

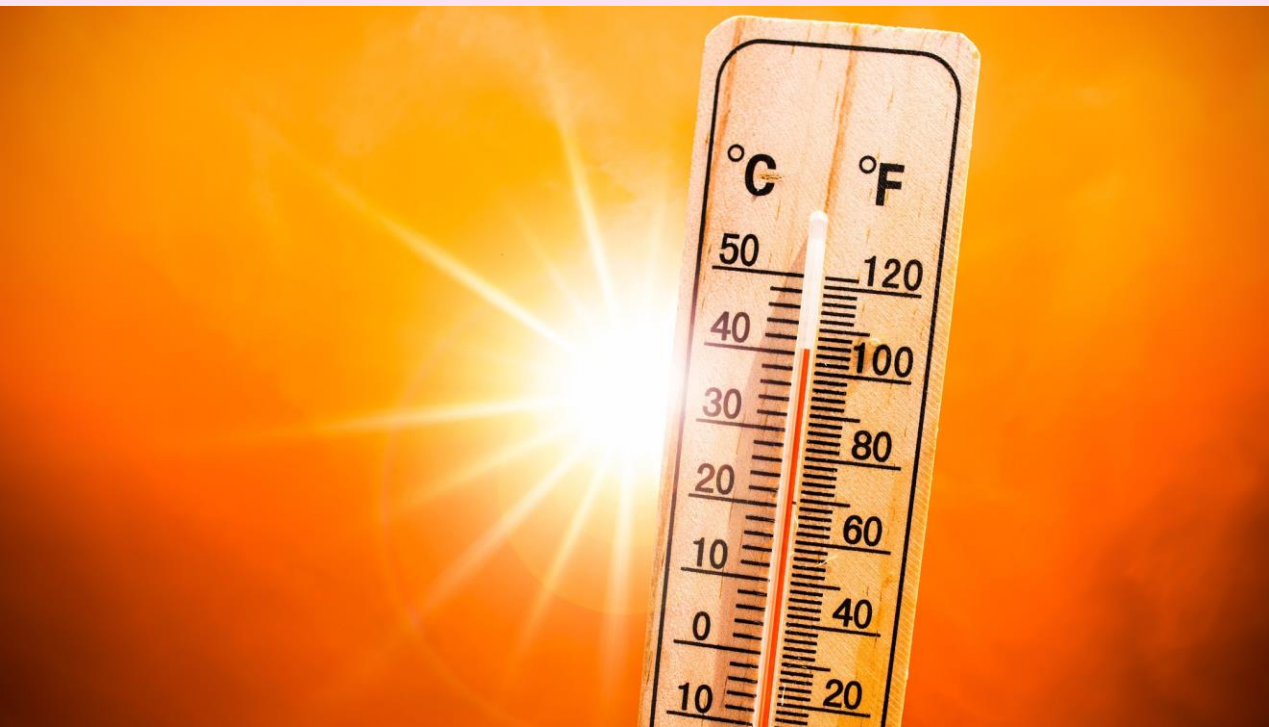
# Temperature and matter

## Y1 Semester 2 Physics

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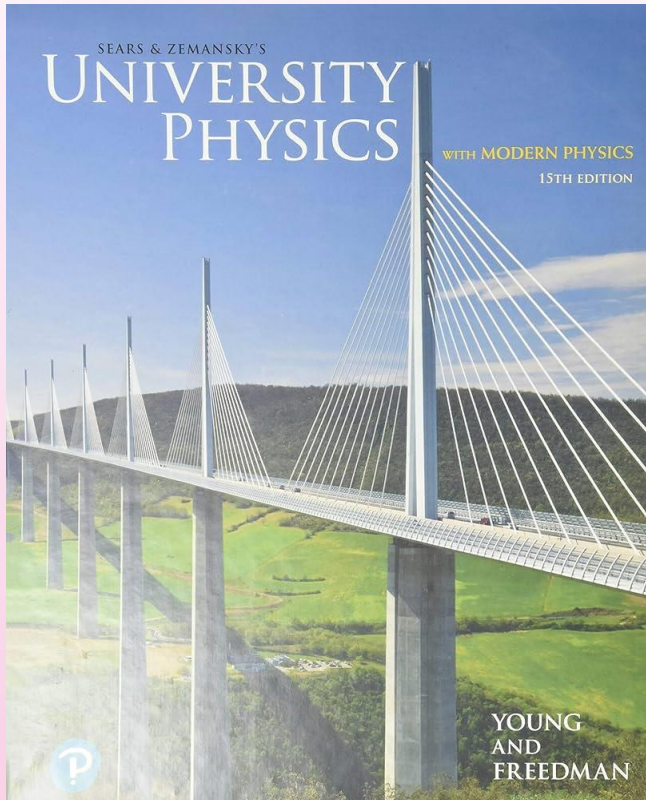
# Course aims

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**

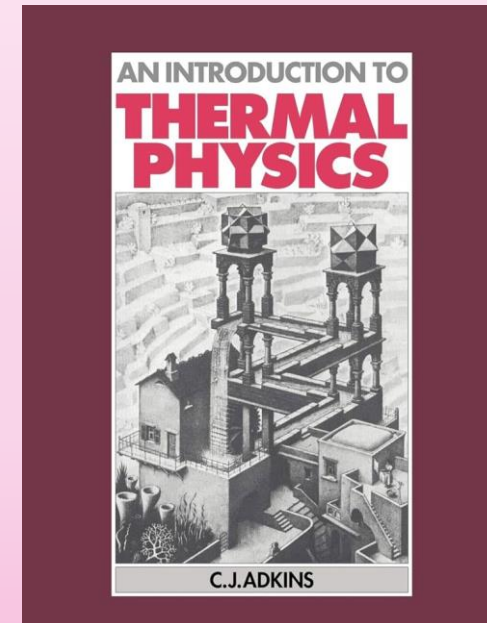
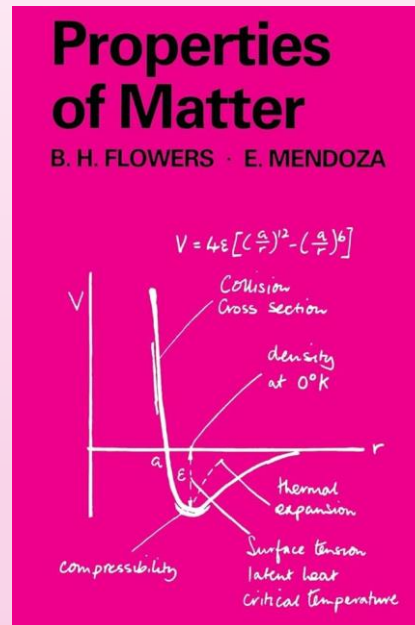
**Macroscopic** -> Matter (solids, liquids, gases...)

**Microscopic** -> Atoms, molecules

# Recommended reading

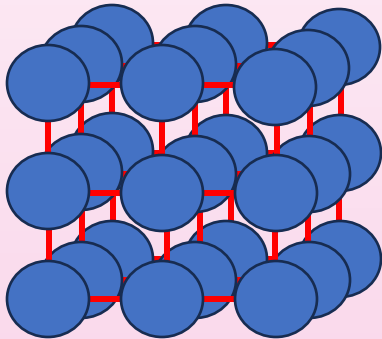


Young and Freedman chapters 14 and 17-19

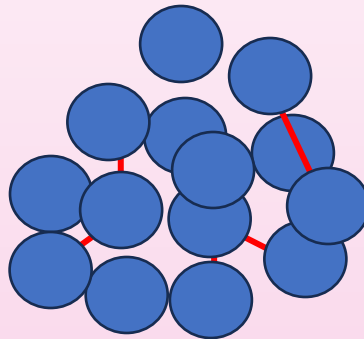


# What are different kinds (states) of matter?

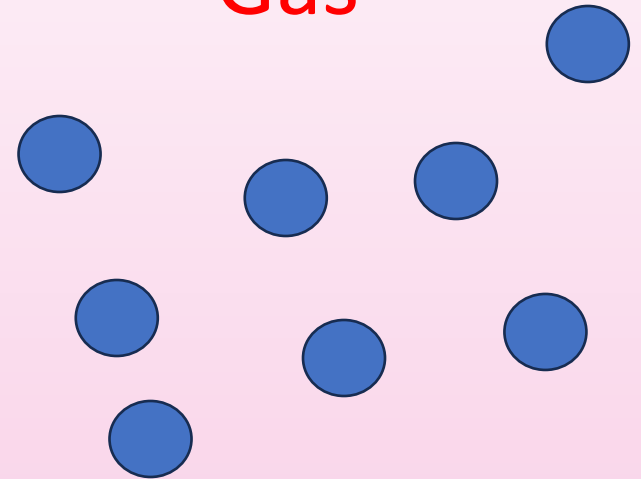
Solid



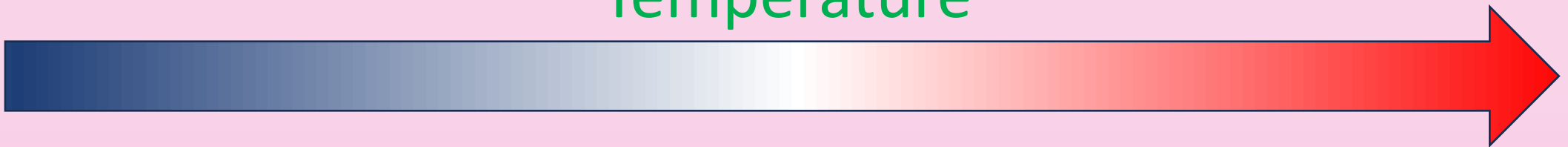
Liquid



Gas



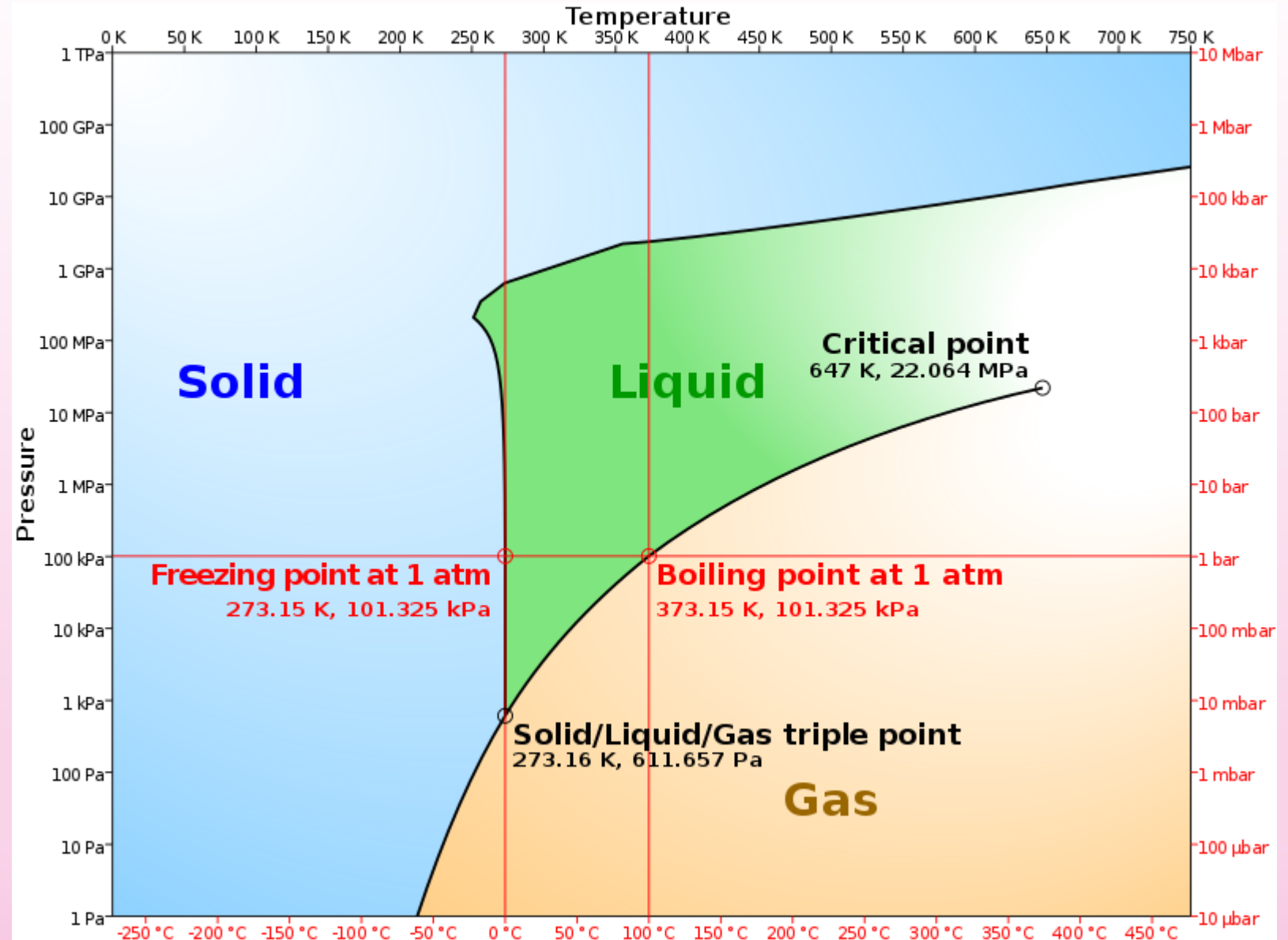
Temperature



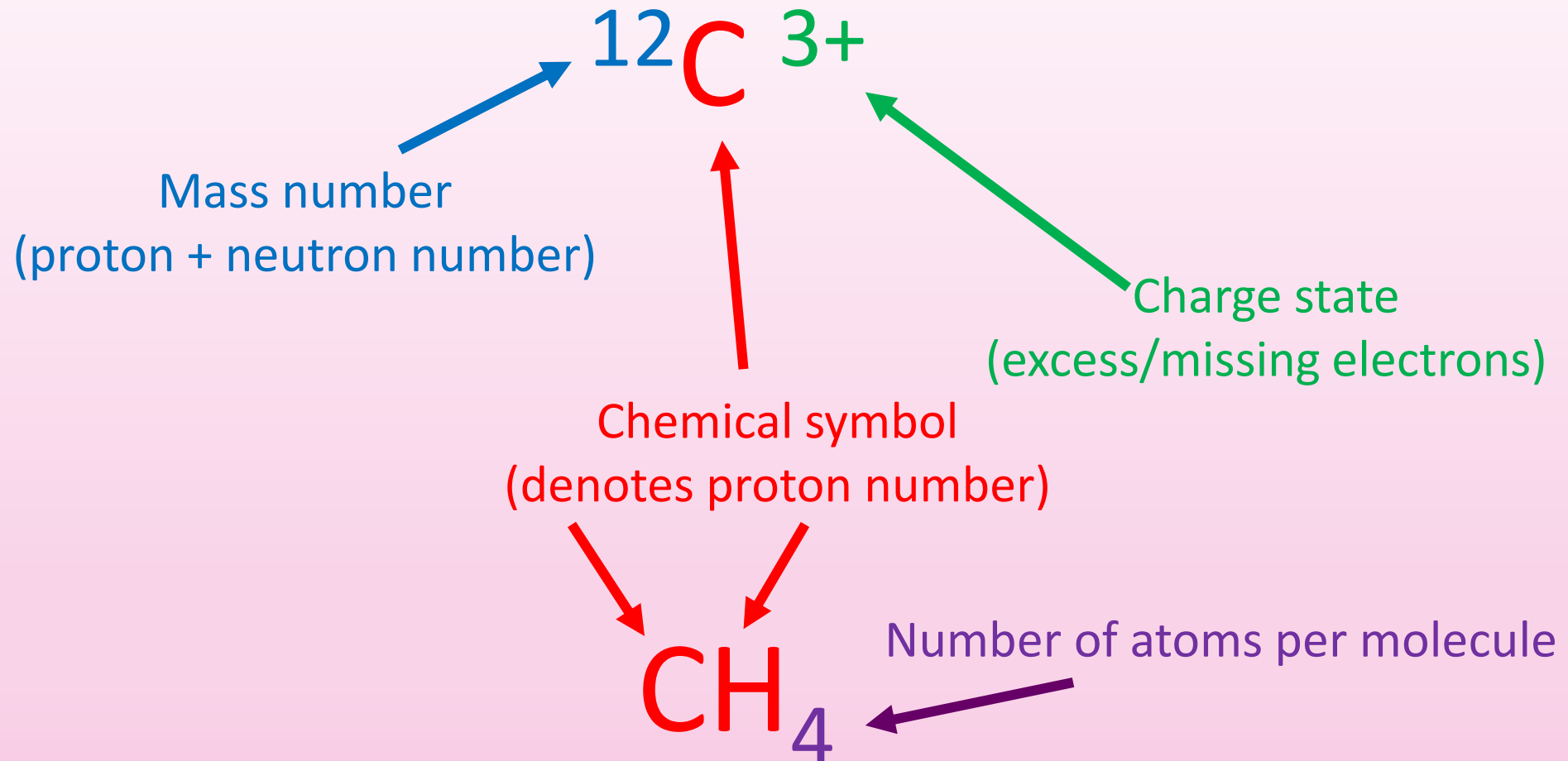
Question: How does pressure fit in?

Phase diagram:

Pressure vs temperature



# Chemical notation



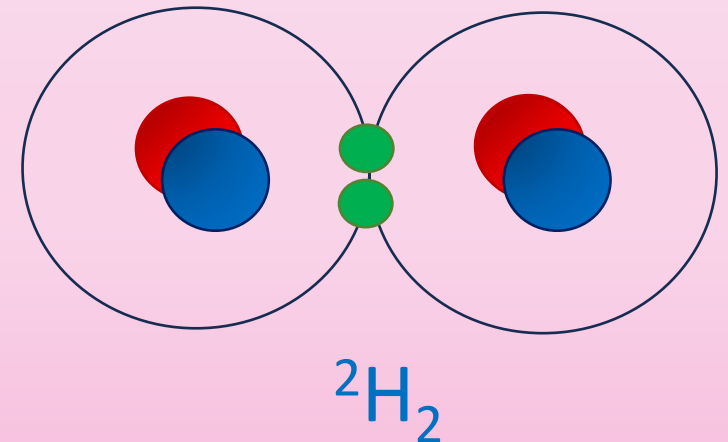
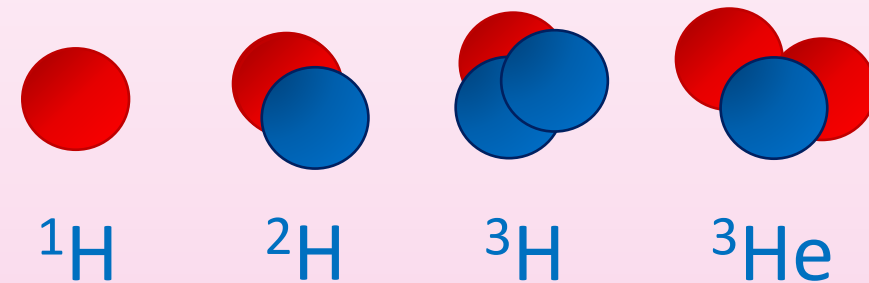
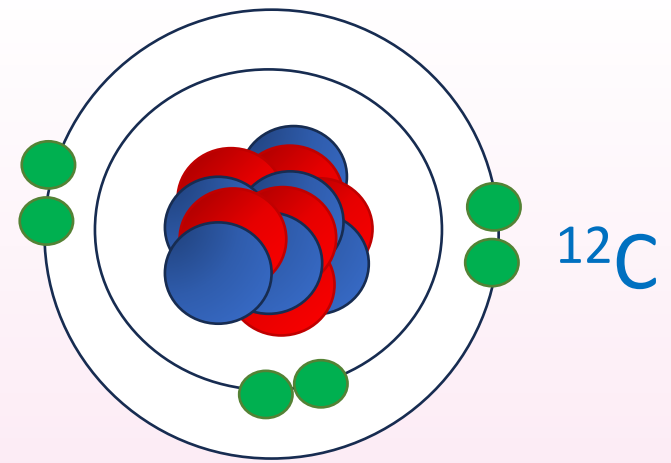


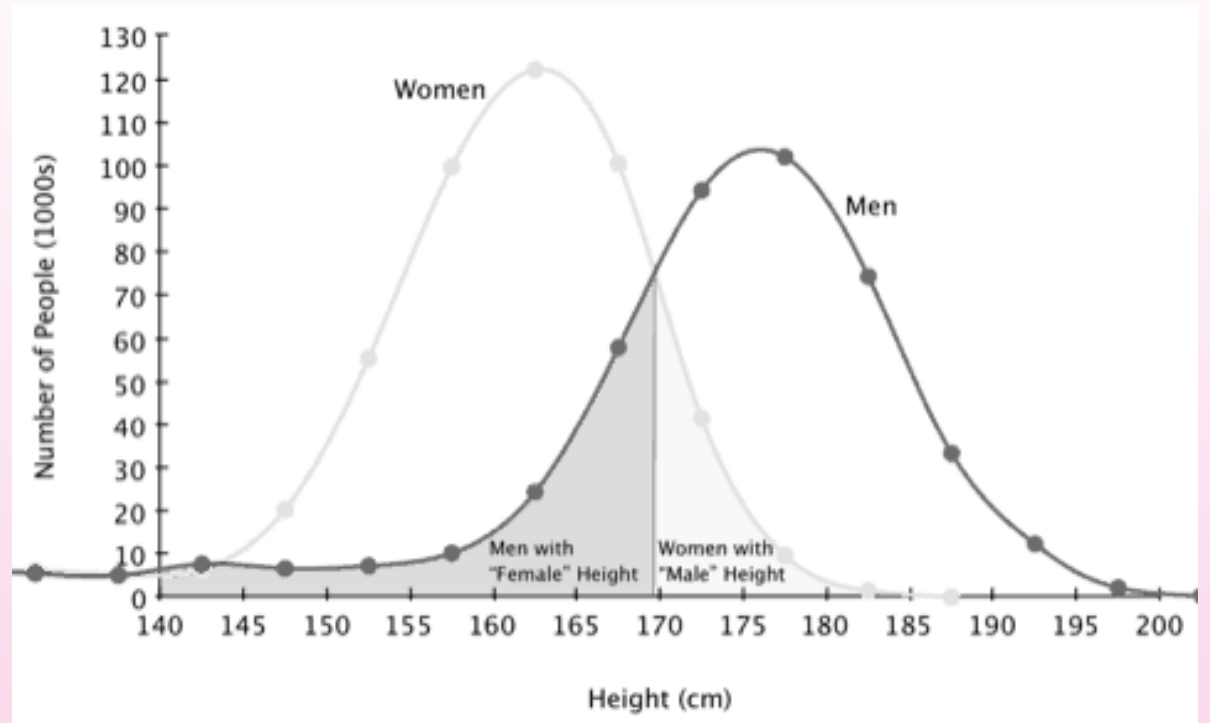
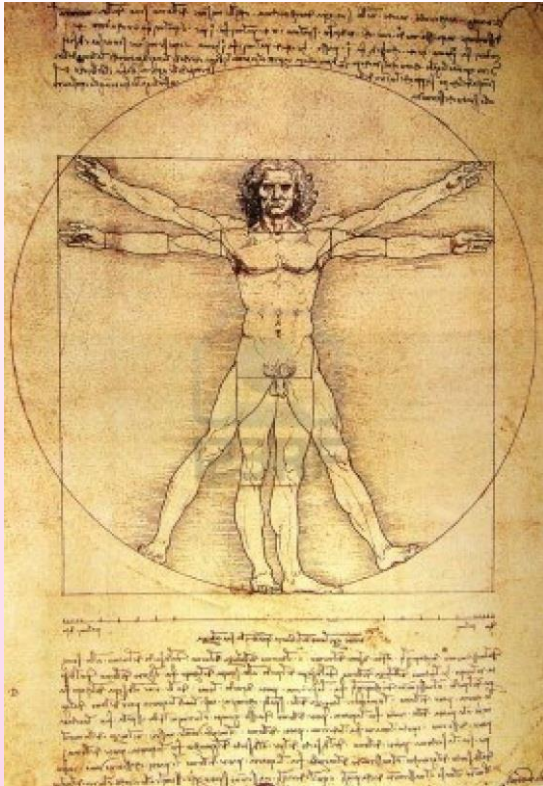
An atom is a neutrally charged particle made up of a nucleus and orbited by electrons

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)

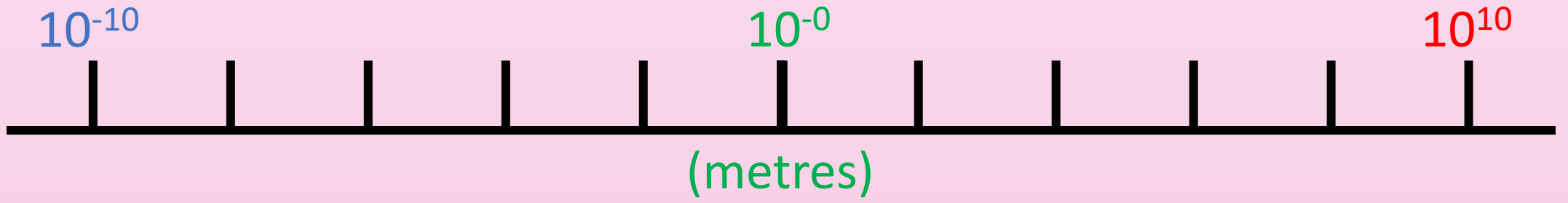
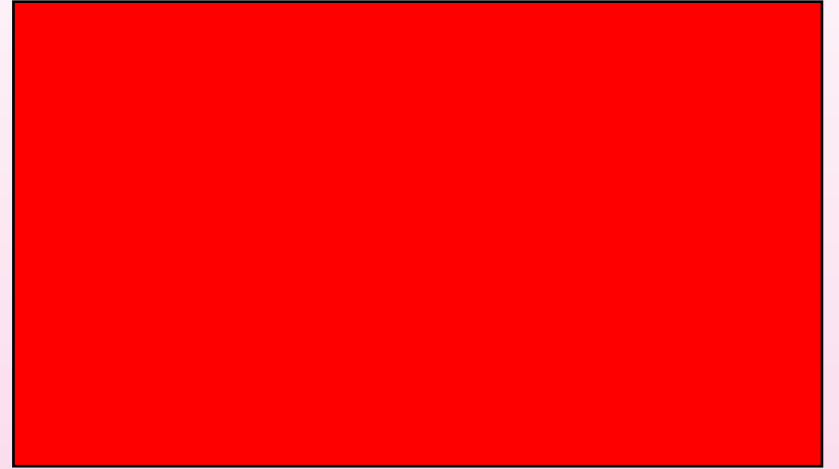




$10^{-0}$

(metres)









20 m

School of Physics & Astronomy

Poynting Building

Poynting Building

Watson Building



# Periodic Table of the Elements

Group

1

Period

1

1.008

1312.0

2.20

+1

-1

**1**

H

Hydrogen

1s<sup>1</sup>

9.0122

989.5

1.57

+2

-2

**4**

Be

Beryllium

1s<sup>2</sup> 2s<sup>2</sup>

22.990

495.8

0.93

+1

-1

**11**

Na

Sodium

[Ne] 3s<sup>1</sup>

24.305

737.7

1.31

+2

-2

**12**

Mg

Magnesium

[Ne] 3s<sup>2</sup>

39.098

418.8

0.82

+1

-1

**19**

K

Potassium

[Ar] 4s<sup>1</sup>

40.078

589.8

1.00

+2

-2

**20**

Ca

Calcium

[Ar] 4s<sup>2</sup>

85.468

403.0

0.82

+1

-1

**37**

Rb

Rubidium

[Kr] 5s<sup>1</sup>

87.62

549.5

0.95

+2

-2

**38**

Sr

Strontium

[Kr] 5s<sup>2</sup>

132.91

375.7

0.79

+1

-1

**55**

Cs

Caesium

[Xe] 6s<sup>1</sup>

137.33

502.9

0.89

+2

-2

**56**

Ba

Barium

[Xe] 6s<sup>2</sup>

(223)

380.0

0.70

+1

-1

**87**

Fr

Francium

[Rn] 7s<sup>1</sup>

(226)

509.3

0.90

+2

-2

**88**

Ra

Radium

[Rn] 7s<sup>2</sup>

standard atomic weight  
or most stable mass number

1st ionization energy  
in kJ/mol

chemical symbol

name

electron configuration

radioactive elements have  
masses in parenthesis

55.845

26

762.5

1.83

**Fe**

Iron

[Ar] 3d<sup>6</sup> 4s<sup>2</sup>

+6  
+5  
+4  
+3  
+2  
+1  
-1  
-2

oxidation states  
most common are bold

13

14

15

16

17

10.81

800.6

2.04

+3

-3

**5**

B

Boron

1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>1</sup>

12.011

1086.5

2.55

+4

-4

**6**

C

Carbon

1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>2</sup>

14.007

1402.3

3.04

+5

-5

**7**

N

Nitrogen

1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>3</sup>

15.999

1313.9

3.44

+6

-6

**8**

O

Oxygen

1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>4</sup>

18.998

1681.0

3.98

+7

-7

**9**

F

Fluorine

1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>5</sup>

20.180

2080.7

-1

+8

-8

**10**

Ne

Neon

1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup>

26.982

577.5

1.61

+3

-3

**13**

Al

Aluminium

[Ne] 3s<sup>2</sup> 3p<sup>1</sup>

28.085

786.5

1.90

+4

-4

**14**

Si

Silicon

[Ne] 3s<sup>2</sup> 3p<sup>2</sup>

30.974

1011.8

2.19

+5

-5

**15**

P

Phosphorus

[Ne] 3s<sup>2</sup> 3p<sup>3</sup>

32.06

999.6

2.58

+6

-6

**16**

S

Sulfur

[Ne] 3s<sup>2</sup> 3p<sup>4</sup>

35.45

1251.2

3.16

+7

-7

**17**

Cl

Chlorine

[Ne] 3s<sup>2</sup> 3p<sup>5</sup>

39.948

1520.6

-1

+8

-8

**18**

Ar

Argon

[Ne] 3s<sup>2</sup> 3p<sup>6</sup>

44.956

633.1

1.36

+3

-3

**21**

Sc

Scandium

[Ar] 3d<sup>1</sup> 4s<sup>2</sup>

47.867

658.8

1.54

+4

-4

**22**

Ti

Titanium

[Ar] 3d<sup>2</sup> 4s<sup>2</sup>

50.942

650.9

1.63

+5

-5

**23**

V

Vanadium

[Ar] 3d<sup>3</sup> 4s<sup>2</sup>

51.996

652.9

1.66

+6

-6

**24**

Cr

Chromium

[Ar] 3d<sup>5</sup> 4s<sup>1</sup>

54.938

717.3

1.55

+7

-7

**25**

Mn

Manganese

[Ar] 3d<sup>5</sup> 4s<sup>2</sup>

55.845

762.5

1.83

+8

-8

**26**

Fe

Iron

[Ar] 3d<sup>6</sup> 4s<sup>2</sup>

58.933

745.5

1.91

+9

-9

**27**

Co

Cobalt

[Ar] 3d<sup>7</sup> 4s<sup>2</sup>

58.693

747.1

1.88

+10

-10

**28**

Ni

Nickel

[Ar] 3d<sup>8</sup> 4s<sup>2</sup>

63.546

906.4

1.90

+11

-11

**29**

Cu

Copper

[Ar] 3d<sup>10</sup> 4s<sup>1</sup>

65.38

906.4

1.65

+12

-12

**30**

Zn

Zinc

[Ar] 3d<sup>10</sup> 4s<sup>2</sup>

69.723

578.8

1.81

+13

-13

**31**

Ga

Gallium

[Ar] 3d<sup>10</sup> 4s<sup>2</sup> 4p<sup>1</sup>

72.630

578.8

2.01

+14

-14

**32**

Ge

Germanium

[Ar] 3d<sup>10</sup> 4s<sup>2</sup> 4p<sup>2</sup>

74.922

578.8

2.18

+15

-15

**33**

As

Arsenic

[Ar] 3d<sup>10</sup> 4s<sup>2</sup> 4p<sup>3</sup>

78.971

578.8

2.55

+16

-16

**34**

Se

Selenium

[Ar] 3d<sup>10</sup> 4s<sup>2</sup> 4p<sup>4</sup>

79.904

578.8

2.96

+17

-17

**35**

Br

Bromine

[Ar] 3d<sup>10</sup> 4s<sup>2</sup> 4p<sup>5</sup>

83.798

578.8

3.00

+18

-18

**36**

Kr

Krypton

[Ar] 3d<sup>10</sup> 4s<sup>2</sup> 4p<sup>6</sup>

88.906

600.0

1.22

+19

-19

**39**

Y

Yttrium

[Kr] 4d<sup>1</sup> 5s<sup>2</sup>

91.224

640.1

1.33

+20

-20

**40**

Zr

Zirconium

[Kr] 4d<sup>2</sup> 5s<sup>2</sup>

92.906

640.1

1.60

+21

-21

**41**

Nb

Niobium

[Kr] 4d<sup>4</sup> 5s<sup>1</sup>

95.95

640.1

2.16

+22

-22

**42**

Mo

Molybdenum

[Kr] 4d<sup>5</sup> 5s<sup>1</sup>

(98)

719.7

2.20

+23

-23

**43**

Tc

Technetium

[Kr] 4d<sup>5</sup> 5s<sup>2</sup>

101.07

719.7

2.20

+24

-24

**44**

Ru

Ruthenium

[Kr] 4d<sup>6</sup> 5s<sup>2</sup>

102.91

719.7

2.28

+25

-25

**45**

Rh

Rhodium

[Kr] 4d<sup>7</sup> 5s<sup>1</sup>

106.42

719.7

2.28

+26

-26

**46**

Pd

Palladium

[Kr] 4d<sup>8</sup> 5s<sup>1</sup>

107.87

731.0

1.93

+27

-27

**47**

Ag

Silver

[Kr] 4d<sup>10</sup> 5s<sup>1</sup>

112.41

731.0

1.69

+28

-28

**48**

Cd

Cadmium

[Kr] 4d<sup>10</sup> 5s<sup>2</sup>

114.82

558.3

1.78

+29

-29

**49**

In

Indium

[Kr] 4d<sup>10</sup> 5s<sup>2</sup> 5p<sup>1</sup>

118.71

558.3

1.96

+30

-30

**50**

Sn

Tin

[Kr] 4d<sup>10</sup> 5s<sup>2</sup> 5p<sup>2</sup>

121.76

558.3

2.05

+31

-31

**51**

Sb

Antimony

[Kr] 4d<sup>10</sup> 5s<sup>2</sup> 5p<sup>3</sup>

127.60

558.3

2.10

+32

-32

**52**

Te

Tellurium

[Kr] 4d<sup>10</sup> 5s<sup>2</sup> 5p<sup>4</sup>

126.90

558.3

2.66

+33

-33

**53**

I

Iodine

[Kr] 4d<sup>10</sup> 5s<sup>2</sup> 5p<sup>5</sup>

131.29

558.3

2.60

+34

-34

**54**

Xe

Xenon

[Kr] 4d<sup>10</sup> 5s<sup>2</sup> 5p<sup>6</sup>

174.97

523.5

1.27

+35

-35

**71**

Lu

Lutetium

[Xe] 4f<sup>14</sup> 5d<sup>1</sup> 6s<sup>2</sup>

178.49

658.5

1.30

+36

-36

**72**

Hf

Hafnium

[Xe] 4f<sup>14</sup> 5d<sup>2</sup> 6s<sup>2</sup>

180.95

761.0

1.50

+37

-37

**73**

Ta

Tantalum

[Xe] 4f<sup>14</sup> 5d<sup>3</sup> 6s<sup>2</sup>

183.84

770.0

2.36

+38

-38

**74**

W

Tungsten

[Xe] 4f<sup>14</sup> 5d<sup>4</sup> 6s<sup>2</sup>

186.21

760.0

1.90

+39

-39

**75**

Re

Rhenium

[Xe] 4f<sup>14</sup> 5d<sup>5</sup> 6s<sup>2</sup>

190.23

840.0

2.20

+40

-40

**76**

Os

Osmium

[Xe] 4f<sup>14</sup> 5d<sup>6</sup> 6s<sup>2</sup>

192.22

880.0

2.20

+41

-41

**77**

Ir

Iridium

[Xe] 4f<sup>14</sup> 5d<sup>7</sup> 6s<sup>2</sup>

195.08

870.0

2.28

+42

-42

**78**

Pt

Platinum

[Xe] 4f<sup>14</sup> 5d<sup>8</sup> 6s<sup>2</sup>

196.97

890.1

2.54

+43

-43

**79**

Au

Gold

[Xe] 4f<sup>14</sup> 5d<sup>10</sup> 6s<sup>1</sup>

200.59

1007.1

2.00

+44

-44

**80**

Hg

Mercury

[Xe] 4f<sup>14</sup> 5d<sup>10</sup> 6s<sup>2</sup>

204.38

589.4

1.62

+45

-45

**81**

Tl

Thallium

[Xe] 4f<sup>14</sup> 5d<sup>10</sup> 6s<sup>2</sup> 6p<sup>1</sup>

207.2

715.6

2.33

+46

-46

**82**

Pb

Lead

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

208.98

703.0

2.02

+47

-47

**83**

Bi

Bismuth

[Xe] 4f<sup>14</sup> 5d<sup>10</sup> 6s<sup>2</sup> 6p<sup>3</sup>

(210)

812.1

2.00

+48

-48

**84**

Po

Polonium

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

(210)

890.0

2.20

+49

-49

**85**

At

Astatine

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

(220)

1037.0

-1

+50

-50

**86**

Rn

Radon

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

(262)

470.0

+3

+3

**103**

Lr

Lawrencium

[Rn] 5f<sup>14</sup> 7s<sup>2</sup> 7p<sup>1</sup>

(261)

470.0

+4

+4

**104**

Rf

Rutherfordium

[Rn] 5f<sup>14</sup> 6d<sup>2</sup> 7s<sup>2</sup>

(262)

470.0

+5

+5

**105**

Db

Dubnium

[Rn] 5f<sup>14</sup> 6d<sup>3</sup> 7s<sup>2</sup>

(266)

470.0

+6

+6

**106**

Sg

Seaborgium

[Rn] 5f<sup>14</sup> 6d<sup>4</sup> 7s<sup>2</sup>

(264)

470.0

+7

+7

**107**

Bh

Bohrium

[Rn] 5f<sup>14</sup> 6d<sup>5</sup> 7s<sup>2</sup>

(277)

470.0

+8

+8

**108**

Hs

Hassium

[Rn] 5f<sup>14</sup> 6d<sup>6</sup> 7s<sup>2</sup>

(268)

470.0

+9

+9

**109**

Mt

Meitnerium

[Rn] 5f<sup>14</sup> 6d<sup>7</sup> 7s<sup>2</sup>

(271)

470.0

+10

+10

**110**

Ds

Darmstadtium

[Rn] 5f<sup>14</sup> 6d<sup>8</sup> 7s<sup>2</sup>

(272)

470.0

+11

+11

**111**

Rg

Roentgenium

[Rn] 5f<sup>14</sup> 6d<sup>9</sup> 7s<sup>2</sup>

(285)

470.0

+12

+12

**112**

Cn

Copernicium

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup>

(284)

470.0

+13

+13

**113**

Nh

Nihonium

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup> 7p<sup>1</sup>

(289)

470.0

+14

+14

**114**

Fl

Flerovium

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup> 7p<sup>2</sup>

(288)

470.0

+15

+15

**115**

Mc

Moscovium

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup> 7p<sup>3</sup>

(292)

470.0

+16

+16

**116**

Lv

Livermorium

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup> 7p<sup>4</sup>

(294)

470.0

+17

+17

**117**

Ts

Tennesse

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup> 7p<sup>5</sup>

(294)

470.0

+18

+18

**118**

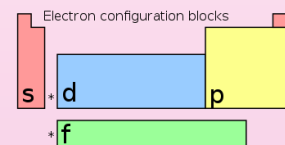
Og

Oganesson

[Rn] 5f<sup>14</sup> 6d<sup>10</sup> 7s<sup>2</sup> 7p<sup>6</sup>

\*

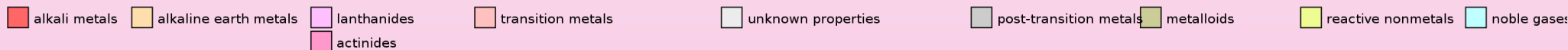
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## Notes

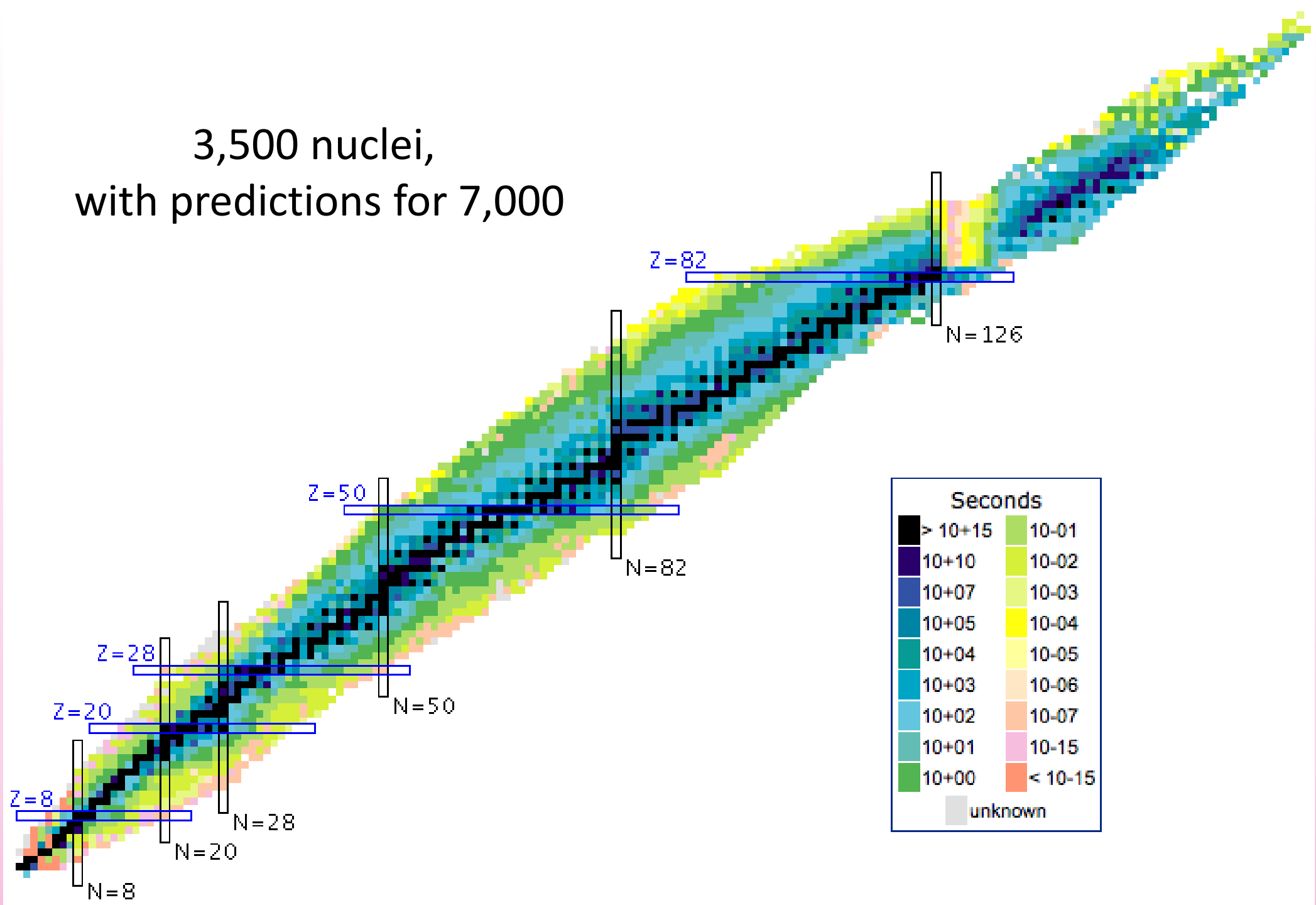
- 1 kJ/mol ≈ 0.0103636 eV
- all elements are implied to have an oxidation state of zero.

by Robert Campion / updated 2016, 2018

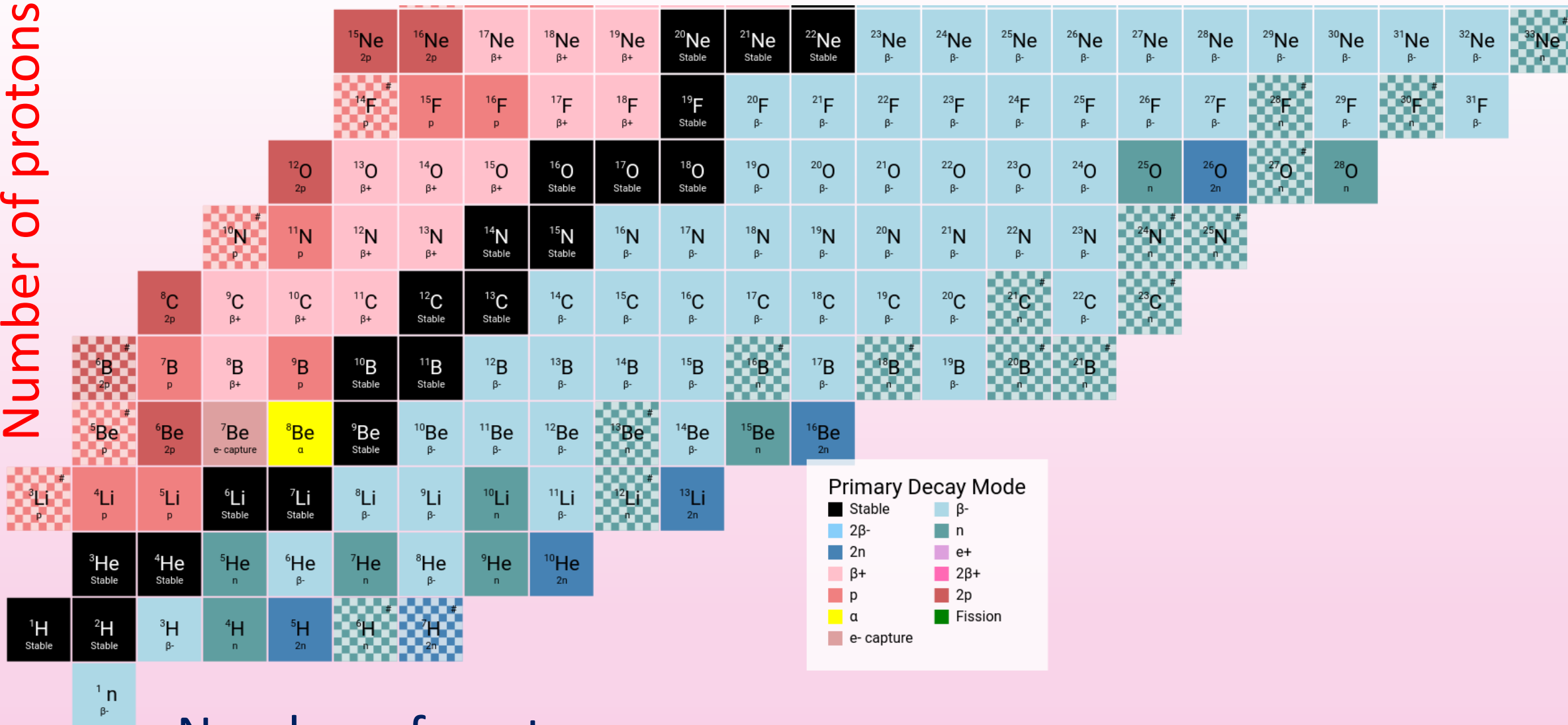


[https://upload.wikimedia.org/wikipedia/commons/thumb/4/4d/Periodic\\_table\\_large.svg/2560px-Periodic\\_table\\_large.svg.png](https://upload.wikimedia.org/wikipedia/commons/thumb/4/4d/Periodic_table_large.svg/2560px-Periodic_table_large.svg.png)

3,500 nuclei,  
with predictions for 7,000



Number of protons



Number of neutrons

# Atomic sizes

How does the size of the atom vary?

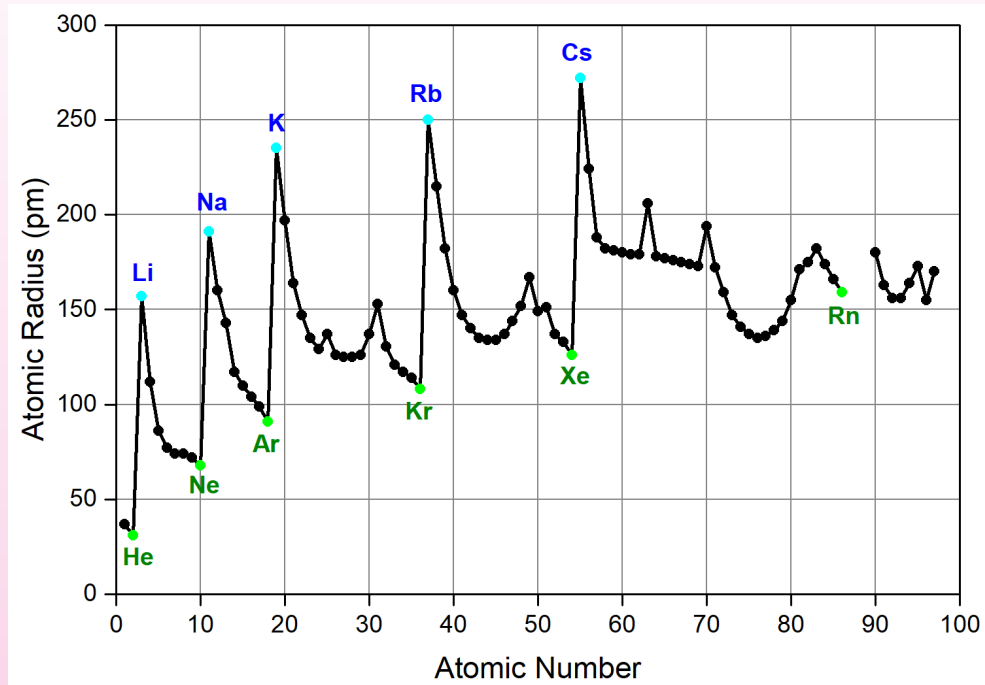
As we add more electrons, it would make sense for the radius of the atom to increase accordingly to fit in the extra electrons.

Does it?

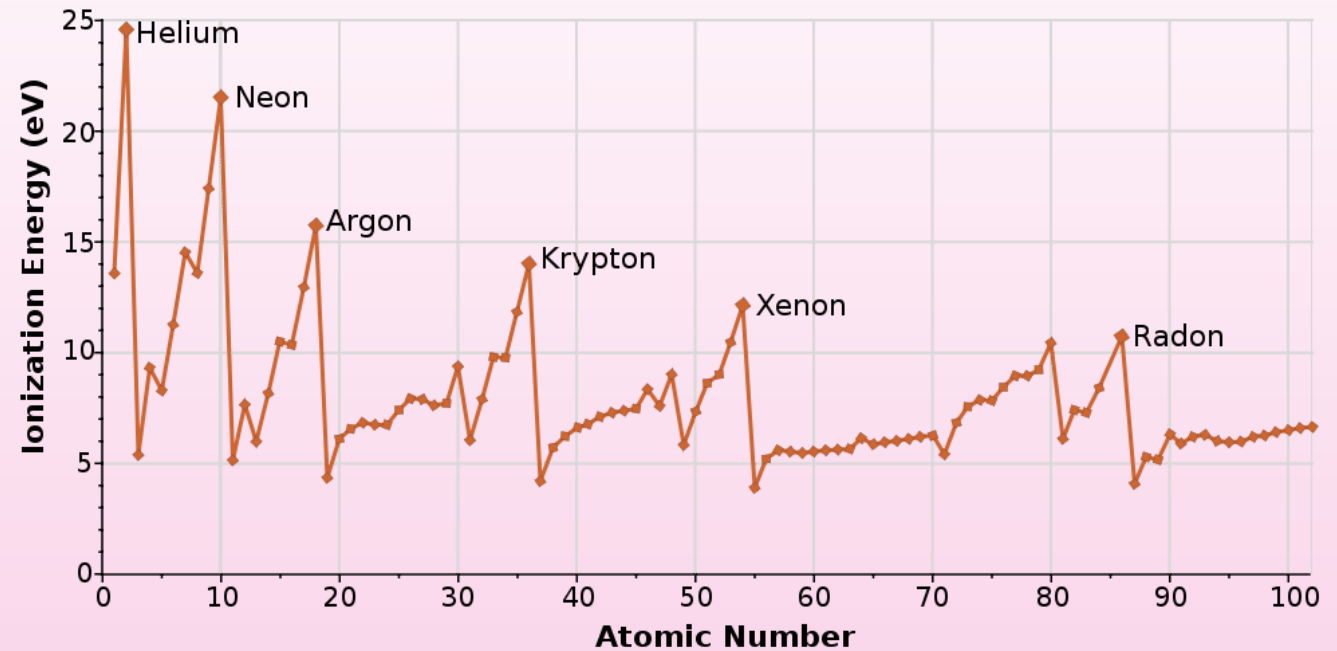
Atom size and properties mostly determined by the outermost electron



# Ionisation and atom size



<https://wisc.pb.unizin.org/app/uploads/sites/564/h5p/content/31/images/image-5cdefc04046e6.png>



<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  $1.2 \times 10^{-15}$  m

# Masses...

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

$$1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$$

The atomic mass of  $^{12}\text{C}$  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  $\sim 10^{27}$  m).

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

# 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<sup>3</sup> (or 22.4 litres) at standard temperature (273.15 K, 0°C) and pressure (10<sup>5</sup> 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