

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?	3
2B	WHAT IS THE STRUCTURE OF A ATOM?	6
2C	HOW DO WE KNOW MOLECULAR STRUCTURES?	11
2D	HOW DO WE EXPLAIN MOLECULAR STRUCTURES?	13
2E	WAVES OF LIGHT	17
2F	WAVE/PARTICLE DUALITY.....	20
2G	THE OZONE SCREEN.....	21
2H	CFCS AND OZONE.....	26

2A What is Ozone?

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

Molecular Oxygen + Energy → Ozone



- 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

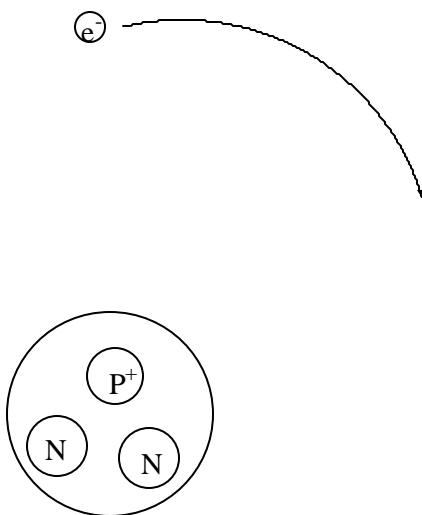
➤ Molecular Oxygen and Ozone are different chemical
forms of the element Oxygen

- The Allotropes of the Element Oxygen
 - Molecular Oxygen, O₂
 - A Diatomic Molecule
 - Liquefies at -183 °C
 - A light blue liquid
 - Odorless
 - Ozone, O₃
 - 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

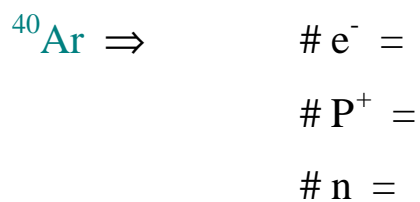
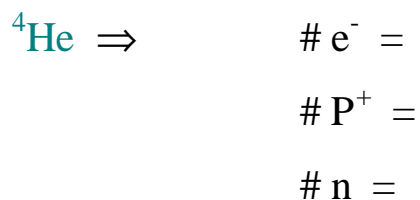
- Isotopes
 - The same **element** (i.e., the same number of protons in the nucleus)
 - Different **Mass** due to different number of Neutrons in the Nucleus
 - Chemically Isotopes react extremely similarly
 - Examples:
 - ^1H (Hydrogen), ^2H (D, Deuterium), and ^3H (T, Tritium)
 - ^{12}C (common, 99%), ^{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**

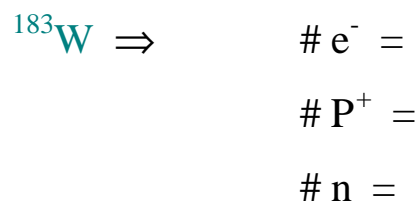
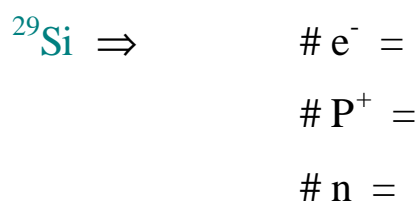
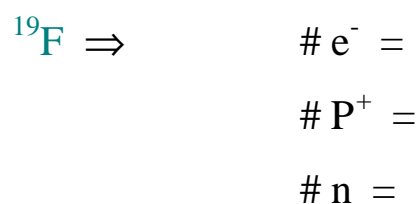
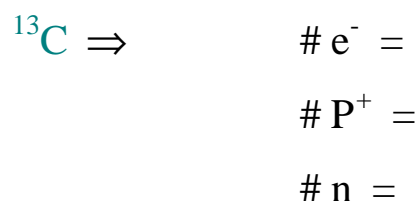
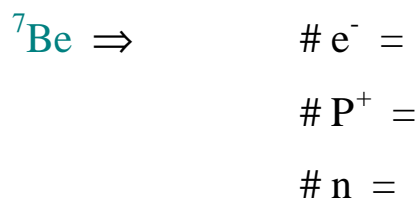
➤ **Atomic Number** \Rightarrow The number of **Electrons** and **Protons** in the neutral atom

➤ **Mass Number** \Rightarrow The total number of **Protons** and **Neutrons**



➤ 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



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 we have known 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?

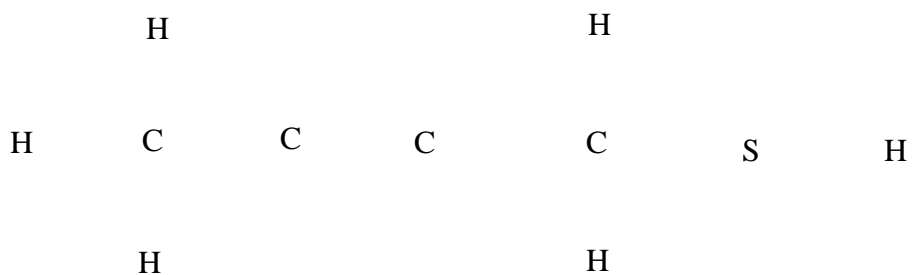
- Theories change over time to better fit the **experimental data**

- A **Theory** should explain all current data and predict future results

- **Lewis Dot Structures**
 - **Lewis** developed this theory to explain known 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

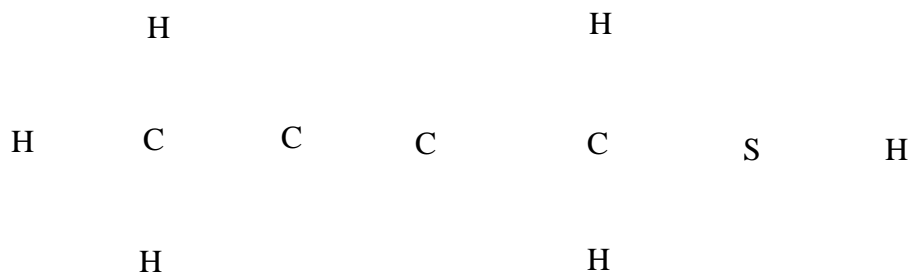
H \Rightarrow one bond and no lone pairs

F, Cl, Br, and I \Rightarrow one bond and three lone pairs

O, S, Se, and Te \Rightarrow two bonds and two lone pairs

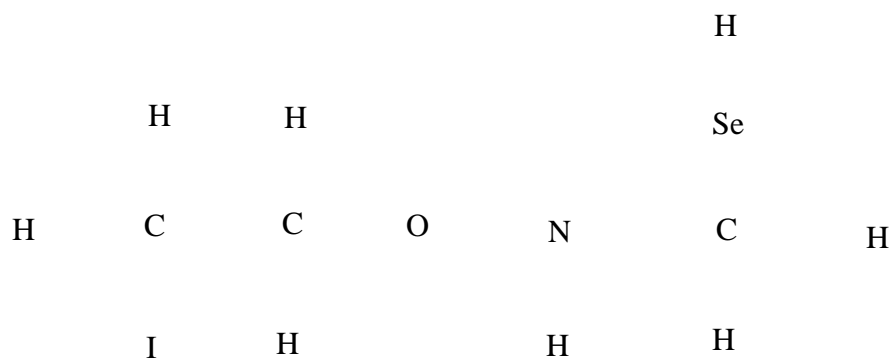
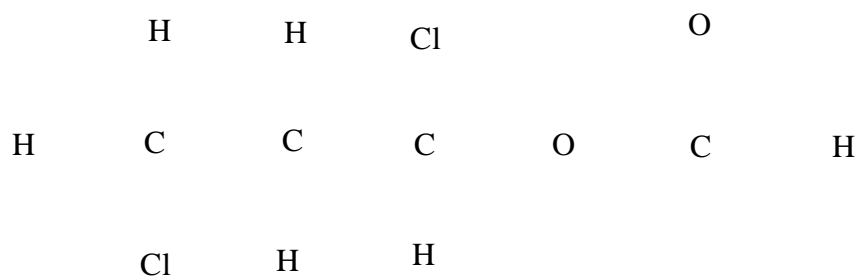
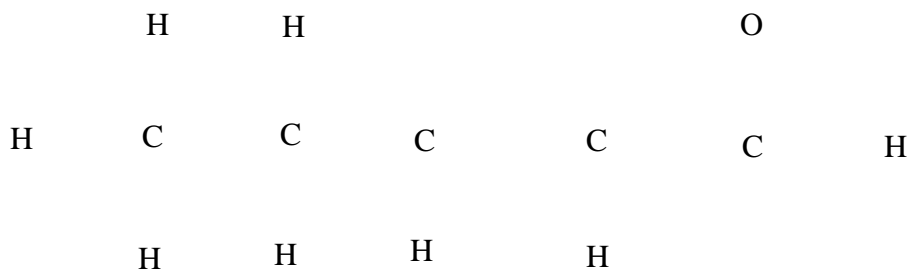
N, P, As, and Sb \Rightarrow three bonds and one lone pair

C, Si, Sn, and Ge \Rightarrow 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
 - $\lambda = C / \nu$
 - $C = \text{Speed of Light} = 3 \times 10^8 \text{ m/sec}$

- **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 \Rightarrow Higher Energy

➤ Lower Frequency \Rightarrow 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, O₂**, absorbs the highest energy UV light
 - UV light with λ less than about 242 nm



- **Ozone, O₃**, 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



➤ Ozone Cycle

➤ Ozone generation in the atmosphere



➤ 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

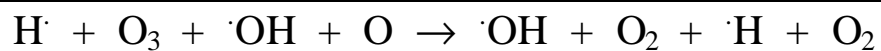
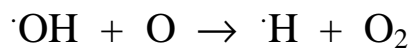
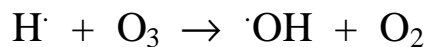
➤ Graphics from Text: Figure 2.6 in 2nd Edition and 2.10 in 3rd Edition, The Chapman Cycle of Ozone in the Atmosphere

➤ Ozone Destruction

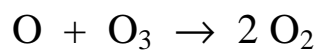
➤ Free Radicals!!!

➤ 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



Net Reaction:



➤ Ozone Loss

➤ Arctic and Antarctic Sensitivity

➤ Caused by extreme cold \Rightarrow tiny crystals whose surfaces are involved in Ozone destruction

➤ Note: Noise levels in data

➤ Graphics from Text: Figure 2.8 in 2nd Edition and 2.7/2.12 in 3rd Edition, Average Ozone loss on the earth

➤ A few percent in continental US

➤ Graphics from Text: Figure 2.9 in 2nd Edition and 2.13 in 3rd 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 expensive but safe
 - non-toxic, non-flammable, non-reactive, and quite volatile

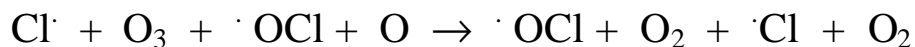
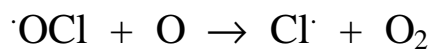
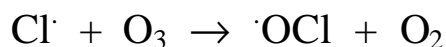
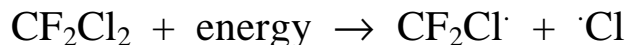
 - Used as refrigerants, blowing agents, propellants, cleaning agents for computer parts, dry cleaning fluids, decaffination

- Classes of **Halocarbons**
 - **CFCs** are **Chlorofluorocarbons**
 - These are chemicals that contain only C, Cl, and F
 - Examples include: **CFCl₃** (**Freon 11**) and **CF₂Cl₂** (**Freon 12**)
 - **Halons** contain C, Br, and F and/or Cl
 - Examples include: **CH₃Br**, **CF₂Br₂** and **CClBr₃**
 - Used for fire extinguishers
 - **Chlorocarbons** contain C, Cl, and H
 - Examples include **CCl₃-CH₃** and **CH₂Cl₂**

➤ 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[·] and Br[·] 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



- 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 CO₂
 - Greenhouse gasses

Index of Vocabulary and Major Topics

I

¹² C.....	8
¹³ C.....	8, 10
¹⁴ C.....	8
¹⁸³ W.....	10
¹⁹ F.....	10
¹ H.....	8

2

²³⁵ U.....	8
²³⁸ U.....	8
²⁹ Si.....	10
² H.....	8

3

³ H.....	8
---------------------	---

4

⁴⁰ Ar.....	9
⁴ He.....	9

7

⁷ Be.....	10
----------------------	----

A

Allotropes.....	4, 5
Amplitude.....	17, 18
Analytical Data.....	11
Antarctic.....	25
Arc Welding.....	3
Arctic.....	25
Ask Students.....	10, 16, 19
atmosphere.....	8
Atmospheric Sunscreen.....	21
Atomic Number.....	9
Atoms.....	6
Average Ozone loss on the earth.....	25

B

blowing agents.....	26
bond.....	15
Bond Angles.....	15
Bond Lengths.....	15
Bonds.....	13

C

C.....	17
Carbon.....	4

catalyze.....	24
CCl ₃ -CH ₃	27
CClBr ₃	27
CF ₂ Br ₂	27
CF ₂ Cl ₂	27
CFC.....	27
CFCl ₃	27
CFCs and Ozone.....	26
CH ₂ Cl ₂	27
CH ₃ Br.....	27
Chapman Cycle.....	23
Charge.....	7
Chlorine - Ozone Correlations.....	29
Chlorocarbons.....	27
Chlorofluorocarbon.....	27
cleaning agents for computer parts.....	26
Core Electrons.....	6
Cost Concerns.....	30

D

D.....	8
decaffeination.....	26
Deuterium.....	8
Diamond.....	4
Diatomic Molecule.....	5
Diffraction.....	20
dry cleaning fluids.....	26

E

e ⁻	7, 9
E = h v.....	20
Electrical Discharges.....	3
electricity.....	13
Electromagnetic Spectrum.....	17, 19
Electromagnetic Waves.....	17
Electron Cloud.....	6
Electrons.....	7, 9
Electrostatic Force.....	7
element.....	4, 8
Energy.....	3
expensive but safe.....	See
experimental data.....	13

F

Free Radicals.....	24
Freon.....	27
Frequency.....	17, 18, 20

G

Graphics from Text	6, 17, 19, 21, 23, 25, 29
Graphite.....	4
Greenhouse gasses	30
Group Activity.....	10, 16, 19

H

Halocarbons.....	26, 27
Halocarbons and Ozone Destruction.....	28
Halons	27
How Do We Explain Molecular Structures	13
How Do We Know Molecular Structures	11
Hydrochlorofluorocarbons.....	30
Hydrogen.....	8

I

in Stable Nuclei.....	7
Infra-Red.....	11
intensity	18
IR	11
isotope.....	9
Isotopes	8

L

Laser Printers	3
Lewis.....	13
Lewis Dot Structures	13
lifetime	22
Light has Both Wave and Particle Like Properties ..	20
Light is Particle Like.....	20
Light is Wave Like.....	20
Lightning.....	3
Liquefies	5
lone pairs.....	15
Lone Pairs.....	13

M

Magnetic Resonance Imaging.....	11
Mass.....	7, 8
Mass Number.....	9
Molecular Oxygen.....	3, 4, 5, 22
molecular shapes	11
molecular structures.....	11
Montreal Treaty.....	30
MRI.....	11

N

n	7, 9
Net Reaction.....	24
neutral atom.....	9
Neutron.....	7
Neutron/Proton Ratio.....	7
Neutrons.....	9
NMR.....	8, 11
Noise levels in data.....	25

non-flammable.....	26
non-reactive.....	26
non-toxic.....	26
Nuclear Magnetic Resonance.....	11
Nuclei.....	6
Nucleus	6, 7

O

O ₂	3, 5, 22
O ₃	3, 5, 22
Octet	14
Odorless	5
Organic Compounds.....	15
Oxygen.....	4
Ozone.....	3, 4, 5, 21, 22
Ozone concentration profile of the atmosphere.....	23
Ozone Cycle.....	23
Ozone Destruction.....	24
Ozone generation.....	23
Ozone Loss.....	25
Ozone loss in Antarctica.....	25

P

P ⁺	7, 9
pencil lead.....	4
periodic table.....	13
Periodic Table.....	9
Photochemical Smog.....	3
Photoelectric Effect	20
photon.....	22
Plank's Constant.....	20
Plank's Relationship	20
propellants	26
properties	4
Protons	7, 9
pulp and paper bleaching.....	5

Q

Quick and Dirty Method for getting Lewis Structures	15
---	----

R

Radicals.....	24
radioactive	8
radioactivity	13
Reactions that destroy Ozone.....	29
refrigerants	26
Rigorous Method of Determining Lewis Dot Structures.....	14
Rubber Baggie model of nucleus.....	8

S

Safety Concerns.....	30
shared pairs of electrons.....	13
Single Crystals	12
Spectroscopic Methods	11

Speed of Light.....	17
Sporting Methods.....	11
Stratosphere.....	28
Stratospheric Ozone Layer.....	21
Strong Nuclear Force.....	7
structures.....	4
Sub-Atomic Particles.....	6
Supercritical CO ₂	30
T	
T.....	8
Technology Concerns.....	30
Tesla Coils.....	3
The Ozone Screen.....	21
Theory.....	13
threshold energy.....	20
Triatomic Molecule.....	5
Tritium.....	8
U	
Ultra Violet-Visible.....	11
Ultra-Violet Radiation.....	21
unpaired electrons.....	24
UV light.....	21, 22
UV-Vis.....	11

V	
Valence Electrons.....	6, 13
volatile.....	26
W	
water purification.....	5
Wave / Particle Duality.....	20
Wave Motion.....	17
Wave Packet Model.....	20
Wave/Particle Duality.....	20
Wavelength.....	17
Waves of Light.....	17
What is Ozone.....	3
What is the Structure of a Atom.....	6
X	
X-Ray Crystallography/Diffraction.....	12
I	
λ	17, 18, 22
n	
v	17, 18