Temperature and matter

Y1 Semester 2 Physics

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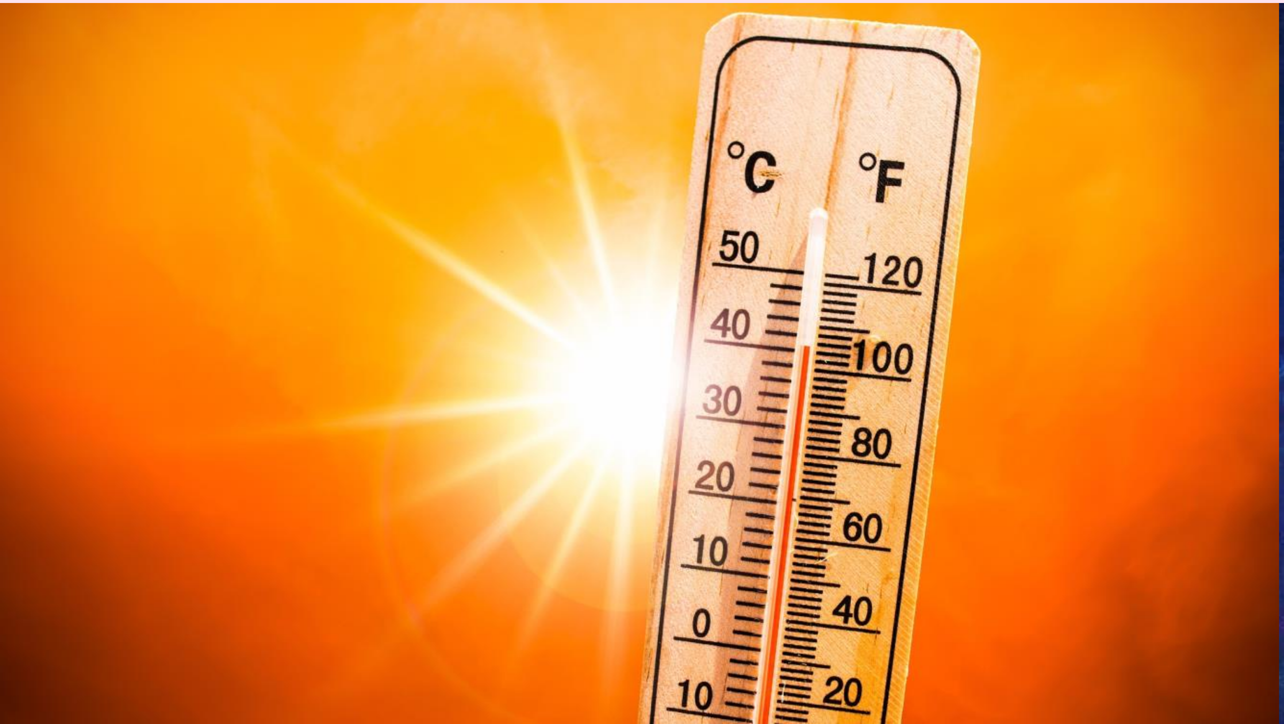


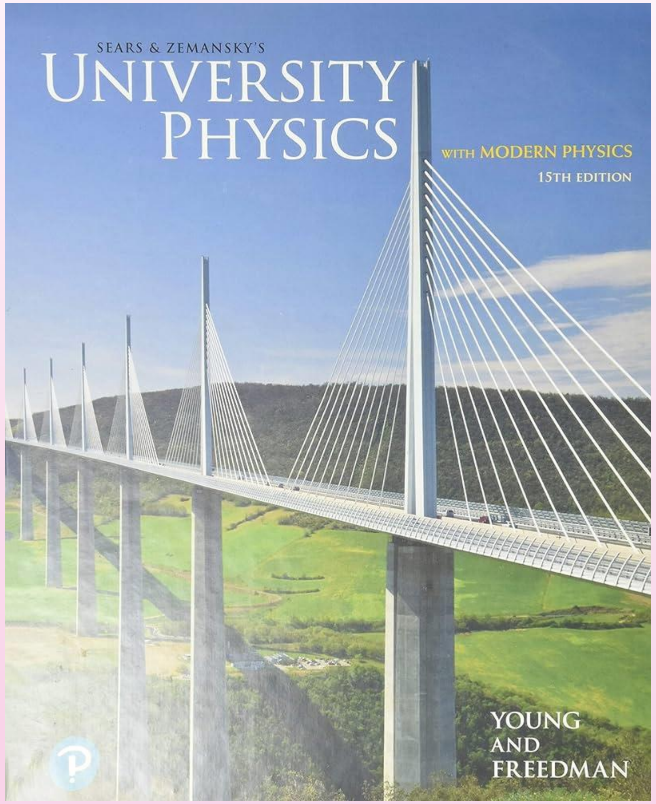
Course aims

We want to be able to explain the properties of matter (the macroscopic world) of different kinds based on their microscopic structure – as well as perhaps understand more about the microscopic behaviour from macroscopic observables

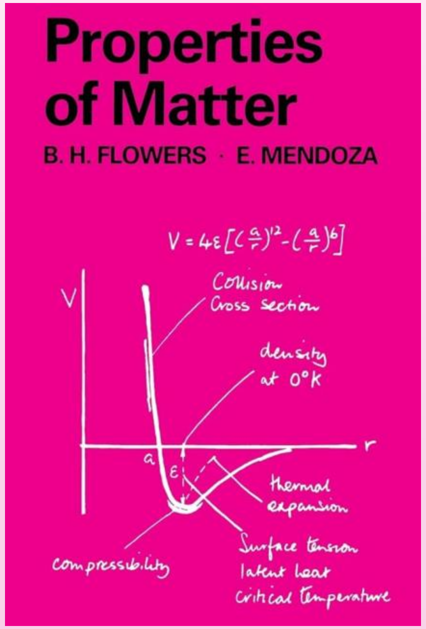
Macroscopic -> Matter (solids, liquids, gases…)

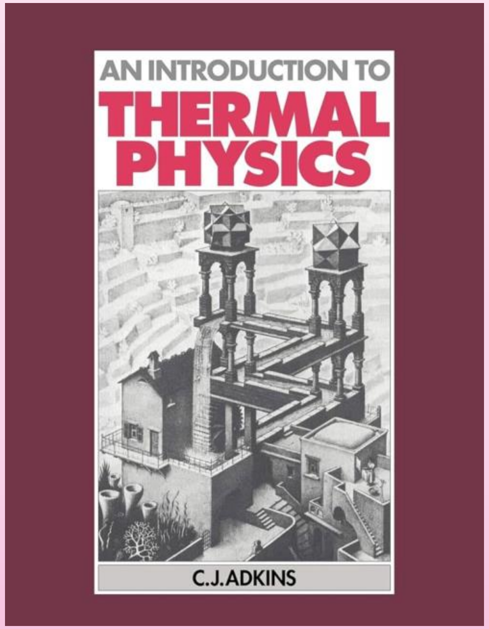
Microscopic -> Atoms, molecules

Recommended reading

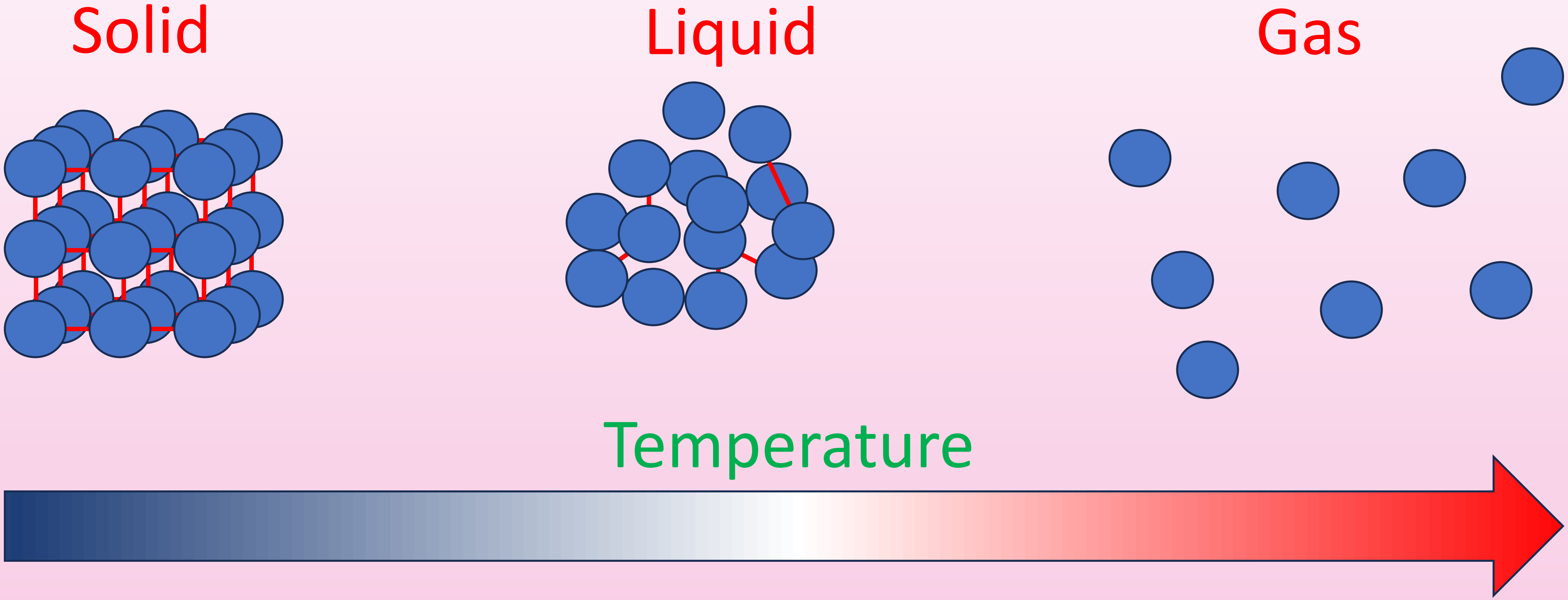


Young and Freedman chapters 14 and 17-19





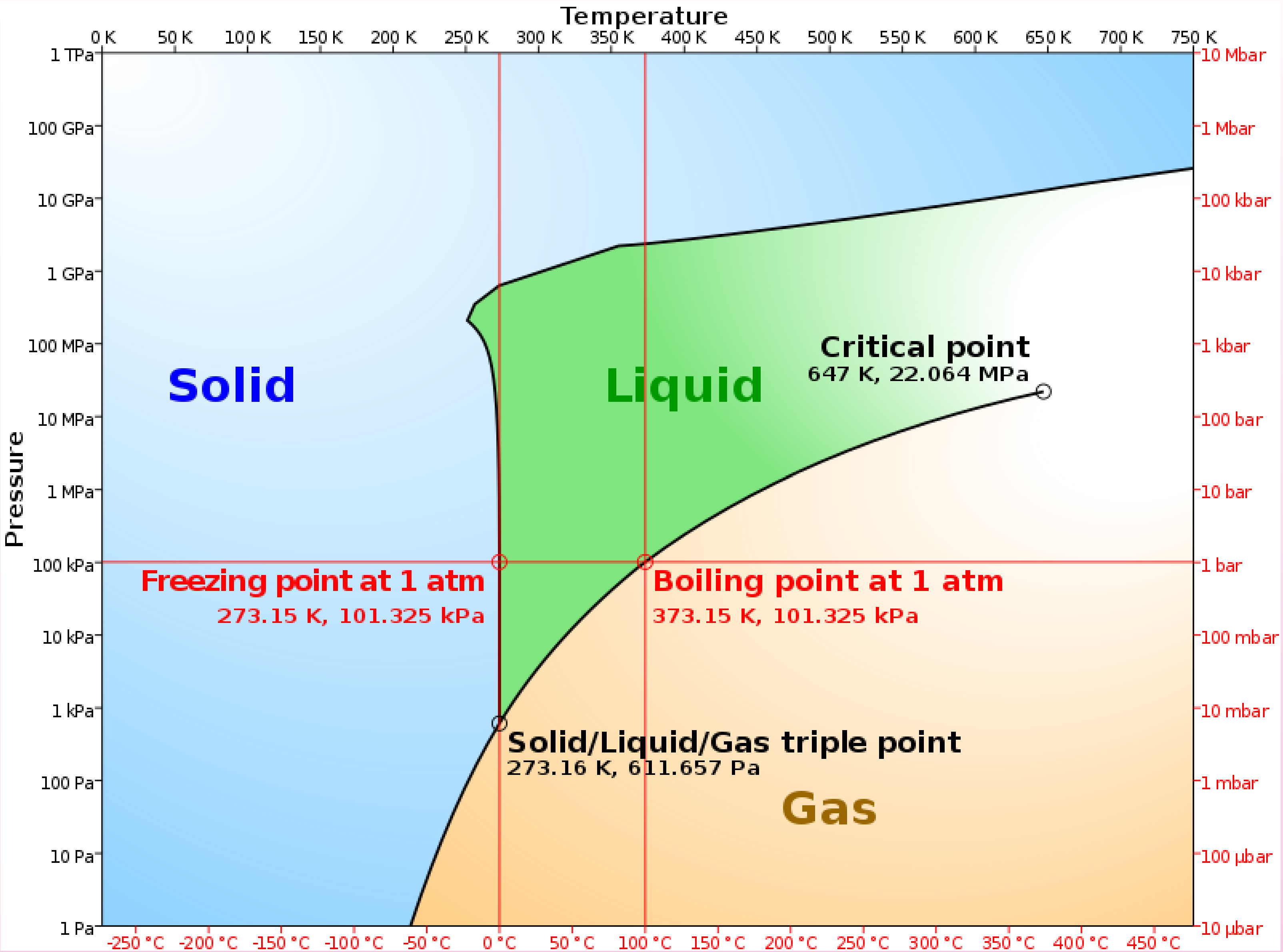
What are different kinds (states) of matter?



Question: How does pressure fit in?

Phase diagram:

Pressure vs temperature



Chemical notation

$^{12}C^{3+}$

Mass number
(proton + neutron number)

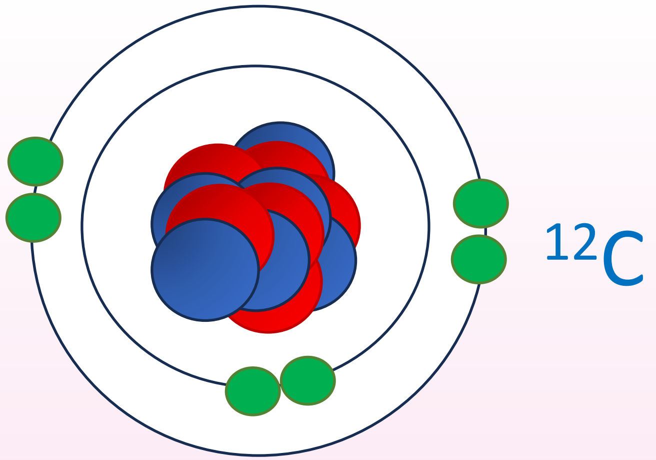
Charge state
(excess/missing electrons)

Chemical symbol
(denotes proton number)

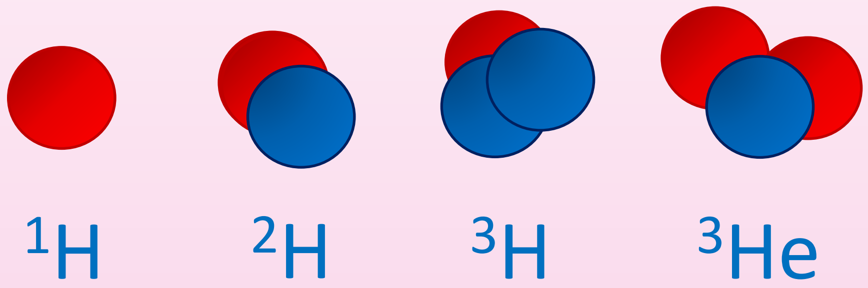
CH_4

Number of atoms per molecule

An atom is a neutrally charged particle made up of a nucleus and orbited by electrons

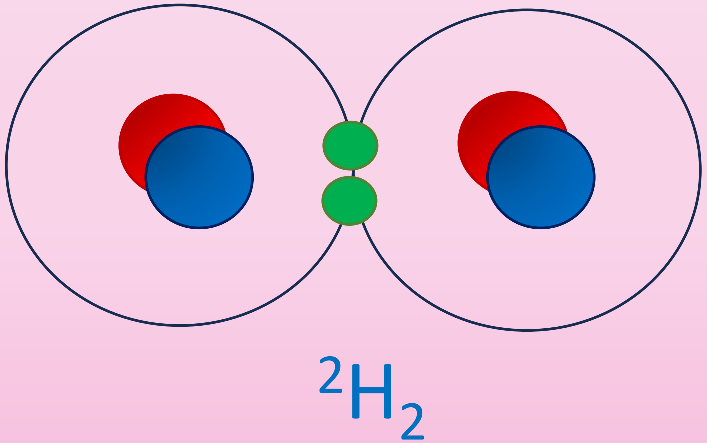


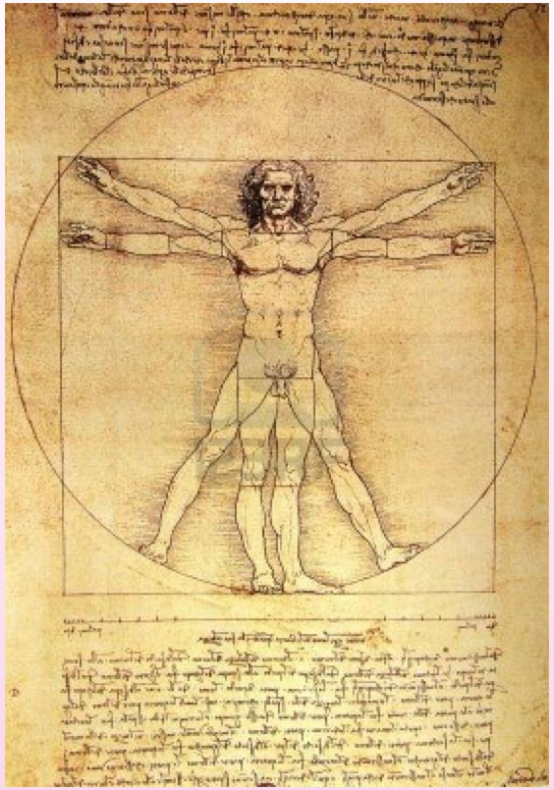
A nucleus consists of a mixture of nucleons (i.e. protons and neutrons) – isotopes are nuclei with a different number of neutrons but the same number of protons

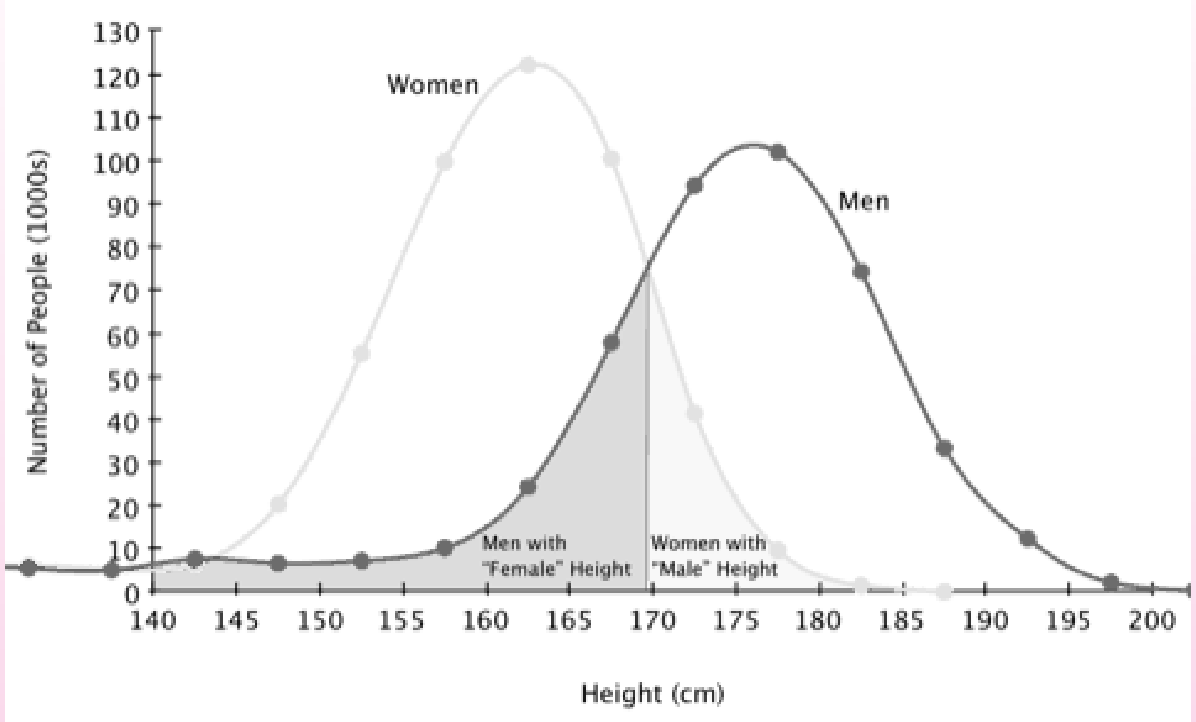


An ion is a charged atom, in which the number of electrons differs from the number of protons -> come in two forms, cations and anions

A molecule is a collection of atoms that are loosely bound together by chemical bonds (in which they share electrons)

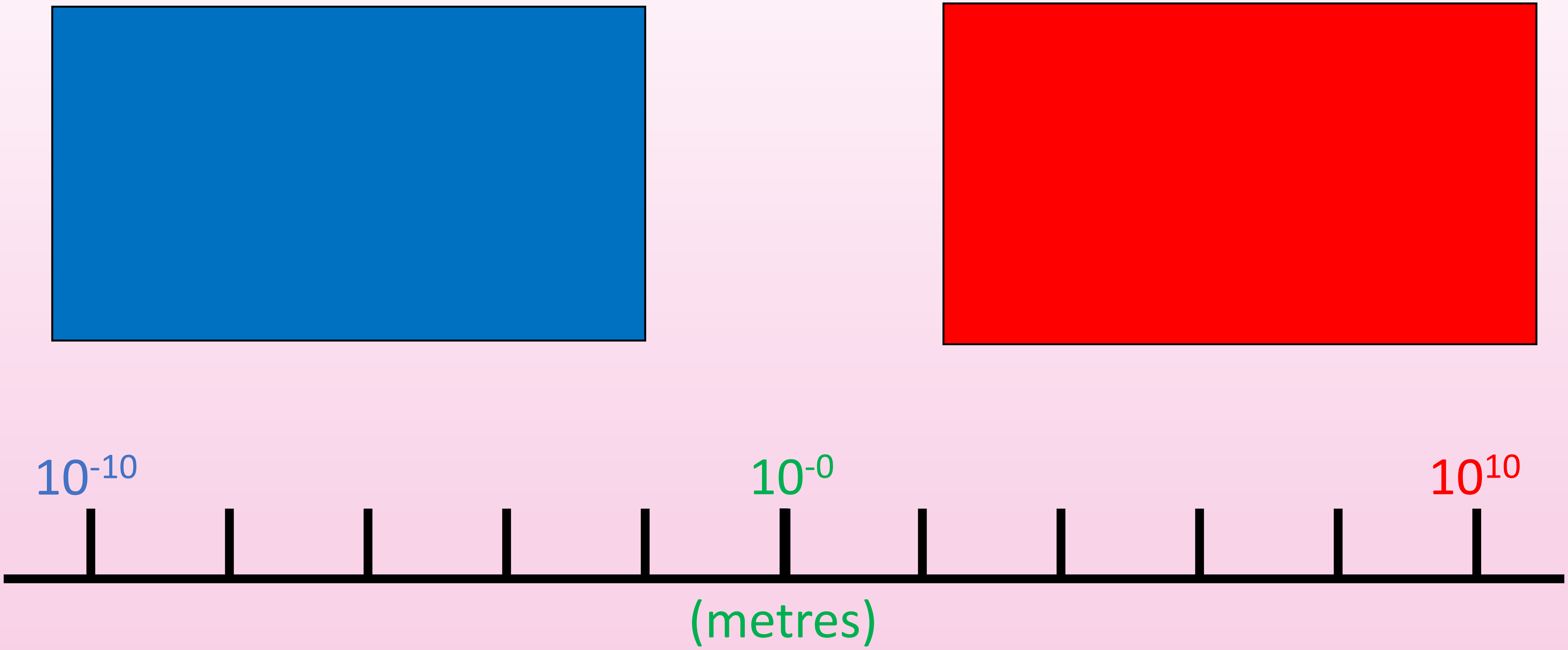





Women
Men
Number of People (1000s)
Height (cm)
Men with "Female" Height
Women with "Male" Height
130
120
110
100
90
80
70
60
50
40
30
20
10
0
140 145 150 155 160 165 170 175 180 185 190 195 200

10^{-0}

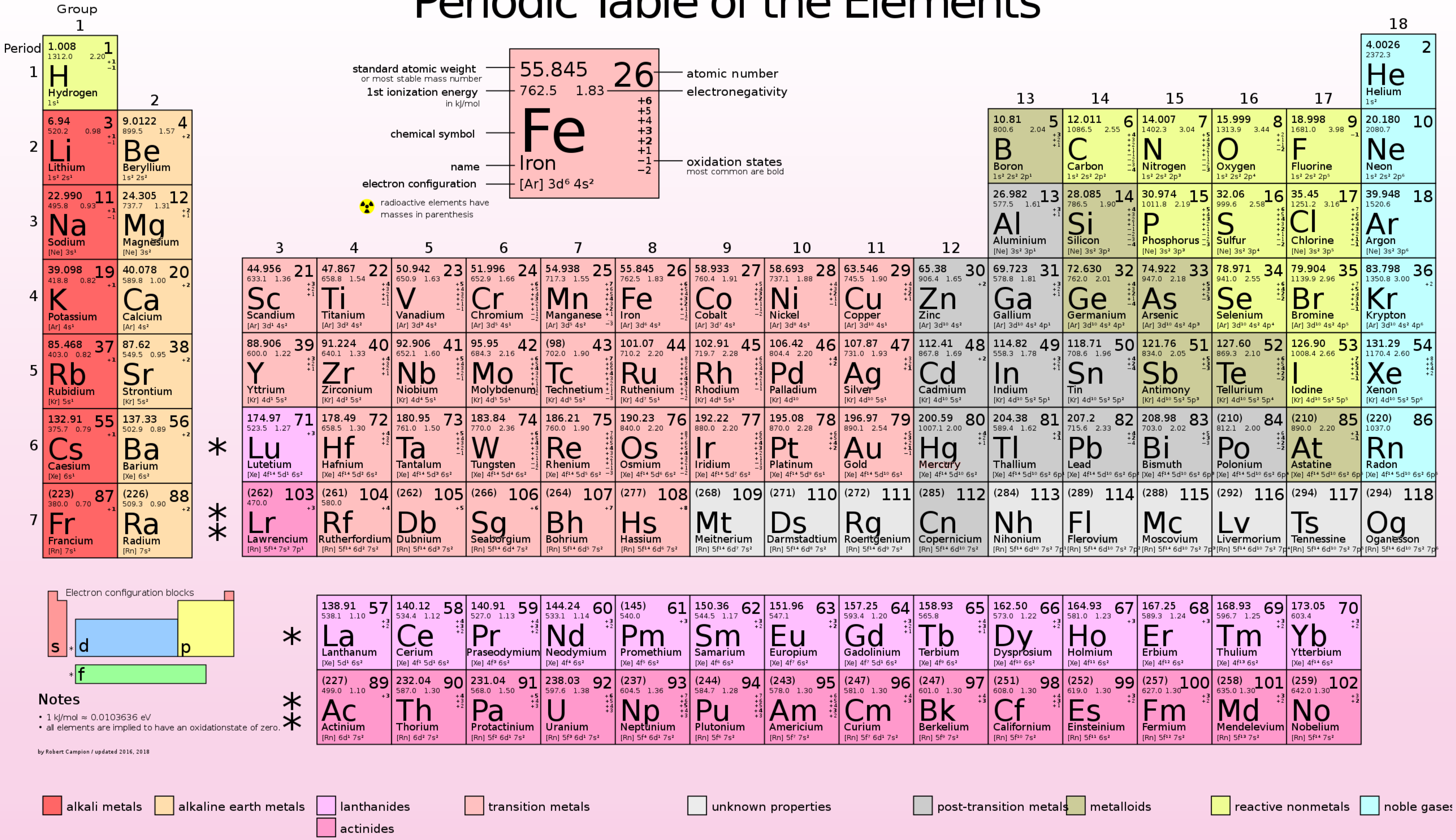
(metres)



10^{-10}
10^{-0}
10^{10}
(metres)

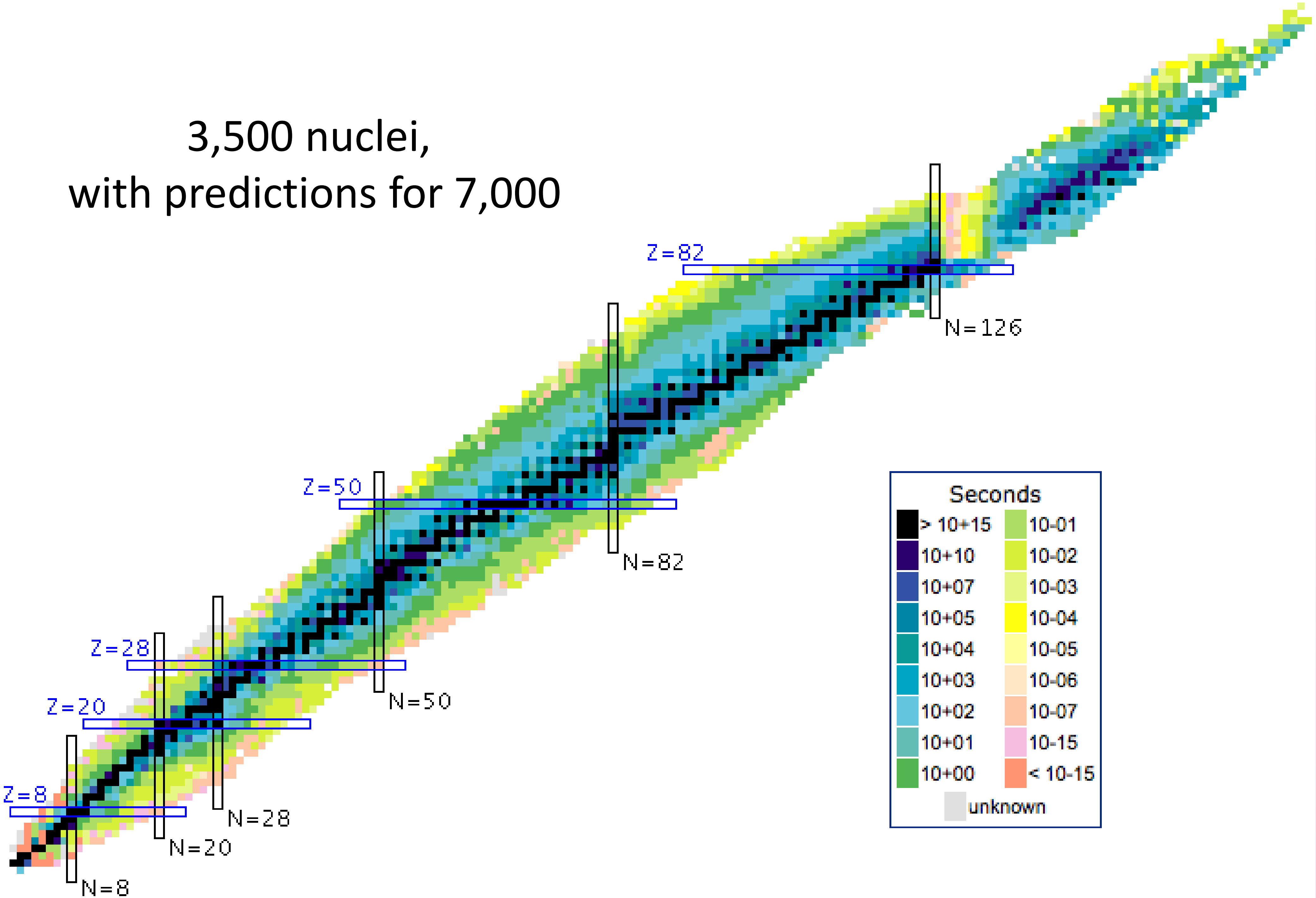

20 m
Watson Building
Poynting Building

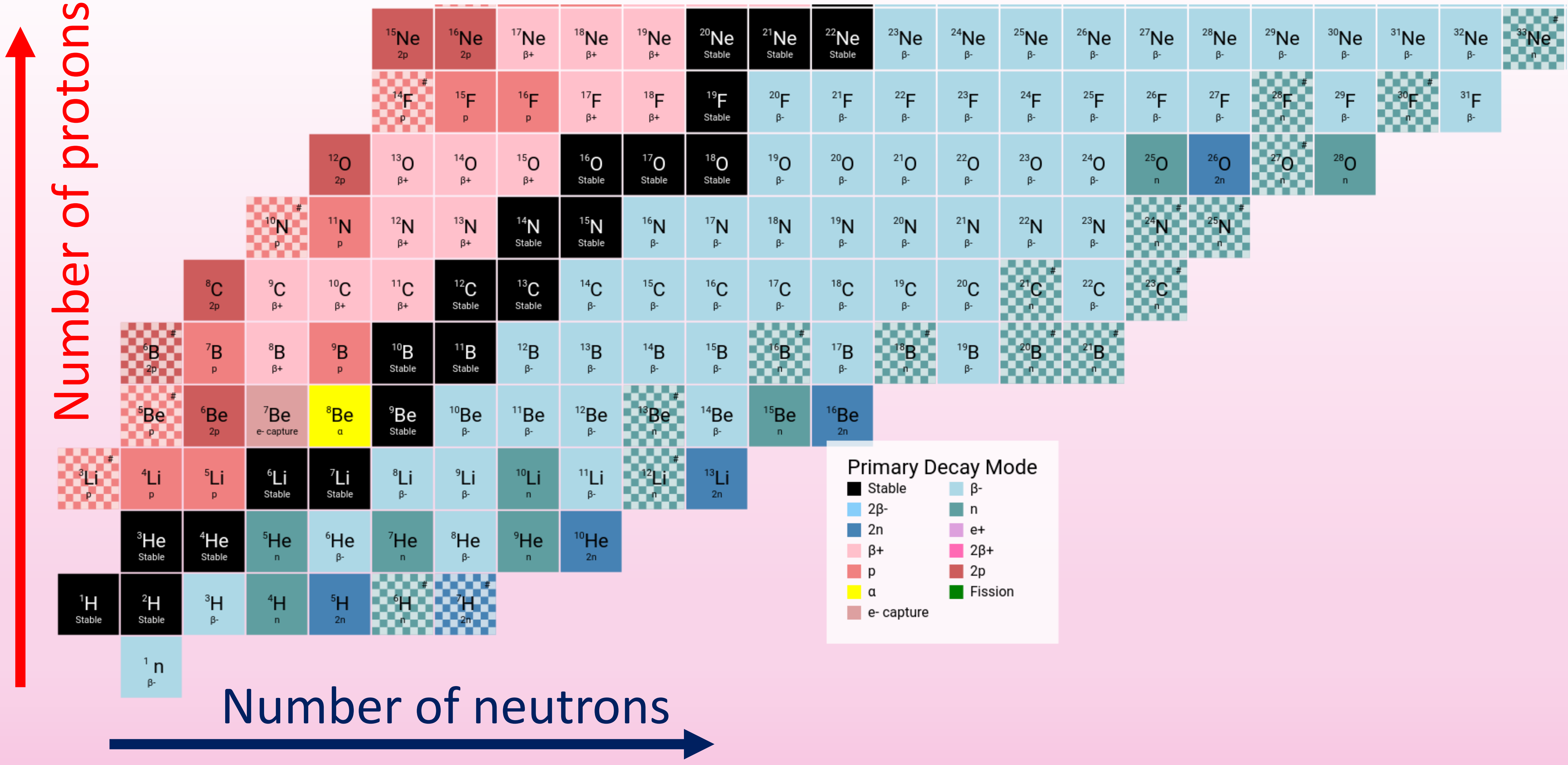
Periodic Table of the Elements



https://upload.wikimedia.org/wikipedia/commons/thumb/4/4d/Periodic_table_large.svg/2560px-Periodic_table_large.svg.png

3,500 nuclei, with predictions for 7,000




Number of protons
Number of neutrons
^{15}Ne 2p
^{16}Ne 2p
^{17}Ne β+
^{18}Ne β+
^{19}Ne β+
^{20}Ne Stable
^{21}Ne Stable
^{22}Ne Stable
^{23}Ne β-
^{24}Ne β-
^{25}Ne β-
^{26}Ne β-
^{27}Ne β-
^{28}Ne β-
^{29}Ne β-
^{30}Ne β-
^{31}Ne β-
^{32}Ne β-
^{33}Ne n
^{14}F p
^{15}F p
^{16}F p
^{17}F β+
^{18}F β+
^{19}F Stable
^{20}F β-
^{21}F β-
^{22}F β-
^{23}F β-
^{24}F β-
^{25}F β-
^{26}F β-
^{27}F β-
^{28}F n
^{29}F β-
^{30}F n
^{31}F β-
^{12}O 2p
^{13}O β+
^{14}O β+
^{15}O β+
^{16}O Stable
^{17}O Stable
^{18}O Stable
^{19}O β-
^{20}O β-
^{21}O β-
^{22}O β-
^{23}O β-
^{24}O β-
^{25}O n
^{26}O 2n
^{27}O n
^{28}O n
^{10}N p
^{11}N p
^{12}N β+
^{13}N β+
^{14}N Stable
^{15}N Stable
^{16}N β-
^{17}N β-
^{18}N β-
^{19}N β-
^{20}N β-
^{21}N β-
^{22}N β-
^{23}N β-
^{24}N n
^{25}N n
^{8}C 2p
^{9}C β+
^{10}C β+
^{11}C β+
^{12}C Stable
^{13}C Stable
^{14}C β-
^{15}C β-
^{16}C β-
^{17}C β-
^{18}C β-
^{19}C β-
^{20}C β-
^{21}C n
^{22}C β-
^{23}C n
^{6}B 2p
^{7}B p
^{8}B β+
^{9}B p
^{10}B Stable
^{11}B Stable
^{12}B β-
^{13}B β-
^{14}B β-
^{15}B β-
^{16}B n
^{17}B β-
^{18}B n
^{19}B β-
^{20}B n
^{21}B n
^{5}Be p
^{6}Be 2p
^{7}Be e- capture
^{8}Be α
^{9}Be Stable
^{10}Be β-
^{11}Be β-
^{12}Be β-
^{13}Be n
^{14}Be β-
^{15}Be n
^{16}Be 2n
^{3}Li p
^{4}Li p
^{5}Li p
^{6}Li Stable
^{7}Li Stable
^{8}Li β-
^{9}Li β-
^{10}Li n
^{11}Li β-
^{12}Li n
^{13}Li 2n
^{3}He Stable
^{4}He Stable
^{5}He n
^{6}He β-
^{7}He n
^{8}He β-
^{9}He n
^{10}He 2n
^{1}H Stable
^{2}H Stable
^{3}H β-
^{4}H n
^{5}H 2n
^{6}H n
^{7}H 2n
^{1}n β-
Primary Decay Mode
Stable
β-
2β-
n
2n
e+
β+
2β+
p
2p
α
Fission
e- capture

Atomic sizes

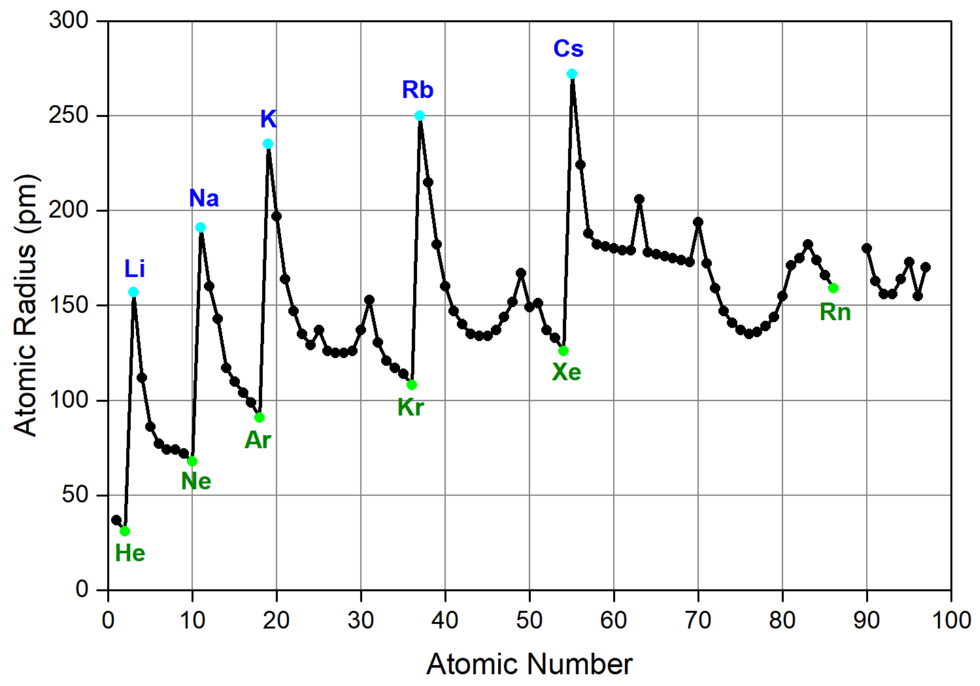
How does the size of the atom vary?

As we add more electrons, it would make sense for the radius of the atom to increase accordingly to fit in the extra electrons.

Does it?

Atom size and properties mostly determined by the outermost electron

Ionisation and atom size



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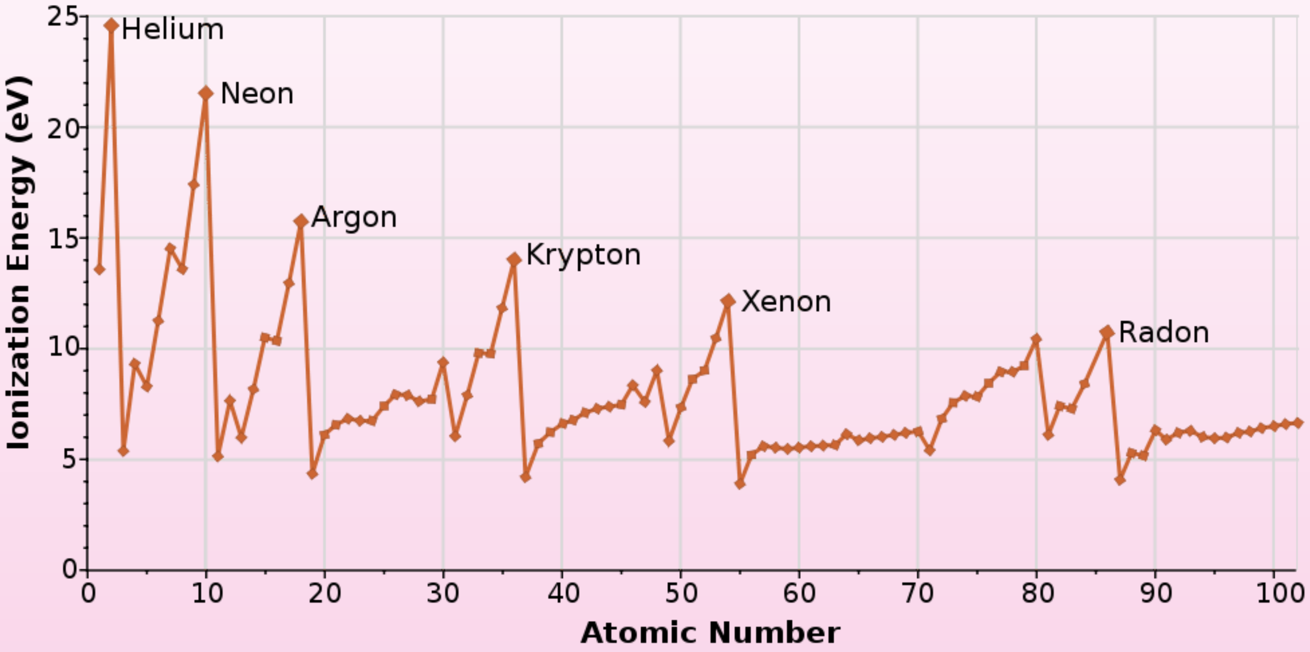

https://www.ck12.org/c/chemistry/periodic-trends%3A-ionization-energy/lesson/Periodic-Trends-Ionization-Energy-CHEM/

Atoms have approximately the same atomic radius and ionisation energy, regardless of number of protons and electrons

Nucleus size

Nuclear size does increase as A increases – how might you expect the nuclear radius, R, to change with A?

Remember that increasing A adds nucleons in all 3 dimensions!

$$R = r_0 A^{1/3}$$

where r_0 is 1.2×10^{-15} m

Masses…

Masses for atoms and molecules are usually given in amu (atomic mass units), defined as 1/12 of the mass of a ^{12}C atom

1 amu = 1.66×10^{-27} kg

The atomic mass of ^{12}C is hence 12 amu… but the masses of the proton and neutron are 1.007 amu and 1.009 amu respectively.

When nucleons come together to form nuclei, mass is converted into binding energy!

… and moles

A mole (mol) is a base unit used to defined amount of substance by the number of atoms in that substance.

1 mole of a substance is defined as consisting of $N_A = 6.022 \times 10^{23}$ atoms or molecules, unthinkably large…
(size of observable universe ~ 10^{27} m).

N_A is known as Avagadro’s number, defined by how many atoms are in 12 grams of ^{12}C

Masses and moles

$$\text{Amount of substance (moles)} = \frac{\text{Number of particles}}{N_A}$$

For atoms:

$$\text{Moles} = \frac{\text{Mass (g)}}{\text{Atomic mass}}$$

For molecules:

$$\text{Moles} = \frac{\text{Mass (g)}}{\text{Molar mass}}$$

For gases: 1 mol occupies 22.4 dm^3 (or 22.4 litres) at standard temperature (273.15 K, 0°C) and pressure (10^5 Pa, 1atm) [STP], regardless of gas

Summary

- We have discussed the difference between atoms, nuclei, ions, molecules and isotopes
- Defined the unit of amount of substance, the mole, and how to calculate it for a given substance for both its mass and the number of particles that constitute it
- Discussed the size of the atom and its surprising invariance despite number of electrons