

CHAPTER 1

Atomic and Molecular Mass

A proton and a neutron have about the same mass. An electron, on the other hand, has much less mass: One neutron weighs about the same amount as 2000 electrons. Thus, the mass of any object comes mostly from the protons and neutrons in the nucleus of its atoms.

We know how many protons an atom has by what element it is, but how do we know the number neutrons?

If you fill a balloon with helium, it will have two different kinds of helium atoms: Most of the helium atoms will have 2 neutrons, but a few will have only 1 neutron. We say that these are two different *isotopes* of helium. We call them helium-4 (or ${}^4\text{He}$) and helium-3 (or ${}^3\text{He}$). Isotopes are named for the sum of protons and neutrons the atom has: helium-3 has 2 protons and 1 neutron.

Watch Khan Academy's **Atomic mass, number, and isotopes** at <https://www.khanacademy.org/science/chemistry/atomic-structure-and-properties/introduction-to-the-atom/v/atomic-number-mass-number-and-isotopes>

A hydrogen atom nearly always has just 1 proton and no neutrons. A helium atom nearly always has 2 protons and 2 neutrons. So, if you have a 100 hydrogen atoms and 100 helium atoms, the helium will have about 4 times more mass than the hydrogen. We say "Hydrogen is about 1 atomic mass unit(amu), and helium-4 is about 4 atomic mass units."

What, precisely, is an atomic mass unit? It is defined as 1/12 of the mass of a carbon-12 atom. Scientists have measured the mass of helium-4, and it is about 4.0026 atomic mass units. (By the way, an atomic mass unit is also called a *dalton*.)

Now you are ready to take a good look at the periodic table of elements. Here is the version from Wikipedia:

Periodic Table of Elements

IA

1

H

Hydrogen

1.01

IIA

3

Li

Lithium

6.94

4

Be

Beryllium

9.01

IIIB

11

Na

Sodium

22.99

12

Mg

Magnesium

24.31

IVB

19

K

Potassium

39.10

20

Ca

Calcium

40.08

VB

21

Sc

Scandium

44.96

22

Ti

Titanium

47.87

VIB

23

V

Vanadium

50.94

24

Cr

Chromium

52.00

VIIA

25

Mn

Manganese

54.94

26

Fe

Iron

55.85

VIIIA

27

Co

Cobalt

58.93

28

Ni

Nickel

58.69

IIIA

29

Cu

Copper

63.55

30

Zn

Zinc

65.38

IVIA

31

Ga

Gallium

69.72

32

Ge

Germanium

72.63

VA

33

As

Arsenic

74.92

34

Se

Selenium

78.97

VIA

35

Br

Bromine

79.90

36

Kr

Krypton

83.80

VIIA

37

I

Iodine

126.90

53

Xe

Xenon

131.29

VIIIA

54

Cs

Cesium

132.91

55

Ba

Barium

137.33

IIIB

56

La

Lanthanum

138.91

57

Ce

Cerium

140.12

IVB

58

Pr

Praseodymium

140.91

59

Nd

Neodymium

144.24

VB

60

Pm

Promethium

(145)

61

Sm

Samarium

150.36

VIB

62

Eu

Europium

151.96

63

Gd

Gadolinium

157.25

VIIA

64

Tb

Terbium

158.93

65

Dy

Dysprosium

162.50

IIIA

66

Ho

Holmium

164.93

67

Er

Erbium

167.26

IVIA

68

Tm

Thulium

168.93

69

Yb

Ytterbium

173.05

VA

70

Lu

Lutetium

174.97

71

La

Lanthanum

175.05

VIA

72

Hf

Hafnium

178.49

73

Ta

Tantalum

180.95

VIIA

74

W

Tungsten

183.84

75

Re

Rhenium

186.21

IIIA

76

Os

Osmium

190.23

77

Ir

Iridium

192.22

IVIA

78

Pt

Platinum

195.08

79

Au

Gold

196.97

VB

80

Hg

Mercury

200.59

81

Tl

Thallium

204.38

VIB

82

Pb

Lead

207.20

83

Bi

Bismuth

208.98

VIIA

84

Po

Polonium

(209)

85

At

Astatine

(210)

IIIA

86

Rn

Radon

(222)

87

Fr

Francium

(223)

IVIA

88

Ra

Radium

(226)

89

Ac

Actinium

(227)

VA

89

Th

Thorium

232.04

90

Pa

Protactinium

231.04

VIA

91

U

Uranium

238.03

92

Np

Neptunium

(237)

VIIA

93

Pu

Plutonium

(244)

94

Am

Americium

(243)

IIIA

95

Cm

Curium

(247)

96

Bk

Berkelium

(247)

IVIA

97

Cf

Californium

(251)

98

Es

Einsteinium

(252)

VA

99

Fm

Fermium

(257)

100

Md

Mendelevium

(258)

VIA

101

No

Nobelium

(259)

102

Lr

Lawrencium

(262)

VIIA

103

He

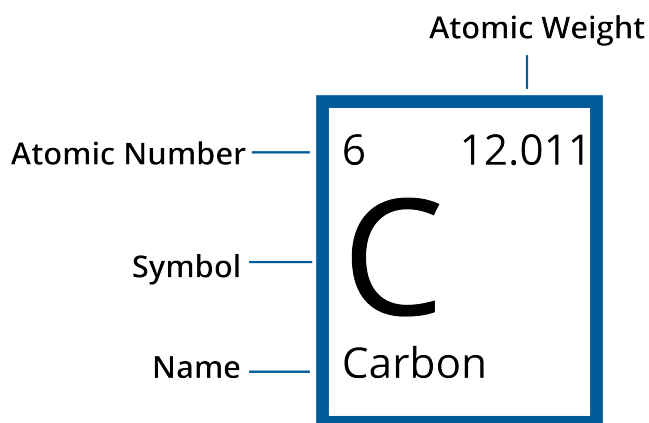
Helium

4.00

Periodic Table of Elements

There is a square for each element. In the middle, you see the atomic symbol and the name of the element. In the upper right corner is the atomic number – the number of protons in the atom.

In the upper left corner is the atomic mass in atomic mass units.



Look at the atomic mass of boron. About 80% of all boron atoms have six neutrons. The other 20% have only 5 neutrons. So most boron atoms have a mass of about 11 atomic mass units, but some have a mass of about 10 atomic mass units. The atomic mass of boron is equivalent to the average mass of a boron atom: 10.811.

Exercise 1 Mass of a Water Molecule

Working Space

Using the periodic table, what is the average mass of one water molecule in atomic mass units?

Answer on Page 7

1.1 Molar Mass

An atomic mass unit is a very, very, very small unit; we would much rather work in grams. It turns out that $6.02214076 \times 10^{23}$ atoms equal 1 mole (a standard measure for chemistry). Scientists use this number so much that they gave it a name: *the Avogadro constant* or *Avogadro's number*.

Watch Khan Academy's discussion of the mole at <https://www.khanacademy.org/science/ap-chemistry-beta/x2eef969c74e0d802:atomic-structure-and-properties/x2eef969c74e0d802:moles-and-molar-mass/v/the-mole-and-avogadro-s-number>

If you have 12 doughnuts, that's a dozen doughnuts. If you have $6.02214076 \times 10^{23}$ doughnuts, you have a *mole* of doughnuts. (Note: it isn't practical to measure doughnuts this way: A mole of doughnuts would be about the size of the earth. We use moles for small things like molecules.)

Let's say you want to know how much a mole of NaCl weighs. From the periodic table, you see that Na has an atomic mass of 22.98976 atomic mass units. And Cl has 35.453 atomic mass units. One atom of NaCl has a mass of $22.98976 + 35.453 = 58.44276$ atomic mass units. Then a mole of NaCl has a mass of 58.44276 grams. Handy, right?

Exercise 2 Burning Methane

Working Space

Natural gas is mostly methane (CH_4). When one molecule of methane burns, two oxygen molecules (O_2) are consumed. One molecule of H_2O and one molecule of CO_2 are produced.

If I need 200 grams of water, how many grams of methane do I need to burn?

(This is how the hero in "The Martian" made water for his garden.

Answer on Page 7

1.2 Heavy atoms aren't stable

When you look at the periodic table, there are a surprisingly large number of elements. You might be told to “Drink milk so that you can get the calcium you need.” However, no one has told you “You should eat kale so that you get enough copernicium in your diet.”

Copernicium, with 112 protons and 173 neutrons, has only been observed in a lab. It is highly radioactive and unstable (meaning it decays): a copernicium atom usually lives for less than a minute before decaying.

The largest stable element is lead, which has 82 protons and between 122 and 126 neutrons. Elements with lower atomic numbers than lead, have at least one stable isotope. Elements with higher atomic numbers than lead don't.

Bismuth, with an atomic number of 83, is *almost* stable. In fact, most bismuth atoms will live for billions of years before decaying.

This is a draft chapter from the Kontinua Project. Please see our website (<https://kontinua.org/>) for more details.

Answers to Exercises

Answer to Exercise 1 (on page 3)

The average hydrogen atom has a mass of 1.00794 atomic mass units.

The average oxygen atom has a mass of 15.9994.

$$2 \times 1.00794 + 15.9994 = 18.01528 \text{ atomic mass units.}$$

Answer to Exercise 2 (on page 4)

From the last exercise, you know that 1 mole of water weighs 18.01528 grams. So 200 grams of water is about 11.1 moles. So you need to burn 11.1 moles of methane.

What does one mole of methane weigh? Using the periodic table: $12.0107 + 4 \times 1.00794 = 16.04246$ grams.

$$16.0424 \times 11.10 = 178.1 \text{ grams of methane.}$$



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