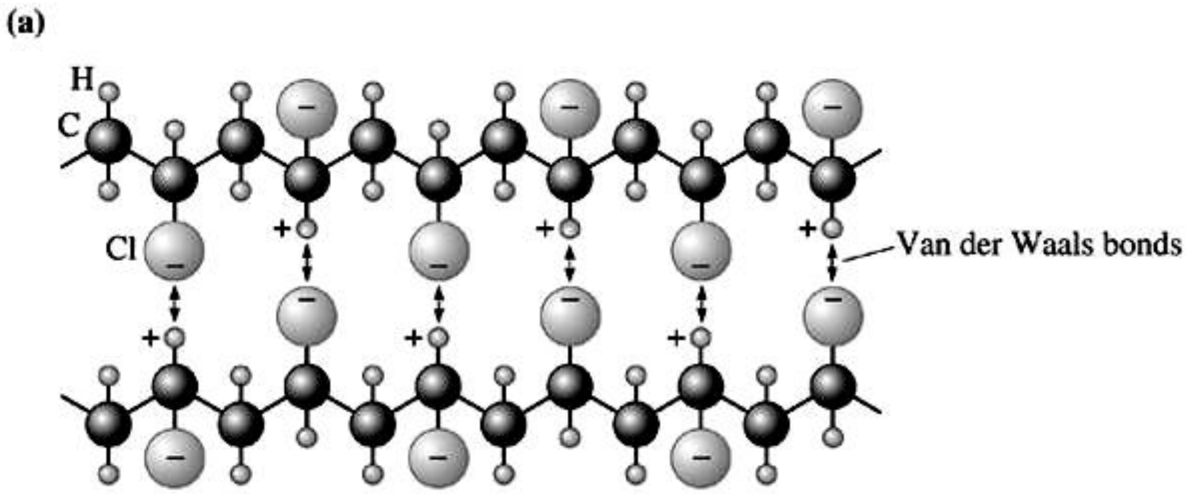
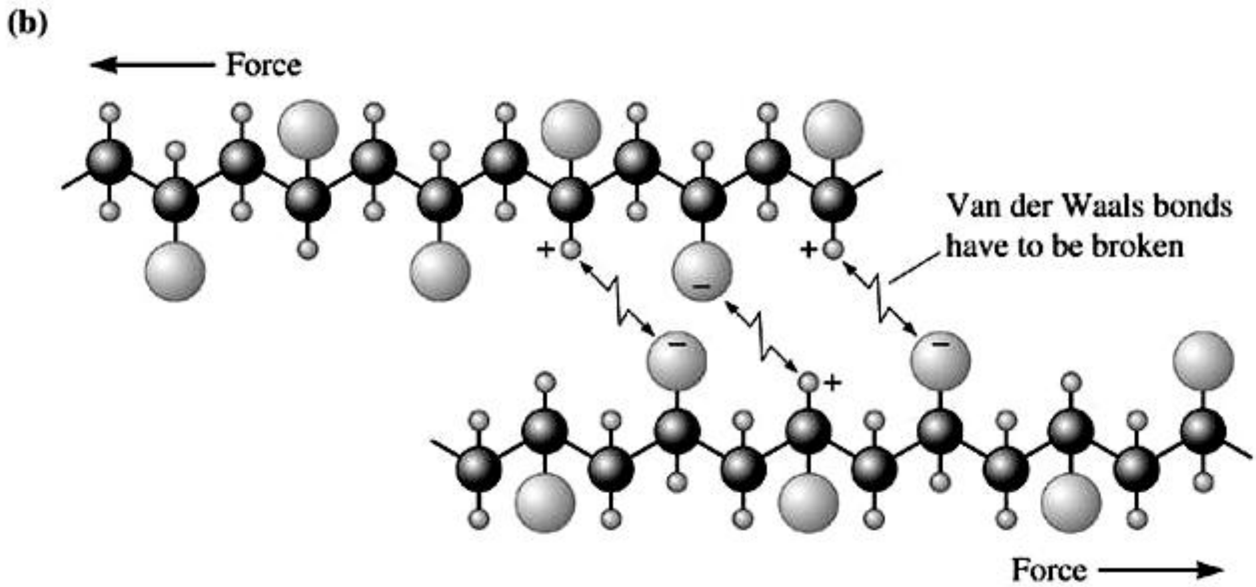



**(**a)In polyvinyl chloride (PVC), the chlorine atoms attached to the polymer chain have a negative charge and the hydrogen atoms are positively charged.
The chains are weakly bonded by van der Waals bonds. This additional bonding makes PVC stiffer,




(b) When a force is applied to the polymer, the week van der Waals bonds are broken and the chains slide easily past one another

## *Binding energy*

If a body has a mass *m*, then it contains an amount of energy:

$$E = mc^2$$

probably the most famous equation in physics. This means that *if* the mass of a nucleus is *less* than the mass of its constituents, then those constituents are in a *lower energy state* when they are bound together inside the nucleus.

-This difference in mass, expressed as energy (normally MeV), is the *binding energy* of those constituents inside the nucleus.

-It is found that the mass of a nucleus is always *less than* the sum of the masses of its constituent neutrons and protons (nucleons).

-What is the reason for this? Well Einstein showed that mass and energy are equivalent. The lower mass shows that the nucleons in the nucleus are in a *lower energy state* than if they were all separate, isolated particles.

-This decrease in mass (known as the mass decrement) gives the *binding energy* of the particular nucleus in terms of the equivalent *mass*.

Working in terms of the actual binding energy, we calculate as follows.

Say for example if we have a nucleus with *Z* protons and *N* neutrons and mass *MA*, where *A* = *Z* + *N* then its binding energy in MeV is given by:

*Eb(MeV)* = (*Zmp* + *Nmn* - *MA)* x 931.494 MeV/u

All in atomic mass units, u or *all* in nuclide masses, u

It means that there must be some force between the nucleons that binds them together in the nucleus. This is the *strong force*.

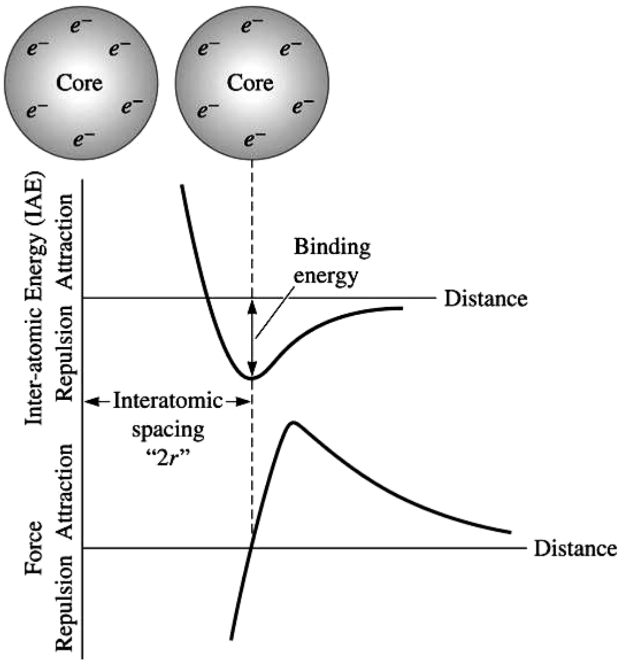
***Notes:***

o Interatomic spacing is equilibrium spacing between the centers of two atoms (at a particular temperature), equilibrium is lowest energy state, attractive and repulsive forces are balanced

o Binding (bond) energy is energy required to separate two atoms from their equilibrium spacing to an infinite distance apart, $E = mc^2$, so each time two atoms bound to each other, some mass is converted into energy, …

o Modulus of elasticity, Young's modulus, is slope of the stress strain curve in elastic region (macroscopic), can be derived from slope of force versus distance curve at interatomic spacing (microscopic)

o Coefficient of thermal expansion and melting temperature can also be explained from binding energy curve



Atoms or ions are separated by equilibrium spacing that corresponds to the minimum interatomic energy for a pair of atoms or ions (or when zero force is acting to repel or attract the atoms or ions, force balance) If there is external influences, e.g. load, temperature change, equilibrium spacing will change.

***The periodic table***

The periodic table contains valuable information about specific elements and can also help identify trends in atomic size, melting point, chemical reactivity, and other properties.

The familiar periodic table (Figure A) is constructed in accordance with the electronic structure of the elements. Not all elements in the periodic table are naturally occurring. Rows in the periodic table correspond to quantum shells, or principal quantum numbers. Columns typically refer to the number of electrons in the outermost *s* and *p* energy levels and correspond to the most common valence. In engineering, we are mostly concerned with

(a) Polymers (plastics) (primarily based on carbon, which appears in Group 4B);

(b) Ceramics (typically based on combinations of many elements appearing in Groups 1 through 5B, and such elements as oxygen, carbon, and nitrogen); and

(c) Metallic materials (typically based on elements in Groups 1, 2 and transition metal elements).

Many technologically important semiconductors appear in Group 4B (e.g., silicon (Si), diamond (C), germanium (Ge)). Semiconductors also can be combinations of elements from Groups 2B and 6B (e.g., cadmium selenide (CdSe), based on cadmium (Cd) from Group 2 and selenium (Se) based on Group 6). These are known as **II–VI** (two-six) **semiconductors**. Similarly, gallium arsenide (GaAs) is a **III–V** (three-five) **semiconductor** based on gallium (Ga) from Group 3B and arsenic (As) from Group 5B. Many **transition elements** (e.g., titanium (Ti), vanadium (V), iron (Fe), nickel (Ni), cobalt (Co), etc.) are particularly useful for magnetic and optical materials due to their electronic configurations that allow multiple valences.

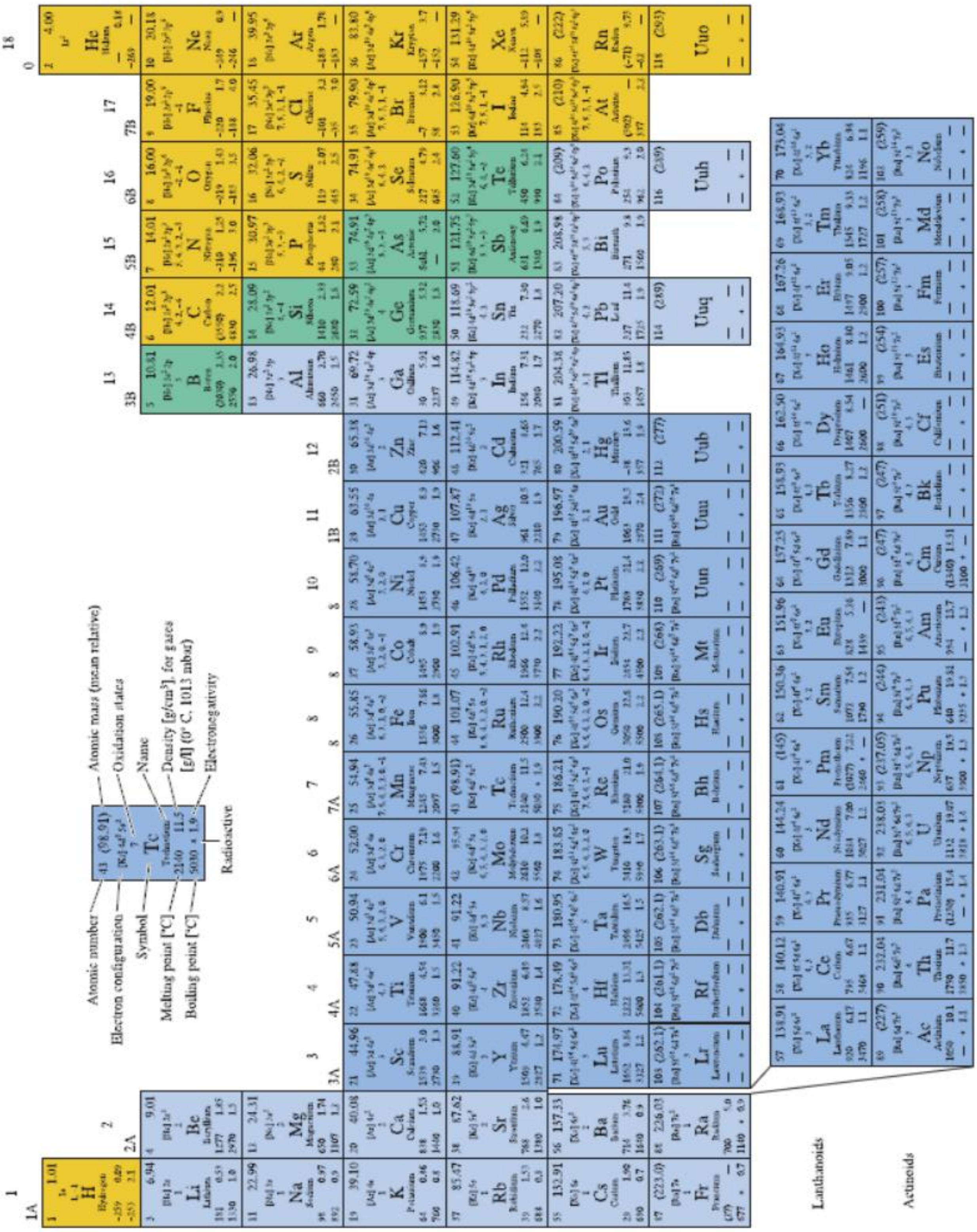


*Figure A: Periodic table of elements.*

All the elements have been classified according to electron configuration in the **periodic table** (Figure below). Here, the elements are situated, with increasing atomic number, in seven horizontal rows called periods. The arrangement is such that all elements that are arrayed in a given column or group have similar valence electron structures, as well as chemical and physical properties. These properties change gradually and systematically, moving horizontally across each period.

The elements positioned in Group 0, the rightmost group, are the inert gases, which have filled electron shells and stable electron configurations. Group VIIA and VIA elements are one and two electrons deficient, respectively, from having stable structures. The Group VIIA elements (F, Cl, Br, I, and At) are sometimes termed the halogens. The alkali and the alkaline earth metals (Li, Na, K, Be, Mg, Ca, etc.) are labeled as Groups IA and IIA, having, respectively, one and two electrons in excess of stable structures. The elements in the three long periods,

Groups IIIB through IIB, are termed the transition metals, which have partially filled *d* electron states and in some cases one or two electrons in the next higher energy shell. Groups IIIA, IVA, and VA (B, Si, Ge, As, etc.) display characteristics that are intermediate between the metals and nonmetals by virtue of their valence electron structures.

The **interatomic spacing** in a solid metal is *approximately* equal to the atomic diameter, or twice the atomic radius *r*. We cannot use this approach for ionically bonded materials, however, since the spacing is the sum of the two different ionic radii.

Key: 29 → Atomic number; Cu → Symbol; 63.54 → Atomic weight

Metal | Nonmetal | Intermediate

| IA | IIA | IIIB | IVB | VB | VIB | VIIB | VIII | VIII | VIII | IB | IIB | IIIA | IVA | VA | VIA | VIIA | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H 1.0080 | | | | | | | | | | | | | | | | | 2 He 4.0026 |
| 3 Li 6.939 | 4 Be 9.0122 | | | | | | | | | | | 5 B 10.811 | 6 C 12.011 | 7 N 14.007 | 8 O 15.999 | 9 F 18.998 | 10 Ne 20.183 |
| 11 Na 22.990 | 12 Mg 24.312 | | | | | | | | | | | 13 Al 26.982 | 14 Si 28.086 | 15 P 30.974 | 16 S 32.064 | 17 Cl 35.453 | 18 Ar 39.948 |
| 19 K 39.102 | 20 Ca 40.08 | 21 Sc 44.956 | 22 Ti 47.90 | 23 V 50.942 | 24 Cr 51.996 | 25 Mn 54.938 | 26 Fe 55.847 | 27 Co 58.933 | 28 Ni 58.71 | 29 Cu 63.54 | 30 Zn 65.37 | 31 Ga 69.72 | 32 Ge 72.59 | 33 As 74.922 | 34 Se 78.96 | 35 Br 79.91 | 36 Kr 83.80 |
| 37 Rb 85.47 | 38 Sr 87.62 | 39 Y 88.91 | 40 Zr 91.22 | 41 Nb 92.91 | 42 Mo 95.94 | 43 Tc (99) | 44 Ru 101.07 | 45 Rh 102.91 | 46 Pd 106.4 | 47 Ag 107.87 | 48 Cd 112.40 | 49 In 114.82 | 50 Sn 118.69 | 51 Sb 121.75 | 52 Te 127.60 | 53 I 126.90 | 54 Xe 131.30 |
| 55 Cs 132.91 | 56 Ba 137.34 | Rare earth series | 72 Hf 178.49 | 73 Ta 180.95 | 74 W 183.85 | 75 Re 186.2 | 76 Os 190.2 | 77 Ir 192.2 | 78 Pt 195.09 | 79 Au 196.97 | 80 Hg 200.59 | 81 Tl 204.37 | 82 Pb 207.19 | 83 Bi 208.98 | 84 Po (210) | 85 At (210) | 86 Rn (222) |
| 87 Fr (223) | 88 Ra (226) | Acti-nide series | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rare earth series | 57 La 138.91 | 58 Ce 140.12 | 59 Pr 140.91 | 60 Nd 144.24 | 61 Pm (145) | 62 Sm 150.35 | 63 Eu 151.96 | 64 Gd 157.25 | 65 Tb 158.92 | 66 Dy 162.50 | 67 Ho 164.93 | 68 Er 167.26 | 69 Tm 168.93 | 70 Yb 173.04 | 71 Lu 174.97 |
| Actinide series | 89 Ac (227) | 90 Th 232.04 | 91 Pa (231) | 92 U 238.03 | 93 Np (237) | 94 Pu (242) | 95 Am (243) | 96 Cm (247) | 97 Bk (247) | 98 Cf (249) | 99 Es (254) | 100 Fm (253) | 101 Md (256) | 102 No (254) | 103 Lw (257) |

***Figure :The periodic table of the elements. The numbers in parentheses are the atomic weights of the most stable or common isotopes.***

Compounds formed from two or more metals (**intermetallic compounds**) may be bonded by a mixture of metallic and ionic bonds, particularly when there is a large difference in electronegativity between the elements. Because lithium has an electronegativity of 1.0 and aluminum has an electronegativity of 1.5, we would expect AlLi to have a combination of metallic and ionic bonding. On the other hand, because both aluminum and vanadium have electronegativities of 1.5, we would expect Al3V to be bonded primarily by metallic bonds.

Many ceramic and semiconducting compounds, which are combinations of metallic and nonmetallic elements, have a mixture of covalent and ionic bonding. As the electronegativity difference between the atoms increases, the bonding becomes more ionic. The fraction of bonding that is covalent can be estimated from the following equation:

$$\text{Fraction covalent} = \exp(-0.25\Delta E^2)$$

where $\Delta E$ is the difference in electronegativities.