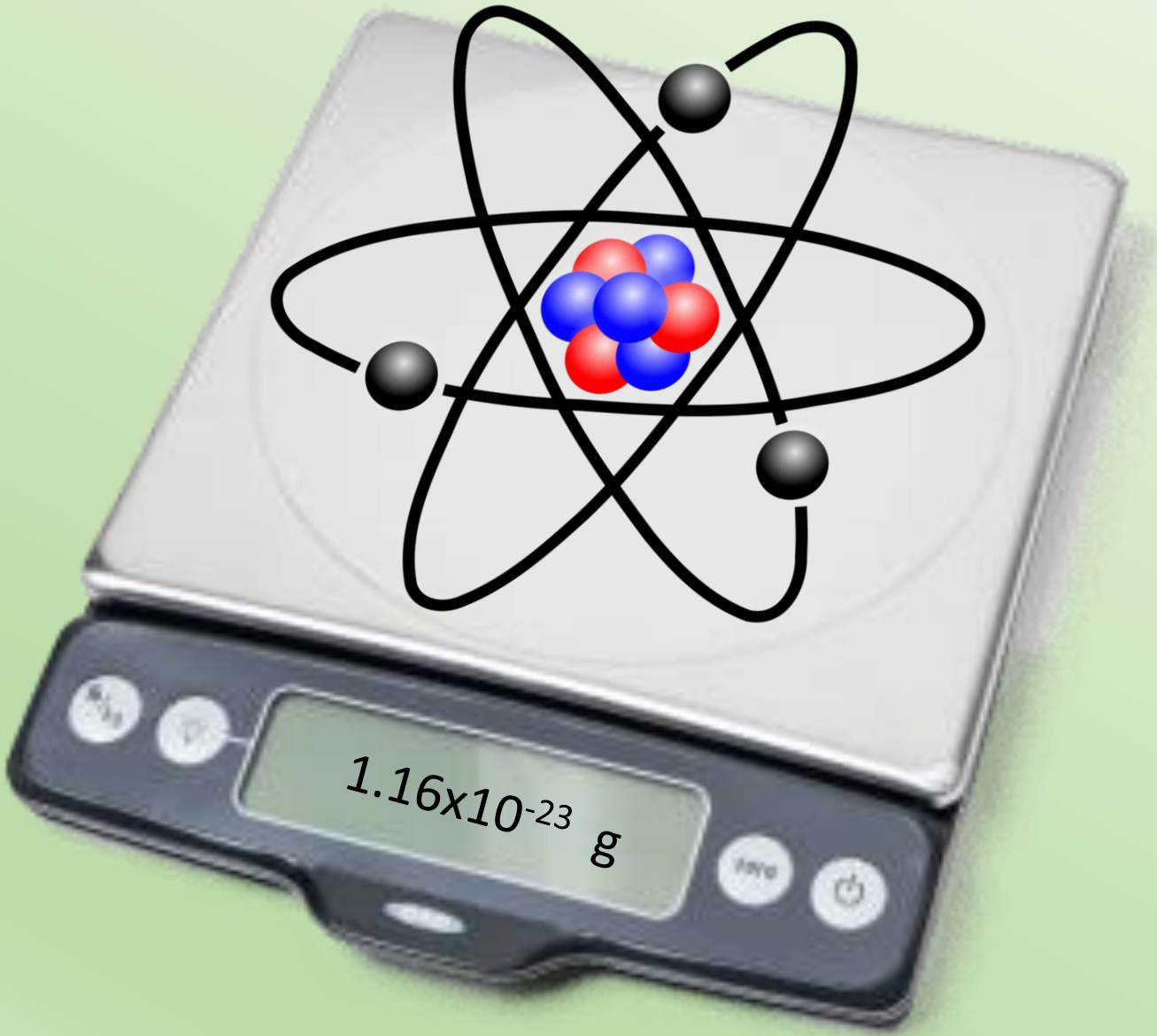
Atomic Mass

Atomic Mass

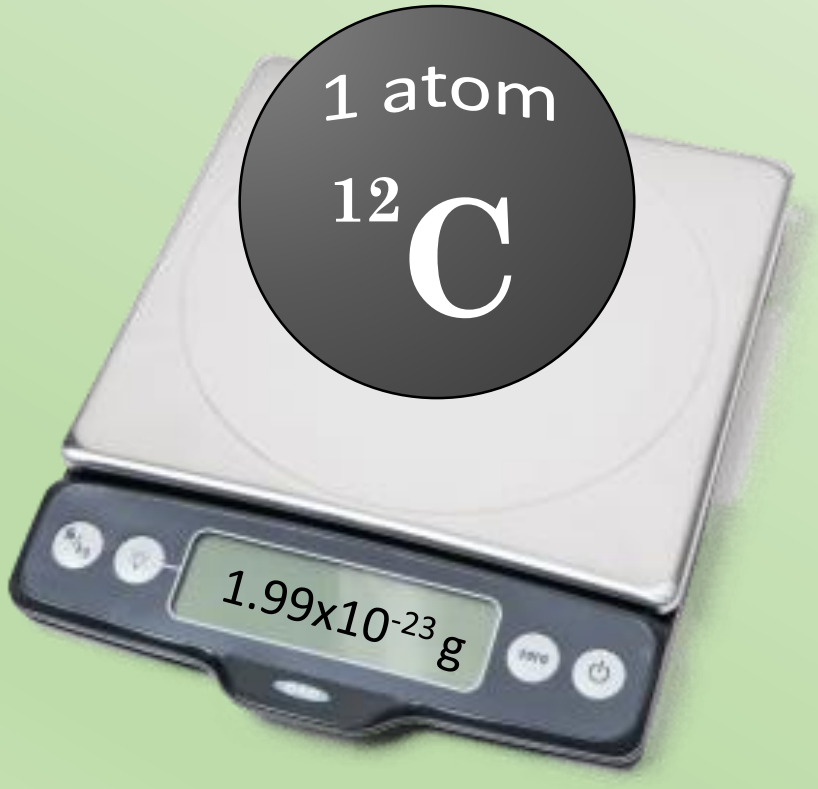


Measuring the mass of atoms

- "grams" is too big a unit; the numbers are too small.
- We need a more convenient unit.

The *(unified)* Atomic Mass Unit (u): 1/12th the mass of a carbon-12 atom $\quad {}^{12}_{6}\mathrm{C} \div 12$

$$1\ \mathrm{u} \approx 1.66 \times 10^{-24}\ \mathrm{g}$$

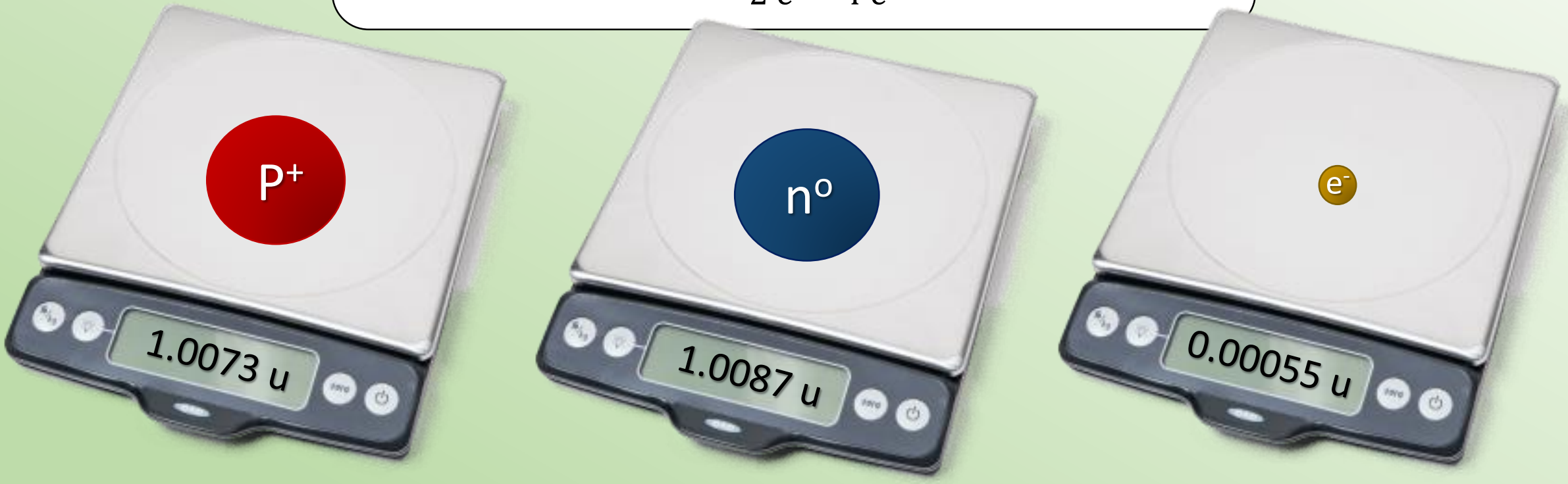


Carbon-12 atom

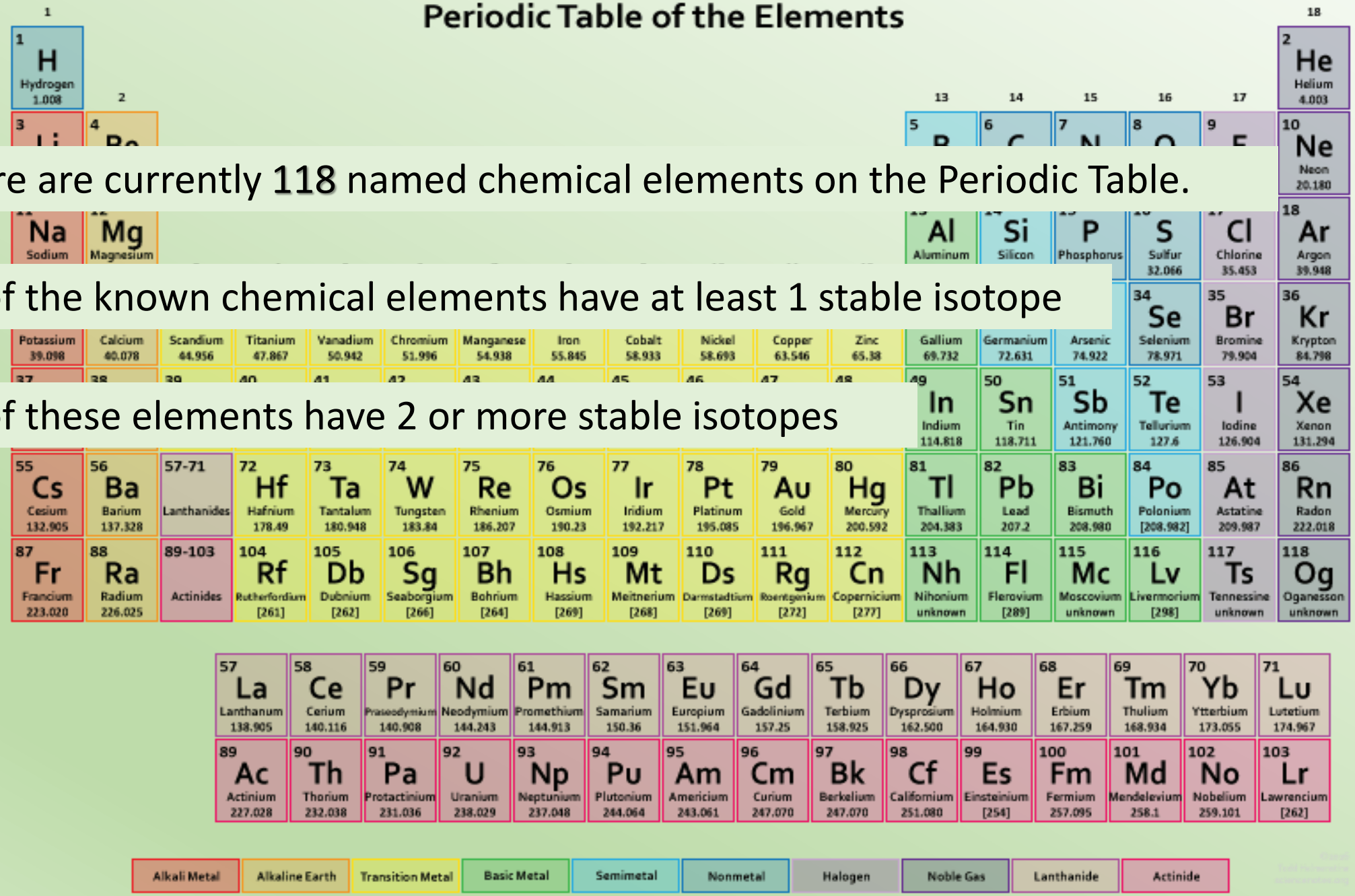
Mass $= 12\ \mathrm{u}$

(also used: $12\ \mathrm{amu}$ or $12\ \mathrm{Da}$)

$^{12}_{6}C$ $6\,p^{+}$ $6\,n^{o}$ $2\,e^{-}$ $4\,e^{-}$ *mass* = 12 u



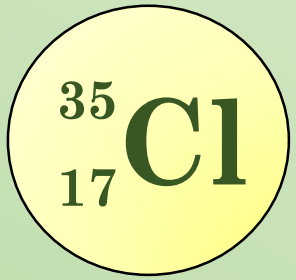
- Protons & neutrons each have a mass of approximately 1 u
- An atom of carbon-12 has a mass of 12 u
- An atom of oxygen-16 has a mass of approximately 16 u
- An atom of hydrogen-1 has a mass of approximately 1 u
- An atom with 3 protons and 4 neutrons has a mass of approximately 7 u
- An atom of potassium with 20 neutrons has a mass of approximately 39 u
- An atom of potassium with 22 neutrons has a mass of approximately 41 u

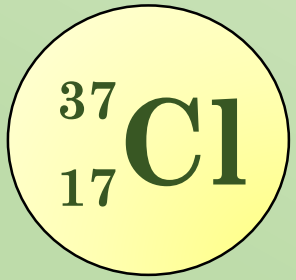

Periodic Table of the Elements
There are currently 118 named chemical elements on the Periodic Table.
80 of the known chemical elements have at least 1 stable isotope
54 of these elements have 2 or more stable isotopes
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide

54 of these elements have 2 or more stable isotopes

Example 1 (Chlorine):

- There are two stable isotopes of chlorine: chlorine-35 & chlorine-37.



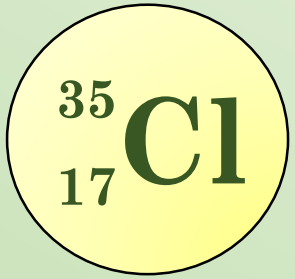


- Since these two types of chlorine atoms have different masses, it is useful to describe the average mass of a chlorine atom.
- Chlorine-35 atoms have a mass of approximately 35 u.
- Chlorine-37 atoms have a mass of approximately 37 u.
- 76% of chlorine atoms have 18 neutrons (chlorine-35).
- 24% of chlorine atoms have 20 neutrons (chlorine-37).

Calculate the average mass of a chlorine atom.

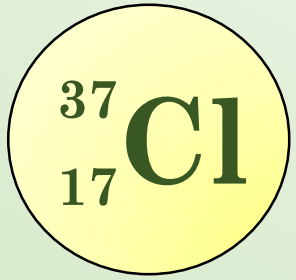
- There are two stable isotopes of chlorine : **chlorine-35** & **chlorine-37**.

76% of chlorine atoms



Mass ≈ **35 u**

24% of chlorine atoms



Mass ≈ **37 u**

Calculate the average mass of a chlorine atom.

$$\text{Average atomic mass} = (0.76)(35\ \text{u}) + (0.24)(37\ \text{u}) = 35.48\ \text{u}$$

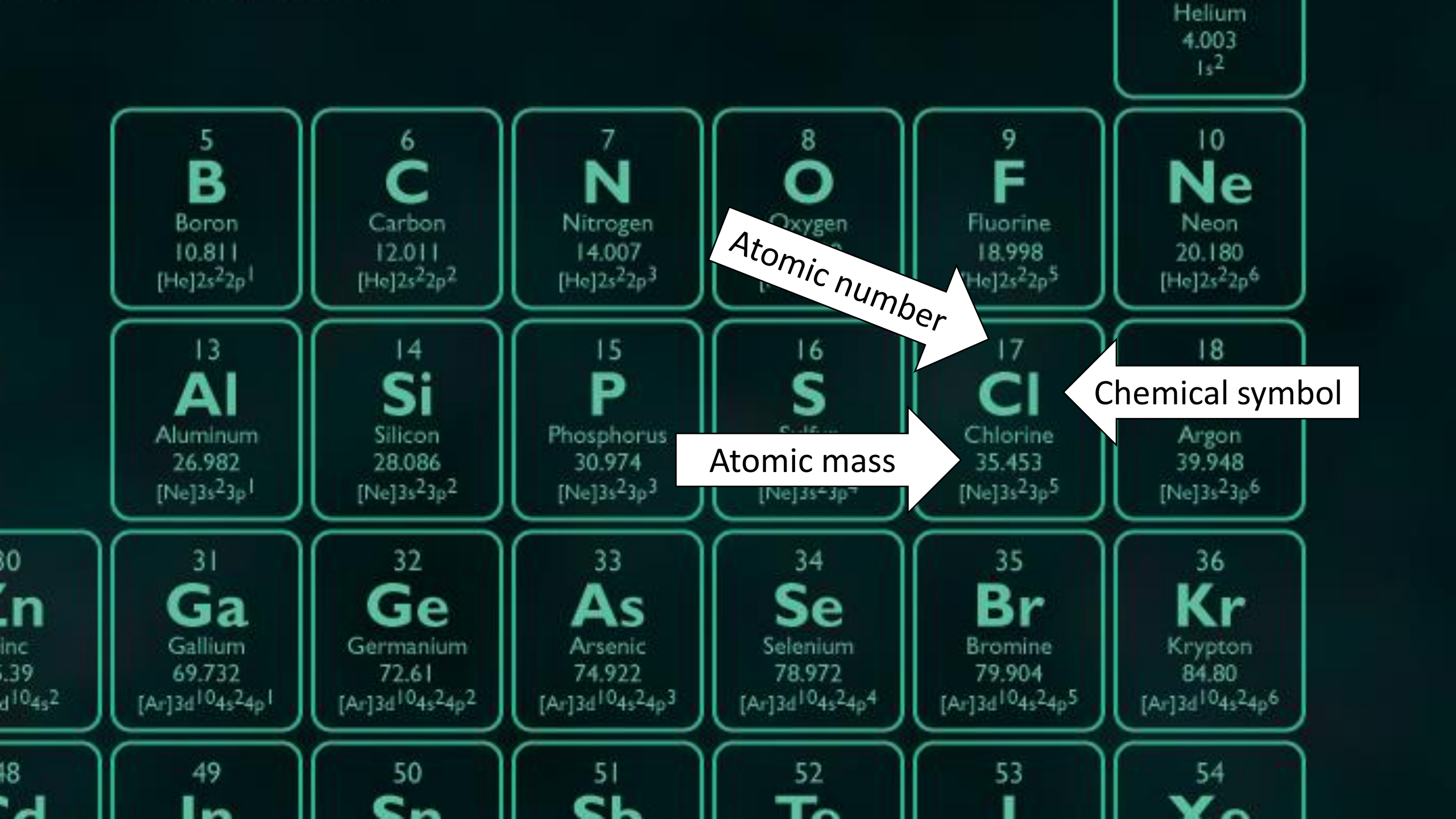
(*a.k.a.* Atomic mass / Atomic weight)

Periodic Table of the Elements

1 H Hydrogen 1.008 $1s^1$																	2 He Helium 4.003 $1s^2$
3 Li Lithium 6.941 $[He]2s^1$	4 Be Beryllium 9.012 $[He]2s^2$											5 B Boron 10.811 $[He]2s^22p^1$	6 C Carbon 12.011 $[He]2s^22p^2$	7 N Nitrogen 14.007 $[He]2s^22p^3$	8 O Oxygen 15.999 $[He]2s^22p^4$	9 F Fluorine 18.998 $[He]2s^22p^5$	10 Ne Neon 20.180 $[He]2s^22p^6$
11 Na Sodium 22.990 $[Ne]3s^1$	12 Mg Magnesium 24.305 $[Ne]3s^2$											13 Al Aluminum 26.982 $[Ne]3s^23p^1$	14 Si Silicon 28.086 $[Ne]3s^23p^2$	15 P Phosphorus 30.974 $[Ne]3s^23p^3$	16 S Sulfur 32.066 $[Ne]3s^23p^4$	17 Cl Chlorine 35.453 $[Ne]3s^23p^5$	18 Ar Argon 39.948 $[Ne]3s^23p^6$
19 K Potassium 39.098 $[Ar]4s^1$	20 Ca Calcium 40.078 $[Ar]4s^2$	21 Sc Scandium 44.956 $[Ar]3d^14s^2$	22 Ti Titanium 47.88 $[Ar]3d^24s^2$	23 V Vanadium 50.942 $[Ar]3d^34s^2$	24 Cr Chromium 51.996 $[Ar]3d^54s^1$	25 Mn Manganese 54.938 $[Ar]3d^54s^2$	26 Fe Iron 55.933 $[Ar]3d^64s^2$	27 Co Cobalt 58.933 $[Ar]3d^74s^2$	28 Ni Nickel 58.693 $[Ar]3d^84s^2$	29 Cu Copper 63.546 $[Ar]3d^{10}4s^1$	30 Zn Zinc 65.39 $[Ar]3d^{10}4s^2$	31 Ga Gallium 69.732 $[Ar]3d^{10}4s^24p^1$	32 Ge Germanium 72.61 $[Ar]3d^{10}4s^24p^2$	33 As Arsenic 74.922 $[Ar]3d^{10}4s^24p^3$	34 Se Selenium 78.972 $[Ar]3d^{10}4s^24p^4$	35 Br Bromine 79.904 $[Ar]3d^{10}4s^24p^5$	36 Kr Krypton 84.80 $[Ar]3d^{10}4s^24p^6$
37 Rb Rubidium 84.468 $[Kr]5s^1$	38 Sr Strontium 87.62 $[Kr]5s^2$	39 Y Yttrium 88.906 $[Kr]4d^15s^2$	40 Zr Zirconium 91.224 $[Kr]4d^25s^2$	41 Nb Niobium 92.906 $[Kr]4d^45s^1$	42 Mo Molybdenum 95.95 $[Kr]4d^55s^1$	43 Tc Technetium 98.907 $[Kr]4d^55s^2$	44 Ru Ruthenium 101.07 $[Kr]4d^75s^1$	45 Rh Rhodium 102.906 $[Kr]4d^85s^1$	46 Pd Palladium 106.42 $[Kr]4d^{10}$	47 Ag Silver 107.868 $[Kr]4d^{10}5s^1$	48 Cd Cadmium 112.411 $[Kr]4d^{10}5s^2$	49 In Indium 114.818 $[Kr]4d^{10}5s^25p^1$	50 Sn Tin 118.71 $[Kr]4d^{10}5s^25p^2$	51 Sb Antimony 121.760 $[Kr]4d^{10}5s^25p^3$	52 Te Tellurium 127.6 $[Kr]4d^{10}5s^25p^4$	53 I Iodine 126.904 $[Kr]4d^{10}5s^25p^5$	54 Xe Xenon 131.29 $[Kr]4d^{10}5s^25p^6$
55 Cs Cesium 132.905 $[Xe]6s^1$	56 Ba Barium 137.327 $[Xe]6s^2$	57-71	72 Hf Hafnium 178.49 $[Xe]4f^{14}5d^26s^2$	73 Ta Tantalum 180.948 $[Xe]4f^{14}5d^36s^2$	74 W Tungsten 183.85 $[Xe]4f^{14}5d^46s^2$	75 Re Rhenium 186.207 $[Xe]4f^{14}5d^56s^2$	76 Os Osmium 190.23 $[Xe]4f^{14}5d^66s^2$	77 Ir Iridium 192.22 $[Xe]4f^{14}5d^76s^2$	78 Pt Platinum 195.08 $[Xe]4f^{14}5d^96s^1$	79 Au Gold 196.967 $[Xe]4f^{14}5d^{10}6s^1$	80 Hg Mercury 200.59 $[Xe]4f^{14}5d^{10}6s^2$	81 Tl Thallium 204.383 $[Xe]4f^{14}5d^{10}6s^26p^1$	82 Pb Lead 207.2 $[Xe]4f^{14}5d^{10}6s^26p^2$	83 Bi Bismuth 208.980 $[Xe]4f^{14}5d^{10}6s^26p^3$	84 Po Polonium [208.982] $[Xe]4f^{14}5d^{10}6s^26p^4$	85 At Astatine 209.987 $[Xe]4f^{14}5d^{10}6s^26p^5$	86 Rn Radon 222.018 $[Xe]4f^{14}5d^{10}6s^26p^6$
87 Fr Francium 223.020 $[Rn]7s^1$	88 Ra Radium 226.025 $[Rn]7s^2$	89-103	104 Rf Rutherfordium [261] $[Rn]5f^{14}6d^27s^2*$	105 Db Dubnium [262] $[Rn]5f^{14}6d^37s^2*$	106 Sg Seaborgium [266] $[Rn]5f^{14}6d^47s^2*$	107 Bh Bohrium [264] $[Rn]5f^{14}6d^57s^2*$	108 Hs Hassium [269] $[Rn]5f^{14}6d^67s^2*$	109 Mt Meitnerium [268] $[Rn]5f^{14}6d^77s^2*$	110 Ds Darmstadtium [269] $[Rn]5f^{14}6d^87s^2*$	111 Rg Roentgenium [272] $[Rn]5f^{14}6d^97s^2*$	112 Cn Copernicium [277] $[Rn]5f^{14}6d^{10}7s^2*$	113 Uut Ununtrium unknown $[Rn]5f^{14}6d^{10}7s^27p^1*$	114 Fl Flerovium [289] $[Rn]5f^{14}6d^{10}7s^27p^2*$	115 Uup Ununpentium unknown $[Rn]5f^{14}6d^{10}7s^27p^3*$	116 Lv Livermorium [298] $[Rn]5f^{14}6d^{10}7s^27p^4*$	117 Uus Ununseptium unknown $[Rn]5f^{14}6d^{10}7s^27p^5*$	118 Uuo Ununoctium unknown $[Rn]5f^{14}6d^{10}7s^27p^6*$

Configurations denoted with a * are unknown and the listed values are predicted.

57 La Lanthanum 138.906 $[Xe]5d^16s^2$	58 Ce Cerium 140.115 $[Xe]4f^15d^16s^2$	59 Pr Praseodymium 140.908 $[Xe]4f^36s^2$	60 Nd Neodymium 144.24 $[Xe]4f^46s^2$	61 Pm Promethium 144.913 $[Xe]4f^56s^2$	62 Sm Samarium 150.36 $[Xe]4f^66s^2$	63 Eu Europium 151.966 $[Xe]4f^76s^2$	64 Gd Gadolinium 157.25 $[Xe]4f^75d^16s^2$	65 Tb Terbium 158.925 $[Xe]4f^96s^2$	66 Dy Dysprosium 162.50 $[Xe]4f^{10}6s^2$	67 Ho Holmium 164.930 $[Xe]4f^{11}6s^2$	68 Er Erbium 167.26 $[Xe]4f^{12}6s^2$	69 Tm Thulium 168.934 $[Xe]4f^{13}6s^2$	70 Yb Ytterbium 173.04 $[Xe]4f^{14}6s^2$	71 Lu Lutetium 174.967 $[Xe]4f^{14}5d^16s^2$
89 Ac Actinium 227.028 $[Rn]6d^17s^2$	90 Th Thorium 232.038 $[Rn]6d^27s^2$	91 Pa Protactinium 231.036 $[Rn]5f^26d^17s^2$	92 U Uranium 238.029 $[Rn]5f^36d^17s^2$	93 Np Neptunium 237.048 $[Rn]5f^46d^17s^2$	94 Pu Plutonium 244.064 $[Rn]5f^67s^2$	95 Am Americium 243.061 $[Rn]5f^77s^2$	96 Cm Curium 247.070 $[Rn]5f^76d^17s^2$	97 Bk Berkelium 247.070 $[Rn]5f^97s^2$	98 Cf Californium 251.080 $[Rn]5f^{10}7s^2$	99 Es Einsteinium [254] $[Rn]5f^{11}7s^2$	100 Fm Fermium 257.095 $[Rn]5f^{12}7s^2$	101 Md Mendelevium 258.1 $[Rn]5f^{13}7s^2$	102 No Nobelium 259.101 $[Rn]5f^{14}7s^2$	103 Lr Lawrencium [262] $[Rn]5f^{14}6d^17s^2$


Helium
4.003
$1s^2$
5
B
Boron
10.811
$[He]2s^22p^1$
6
C
Carbon
12.011
$[He]2s^22p^2$
7
N
Nitrogen
14.007
$[He]2s^22p^3$
8
O
Oxygen
9
F
Fluorine
18.998
$[He]2s^22p^5$
10
Ne
Neon
20.180
$[He]2s^22p^6$
13
Al
Aluminum
26.982
$[Ne]3s^23p^1$
14
Si
Silicon
28.086
$[Ne]3s^23p^2$
15
P
Phosphorus
30.974
$[Ne]3s^23p^3$
16
S
17
Cl
Chlorine
35.453
$[Ne]3s^23p^5$
18
Argon
39.948
$[Ne]3s^23p^6$
Atomic number
Chemical symbol
Atomic mass
31
Ga
Gallium
69.732
$[Ar]3d^{10}4s^24p^1$
32
Ge
Germanium
72.61
$[Ar]3d^{10}4s^24p^2$
33
As
Arsenic
74.922
$[Ar]3d^{10}4s^24p^3$
34
Se
Selenium
78.972
$[Ar]3d^{10}4s^24p^4$
35
Br
Bromine
79.904
$[Ar]3d^{10}4s^24p^5$
36
Kr
Krypton
84.80
$[Ar]3d^{10}4s^24p^6$
49
50
51
52
53
54

Example 2 (Copper):

- There are two stable isotopes of copper.
- 69.15% of copper atoms contain 34 neutrons in the nucleus.
- The remaining copper atoms have a mass number of 65.

Complete the following table, then calculate the average atomic mass of copper.

Copper, Cu			
Atomic Number	# Neutrons	Mass Number	Relative Abundance
	34		69.15%
		65	

$$\text{Average atomic mass} = (0.6915)(63\ \text{u}) + (0.3085)(65\ \text{u}) = 63.62\ \text{u}$$

The atomic masses calculated so far (examples 1 & 2) do not exactly match the values appearing on the periodic table.

This is because we approximated the mass of the isotope by using the mass number; close, but we could be more accurate if we were given more accurate values for the masses of the isotopes.

Example 3 (Copper / using more accurate masses):

Example 3 (Copper / using more accurate masses):

Copper, Cu				
Atomic Number	# Neutrons	Mass Number		Relative Abundance
29	34	63		69.15%
29	36	65		30.85%

Average atomic mass $\approx (0.6915)(62.930\ \text{u}) + (0.3085)(64.928\ \text{u}) =$ **63.546 u**

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11 Na Sodium 22.990 $[Ne]3s^1$	12 Mg Magnesium 24.305 $[Ne]3s^2$											13 Al Aluminum 26.982 $[Ne]3s^23p^1$	14 Si Silicon 28.086 $[Ne]3s^23p^2$	15 P Phosphorus 30.974 $[Ne]3s^23p^3$	16 S Sulfur 32.066 $[Ne]3s^23p^4$	17 Cl Chlorine 35.453 $[Ne]3s^23p^5$	18 Ar Argon 39.948 $[Ne]3s^23p^6$
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Configurations denoted with a * are unknown and the listed values are predicted.

57 La Lanthanum 138.906 $[Xe]5d^16s^2$	58 Ce Cerium 140.115 $[Xe]4f^15d^16s^2$	59 Pr Praseodymium 140.908 $[Xe]4f^36s^2$	60 Nd Neodymium 144.24 $[Xe]4f^46s^2$	61 Pm Promethium 144.913 $[Xe]4f^56s^2$	62 Sm Samarium 150.36 $[Xe]4f^66s^2$	63 Eu Europium 151.966 $[Xe]4f^76s^2$	64 Gd Gadolinium 157.25 $[Xe]4f^75d^16s^2$	65 Tb Terbium 158.925 $[Xe]4f^96s^2$	66 Dy Dysprosium 162.50 $[Xe]4f^{10}6s^2$	67 Ho Holmium 164.930 $[Xe]4f^{11}6s^2$	68 Er Erbium 167.26 $[Xe]4f^{12}6s^2$	69 Tm Thulium 168.934 $[Xe]4f^{13}6s^2$	70 Yb Ytterbium 173.04 $[Xe]4f^{14}6s^2$	71 Lu Lutetium 174.967 $[Xe]4f^{14}5d^16s^2$
89 Ac Actinium 227.028 $[Rn]6d^17s^2$	90 Th Thorium 232.038 $[Rn]6d^27s^2$	91 Pa Protactinium 231.036 $[Rn]5f^26d^17s^2$	92 U Uranium 238.029 $[Rn]5f^36d^17s^2$	93 Np Neptunium 237.048 $[Rn]5f^46d^17s^2$	94 Pu Plutonium 244.064 $[Rn]5f^67s^2$	95 Am Americium 243.061 $[Rn]5f^77s^2$	96 Cm Curium 247.070 $[Rn]5f^76d^17s^2$	97 Bk Berkelium 247.070 $[Rn]5f^97s^2$	98 Cf Californium 251.080 $[Rn]5f^{10}7s^2$	99 Es Einsteinium [254] $[Rn]5f^{11}7s^2$	100 Fm Fermium 257.095 $[Rn]5f^{12}7s^2$	101 Md Mendelevium 258.1 $[Rn]5f^{13}7s^2$	102 No Nobelium 259.101 $[Rn]5f^{14}7s^2$	103 Lr Lawrencium [262] $[Rn]5f^{14}6d^17s^2$


Atomic number
Atomic mass
13
Al
Aluminum
26.982
[Ne]3s²3p¹
14
Si
Silicon
28.086
[Ne]3s²3p²
26
Fe
Iron
55.933
[Ar]3d⁶4s²
27
Co
Cobalt
58.933
[Ar]3d⁷4s²
28
Ni
29
Cu
Copper
63.546
[Ar]3d¹⁰4s¹
30
Zn
Zinc
65.39
[Ar]3d¹⁰4s²
31
Ga
Gallium
69.732
[Ar]3d¹⁰4s²4p¹
32
Ge
Germanium
72.61
[Ar]3d¹⁰4s²4p²
44
Ru
Ruthenium
101.07
[Kr]4d⁷5s¹
45
Rh
Rhodium
102.906
[Kr]4d⁸5s¹
46
Pd
Palladium
106.42
[Kr]4d¹⁰
47
Ag
Silver
107.868
[Kr]4d¹⁰5s¹
48
Cd
Cadmium
112.411
[Kr]4d¹⁰5s²
49
In
Indium
114.818
[Kr]4d¹⁰5s²5p¹
50
Sn
Tin
118.71
[Kr]4d¹⁰5s²5p²
76
77
78
79
80
81
82