Introduction to CHEM110

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Why Are You Here?

1. Basic fundamentals of chemistry
    a) Physical Science → chemistry, physics, mathematics
    b) Biological Science → zoology, biology, biochemistry, biotech, genetics
    c) Applied Science → medicine, nursing, dentistry, engineering, agriculture, home economics

2. Learn to THINK CRITICALLY → problem solving
    a) Relevant for everything
    b) What university is all about !!!

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What is CHEMISTRY ???

- The science that describes MATTER
  - the PROPERTIES and CHANGES it undergoes
  - the ENERGY that accompanies those changes

- Built on math and physics and underpins the life sciences e.g. biology and medicine

- Chemistry is the CENTRAL SCIENCE

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What do CHEMISTS actually do ?

WHAT → try to gain a fundamental **UNDERSTANDING** and **DESCRIPTION** of **MATTER**

HOW → by **ASKING** questions and then **INVESTIGATING** those questions

Fundamental Questions

- HOW and WHY do substances combine?
  - What is the energy involved?
- HOW is matter constructed?
  - How does this relate to the properties of matter, such as color ?
- WHAT factors influence stability
  - How can we force changes ?
  - What factors control the rate of change ?

What We Will Do In CHEM110

- Learn how chemists DESCRIBE and view the material world
  - MATTER
  - ENERGY

- Acquire SKILLS useful for understanding chemistry
  - Thinking critically
  - Solving problems

How Do We Learn Chemistry?

1. **FACTS and DEFINITIONS**

2. **PROBLEM SOLVING**

Learning Chemistry

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Learning Chemistry

Practice

Practice

Practice

Practice

Practice

Practice

PRACTICE

PRACTICE

Practice

Practice

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RESPONSILBILTIES

- **LECTURER → guide your learning**
- **STUDENT**
  - **Read & summarize text book, understand & learn the subject matter according to learning objectives provided**
  - **HOMEWORK → practice !!!!!!!!!**
  - **It's YOUR education → take responsibility for it**

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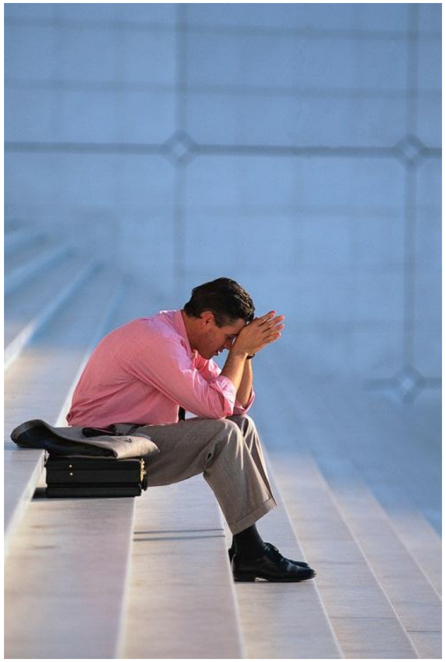
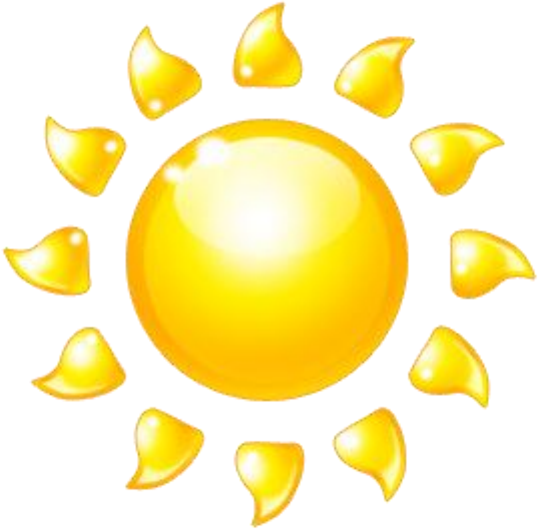
PERSPECTIVE

The sun will still come up …





CHEM110 – Chapter 1

THE ATOM

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What is CHEMISTRY?

- Study of MATTER → anything that takes up space and has mass
- Everything you can see, smell, touch, or taste
- Central to this → STRUCTURE of matter

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What is CHEMISTRY?

First … let's define some terms used to describe MATTER

What is CHEMISTRY?

Fundamental building block →

THE ATOM

1.1 ATOMS

- Chemically discrete species
- Central positively charged nucleus
  - protons (+1) and neutrons (neutral)
- Nucleus surrounded by negatively charged electrons
- Always electrically neutral
  - # electrons = # protons → ALWAYS!!!!!

1.1 MOLECULES

- Collection of atoms with a definite structure held together by covalent bonds
- Always electrically neutral

1.1 IONS

- Chemical species that have either a positive or negative electric charge

- Cation → ions with a positive charge e.g., Na^+, NH_4^+

- Anion → ions with a negative charge e.g., Cl^-, NO_3^-, SO_4^{2-}

1.1 IONS

- Removing or adding electrons from atoms or molecules produces ions

$$Na \rightarrow Na^{+} + e^{-}$$

Removing an e^{-}

$$Cl + e^{-} \rightarrow Cl^{-}$$

Adding an e^{-}

1.1 ELEMENTS

- Collections of a single type of atom only
- Currently 118 different elements
- Elements are arranged in the periodic table

1.1 PERIODIC TABLE of the ELEMENTS

metals | nonmetals | metalloids

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (97.91)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57–71 *	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209.0)	85 At (210.0)	86 Rn (222.0)
7	87 Fr (223)	88 Ra (226)	89–103 **	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 Cn (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)	117 Uus (294)	118 Uuo (294)

*lanthanoid series	57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.1	71 Lu 175.0
**actinoid series	89 Ac (227)	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

1.1 COMPOUNDS

- **Substances containing two or more elements in definite and unchanging proportion**
  - **Molecules → H_2O, CH_3CH_2OH** **Individual Units**
  - **Ionic Compounds → NaCl, MgO**
  - **Covalently bonded network of atoms → C (diamond, graphite, buckyballs)**

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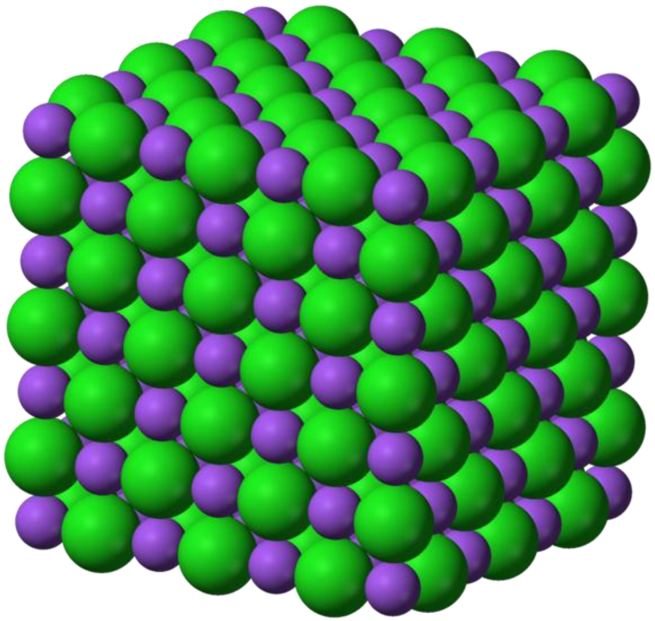
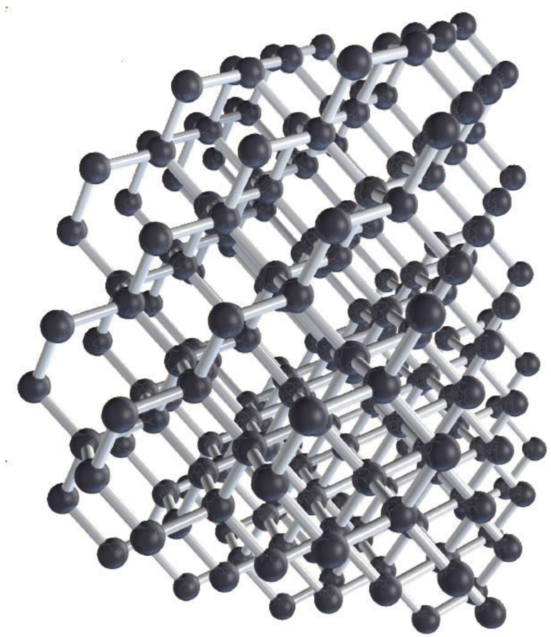
1.1 COMPOUNDS

- **There are no individual units in an ionic compound or covalent networks**



NaCl



Diamond (C)

1.1 CHEMICAL REACTIONS

Atoms

Molecules

Ions

Elements

Compounds

→ Making and/or breaking of bonds →

Atoms

Molecules

Ions

Elements

Compounds

Reactants → Reacts to → Products

1.2 THE ATOMIC THEORY

- The 'beginning' of modern atomic theory …
  - Law of Conservation of Mass → No detectable gain or loss of mass occurs in chemical reactions, i.e., mass is neither created nor destroyed in chemical reactions
  - Law of Definite Proportions → In a given chemical compound, the elements are always combined in the same proportions by mass

1.2 THE ATOMIC THEORY

Worked Example 1.1 - A sample of molybdenum disulfide contains 1.50 g of Mo for each 1.00 g of S. If a different sample contains 2.50 g of S, what mass of Mo does it contain?

Solution - The law of definite proportions states that the proportions of Mo and S by must be the same in both samples

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1.2 THE ATOMIC THEORY

Dalton's Atomic Theory

→ **built on conservation of mass and definite proportion laws**

1.2 THE ATOMIC THEORY

1. Matter consists of tiny particles called atoms.
2. Atoms are indestructible. In chemical reactions, the atoms rearrange but they do not themselves break apart.
3. In any sample of a pure element, all atoms are identical in mass and other properties.
4. The atoms of different elements differ in mass and other properties.
5. When atoms of different elements combine to form a given compound, the constituent atoms in the compound are always present in the same fixed ratio.

1.2 THE ATOMIC THEORY

- **Chemical equations describe chemical reactions**

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$$

Reactants

Reacts to

Products

This reaction is described as balanced

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1.2 THE ATOMIC THEORY

Law of Multiple Proportions → whenever two elements form more than one compound, the different masses of one element that combine with the same mass of the other element are in the ratio of small whole numbers.

1.2 THE ATOMIC THEORY

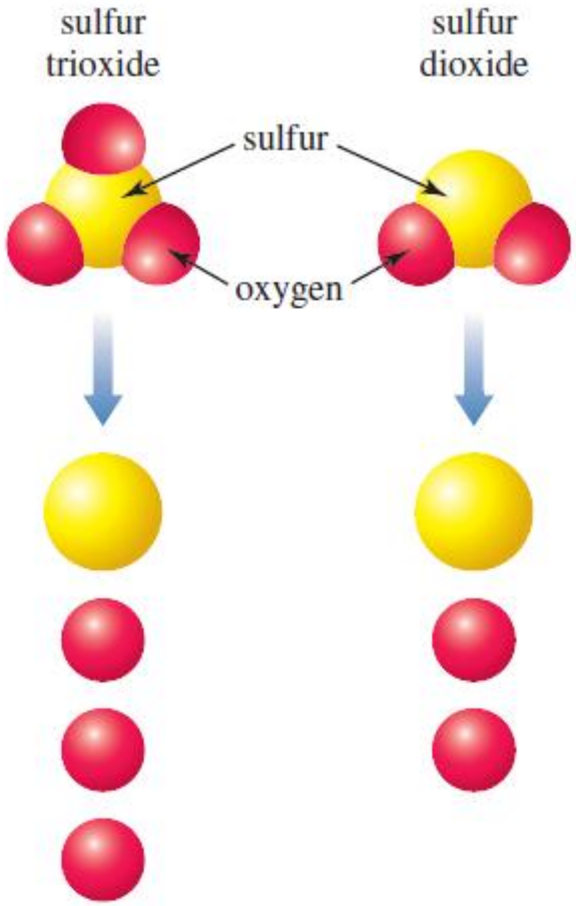


Figure 1.1

Law of Multiple Proportions

- Each molecule has 1 sulfur atom → so each has the same mass of sulfur

- Oxygen ratio is 3 to 2 both by number of atoms and mass

TABLE 1.1 Mass composition of sulfur dioxide and sulfur trioxide.

Compound	Mass of sulfur	Mass of oxygen
SO_2	1.00 g	1.00 g
SO_3	1.00 g	1.50 g

$$\frac{\text{mass of oxygen in } SO_3}{\text{mass of oxygen in } SO_2} = \frac{1.50\text{ g}}{1.00\text{ g}} = \frac{3}{2}$$

1.2 THE ATOMIC THEORY

Scanning tunnel microscopy and atomic force microscopy now allow scientists to view and manipulate individual atoms

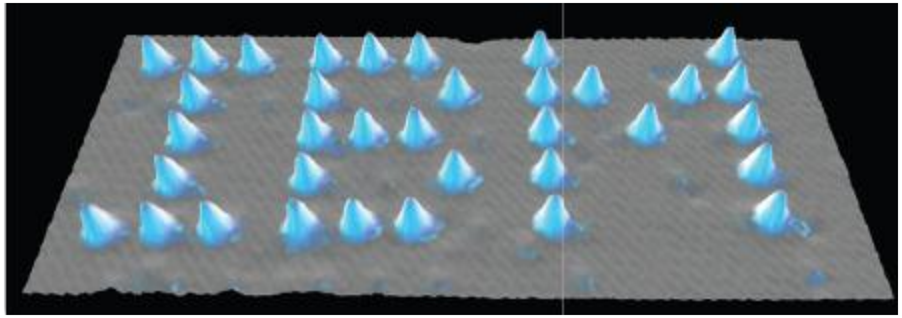


Figure 1.4
Individual Xe atoms

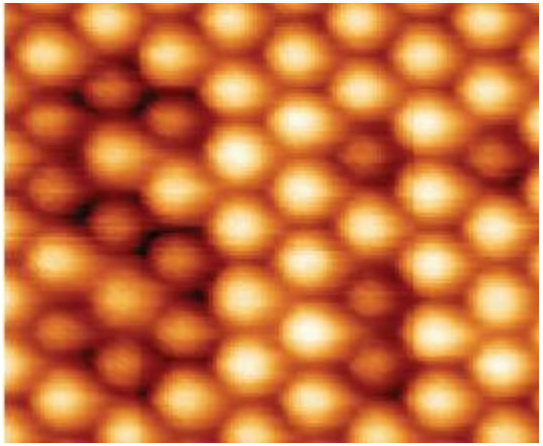
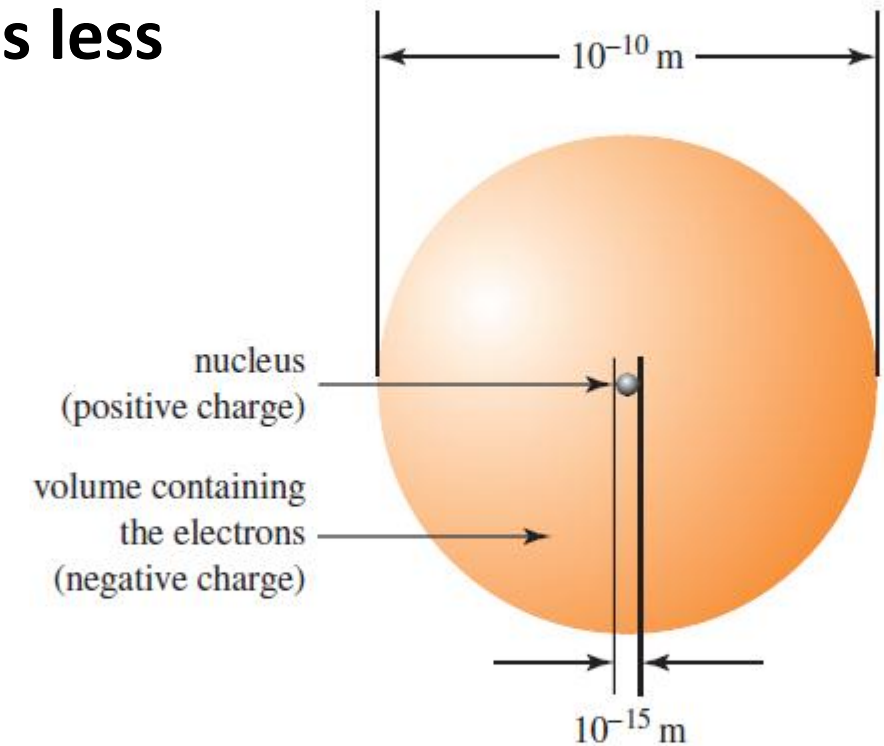


Figure 1.6
Si and Sn atoms

1.3 THE STRUCTURE OF THE ATOM

- **Atoms are comprised of a nucleus and surrounding electron(s)**
  - **The nucleus occupies less than 0.1% of the total atomic volume**
  - **The nucleus is comprised of protons and neutrons**

Figure 1.10



1.3 THE STRUCTURE OF THE ATOM

$$^{A}_{Z}X$$

- **X** is the **chemical symbol** for any element
- **Z** is the **atomic number** → the number of protons in the nucleus
- **A** is the **mass number** → the number of protons plus the number or neutrons in the nucleus

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1.3 THE STRUCTURE OF THE ATOM

In a neutral atom the atomic number Z is also equal to the number of electrons

$$\boxed{{}^{A}_{Z}X} \qquad {}^{2}_{1}H$$

X = H → hydrogen

Z = 1 → 1 proton (also indicates 1 electron)

A = 2 → protons + neutrons = 2)

It is common to write in shorthand version as ^{2}H

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The Composition of Atoms

Worked Example 1.2 page 9 - The following radioactive isotopes have medical applications. Determine the number of protons, neutrons and electrons in each isotope.

(a) $^{165}_{66}\mathrm{Dy}$

(b) $^{131}_{53}\mathrm{I}$

(c) $^{59}_{26}\mathrm{Fe}$

1.3 THE STRUCTURE OF THE ATOM

Isotopes → atoms of an element with the same number of protons but different numbers of neutrons

$^{A}_{Z}X$

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$

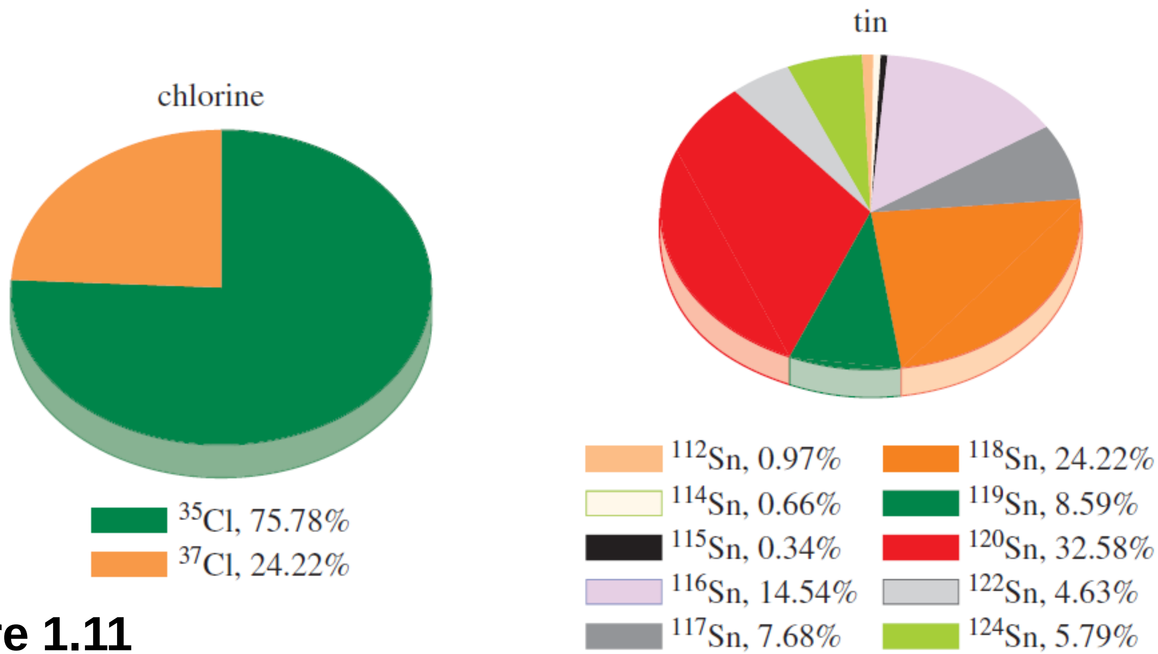

Figure 1.11

1.3 THE STRUCTURE OF THE ATOM

- **Atomic mass unit (u)** (1 u = 1.666 054 × 10^{-27} kg) is equal to 1/12 mass of one atom of ^{12}C
- **The masses of all atoms are measured relative to this**
- **Average atomic masses account for isotopic abundances**

Element name	Symbol	Atomic number	Atomic mass range (u)	Conventional atomic mass (u)
hydrogen	H	1	[1.007 84; 1.008 11]	1.008
lithium	Li	3	[6.938; 6.997]	6.94
boron	B	5	[10.806; 10.821]	10.81

Table 1.3

Calculating average atomic masses from isotopic abundances

Worked Example 1.3 page 11 – Naturally occurring titanium, Ti, is a mixture of five isotopes and has the following isotopic composition:

$$^{46}_{22}\mathrm{Ti}(8.25\%),\ ^{47}_{22}\mathrm{Ti}(7.44\%),\ ^{48}_{22}\mathrm{Ti}(73.72\%),\ ^{49}_{22}\mathrm{Ti}(5.41\%),\ ^{50}_{22}\mathrm{Ti}(5.18\%)$$

The atomic masses of the isotopes are as follows:

$$^{46}_{22}\mathrm{Ti}(45.9526316\ \mathrm{u}),\ ^{47}_{22}\mathrm{Ti}(46.9517631\ \mathrm{u}),\ ^{48}_{22}\mathrm{Ti}(47.9479463\ \mathrm{u}),$$
$$^{49}_{22}\mathrm{Ti}(48.9478700\ \mathrm{u}),\ ^{50}_{22}\mathrm{Ti}(49.9447912\ \mathrm{u})$$

Use this information to calculate the average atomic mass of titanium.

Calculating average atomic masses from isotopic abundances

$^{46}_{22}\text{Ti}(8.25\%)$, $^{47}_{22}\text{Ti}(7.44\%)$, $^{48}_{22}\text{Ti}(73.72\%)$, $^{49}_{22}\text{Ti}(5.41\%)$, $^{50}_{22}\text{Ti}(5.18\%)$

$^{46}_{22}\text{Ti}(45.9526316\text{ u})$, $^{47}_{22}\text{Ti}(46.9517631\text{ u})$, $^{48}_{22}\text{Ti}(47.9479463\text{ u})$,
$^{49}_{22}\text{Ti}(48.9478700\text{ u})$, $^{50}_{22}\text{Ti}(49.9447912\text{ u})$

1.4 THE PERIODIC TABLE OF ELEMENTS

- Elements may be ordered on the basis of increasing atomic number (Z)
- First published in 1869 by Mendeleev but ordered by increasing atomic mass
- The periodic table is organised into:
  - Horizontal rows called periods
  - Vertical columns called groups


Figure 1.14

1.4 THE PERIODIC TABLE OF ELEMENTS

1

Periods

2

3

4

5

6

7

1.4 THE PERIODIC TABLE OF ELEMENTS

1 18

Groups

2 13 14 15 16 17

3 4 5 6 7 8 9 10 11 12

1.4 THE PERIODIC TABLE OF ELEMENTS

metals

	1	2	3	4	5	6	7	8	9	10	11	12				
2	3 Li 6.941	4 Be 9.012														
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98			
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72			
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (97.91)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7		
6	55 Cs 132.9	56 Ba 137.3	57–71 *	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	
7	87 Fr (223)	88 Ra (226)	89–103 **	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 Cn (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)

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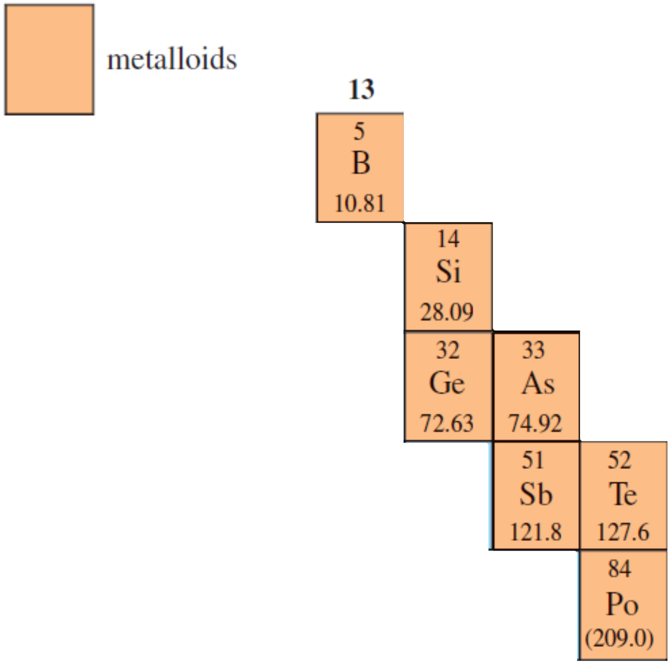
**actinoid series	89 Ac (227)	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

1.4 THE PERIODIC TABLE OF ELEMENTS



1.4 THE PERIODIC TABLE OF ELEMENTS

nonmetals

	1	14	15	16	17	18
1	1 H 1.008					2 He 4.003
		6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
			15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
				34 Se 78.96	35 Br 79.90	36 Kr 83.80
					53 I 126.9	54 Xe 131.3
					85 At (210.0)	86 Rn (222.0)

1.4 THE PERIODIC TABLE OF ELEMENTS

Period	1
1	1 H 1.008
2	3 Li 6.941
3	11 Na 22.99
4	19 K 39.10
5	37 Rb 85.47
6	55 Cs 132.9
7	87 Fr (223)

Group 1 – Alkali metals

1.4 THE PERIODIC TABLE OF ELEMENTS

Group 2 – Alkaline earth metals

2
4 Be 9.012
12 Mg 24.31
20 Ca 40.08
38 Sr 87.62
56 Ba 137.3
88 Ra (226)

1.4 THE PERIODIC TABLE OF ELEMENTS

Group 15 - Pnictogens

15
7 N 14.01
15 P 30.97
33 As 74.92
51 Sb 121.8
83 Bi 209.0
115 Uup (288)

1.4 THE PERIODIC TABLE OF ELEMENTS

Group 16 - Chalcogens

16
8 O 16.00
16 S 32.07
34 Se 78.96
52 Te 127.6
84 Po (209.0)
116 Uuh (292)

1.4 THE PERIODIC TABLE OF ELEMENTS

Group 17 - Halogens

17
9 F 19.00
17 Cl 35.45
35 Br 79.90
53 I 126.9
85 At (210.0)
117 Uus (294)

1.4 THE PERIODIC TABLE OF ELEMENTS

Transition Metals

39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (97.91)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4
	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6
	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)				112 Cn (285)

1.4 THE PERIODIC TABLE OF ELEMENTS

Lathanoids and Actinoids – rare earth elements

1.4 THE PERIODIC TABLE OF ELEMENTS

	1	2	
1	1 H 1.008		2 He 4.003
2	3 Li 6.941	4 Be 9.012	
3	11 Na 22.99	12 Mg 24.31	
4	19 K 39.10	20 Ca 40.08	
5	37 Rb 85.47	38 Sr 87.62	
6	55 Cs 132.9	56 Ba 137.3	
7	87 Fr (223)	88 Ra (226)	

S-block elements
Helium is placed next to hydrogen.

1.4 THE PERIODIC TABLE OF ELEMENTS

f-block elements

57	58	59	60	61	62	63	64	65	66	67	68	69	70
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
138.9	140.1	140.9	144.2	(145)	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1
89	90	91	92	93	94	95	96	97	98	99	100	101	102
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
(227)	232.0	231.0	238.0	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)

1.4 THE PERIODIC TABLE OF ELEMENTS

d-block elements
Ytterbium and Nobelium is placed under Yttrium

21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38
39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (97.91)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4
57–71 *	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6
89–103 **	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 Cn (285)

71 Lu 175.0
103 Lr (262)

1.4 THE PERIODIC TABLE OF ELEMENTS

p-block elements

5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209.0)	85 At (210.0)	86 Rn (222.0)
113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)	117 Uus (294)	118 Uuo (294)

1.5 ELECTRONS IN ATOMS

- Many of the chemical properties of an atom and its chemical reactivity are determined by the electrons
  - Electrons occupy regions of space called orbitals
  - Each orbital has a characteristic electron distribution and energy

1.5 ELECTRONS IN ATOMS

- An electronic transition occurs when an atom absorbs a specific amount of energy and an electron is promoted to a higher energy orbital to form an excited state

- Orbitals have definite energies → this is a fundamental principle of quantum mechanics called quantisation

1.5 ELECTRONS IN ATOMS

- **ELECTRONS**
  – **single negative charge**
  – **have an intrinsic property called spin**
  – **spin can only have two values**

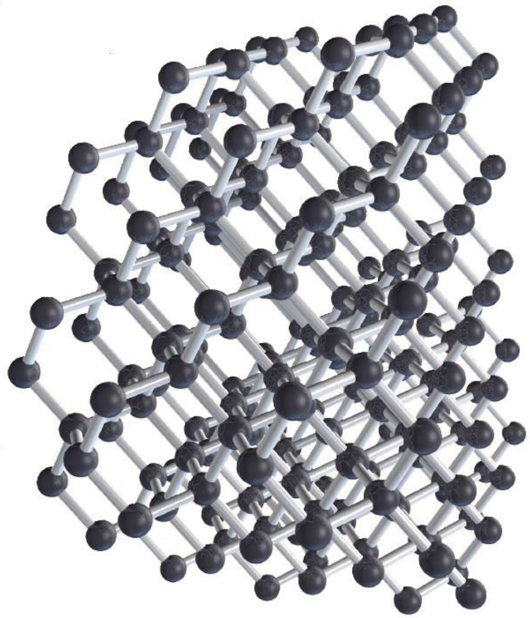
↑ (spin up)
↓ (spin down)

  – **each orbital within an atom can contain a maximum of 2 electrons**
    - **1 spin up and 1 spin down ↑↓**

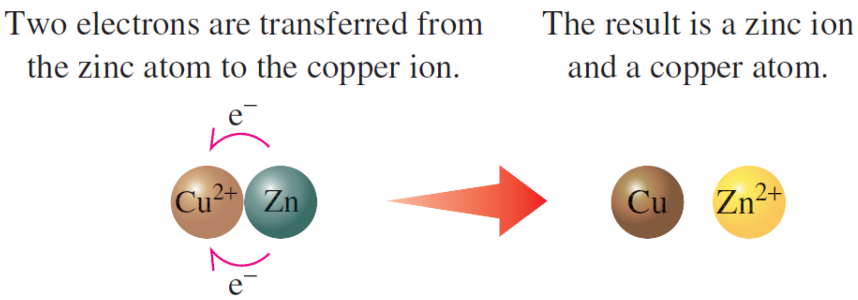
1.5 ELECTRONS IN ATOMS

- **Covalent chemical bonds usually consist of 1, 2 or 3 pairs of electrons shared between atoms**

Diamond



- **Redox reactions involve transfer of one or more electrons between chemical species**



CHAPTER SUMMARY

- **Atoms are the fundamental building block of all matter**
- **The existence of atoms was proposed on the basis of:**
  - **the law of conservation of mass**
  - **the law of definite proportions**
  - **the law of multiple proportions**
- **The atom is comprised of three subatomic particles; the electron, proton and neutron**

CHAPTER SUMMARY

- **Elements comprise only a single type of atom**
- **The periodic table arranges all known elements in order of increasing atomic number**
- **Electrons occupy regions of space called orbitals**
  - **energies of electrons in an atom are determined by the energies of the orbitals → so electrons in atoms have only certain well-defined energies**

Ch 1 – Learning Objectives

1. Differentiate between atoms, molecules, ions, elements and compounds
2. Discuss the atomic theory
3. Describe the structure of the atom
4. Recognize the periodic table of elements
5. Understand the concept of electrons in atoms

Ch 1 – Wrap up

- Summary – pg 16
- Key Concepts and Equations – pg 18
- Key Terms – pg 18
- Review Questions – pg 19
- Review Problems – pg 20
- Additional Problems – pg 21