Chemistry 500: Chemistry in Modern Living

Topic 2: Protecting the Ozone Layer

Atoms and Light

Chemistry in Context, 2nd Edition: Chapter 2, Pages 35-72

Chemistry in Context, 3rd Edition: Chapter 2, Pages 45-92

Outline Notes by Dr. Allen D. Hunter, YSU Department of Chemistry, ©2000.

Outline

2A What is Ozone?

- Ozone Formation
  - Produced from a variety of processes:
    - Photochemical Smog (Topic 1)
    - High Voltage Electrical Discharges

Molecular Oxygen + Energy → Ozone

$$3\ O_2 + \text{Energy} \rightarrow 2\ O_3$$

- Can be smelled at 10 ppb
- Arc Welding
- Lightning Storms
- Laser Printers
- Tesla Coils

- Allotropes
- Different forms of the same element
  - They have different chemical structures
  - Hence different chemical properties

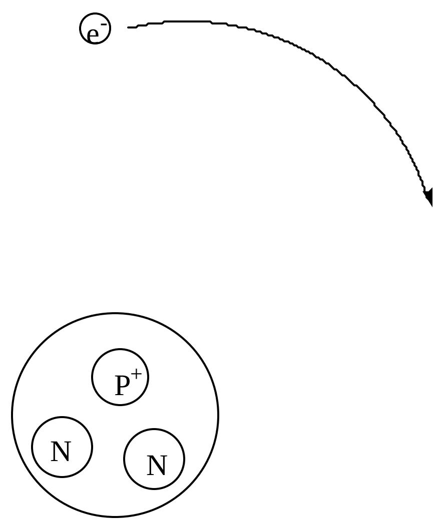
- Examples include:
  - Graphite (found in pencil lead) and Diamond (on rings) are different chemical forms of the element Carbon
  - Molecular Oxygen and Ozone are different chemical forms of the element Oxygen

- The Allotropes of the Element Oxygen
  - Molecular Oxygen, O_2
    - A Diatomic Molecule
    - Liquefies at -183 °C
    - A light blue liquid
    - Odorless
  - Ozone, O_3
    - A Triatomic Molecule
    - Liquefies at -112 °C
    - A dark blue liquid
    - Used in water purification and pulp and paper bleaching
    - Characteristic Odor
  -

2B What is the Structure of a Atom?

- Graphics from Text: Table 2.1, the Properties of Sub-Atomic Particles

- Overview of Atoms and Nuclei
  - Diagram Not to Scale!
    - Nucleus actually tremendously smaller than the electron cloud
    - The Electron Cloud includes both Core Electrons and Valence Electrons



- Electrons, e^-
  - Surround the Nucleus
  - Mass of 1/1838 AMU
  - Charge of -1
- Protons, P^+
  - In the Nucleus
  - Mass of 1 AMU
  - Charge of +1
- Neutron, n
  - In the Nucleus
  - Mass of 1 AMU
  - Charge of 0

- Neutron/Proton Ratio in Stable Nuclei
  - Due to balance of Strong Nuclear Force and Electrostatic Force

- Evidence for this structure
  - High Energy Diffraction / Collision Experiments
- Rubber Baggie model of nucleus
- Isotopes
  - The same element (i.e., the same number of protons in the nucleus)
  - Different Mass due to different number of Neutrons in the Nucleus
  - Chemically Isotopes react extremely similarly
  - Examples:
    - ^{1}H(Hydrogen), ^{2}H (D, Deuterium), and ^{3}H (T, Tritium)
    - ^{12}C (common, 99%), ^{13}C (rare, 1%, NMR), and ^{14}C (very rare, produced in upper atmosphere, radioactive)
    - ^{238}U (non-radioactive) and ^{235}U (radioactive)

- The Periodic Table
  - Use the Periodic Table to Evaluate the Number of e^-, P^+, and n in each isotope
  - Atomic Number ⇒ The number of Electrons and Protons in the neutral atom
  - Mass Number ⇒ The total number of Protons and Neutrons

^{4}He ⇒ # e^- =

P^+ =

n =

^{40}Ar ⇒ # e^- =

P^+ =

n =

- Ask Students: For each of the following isotopes, give the total number of protons, neutrons, and electrons and then the number of valence electrons and core electrons.
  - Group Activity

$^{7}Be \Rightarrow$ # e^- =

P^+ =

n =

$^{13}C \Rightarrow$ # e^- =

P^+ =

n =

$^{19}F \Rightarrow$ # e^- =

P^+ =

n =

$^{29}Si \Rightarrow$ # e^- =

P^+ =

n =

$^{183}W \Rightarrow$ # e^- =

P^+ =

n =

2C How Do We Know Molecular Structures?

- How do we know molecular structures?

  - Analytical Data

  - Spectroscopic Methods
    - Sporting Methods
    - Specific absorption of light
    - NMR = Nuclear Magnetic Resonance (cf. MRI, Magnetic Resonance Imaging)
    - Infra-Red (IR)
    - Ultra Violet-Visible (UV-Vis)

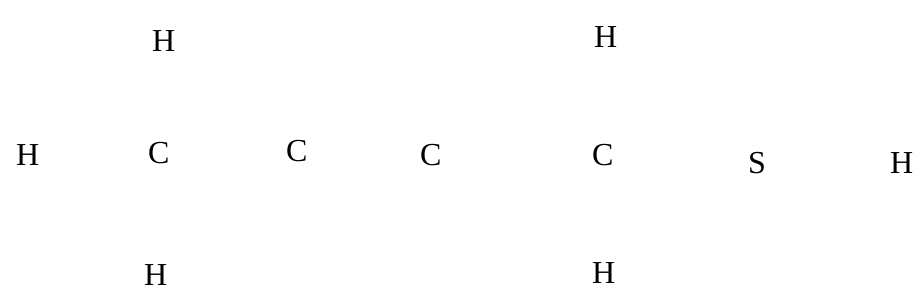
  - From the mid 1850s have know many molecular shapes but were not able to explain them other than to say the atoms were connected

- X-Ray Crystallography/Diffraction
  - Non-Sporting Method
  - Single Crystals
  - Hardware
  - Data Collection
  - Data Analysis

2D How Do We Explain Molecular Structures?

- Theories change over time to better fit the experimental data
- A Theory should explain all current data and predict future results
- Lewis Dot Structures
  - Lewis developed this theory to explain know molecular structures, reactivity data, and emerging ideas like electricity and radioactivity
    - Bonds were due to shared pairs of electrons
    - Lone Pairs of Valence Electrons remain on many atoms
    - Only the Valence Electrons Contribute to bonding
      - This accounts for the fact that elements underneath one another on the periodic table react similarly

- Rigorous Method of Determining Lewis Dot Structures
  - Count the total number of valence electrons for the molecules
  - Distribute them around the atoms such that each atom gets as close to a complete Octet as possible
    - An Octet is 8 for most elements but 2 for Hydrogen and Helium
    - Some elements will allow / settle for greater or lesser than 8 electrons but we won't see these in Chem. 500



- Quick and Dirty Method for getting Lewis Structures
  - An oversimplification that can break down but works well for most Organic Compounds
    - Bond Lengths
    - Bond Angles

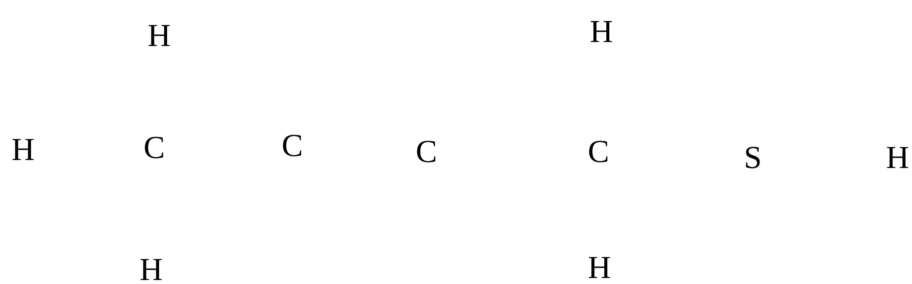
H ⇒ one bond and no lone pairs

F, Cl, Br, and I ⇒ one bond and three lone pairs

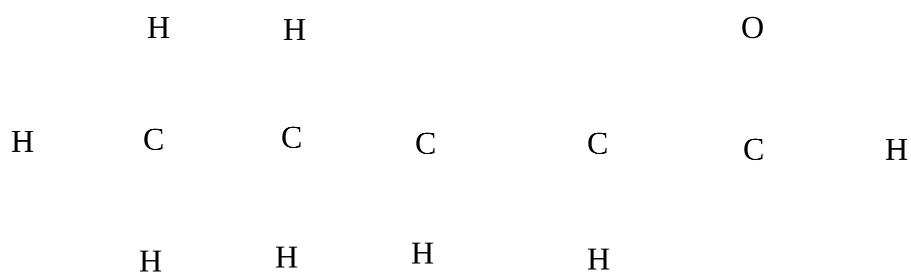
O, S, Se, and Te ⇒ two bonds and two lone pairs

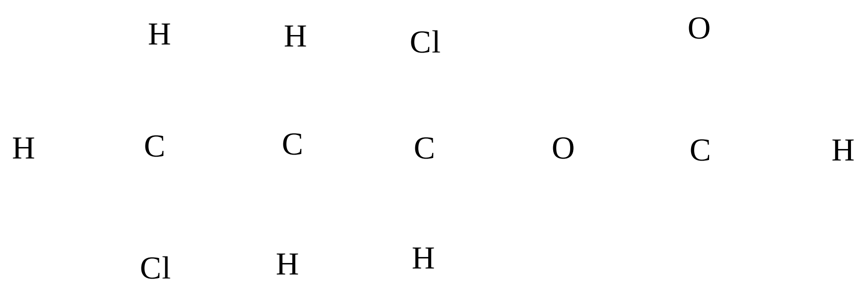
N, P, As, and Sb ⇒ three bonds and one lone pair

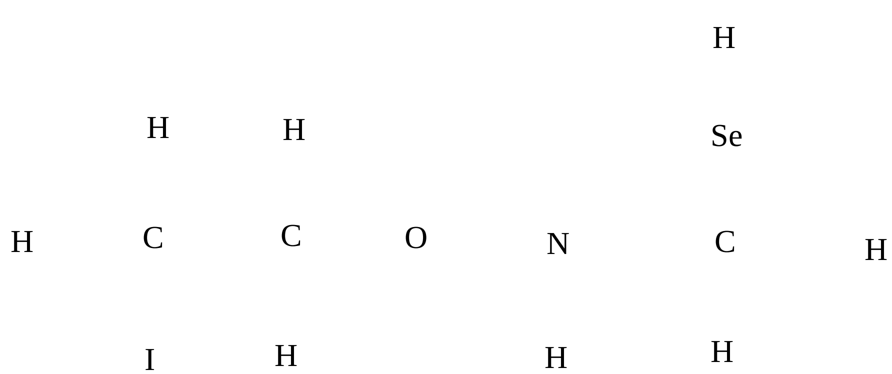
C, Si, Sn, and Ge ⇒ four bonds and no lone pairs



- Ask Students: For each of the following molecules, draw the correct Lewis Dot Structures including all Bonds and Lone Pairs
  - Group Activity







2E Waves of Light

- Graphics from Text: Figure 2.1, Wave Motion
  - The relationship between Frequency, Wavelength, and Amplitude for Electromagnetic Waves

- Electromagnetic Spectrum
  - Wavelength of Electromagnetic Waves
    - Long wavelengths correspond to low energy waves
    - Is inversely related to the Frequency of Electromagnetic Waves
      - Wavelength = Speed of Light / Frequency
      - $\lambda = C / \nu$
      - C = Speed of Light = 3×10^{8} m/sec

- Frequency of Electromagnetic Waves
  - High frequency corresponds to high energy waves
  - Is inversely related to the Wavelength of Electromagnetic Waves
    - Frequency = Speed of Light / Wavelength
    - $\nu = C / \lambda$

- Amplitude of Electromagnetic Waves
  - Is related to the intensity of the wave

- Graphics from Text: Figure 2.2, the Electromagnetic Spectrum
  - The relationship between frequency and wavelength for various types of electromagnetic radiation

- Graphics from Text: Figure 2.3, Solar Radiation Profile
  - The distribution of electromagnetic radiation of various energies produced by the sun as they appear from just above the earth's atmosphere
    - Note: the Overall Profile (Black Body Radiation)
    - The Spikes and Valleys (Specific Absorptions by Materials between the eye and the sun.

- Ask Students: As the temperature of the object changes, how will the shape of Figure 2.3 change?
  - Group Activity

2F Wave/Particle Duality

- Light is Wave Like
  - Evidence includes Diffraction
    - I.e., light bends
- Light is Particle Like
  - Evidence includes Photoelectric Effect
    - I.e., there is a threshold energy for light to cause its effects
- Wave / Particle Duality
  - Light has Both Wave and Particle Like Properties
    - Plank's Relationship $E = h \nu$
    - h is Plank's Constant (6.63×10^{-34} joule seconds)
    - Higher Frequency ⇒ Higher Energy
    - Lower Frequency ⇒ Lower Energy
    - Wave Packet Model

2G The Ozone Screen

- Graphics from Text: Figure 2.4 (3rd Edition only), Atmospheric Sunscreen
  - The atmosphere (and especially the Stratospheric Ozone Layer) acts as sunscreen to select out which wavelengths of light reach the earth's surface

- Graphics from Text: Figure 2.4 in 2nd Edition and 2.5 in 3rd Edition, Atmosphere's effect on solar radiation reaching the earth's surface
  - The atmosphere "screens" us from high energy UV light reaching the surface

- Graphics from Text: Figure 2.5 in 2nd Edition and 2.6 in 3rd Edition, Ozone's Absorption of Ultra-Violet Radiation
  - Ozone absorbs high energy UV light

- Molecular reasons for these effects
  - Molecular Oxygen, O_2, absorbs the highest energy UV light
    - UV light with λ less than about 242 nm

$$O_2 + \text{photon} \rightarrow 2\,O$$

  - Ozone, O_3, absorbs the medium energy UV light
    - UV light with λ less than about 320 nm (i.e., lower energy)
    - Ozone has a typical lifetime of about one or two hundred seconds
    - Ozone has a weaker O-O bond than molecular oxygen and this bond is therefore broken by lower energy photons

$$O_3 + \text{photon} \rightarrow O_2 + O$$

- Ozone Cycle
  - Ozone generation in the atmosphere

$$O + O_2 \rightarrow 0_3 \text{ (formation of ozone)}$$

  - Graphics from Text: Figure 2.7 in 2nd Edition and 2.11 in 3rd Edition, Ozone concentration profile of the atmosphere
    - Ozone concentrations are highest in the part of the stratosphere referred to as the Ozone Layer

  - Graphics from Text: Figure 2.6 in 2nd Edition and 2.10 in 3rd Edition, The Chapman Cycle of Ozone in the Atmosphere

- Ozone Destruction
  - Free Radicals!!!
    - Radicals are molecules or atoms with one or more unpaired electrons
    - This makes them extremely reactive and they can catalyze reaction such as Ozone destruction

$$H_2O + \text{energy} \rightarrow H^{\cdot} + {}^{\cdot}OH$$

$$H^{\cdot} + O_3 \rightarrow {}^{\cdot}OH + O_2$$

$${}^{\cdot}OH + O \rightarrow {}^{\cdot}H + O_2$$

$$H^{\cdot} + O_3 + {}^{\cdot}OH + O \rightarrow {}^{\cdot}OH + O_2 + {}^{\cdot}H + O_2$$

Net Reaction: $O + O_3 \rightarrow 2\,O_2$

- Ozone Loss
  - Arctic and Antarctic Sensitivity
    - Caused by extreme cold ⇒ tiny crystals whose surfaces are involved in Ozone destruction
    - Note: Noise levels in data
  - Graphics from Text: Figure 2.8 in 2^{nd} Edition and 2.7/2.12 in 3^{rd} Edition, Average Ozone loss on the earth
    - A few percent in continental US
  - Graphics from Text: Figure 2.9 in 2^{nd} Edition and 2.13 in 3^{rd} Edition, Ozone loss in Antarctica
    - About 50% in the high Antarctic

2H CFCs and Ozone

- Halocarbons
  - Compounds containing only C, Cl, F, Br, and H
  - Are typically <u>expensive</u> but <u>safe</u>
    - non-toxic, non-flammable, non-reactive, and quite volatile
  - Used as refrigerants, blowing agents, propellants, cleaning agents for computer parts, dry cleaning fluids, decaffination

- Classes of Halocarbons
  - CFCs are Chlorofluorocarbons
    - These are chemicals that contain only C, Cl, and F
    - Examples include: $CFCl_3$ (Freon 11) and CF_2Cl_2 (Freon 12)
  - Halons contain C, <u>Br</u>, and F and/or Cl
    - Examples include: CH_3Br, CF_2Br_2 and $CClBr_3$
    - Used for fire extinguishers
  - Chlorocarbons contain C, Cl, and H
    - Examples include CCl_3-CH_3 and CH_2Cl_2

- Halocarbons and Ozone Destruction
  - They are generally safe at ground level, why are they dangerous in the Stratosphere?
    - They are so stable that unlike most chemicals they escape destruction in the decade or so it takes them to make it to the Stratosphere
    - This means that they can transfer Chlorine and Bromine atoms here much better than other chemicals
    - In the Stratosphere, these Cl and Br containing compounds produce $Cl^{\cdot}$ and $Br^{\cdot}$ radicals which catalyze Ozone destruction
      - Bromine radicals are much less concentrated but are much more destructive
      - The man made examples of halocarbons are typically more stable than the natural ones and therefore typically make it to the Stratosphere better

- Reactions that destroy Ozone

$$CF_2Cl_2 + \text{energy} \rightarrow CF_2Cl^{\cdot} + {}^{\cdot}Cl$$

$$Cl^{\cdot} + O_3 \rightarrow {}^{\cdot}OCl + O_2$$

$${}^{\cdot}OCl + O \rightarrow Cl^{\cdot} + O_2$$

$$Cl^{\cdot} + O_3 + {}^{\cdot}OCl + O \rightarrow {}^{\cdot}OCl + O_2 + {}^{\cdot}Cl + O_2$$

Net Reaction: $$O + O_3 \rightarrow 2\,O_2$$

- Note: this reaction is very similar to that for Ozone destruction by hydrogen radicals, it is just much faster and thus more efficient
- The analogous reaction with bromine radicals is even faster and more efficient

- Graphics from Text: Figure 2.11 in 2nd Edition and 2.15 in 3rd Edition, Chlorine - Ozone Correlations

- Solutions?
  - Many now in place or being put into effect
    - "Montreal Treaty"
    - Cost Concerns
    - Safety Concerns
    - Technology Concerns
    - Hydrochlorofluorocarbons
    - Supercritical CO_2
    - Greenhouse gasses

Index of Vocabulary and Major Topics