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Matter & Energy:
The Structure of Matter & Chemical Bonds

EVPP 110 Lecture
GMU
Dr. Largen

2 Sections

- ✓Atoms & molecules
- ✓Properties of Water
- ✓Rearrangements of Atoms

3 Atoms and Molecules

4 **Atoms & Molecules -**
Biological function starts at chemical level

- ✓ **reductionist approach**
  - – scientific approach
    - » whole best understood by studying parts

5 **Atoms & Molecules -**
Biological function starts at the chemical level

- ✓to understand chemical structure and function
  - – start small
    - structures at each level are combined into each higher level
  - – *note the hierarchical aspect of this idea*

6 **Atoms & Molecules -**
Biological function starts at the chemical level

- ✓matter in all living things

– made up of chemicals
– structure and function
  • interrelated at every level

7 **Atoms & Molecules -**
Biological function starts at the chemical level

✓example
– certain **atoms** come together to form complex **molecule** chlorophyll
– many chlorophyll molecules are located in **organelles** called chloroplasts
– many chloroplasts are located in **cells** of photosynthetic **tissues** in structures (**organs**) such as **leaves** of **plants**

8 
Figure 2.1 The hierarchy of biological order from atom to organism (*Biology*, 6th Ed., Campbell & Reece)

9 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓life is composed of **matter**
✓matter is composed of chemical **elements**

10 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**Matter**
–
  • **mass** – amount of a substance
    –
    –
  • **weight** – force gravity exerts on substance
    –
    –

11 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**Matter**
– three states (phases) on earth
  • **gas**

- **liquid**
- **solid**

12 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Matter
– **gas**
•

– liquid
– solid

13 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Matter
– gas
– **liquid**
•

– solid

14 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Matter
– gas
– liquid
– **solid**
•

15 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓chemical **element**
– substance which cannot be broken down into any other substance
•

– each element consists of one type of atom

•

16 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**naturally occurring elements**
– 92 naturally occurring
•

✓**man-made elements**
– additional 12 - 17 man-made elements
•
•

17 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**distribution of elements** (non-living vs. living)
– in crust of earth (non-living)
• 9 elements constitute ~99% (by mass) of earth's crust
–

»

18 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓**distribution of elements** (non-living vs. living)
– in living organisms
• of 92 naturally occurring elements
– ~ 25 are essential to life
» 14 of which are found in organisms in any more than **trace** (>0.01%) amounts
» **trace elements**

»

19 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓ of 25 elements essential to life
– 11 are found in > than trace amounts
• 4 make up ~96% of human body
– **C**
– **H**
– **O**
– **N**

- 7 make up remaining ~4% of human body
  - **Ca, P, K, S, Na, Cl,Mg**

20 Table 2.1 Naturally Occurring Elements in the Human Body (*Biology*, 6th Ed., Campbell & Reece)

21 **Atoms & Molecules -**
Life requires about 25 chemical elements

✓Each element has a symbol
- –
  - •
  - examples
    - gold (Au) - from Latin word *aurum*
    - oxygen (O) - from English word *oxygen*

22 **Atoms & Molecules -**
Elements can combine to form compounds

✓Elements combine to form molecules and compounds
- **– element**
- **– molecule**
- **– compound**

23 **Atoms & Molecules -**
Elements can combine to form compounds

✓element
- –
- – can't be broken down
  - •
- – atoms with same atomic number
  - •

✓molecule
✓compound

24 **Atoms & Molecules -**
Elements can combine to form compounds

✓element
✓molecule
- – group of atoms of same type held together
  - •
- – example
  - molecule of oxygen (O_2)

✓compound

25 **Atoms & Molecules -**
Elements can combine to form compounds

✓element
✓molecule
✓**compound**
– molecule containing atoms of 2 or more elements combined in a fixed ratio
– example
• water
– H_2O
–

26 **Atoms & Molecules -**
Elements can combine to form compounds

✓**Compounds**
– more common than pure elements
•
– example., table salt (NaCl)
– in living organisms
• contain at least 3 or 4 different elements
– mainly C, H, O, N

27 Figure 2.2 The emergent properties of a compound (*Biology*, 6th Ed., Campbell & Reece)

28 **Atoms & Molecules -**
Elements can combine to form compounds

✓**Compounds**
– described by combination of symbols and numerals
• **chemical formula (**or **molecular formula)**
• **structural formula**

29 **Atoms & Molecules -**
Elements can combine to form compounds

✓**chemical formula** or **molecular formula**
– consists of chemical symbols and numbers
•
•
– example
• chemical formula for water is **H_2O**

•

30 **Atoms & Molecules -**
Elements can combine to form compounds

✓**structural formula**
– shows arrangement of atoms
•

– example
• structural formula for water is **H-O-H**

31 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons
✓Each element consists of one kind of **atom**
–
– **"atom**" from Greek word meaning "indivisible"
• **atom** is smallest unit of matter
–

32 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons
✓**atoms**
– composed of many types of subatomic particles
– **nucleus** contains
• **protons**
• **neutrons**
– **electrons** orbit nucleus
– others particles
• discussed primarily by physicists

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34 **Web/CD Activity 2B:**
Structure of the Atomic Nucleus

35 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons
✓**protons (p)**
– type of charge =
– where found =
– relative mass =

36

37 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons
✓**neutrons (n)**
– type of charge =
– where found =

– relative mass =

38

39 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**electrons (e)**

– type of charge =

– relative mass =

– where found =

40

41 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**Electron orbitals** can be

– various shapes

•

•

✓electrons orbit nucleus

•

•

42 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**Electron orbitals**

– arrangement of electrons in their orbits

• is key to chemical behavior of atom

– will return to this point shortly

43 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓All atoms of a particular element

– have same unique number of protons

• known as the element's

– **atomic number**

» number of protons in atom's nucleus

» top number in box for element in periodic table

44

45 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓atom's **atomic mass** (also called **atomic weight** or **mass number**)

– equal to sum of masses of atom's protons & neutrons

• measured in **daltons**

–

–

- bottom number in box for element in periodic table

46

47 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓ **isotopes**

– atoms of same element that vary in neutron number and atomic mass

•

– isotopes of carbon

• carbon ^{12}C

–

• carbon ^{13}C

–

• carbon ^{14}C

–

48 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**Isotopes** can be

– **stable**

• nuclei remain permanently intact

–

– **unstable** (or **radioactive**)

• nuclei decays spontaneously, giving off particles and energy

–

49 **Atoms & Molecules -**
Atoms consist of protons, neutrons and electrons

✓**Isotopes** can be

– **unstable** (or **radioactive**)

• nucleus tends to break up into elements with lower atomic numbers

– emits significant amount of energy, called **radioactive decay**

» **radioactive isotopes**

»

50 **Atoms & Molecules -**
Radioactive isotopes can help us or harm us

✓**Radioactive isotopes** can be

– harmful to life

•

•

•

•

51 **Atoms & Molecules -**
Radioactive isotopes can help us or harm us

✓**Radioactive isotopes** can have

– beneficial uses

•

•

•

•

52 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓**Electrons**

– orbit nucleus of atom

– arrangement in orbits is key to chemical behavior of atom

– vary in amount of energy they possess

• farther nucleus, greater its energy

53 Figure 2.9 Energy levels of an atom's electrons (*Biology*, 6th Ed., Campbell & Reece)

54 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓electrons are far from nucleus

– analogy:

– result

•

•

•

55 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓electrons in atom occur only at certain energy levels

– called **electron shells** (or **electron energy levels**)

✓atoms may have 1, 2 or more electron shells

–

–

–

56 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓first four **electron energy shells**

– covers most biologically significant elements

– first, innermost energy shell

• can accommodate only 2 electrons

•

– second, third, fourth energy shells

• can each accommodate 8 electrons

•

57

58 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓atom has # of electron shells needed accommodate its number of electrons

- atom with 6 electrons (C) has 2 shells
  - 2 electrons in innermost shell
  - 4 electrons in outermost shell
- atom with 11 electrons (Na) has 3
  - 2 electrons in innermost shell
  - 8 electrons in second shell
  - 1 electron in outermost shell

59 Figure 2.11 Electron orbitals ((*Biology*, 6th Ed., Campbell & Reece)

60 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓Energy

– required to keep electrons in their orbits

- electrons have potential energy of position
  - more potential energy in outermost shells than in innermost shells

»

»

61 Figure 2.9 Energy levels of an atom's electrons (*Biology*, 6th Ed., Campbell & Reece)

62 Web/CD Activity 2C:
Electron Arrangement

63 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓number of electrons in outermost shell

– determines chemical properties of element

- partially full outer shells = reactive
  –
- full outer shells = unreactive (inert)

64 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓example

– hydrogen (H) is highly reactive

- one shell, only one electrons
  –

–

65

66 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓example

– helium (He) is highly unreactive (inert)

• one shell, two electrons

–

–

67

68 **Atoms & Molecules -**
Electron arrangement determines the chemical properties of an atom

✓How does a chemical reaction enable an atom to fill its outer electron shell?

– 2 atoms w/incomplete outer shells react

• each atom gives up or acquires electrons

–

– results in atoms being held together by **chemical bonds**

69 Figure 2.10 Electron configurations of the first 18 elements (*Biology*, 6th Ed., Campbell & Reece)

70 Web/CD Activity 2D:
Build an Atom

71 **Atoms & Molecules -**
Chemical bonds

✓strong chemical bonds

– **ionic bonds**

– **covalent bonds**

• **nonpolar covalent bonds**

• **polar covalent bonds**

✓weak chemical bonds

– **hydrogen bonds**

72 **Atoms & Molecules -**
Chemical bonds

✓strong chemical bonds

– **ionic bonds**

– covalent bonds

• nonpolar covalent bonds

- polar covalent bonds

✓weak chemical bonds

– hydrogen bonds

73 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓electron transfer between 2 atoms moves 1 unit of negative charge from one atom to other

– original atom now has +1

•

– recipient atom now has charge of -1

•

•

74 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**ions**

– atoms in which number of electrons does not equal number of protons

• carry a net electrical charge (+ or -)

– types of ions

• cations

• anions

75 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**cation**

– atom with net positive charge (+)

•

–

– example:

• sodium (Na) atom losses an electron, becomes sodium ion, or cation (Na^+), with charge of +1

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77 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**Anion**

– atom with net negative charge (-)

•

–

– example

• chlorine (Cl) atom, gains one electron, becomes chlorine ion, or anion (Cl^-), with charge of -1

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79 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓two ions with opposite charge attract each other

– attraction called an **ionic bond**

• resulting compound is electrically neutral

80 **Atoms & Molecules -**
Ionic bonds are attractions between ions of opposite charge

✓**ionic bond**

– results from transfer of electron from one atom to another atom

• resulting in two ions

– cation

– anion

– oppositely charged ions are attracted to each

•

– resulting compound is electrically neutral

81 Figure 2.14 Electron transfer and ionic bonding (*Biology*, 6th Ed., Campbell & Reece)

82 Figure 2.15 A sodium chloride crystal (*Biology*, 6th Ed., Campbell & Reece)

83 Web/CD Activity 2G:
Ionic Bonds

84 **Atoms & Molecules -**
Chemical bonds

✓strong chemical bonds

– ionic bonds

– **covalent bonds**

• nonpolar covalent bonds

• polar covalent bonds

✓weak chemical bonds

– hydrogen bonds

85 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**covalent bond**

– occurs when two atoms share one or more pairs of outer shell electrons

• results in both atoms having a full outer electron shell

–

–

86 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓why is a covalent bond so stable?

–

– resulting molecule (compound)
  • has no net electrical charge

  • outer shells are full
  • no free electrons to form bonds

87 
Figure 2.12 Covalent bonding in four molecules (*Biology*, 6th Ed., Campbell & Reece)

88 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓More than one covalent bond can form between two atoms
– single covalent bond
– double covalent bond
– triple covalent bond

89 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**single covalent bond**
– one pair of electrons shared by two atoms
– represented by
  •
  • example, H - H
– least strong of covalent bonds

90

91 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**double covalent bond**
– two pairs of electrons shared by two atoms
  • represented by
    –
    – example, O=O
– stronger than single covalent bond
  •

92

93 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

✓**triple covalent bond**
– three pairs of electrons shared by two atoms
  • represented by
  •
  • example, N ≡ N
– strongest covalent bonds
  •

94 Web/CD Activity 2E:

Covalent Bonds

95 **Atoms & Molecules -**
Covalent bonds, the sharing of electrons, joins atoms into molecules

- ✓covalent bond energy
  - – forming bond requires input of energy
    - energy is stored in bond
  - – breaking bond results in release of energy
    - released energy becomes available to do work

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Atoms & Molecules -
Covalent bonds, polar versus non-polar

- ✓Atoms in a covalently bonded molecule
  - – in tug-of-war for shared electrons
- ✓**electronegativity**
  - – measure of attraction (affinity) for shared electrons in covalent bond
    - stronger electronegativity = stronger pull on shared electron

97 **Atoms & Molecules -**
Chemical bonds

- ✓strong chemical bonds
  - – ionic bonds
  - – covalent bonds
    - **nonpolar covalent bonds**
    - polar covalent bonds
- ✓weak chemical bonds
  - – hydrogen bonds

98 **Atoms & Molecules -**
Covalent bonds, polar versus non-polar

- ✓Because of concept of electronegativity**,**
  - – **covalent bonds** can be divided into two categories
    - **nonpolar covalent bonds**
    - **polar covalent bonds**

99 **Atoms & Molecules -**
Covalent bonds, polar versus non-polar

- ✓**nonpolar covalent bond**
  - – covalent bond between atoms with similar electronegativity
  - – result, electrons are shared equally between two atoms
  - – examples
    - O_2
    - H_2
    - CH_4 (methane)

100 Figure 2.12 Covalent bonding in four molecules (*Biology*, 6th Ed., Campbell & Reece)

101 **Atoms & Molecules - Chemical bonds**

✓strong chemical bonds
- ionic bonds
- covalent bonds
  - nonpolar covalent bonds
  - **polar covalent bonds**

✓weak chemical bonds
- hydrogen bonds

102 **Atoms & Molecules - Covalent bonds, polar versus non-polar**

✓**polar covalent bond**
- a covalent bond between atoms that differ in electronegativity
  - atom with greater electonegativity pulls shared electrons closer
- results in bond has two dissimilar ends
  - "poles", with partial + and partial - charges
- resulting molecules are said to be "polar"
- example = H_2O

103 Figure 2.13 Polar covalent bonds in a water molecule (Biology, *6th Ed., Campbell & Reece)*

104 Web/CD Activity 2F: Nonpolar and Polar Molecules

105 **Atoms & Molecules - Chemical bonds**

✓strong chemical bonds
- ionic bonds
- covalent bonds
  - nonpolar covalent bonds
  - polar covalent bonds

✓weak chemical bonds
- **hydrogen bonds**

106 **Atoms & Molecules - Hydrogen bonds**

✓**hydrogen bonds**
- result when polar molecules interact with one another
- partial – charge of one molecule is attracted to the partial + charge of another molecule
- in the case of water:
  - oxygen is very electronegative
  -

107 Figure 2.16 A hydrogen bond (*Biology*, 6th Ed., Campbell & Reece)

108 Web/CD Activity 2H: Hydrogen Bonds

109 The End