EE113FZ
Solid State Electronics
Lecture 2: Atoms & The Periodic Table

Zhu DIAO

Email: zhu.diao@mu.ie

What is to be discussed today?

- Terminology used in describing matter.
- What is an atom and what is in it.
- Introduction to the periodic table of elements.
- How atoms interact.
- Beyond simple atoms (complications due to charge, mass, and bonding structures).
- Different types of molecular arrangements.

Key Terms

- Atoms – the smallest part of an element that can react.
- Element – a substance made entirely from one type of atom. There are ~118 elements currently.
- Molecule – the smallest part of an element or compound that can exist and still retain the properties of that element or compound.
- Mixture – made of 2 or more substances each of which maintains its identity and can be separated.
- Compound – made of 2 or more substances and the properties of the substance are different and can not be separated.

What is an Atom?

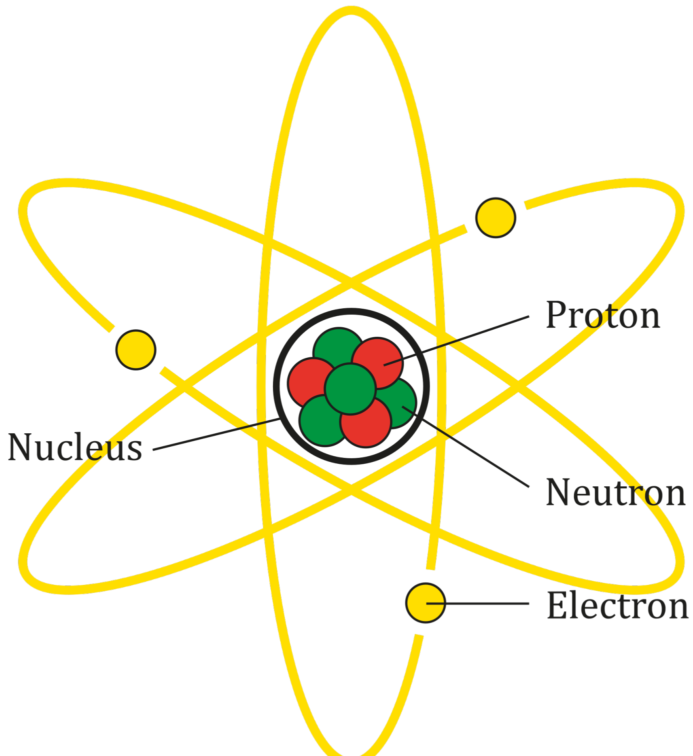
- Atoms are the building blocks of everything.
- Combinations of atoms create all that is known as matter.
- Atoms are made up by 3 subatomic particles:
  - Neutrons – no charge and a large mass, found in the centre of an atom.
  - Protons – a positive charge and a large mass, found in the centre of an atom.
  - Electrons – a negative charge with small mass, found outside the centre of an atom.

What is an Atom?

- As electronic engineers, we are only interested in electrons and protons!
- Both protons and neutrons are composite subatomic particles. They are made of elementary subatomic particles, e.g., quarks. But this is all too complicated for electronic engineers.
- Also antimatter is the same as matter but with an opposite charge ☺. It is unfortunately not very stable (one can generate them on particle accelerators but it is not of much use to electronic engineers, at least for now).

What Does an Atom Look Like?

- Might look something like the figure below, with the protons and neutrons closely packed together in a core with the electrons traveling in orbits around the core.



https://bar.wikipedia.org/wiki/Datei:Atom_Diagram.svg

Summary: What is an Atom?

Component	Charge	Mass	Location
Neutron	None	Large	Centre
Proton	Positive (+)	Large	Centre
Electron	Negative (-)	Very small	Outside

The Periodic Table of Elements

- There are many different types of elements.
- They are listed and arranged in what is called the periodic table of elements.
- They are listed by the number of protons (atomic number, a term you will learn in a few minutes) in the atoms of each element, from lowest to highest.
- They are also listed by how fast (how aggressively) they react to other elements.

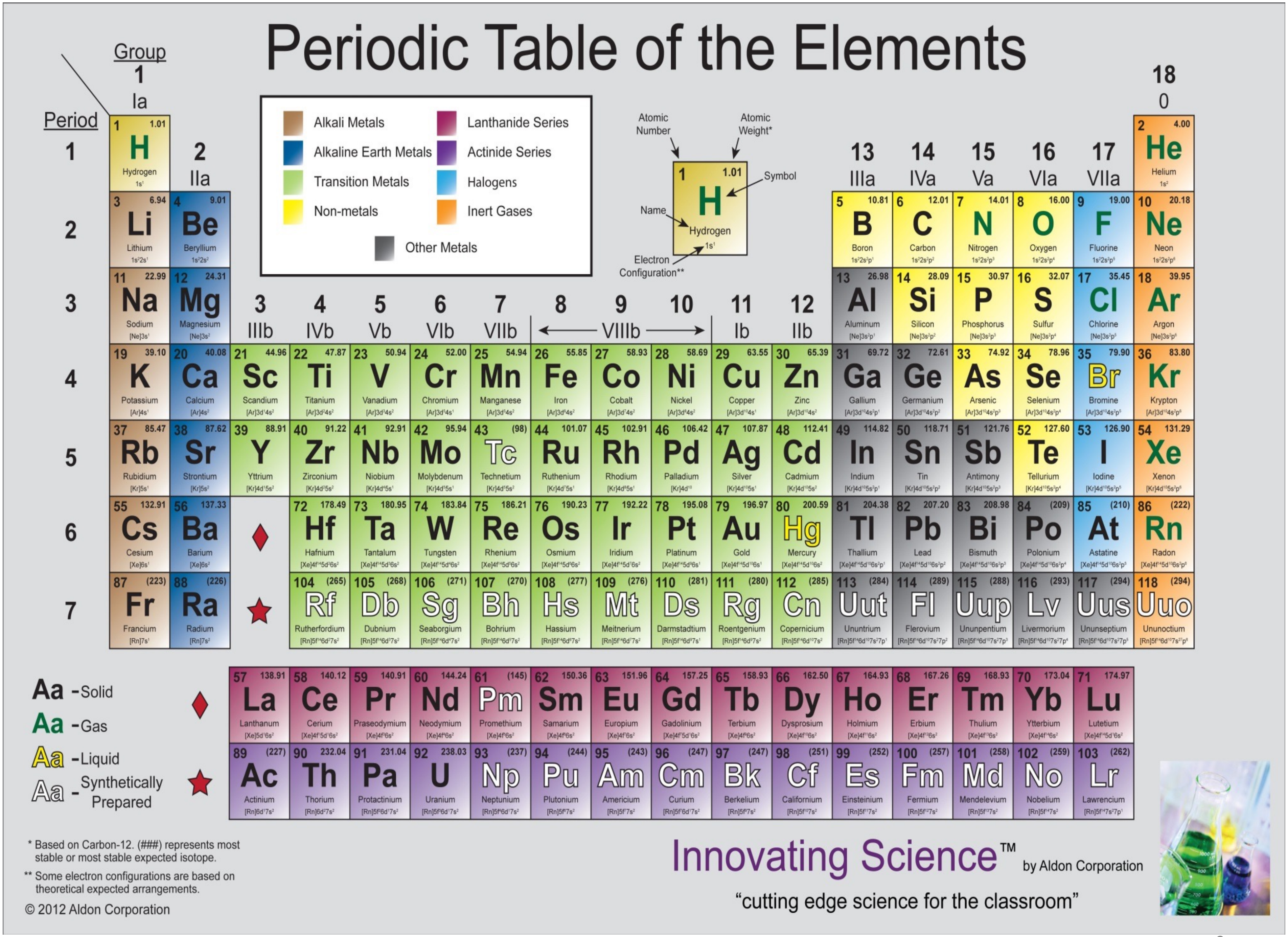
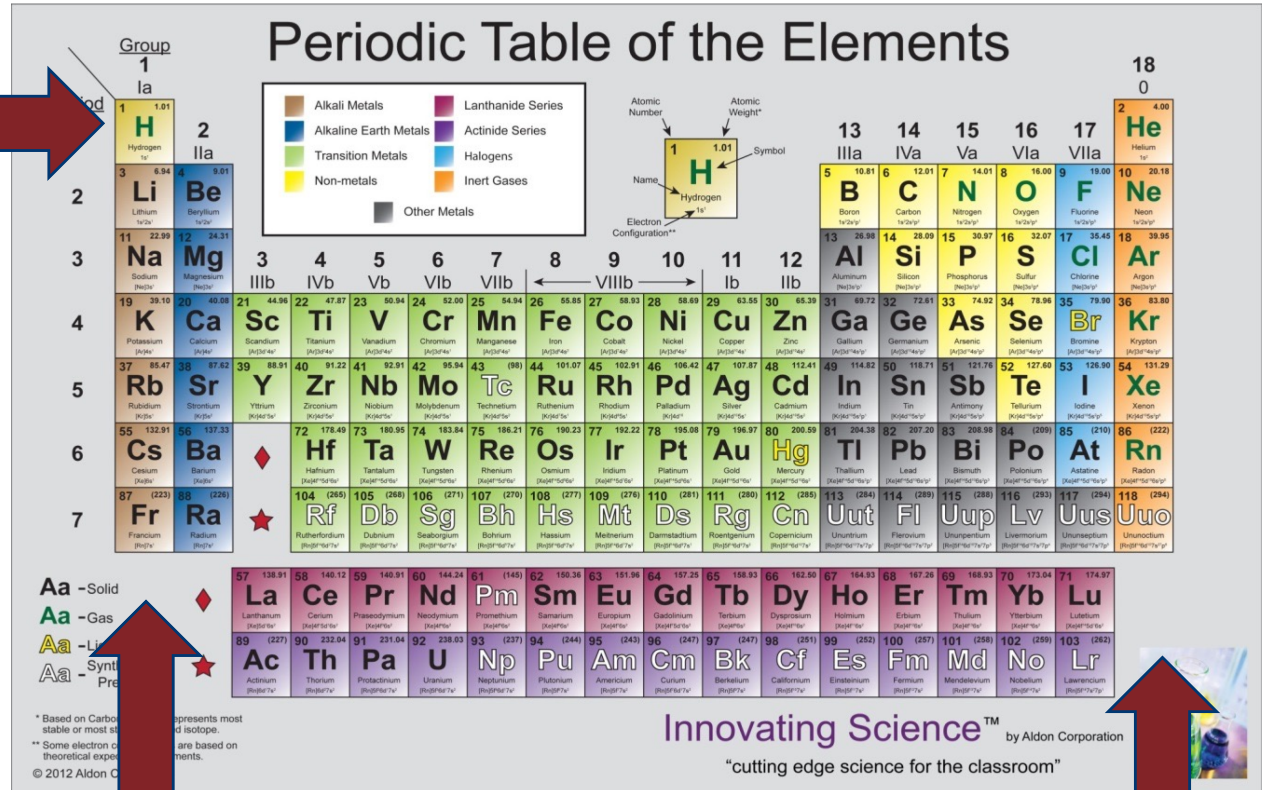

Periodic Table of the Elements
Group
Period
1 Ia
2 IIa
3 IIIb
4 IVb
5 Vb
6 VIb
7 VIIb
8 9 10 VIIIb
11 Ib
12 IIb
13 IIIa
14 IVa
15 Va
16 VIa
17 VIIa
18 0
Alkali Metals
Alkaline Earth Metals
Transition Metals
Non-metals
Lanthanide Series
Actinide Series
Halogens
Inert Gases
Other Metals
Atomic Number
Atomic Weight*
Symbol
Name
Electron Configuration**
1 1.01 H Hydrogen 1s¹
1 1.01 H Hydrogen
2 4.00 He Helium
3 6.94 Li Lithium
4 9.01 Be Beryllium
5 10.81 B Boron
6 12.01 C Carbon
7 14.01 N Nitrogen
8 16.00 O Oxygen
9 19.00 F Fluorine
10 20.18 Ne Neon
11 22.99 Na Sodium
12 24.31 Mg Magnesium
13 26.98 Al Aluminum
14 28.09 Si Silicon
15 30.97 P Phosphorus
16 32.07 S Sulfur
17 35.45 Cl Chlorine
18 39.95 Ar Argon
19 39.10 K Potassium
20 40.08 Ca Calcium
21 44.96 Sc Scandium
22 47.87 Ti Titanium
23 50.94 V Vanadium
24 52.00 Cr Chromium
25 54.94 Mn Manganese
26 55.85 Fe Iron
27 58.93 Co Cobalt
28 58.69 Ni Nickel
29 63.55 Cu Copper
30 65.39 Zn Zinc
31 69.72 Ga Gallium
32 72.61 Ge Germanium
33 74.92 As Arsenic
34 78.96 Se Selenium
35 79.90 Br Bromine
36 83.80 Kr Krypton
37 85.47 Rb Rubidium
38 87.62 Sr Strontium
39 88.91 Y Yttrium
40 91.22 Zr Zirconium
41 92.91 Nb Niobium
42 95.94 Mo Molybdenum
43 (98) Tc Technetium
44 101.07 Ru Ruthenium
45 102.91 Rh Rhodium
46 106.42 Pd Palladium
47 107.87 Ag Silver
48 112.41 Cd Cadmium
49 114.82 In Indium
50 118.71 Sn Tin
51 121.76 Sb Antimony
52 127.60 Te Tellurium
53 126.90 I Iodine
54 131.29 Xe Xenon
55 132.91 Cs Cesium
56 137.33 Ba Barium
72 178.49 Hf Hafnium
73 180.95 Ta Tantalum
74 183.84 W Tungsten
75 186.21 Re Rhenium
76 190.23 Os Osmium
77 192.22 Ir Iridium
78 195.08 Pt Platinum
79 196.97 Au Gold
80 200.59 Hg Mercury
81 204.38 Tl Thallium
82 207.20 Pb Lead
83 208.98 Bi Bismuth
84 (209) Po Polonium
85 (210) At Astatine
86 (222) Rn Radon
87 (223) Fr Francium
88 (226) Ra Radium
104 (265) Rf Rutherfordium
105 (268) Db Dubnium
106 (271) Sg Seaborgium
107 (270) Bh Bohrium
108 (277) Hs Hassium
109 (276) Mt Meitnerium
110 (281) Ds Darmstadtium
111 (280) Rg Roentgenium
112 (285) Cn Copernicium
113 (284) Uut Ununtrium
114 (289) Fl Flerovium
115 (288) Uup Ununpentium
116 (293) Lv Livermorium
117 (294) Uus Ununseptium
118 (294) Uuo Ununoctium
57 138.91 La Lanthanum
58 140.12 Ce Cerium
59 140.91 Pr Praseodymium
60 144.24 Nd Neodymium
61 (145) Pm Promethium
62 150.36 Sm Samarium
63 151.96 Eu Europium
64 157.25 Gd Gadolinium
65 158.93 Tb Terbium
66 162.50 Dy Dysprosium
67 164.93 Ho Holmium
68 167.26 Er Erbium
69 168.93 Tm Thulium
70 173.04 Yb Ytterbium
71 174.97 Lu Lutetium
89 (227) Ac Actinium
90 232.04 Th Thorium
91 231.04 Pa Protactinium
92 238.03 U Uranium
93 (237) Np Neptunium
94 (244) Pu Plutonium
95 (243) Am Americium
96 (247) Cm Curium
97 (247) Bk Berkelium
98 (251) Cf Californium
99 (252) Es Einsteinium
100 (257) Fm Fermium
101 (258) Md Mendelevium
102 (259) No Nobelium
103 (262) Lr Lawrencium
Aa - Solid
Aa - Gas
Aa - Liquid
Aa - Synthetically Prepared
* Based on Carbon-12. (###) represents most stable or most stable expected isotope.
** Some electron configurations are based on theoretical expected arrangements.
© 2012 Aldon Corporation
Innovating Science™ by Aldon Corporation
"cutting edge science for the classroom"

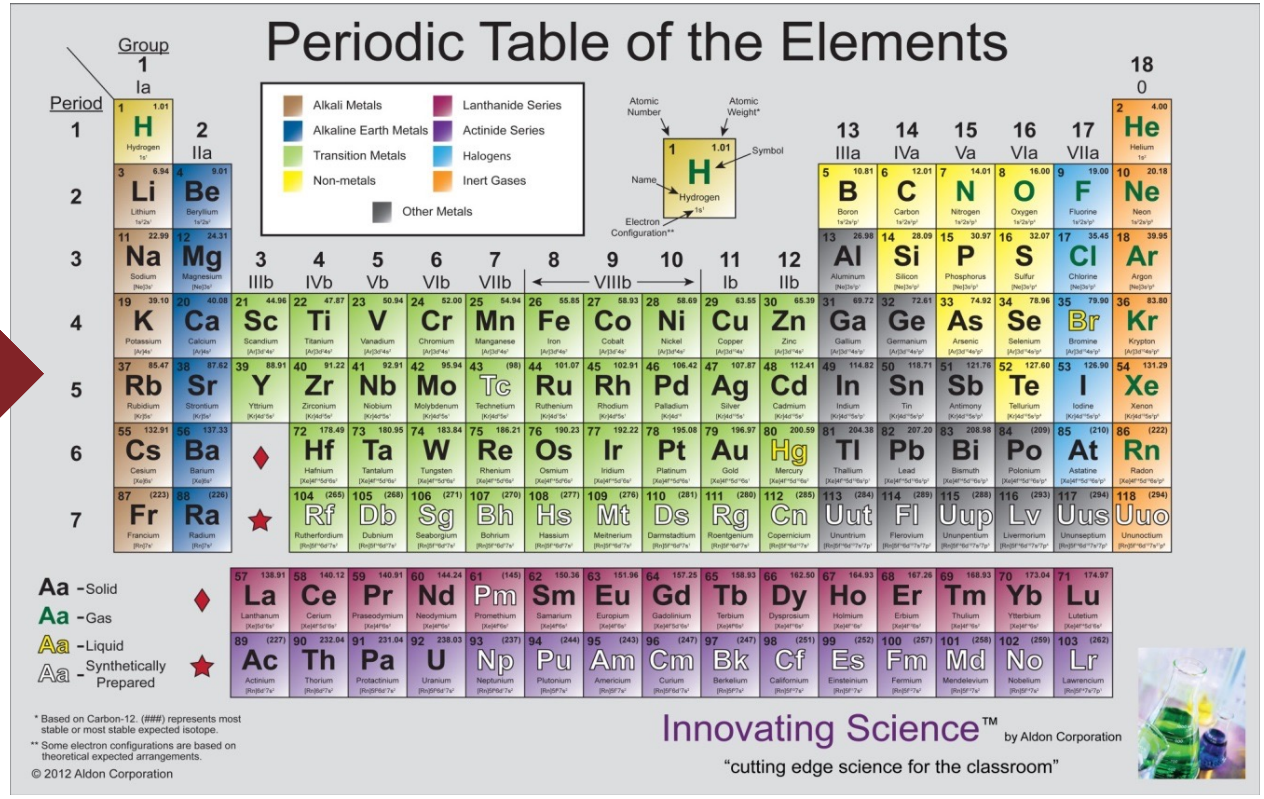
Table arranged from the least number of protons, H for hydrogen with only a single proton, to the most number of protons.



Listed in columns – most reactive on the left to least reactive on the right.

All the elements in Group 1 are very reactive!

The further down the column the more vigorous the reaction!



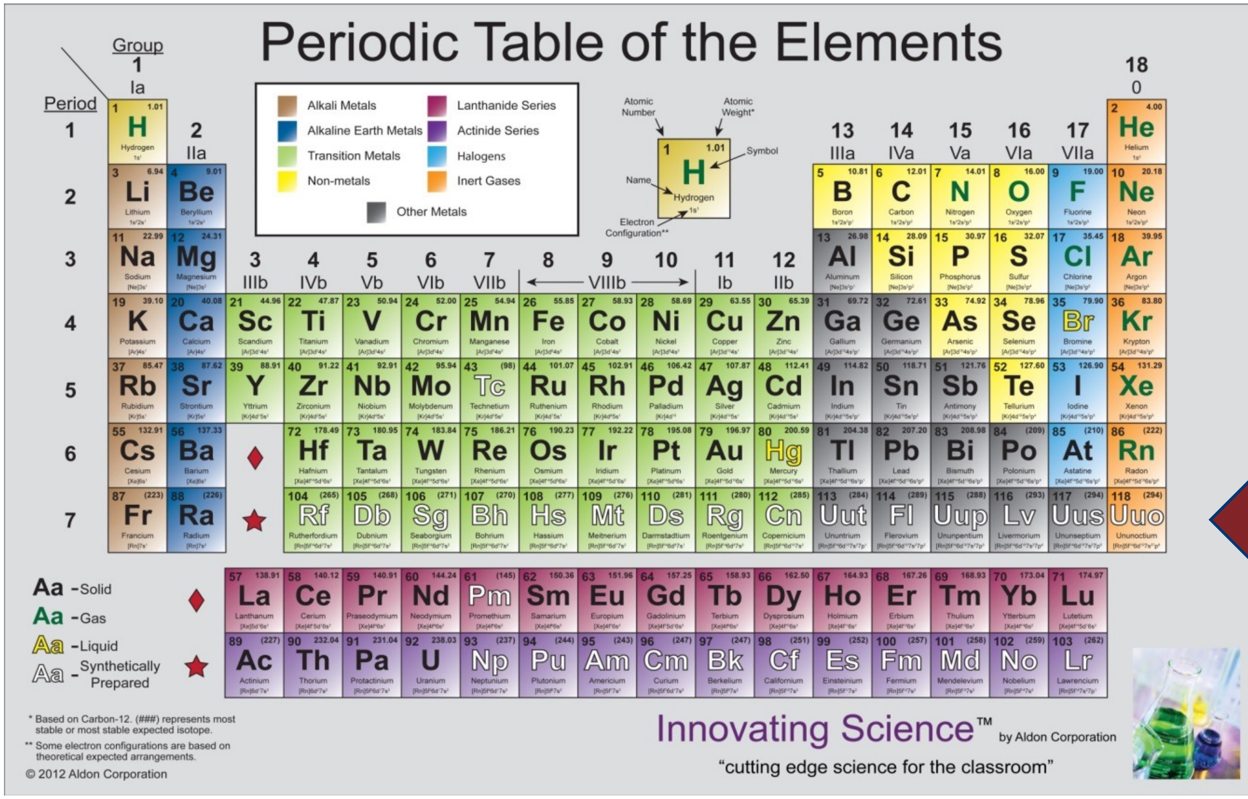
Also known as alkaline metals.

Almost empty outer electron shells.

Less dense than water (floats), low ionisation energy.

https://www.youtube.com/watch?v=QQF61CFOySw

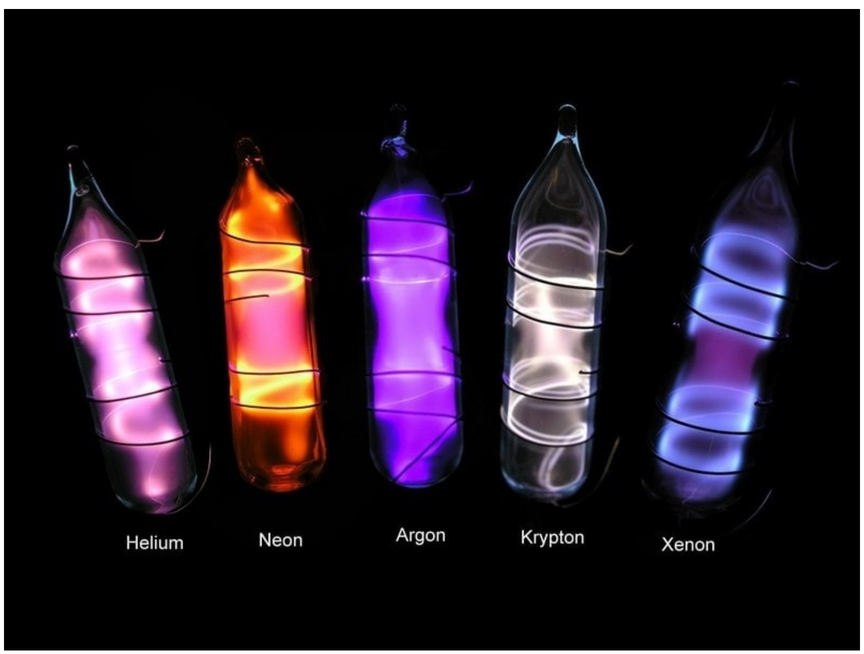
Gives you an idea of the reaction rate. Do not try any of this unless you are in a lab!



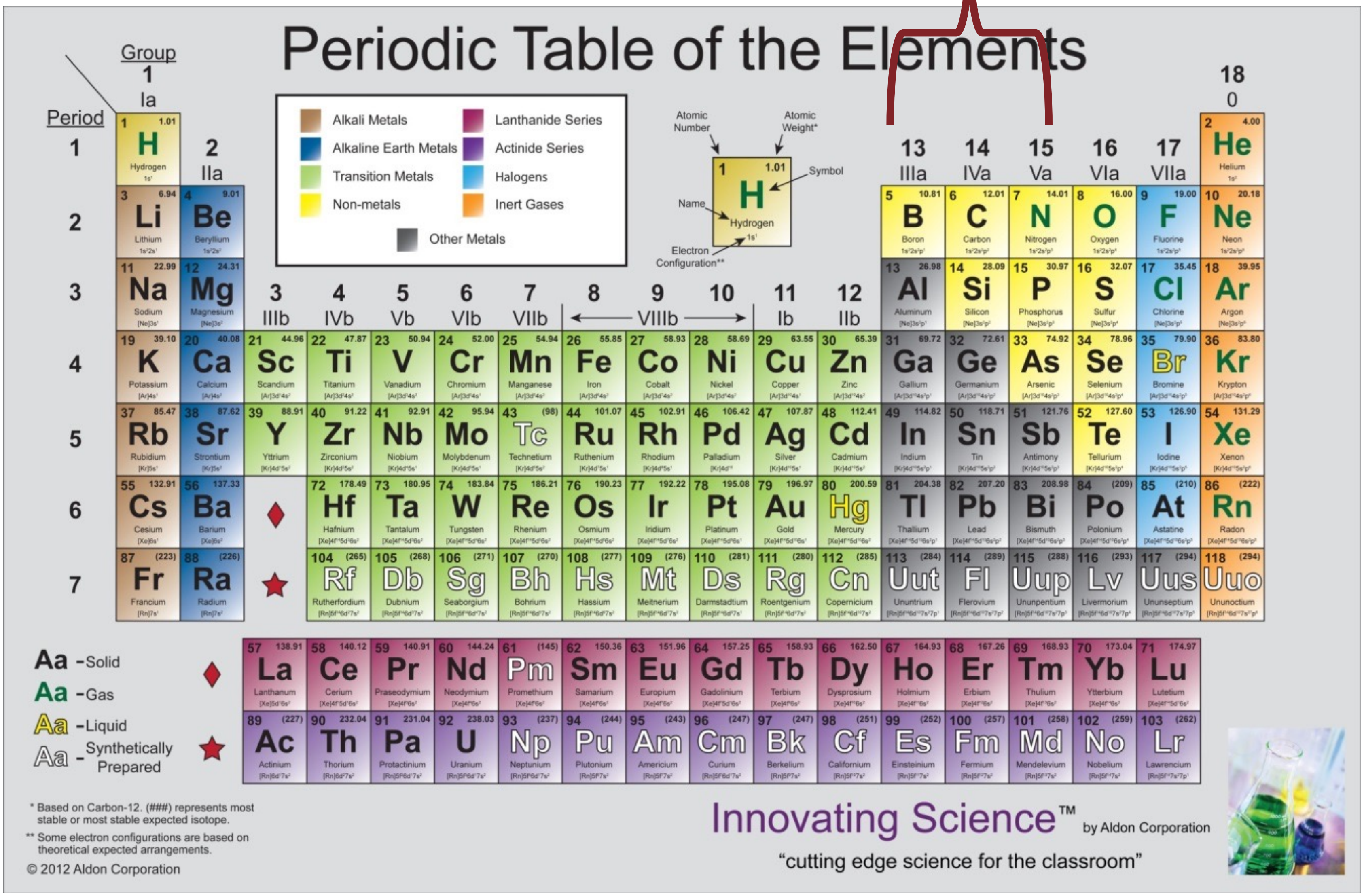
Group 18 are the noble gases.

Not reactive unless exposed to an electric field. They have pretty colours.

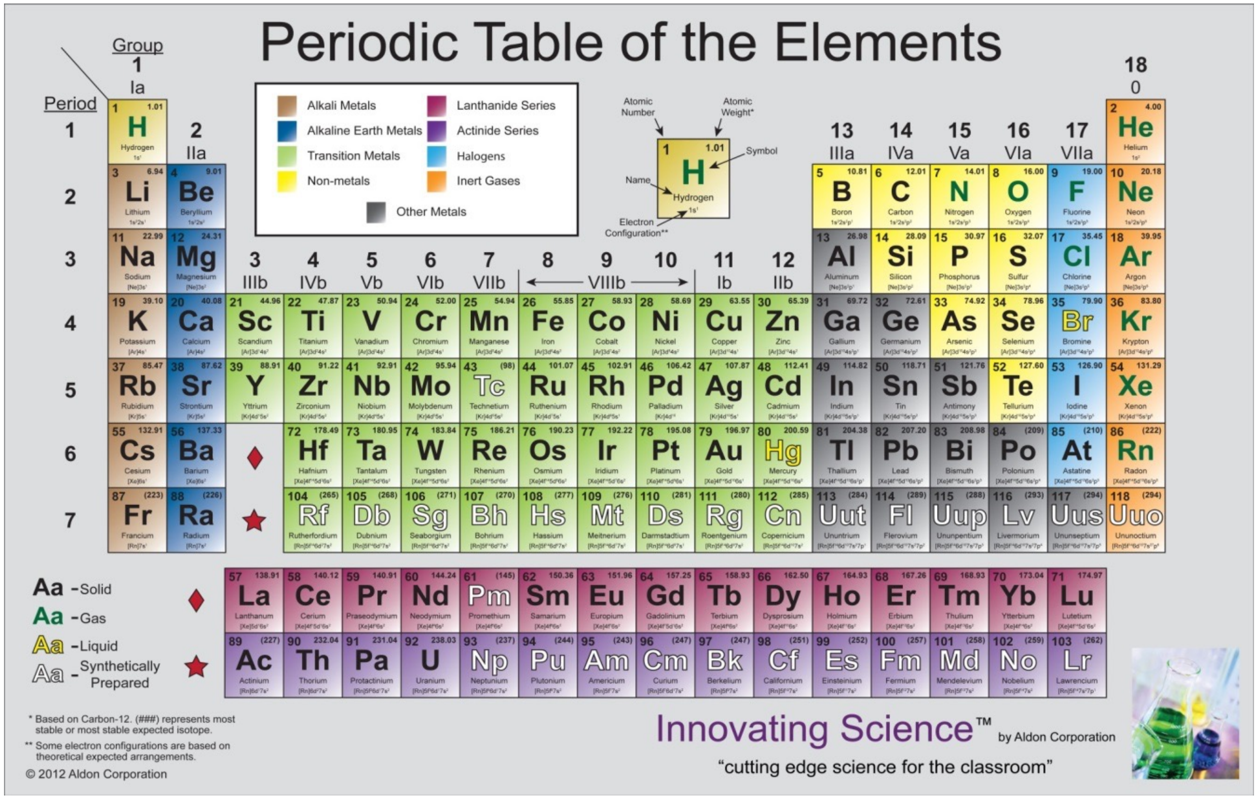
Full outer electron shell.



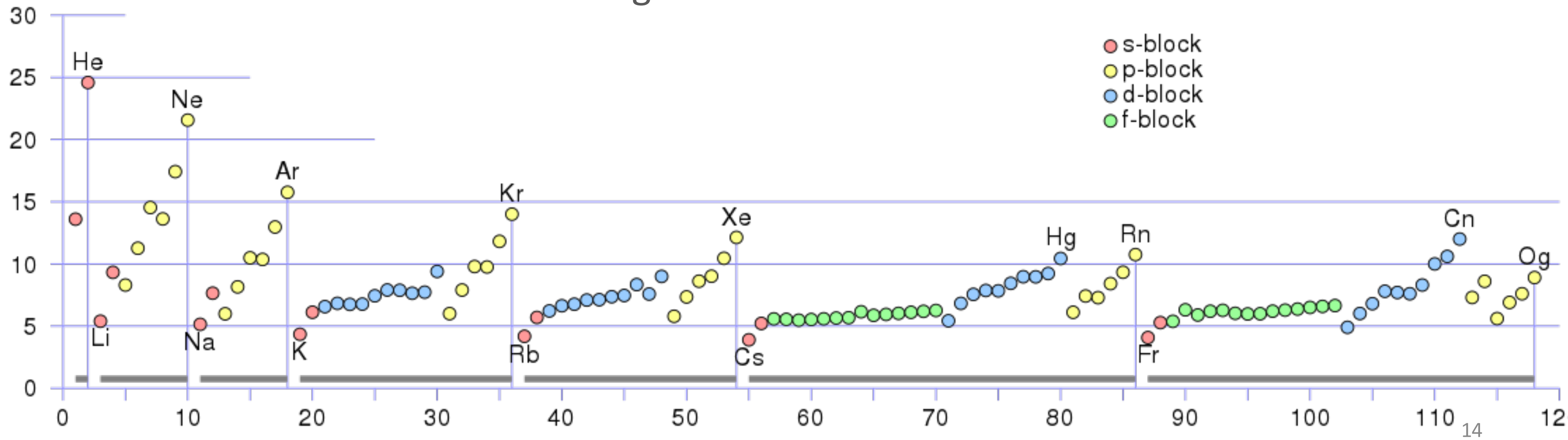
We will be most interested in columns 13, 14 and 15 but more on that later.



The outermost electron shell fills up as we move from the left to the right.



Ionisation energy, the energy needed to remove the most loosely bound electron, increases from the left to the right.

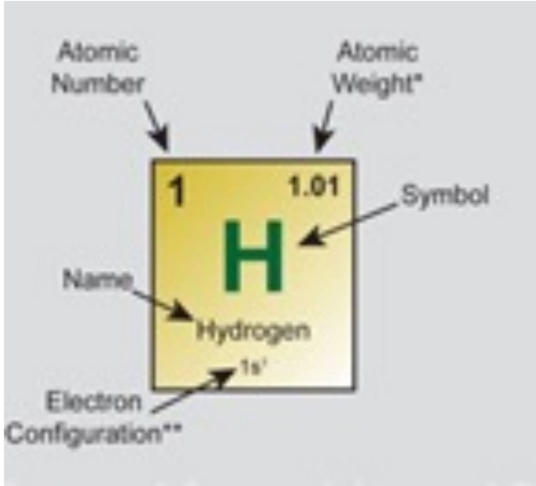


How Do Atoms Function?

- Atoms function by interacting with other atoms around them.
- Three main ways to do this:
  - Bonding – of which there are various types;
  - Crystal formation – starts with bonding but then continues to grow;
  - Fusion – where the nuclei of atoms combine making a bigger atom!
- To understand how these processes happen we need to look at the various quantities that describe an atom.

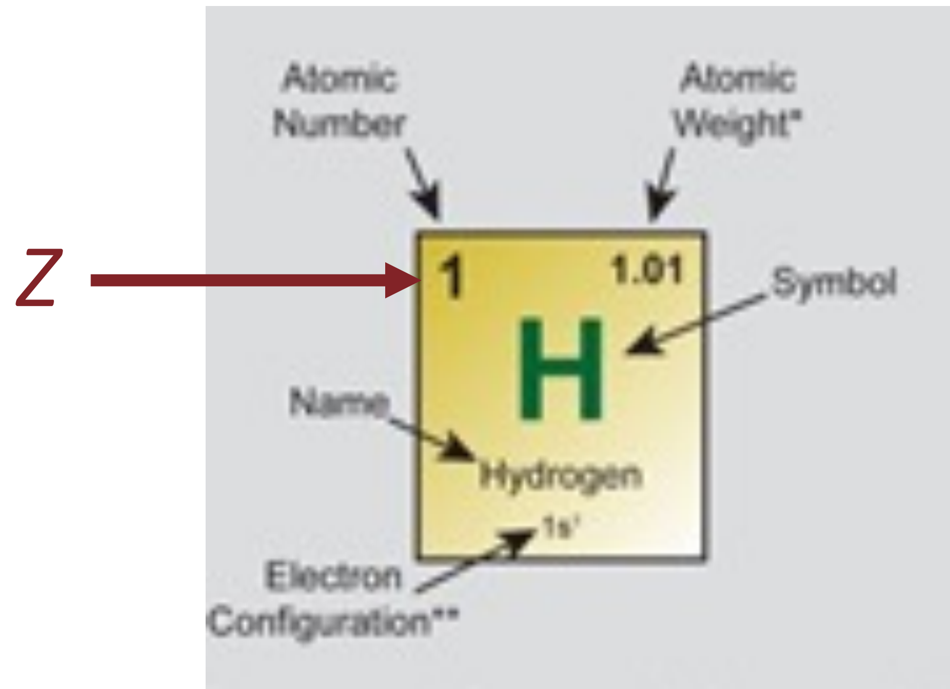
Numbers Associated with an Atom

- There is a lot of information about an atom based on numbers provided in the periodic table.
- These include:
  - Number of protons;
  - Number of neutrons;
  - Number of electrons;
  - Atomic weight;
  - How the electrons are arranged.



- They have their own symbols and we need a little math to get all the answers.

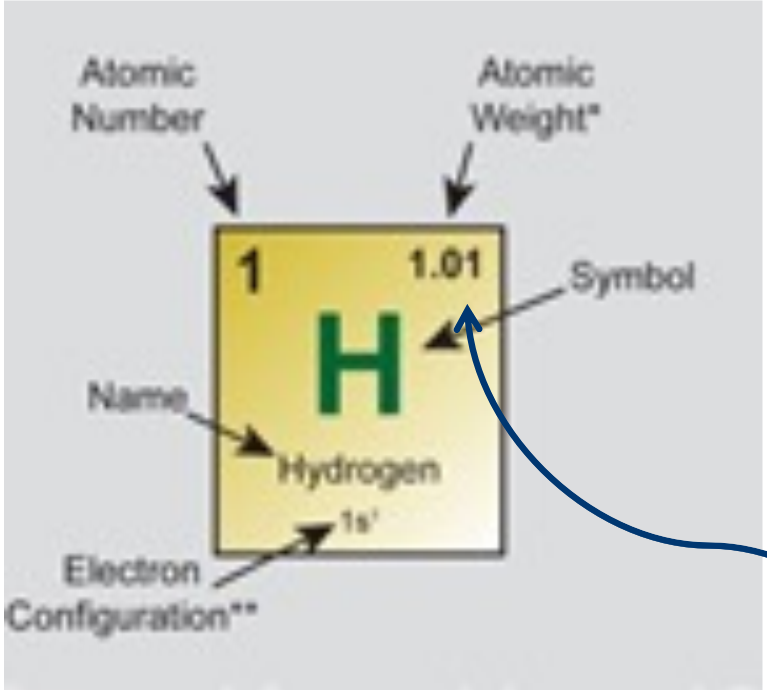
Atomic Number



The atomic number is the number of protons in that atom (top left side).

This is also know by the symbol, *Z*.

Atomic Weight



The atomic weight gives information about the number of neutrons.

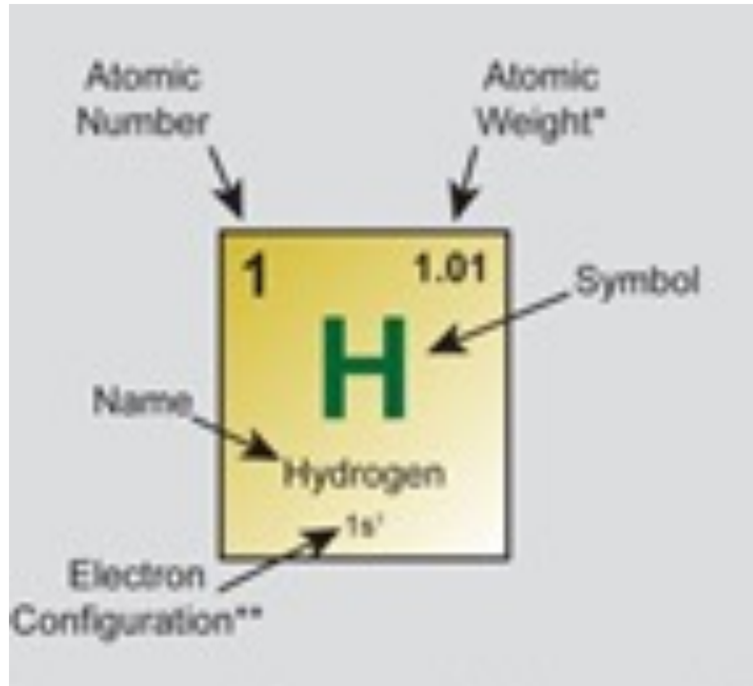
The number of neutrons = (rounded atomic weight) – (atomic number).

The number of neutrons = $A - Z$ (some complication here but we will see it later).

The atomic weight is also known by the symbol, A.

Number of Electrons

What about electrons?



The number of electrons = the number of protons – why?

As the overall charge on an atom is neutral, so they have to be equal.

Remember that protons have positive charges and electrons have negative charges.

It can also be found under the electron configuration number in the bottom centre.

Example: Numbers for Hydrogen (H)

So let's do an easy example – take hydrogen, the first element in the periodic table.

Atomic number, $Z = 1$.

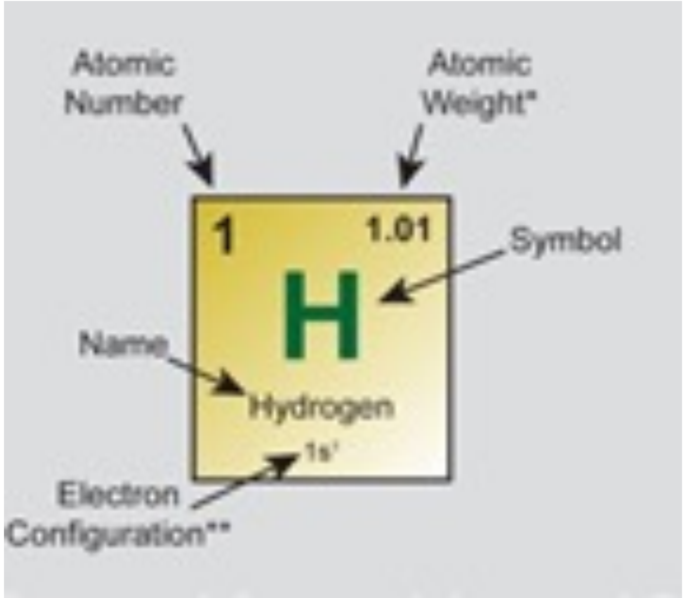
No. of protons = atomic number = 1.

No. of electrons = no. of protons = 1.

No. of neutrons =
(atomic weight, A) rounded – (atomic number, Z).

Atomic weight, A, = 1.01, round this to 1.

No. of neutrons = 1 – 1 = 0.



Example: Numbers for Silicon (Si)

So let's do another easy example – take silicon (Si), the 14th element in the periodic table.

Atomic number, Z = 14.

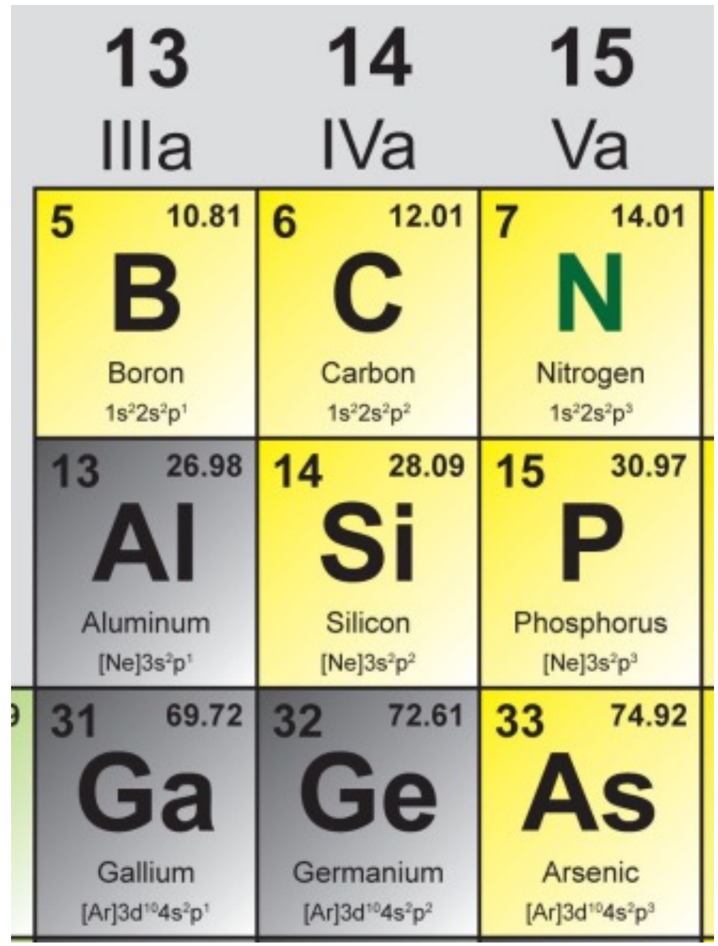
No. of protons = atomic number = 14.

No. of electrons = no. of protons = 14.

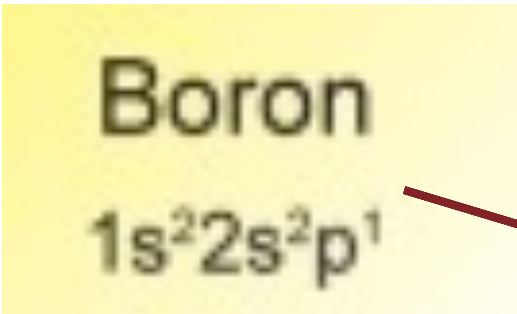
No. of neutrons =
(atomic weight, A) rounded – (atomic number, Z).

Atomic weight, A = 28.09, round it to 28.

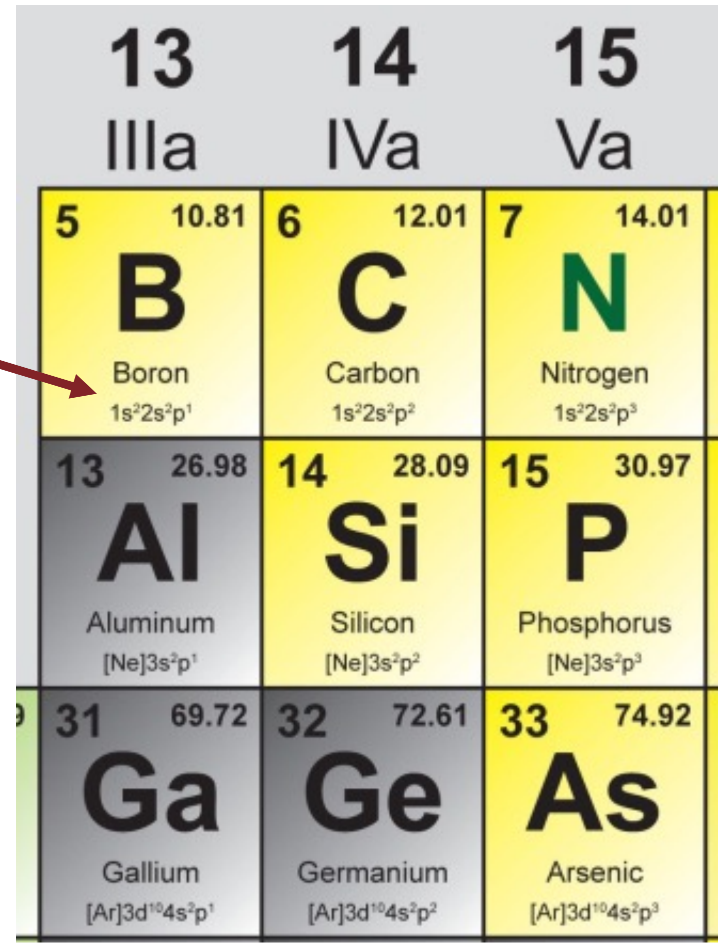
No. of neutrons = 28 – 14 = 14.



Electron Configuration



This is the electron configuration.
More on this important aspect later!



When Things Break Down

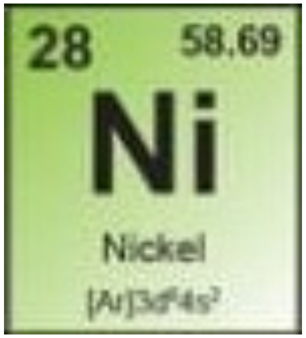
So let's do another example – take nickel (Ni), the 28th element in the periodic table.

Atomic number, Z = 28.

No. of protons = atomic number = 28.

No. of electrons = no. of protons = 28.

No. of neutrons =
(atomic weight, A) rounded – (atomic number, Z).



Atomic weight, A = 58.69, shall we round it up to 59 or round it down to 58?

No. of neutrons = 59 – 28 = 31 or 58 – 28 = 30, which one is correct?

When Things Break Down

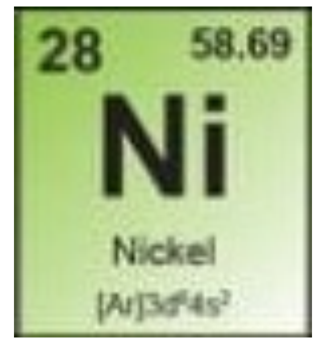
So let's do another example – take nickel (Ni), the 28th element in the periodic table.

Atomic number, Z = 28.

No. of protons = atomic number = 28.

No. of electrons = no. of protons = 28.

No. of neutrons =
(atomic weight, A) rounded – (atomic number, Z).



Atomic weight, A = 58.69, shall we round it up to 59 or round it down to 58?

No. of neutrons = 59 – 28 = 31 or 58 – 28 = 30, which one is correct?

Well, the answer is, they can both be correct.
If you feel that this is not confusing enough, there are some other numbers, ranging from 20 to 50 that can all be correct!

Beyond Simple Atoms

- The nature is unfortunately not as simple as what we just discussed.
- There are at least three factors that complicate things:
  - Charge;
  - Mass;
  - Bonding structure.

Charge: Ion & Cation

- Atoms are neutrally charged overall (the number of protons = number of electrons);
- Give it an extra charge, of any type, and it now becomes an ion;
- If an atom has an extra positive charge (it usually happens when it lost an electron), it will be represented by a "+" symbol, for example, H^+;
- A positively charged ion is also called a cation.

Charge: Ion & Anion

- Similarly if an atom receives an extra electron, it becomes a negatively charged ion;
- It will be represented by the "–" symbol, for example, O^-;
- In the case of 2 extra electrons, it will be noted as O^{2-};
- A negatively charged ion is also called an anion.

Mass: Isotopes

- The atomic mass of atoms can be different even if they retain the same atomic number;
- This means that the number of neutrons is different but the number of protons is the same;
- One of the most common example is carbon (C), where its atomic mass can be 12, 13 or 14 daltons (1 dalton ≈ the mass of a proton or the mass of a neutron);
- They are referred to as carbon-12, carbon-13 and carbon-14 (carbon-12 is the most common one);
- Variations of mass of the same element are called Isotopes. It has no effect on the chemical properties of atoms.
- Isotopes are widely used in archaeology (radiocarbon dating uses carbon-14), medicine (gamma rays and deuterium metabolic imaging), and food processing.

Mass: Isotopes

- Now you will ask which isotope's "atomic weight" we are really referring to in the periodic table.
- The answer is "all of them" and at the same time "none of them".
- Standard atomic weight (what we find in the periodic table) of a chemical element is the weighted arithmetic mean of the relative isotopic masses of all isotopes of that element weighted by each isotope's abundance on Earth.

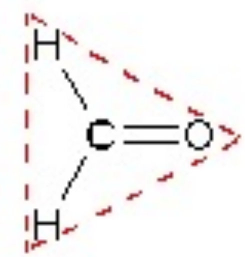
Bonding Structure: Allotropes

- The same element can have different physical appearances.
- This is due to different bonding arrangements that can occur (when atoms gather together to form solids).
- They are called allotropes and the best known is carbon:
  - Graphite – a sheet of hexagonal lattice, very slippery;
  - Diamond – a tetrahedral lattice, very, very strong.

Common Molecular Arrangements

- We will deal with this topic in more detail a little later on.
- Three main types of molecular arrangements:
  - Linear, where the bond angle is 180°;
  - Trigonal, where the bond angle is 120°;
  - Tetrahedral, where the bond angle is 109.5°.
- The size of these angles has to do with valence shells and electron pairs. More on this later.

Common Molecular Arrangements

Configuration	Bonding Partners	Bond Angles	Example
Tetrahedral	4	109.5°	
Trigonal	3	120°	
Linear	2	180°