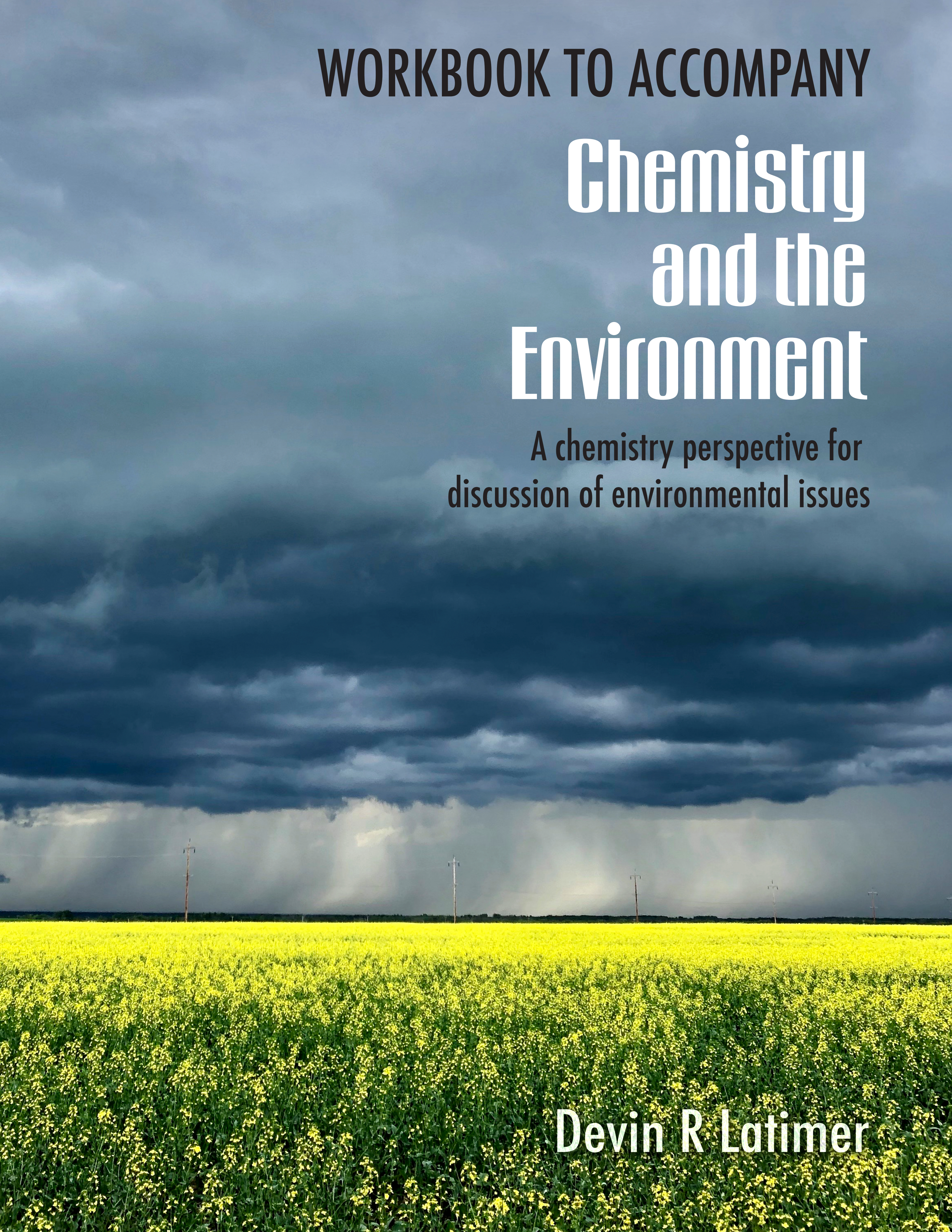


WORKBOOK TO ACCOMPANY

Chemistry and the Environment

A chemistry perspective for discussion of environmental issues

Devin R Latimer

Cover photo by Steve Schlachter

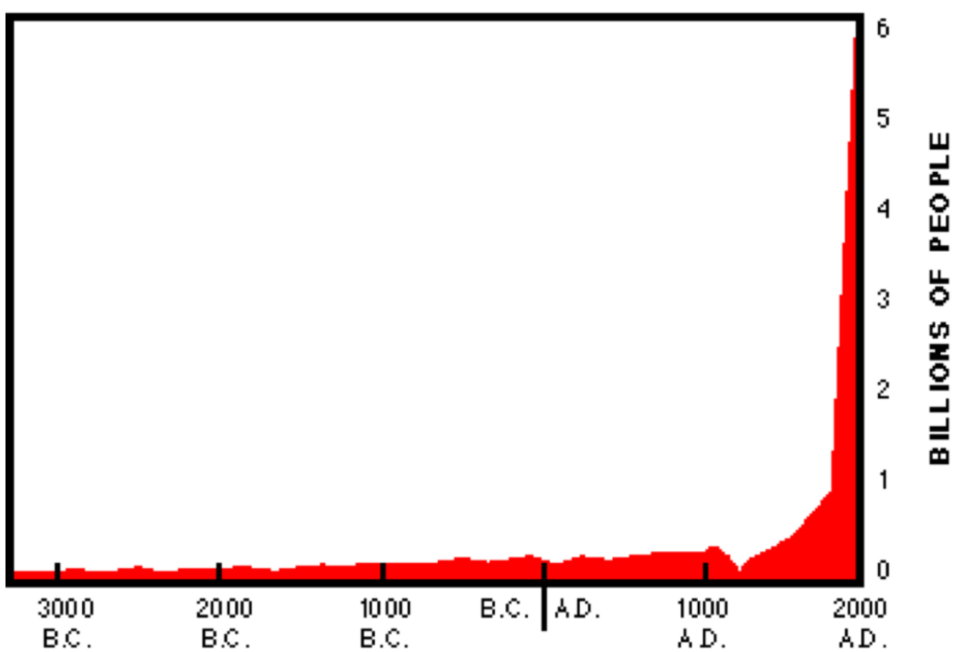
Cover design by Keri Latimer

Workbook Contents

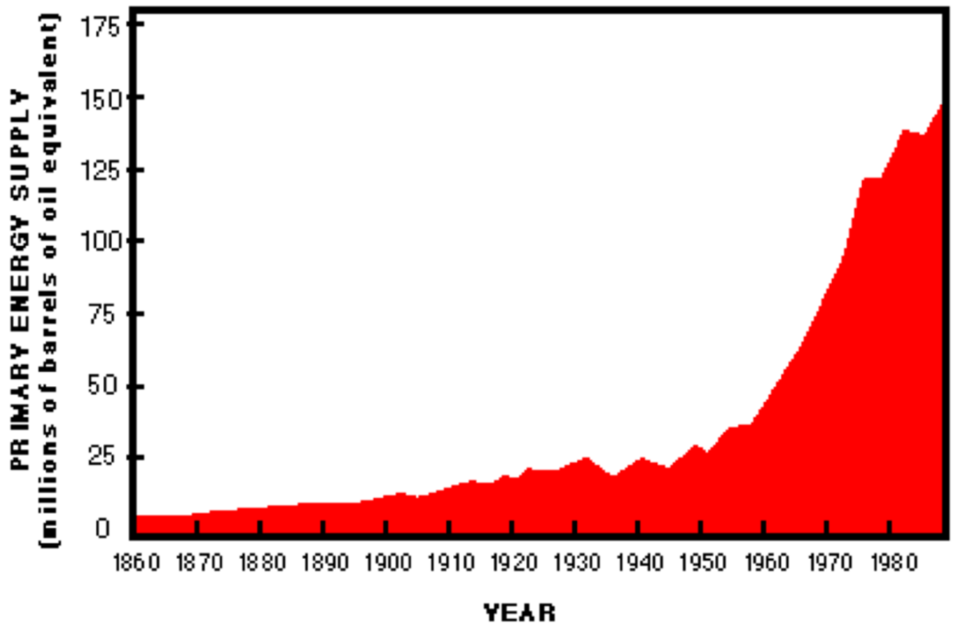
Introductory Focus

Drastic environmental change has often come during times of revolution – be it scientific, societal or ideological. This text offers a chemical background to support discussions of environmental issues of our times. In this, you will be introduced to the basics of chemistry and then we will use that information to focus on discussions involved in the following topics: Air Pollution, The Ozone Layer, Climate Change, Energy (Fossil Fuels, Nuclear Energy, Alternative Energy), Water Quality, Acid Precipitation and Polymers.

The figure below represents the trend in world population over the past 5000 years. Noteworthy are the bumps and dips in population over that time, but perhaps most striking is the sharp increase in population leading up to today at the far right end of the graph. Population continues to grow at the rate of approximately 1% worldwide. It is an interesting exercise to refer to a site such as worldometers.info to see the world population as of today and then calculate 1% (0.01) of that number. Divide by 365 to get the daily population growth and you will see that human population is growing by approximately a quarter million people every day.



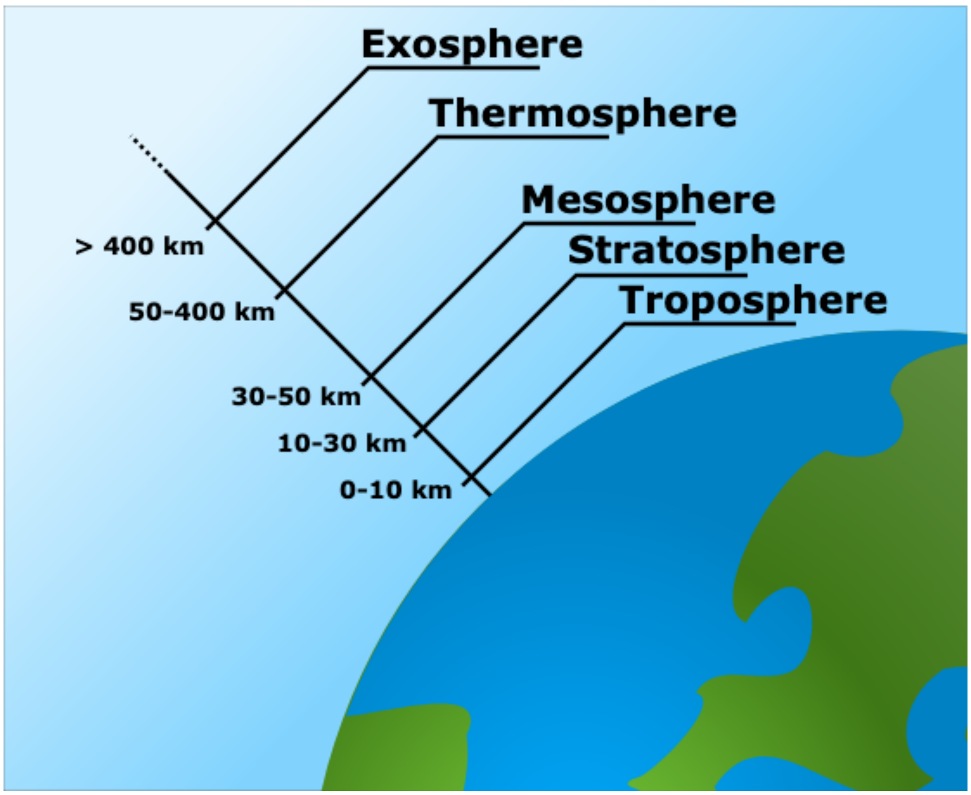
Likewise, our use of energy shows a large upsurge in the 20th century that continues today with energy use growing at the rate of approximately 2%.



It is in this context that we begin the work-book style discussions ('Focus' sections) in this text. A staggering number of human beings using a staggering amount of energy and materials on a finite and complicated planet is having drastic environmental consequences. We deal with these consequences every day - some quite successfully, some less successfully. Studying the scientific principles involved in tandem with the debates involved with these issues is crucial in deciding on the best paths to move forward.

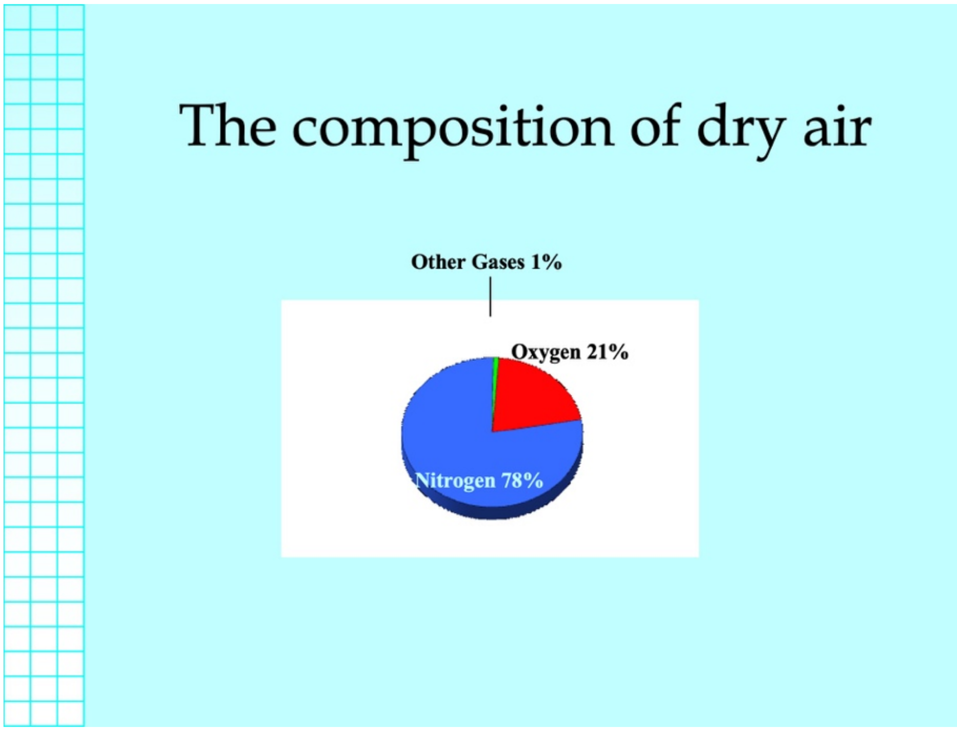
Focus on Air

Some simple chemistry is now explored in the context of air and air pollution (ie. what we should be breathing *vs* what we are breathing). This section deals with gaseous components of the atmosphere, and more specifically, components of the troposphere, the region of the atmosphere where earth's inhabitants live and breathe every day.



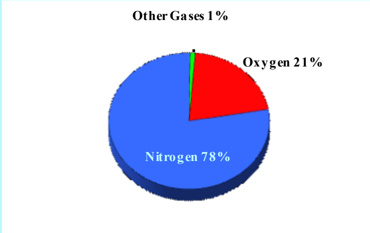
"File:Atmospheric Layers.svg" by Original by en:Bredk, converted to SVG by tiZom, globe borrowed from File:Earth clip art.svg is licensed under CC BY-SA 3.0

As seen in the following figure, air is mostly nitrogen, which is inert to us, and oxygen, which is important for respiration for all aerobic organisms. Argon and carbon dioxide make up 9/10 of the remaining 1% of air molecules. Thus, 'pollution' is typically found in the remaining 0.1% of air.



Refer to the information discussed in parts I-IV of this text and elaborate on the following focus boxes, solving the problems that appear.

The composition of dry air



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Major common air pollutants (small parts of the 1%)

- Carbon monoxide (oxygen delivery)
- Ozone (respiratory)
- Sulfur oxides (respiratory)
- Nitrogen oxides (respiratory)

2

Atoms and Molecules

- we will normally deal with them in terms of their chemical symbol
- examples:

  Carbon = C

  Carbon Monoxide = CO

  Carbon Dioxide = CO_2

  Sulfur Oxides = SO_x

  Nitrogen Oxide = NO_x

3

chemistry

- Chemical Reactions
  reactants ⟶ products
- Law of Conservation of Matter
  atoms on left = atoms on right

4

Coal = carbon, trace sulfur

5

- What is the balanced chemical reation for the combustion of solid carbon ($C_{(s)}$) with oxygen ($O_{2(g)}$) to form carbon dioxide?

6

- Show how these common air pollutants might be produced from the combustion of coal:

- Carbon Monoxide
- Sulfur Dioxide and Sulfur Trioxide
- Nitrogen Monoxide and Nitrogen Dioxide

7

- Write the balanced chemical reations for the combustion of methane (CH_4), ethane (C_2H_6), ethanol (C_2H_5OH), and octane (C_8H_{18}). Use chemical reactions to demonstrate the difference between the reaction to form carbon dioxide and the formation of carbon monoxide.

8

Catalytic Converter

Exhaust emission device that facilitates the conversion of toxic pollutants to less toxic substances.

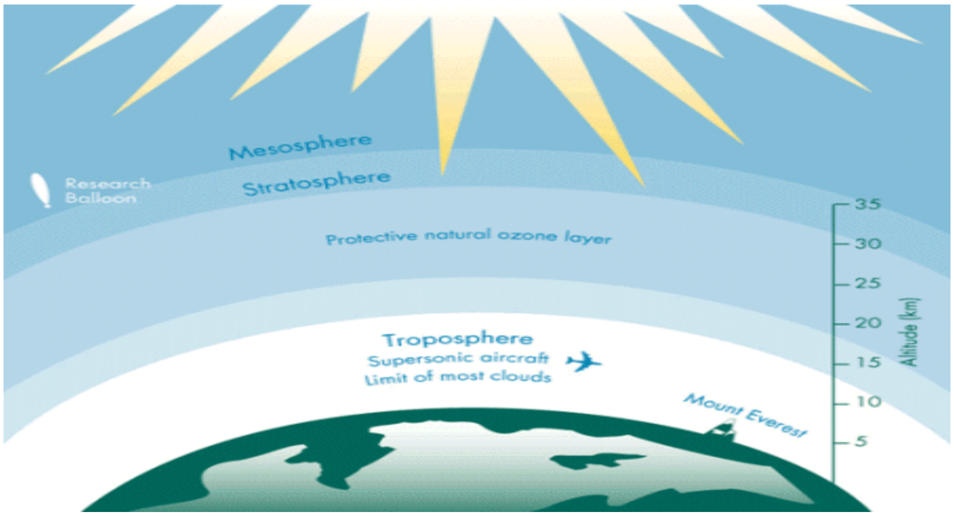
Catalyst - a substance that increases the rate of a chemical reaction, but does not itself undergo permanent change.

Ex: Show the general reaction for the conversion of carbon monoxide and oxygen gas to carbon dioxide via a platinum catalyst.

9

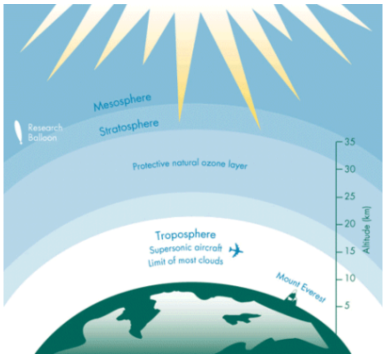
Focus on The Ozone Layer

Basic chemical structures, bond energies and the breaking of bonds by electromagnetic radiation is sufficient background to take an elementary look at a very important set of reactions taking place in another part of the atmosphere, the stratosphere.



© Environment and Climate Change Canada. Layers of the Atmosphere. Government of Canada https://www.canada.ca/en/environment-climate-change/services/air-pollution/issues/ozone-layer/depletion-impacts/about.html

The four reactions of the Chapman cycle are key to protecting life on earth from harmful ultraviolet radiation. It was determined that a set of anthropogenic compounds were putting this protective ozone layer at risk. Refer to the information discussed in the previous Focus section as well as parts VI and VII of this text and elaborate on the following focus boxes, solving the problems that appear. Use the information to frame the story of the thinning ozone layer through the science and events.



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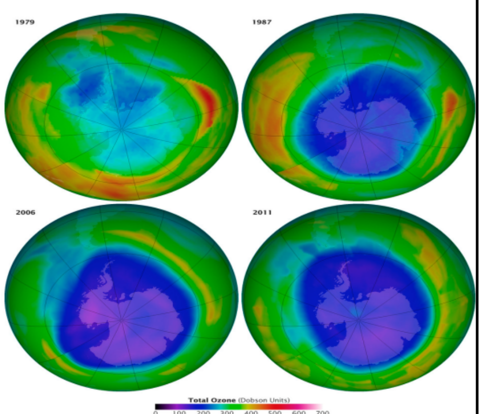
https://www.canada.ca/en/environment-climate-change/services/air-pollution/issues/ozone-layer/depletion-impacts/about.html

1

Antarctic ozone hole



Antarctic Ozone, July - September 2010

- http://www.flickr.com/photos/gsfc/4995772362/
  - Animation provided by NASA/Goddard Space Flight Center.

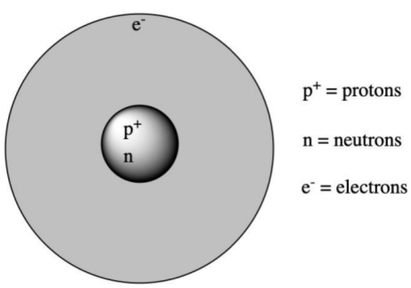
3

Atomic Theory

- matter is composed of discrete units called atoms, arranged in unique ways.
- However, atoms are also made up of smaller particles …

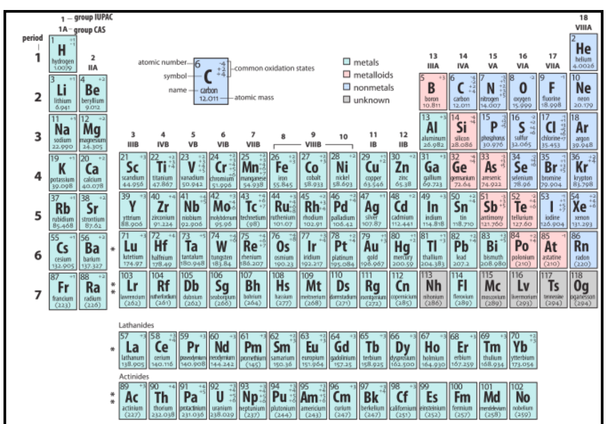
4

Classical view of the atom



- nuclei are composed of protons and neutrons
- electrons exist outside the nucleus

5



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Atomic Symbols

- atomic number (Z)
  - # of protons in nucleus
  - uniquely labels each element
- mass number (M)
  - # of protons and neutrons in the nucleus

$$^{M}_{Z}X$$

7

What are the # of protons and neutrons in ^{238}U ?

- A. 238 protons, 92 neutrons
- B. 92 protons, 156 neutrons
- C. 92 protons, 146 neutrons
- D. 156 protons, 92 neutrons
- E. 146 protons, 92 neutrons

8

What are the # of protons and neutrons in ^{1}H? ^{2}H?

9

Isotopes

- isotopes: same Z, different M
- Ex: What is the number of protons and neutrons in the following isotopes?

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$ ^{12}C ^{13}C ^{14}C

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Atoms and Ions

protons: +1 charge

electrons: -1 charge

- atoms
  - same number of electrons & protons
- ions
  - ionic charge (q) = #protons - #electrons
  - positive ions are cations
  - negative ions are anions

$^{35}_{17}Cl^{-}$ $^{23}_{11}Na^{+}$

11

What is the # of protons, neutrons and electrons in $^{23}Na^{+}$

- A. 23 protons, 23 neutrons, 11 electrons
- B. 12 protons, 11 neutrons, 11 electrons
- C. 11 protons, 11 neutrons, 12 electrons
- D. 11 protons, 12 neutrons, 12 electrons
- E. 11 protons, 12 neutrons, 10 electrons

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What is the # of protons, neutrons and electrons in $^{74}Se^{2-}$

- A. 74 protons, 34 neutrons, 32 electrons
- B. 34 protons, 40 neutrons, 36 electrons
- C. 40 protons, 74 neutrons, 42 electrons
- D. 34 protons, 40 neutrons, 40 electrons
- E. 32 protons, 34 neutrons, 74 electrons

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Quantum Theory

- both matter and light had to be viewed as having particle properties as well as wave properties.
  - light ----> photons
  - electrons ---> waves

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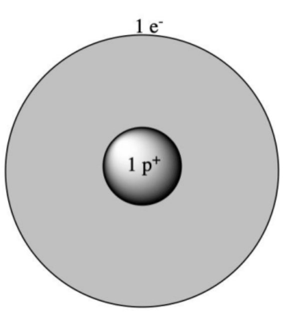
Classical view of the H atom



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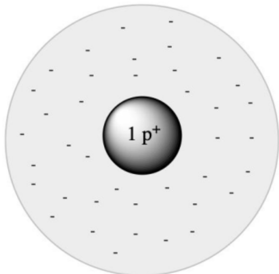
Quantum-mechanical view of the H atom



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Quantum theory: electrons do not exist in any well-defined area of space and have only certain 'allowed' energy levels. These energy levels have a maximum capacity for electrons.

Exercise: Determine the electron configurations for the first 18 elements (z = 1 to z = 18).

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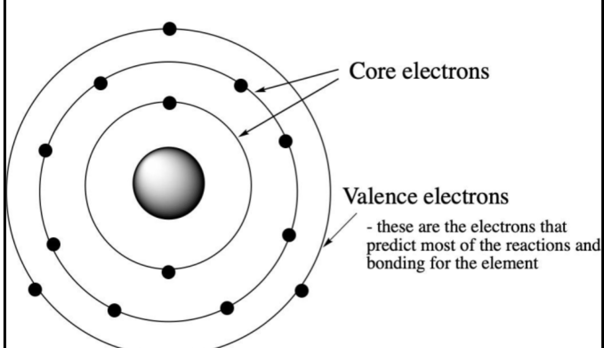

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Note: periodic table

- Most periodic tables are labelled such that group A numbers refer to the number of valence electrons.

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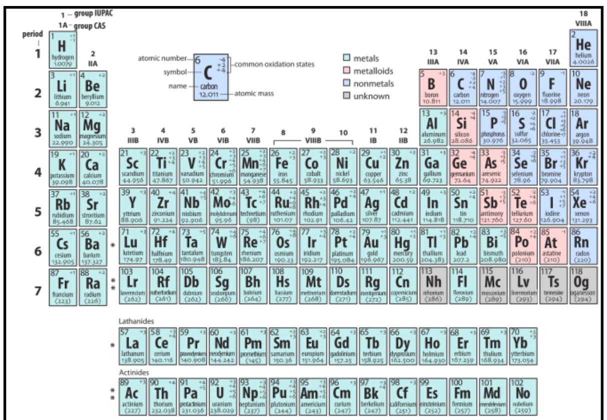

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How many valence electrons does a neutral oxygen atom have?

- (a) 2
- (b) 6
- (c) 8
- (d) 16
- (e) 32

21

How many electrons does a neutral fluorine atom have?

- (a) 9
- (b) 8
- (c) 7
- (d) 6
- (e) 5

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Lewis Structures

- Draw the atomic symbol
- Determine the number of valence electrons for the element
- Place 1 electron at a time in each of 4 spaces around the atomic symbol
- Each space can hold 2 electrons
- Ex: Draw the Lewis structures for the first 18 elements (Z=1 to Z=18).

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Noble Gases - Group VIIIA

-The noble gases, noted for their stability, share a common 'closed shell' electron configuration.
-All of the noble gases have 8 valence electrons (except for helium which has 2).

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Lewis Structures of Molecules

- many elements will form molecules based on the ***closed shell rule***.
  - atoms will
    - gain or lose e^- (ionic compounds)
    - share e^- (covalent compounds)

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Covalent examples – Draw the Lewis structures for the following molecules:

H_2 F_2 CH_4 CCl_4 NH_3 H_2S
O_2 CO_2 CO

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Covalent Bonds

- The first covalent bond formed between two elements is between orbitals that are in the direction of the bond. These are known as **σ** bonds.
- Any further bonding that occurs is between orbitals that are at right angles to the direction of the bond. These are known as π bonds.

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Bond Length/Bond Strength

- The greater the number of bonds (pairs of electrons) between two particular atoms in a molecule, the closer the two atoms will be to each other and the stronger the bond will be.
  - for example, it takes more energy to break the CO bond in carbon monoxide than it does to break the CO bond in carbon dioxide

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Draw the Lewis structures (including all ***resonance*** structures) of ozone (O_3, one O is central to the other two)

- the electron pair forming the **π** bond is 'delocalized' over the three oxygen atoms, as opposed to being 'localized' between two atoms like the **σ** bonds are.

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Ozone

- has two equivalent O-O bonds and their properties are intermediate between that normally found for a O-O single bond and that normally found for an O-O double bond.

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Example

Draw all of the resonance structures of the Nitrate ion, NO_3^-

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Electromagnetic Radiation (Light)

- A form of energy (photons) that exhibit wave-like behavior as they travel through space. The **energy** can be characterized by:
  - **wavelength**: the distance between peaks where the level of the field is the same. The longer the wavelength, the lower the **energy** of the light.
  - **frequency**: how many waves pass a given point in a given amount of time. The higher the frequency, the higher the **energy** of the light.

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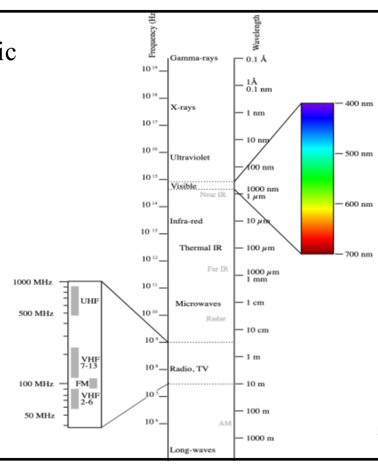
Electromagnetic Spectrum



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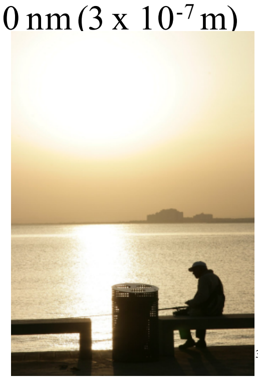
FM radio wave at 3 m (1 x 10^8 Hz)

- The photons have an energy that our bodies are unable to detect unless it is fed through a receiver and converted into sound.

UV light with wavelength = 300 nm (3 x 10^{-7} m)

- The photons have an energy which is on the order of covalent bond energies and may break covalent bonds.



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Stratospheric Ozone: Its Formation and Fate

- each day, ~ 300,000 tons of ozone are created and destroyed in the four reactions of the ***Chapman Cycle.*** The constant creation and destruction of ozone results in a *steady state* (constant amount) of the compound.

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Chapman cycle

- Sketch the reactions of the Chapman cycle and demonstrate how certain frequencies of the sun's UV light are filtered out in the stratosphere.
- Identify any 'free radicals'- an unstable chemical species with an unpaired electron.

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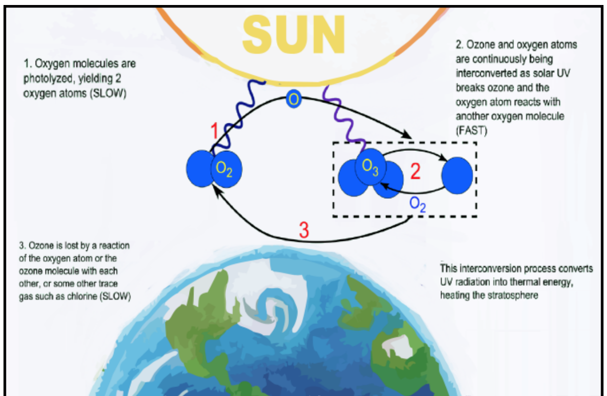

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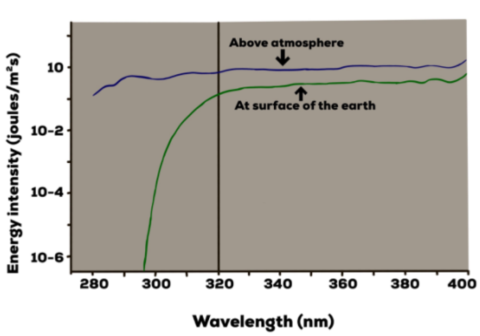
Elaborate on this graph. Why is there less intensity of electromagnetic radiation of lower wavelengths at the surface of the earth?



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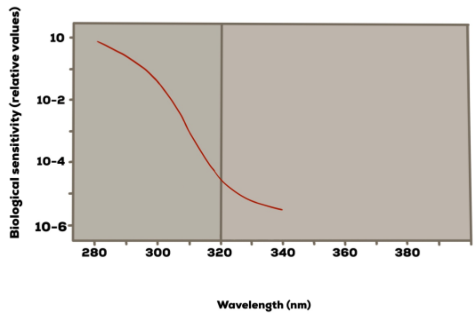
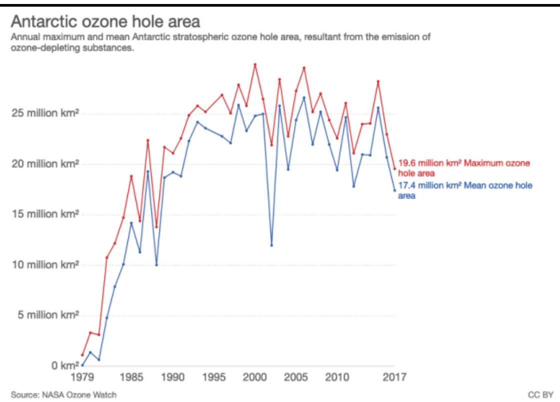
Elaborate on this graph. Why is biological sensitivity higher for electromagnetic radiation of lower wavelengths?





"File:Antarctic_ozone_hole_area,_OWID.svg" by Our World In Data is licensed under CC BY 3.0

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Chlorofluorocarbons

- anthropogenic chemicals introduced as a safe alternative to the relatively unsafe substances used in refrigeration.
  - Ex: CF_2Cl_2

    heat + $CF_2Cl_{2\,(l)} \rightleftharpoons CF_2Cl_{2\,(g)}$

- Due in part to their inertness, they soon found many other uses.

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Chlorofluorocarbons

- Their inertness is due to the great strength of the C-F and C-Cl bonds. However, rather than remaining harmless in the troposphere, they eventually find their way up to the stratosphere where they react with high energy electromagnetic radiation and Cl radicals are released.

43

Show the reaction sequence that demonstrates catalytic destruction of ozone by chlorine radicals

- one Cl radical can break down over 100,000 ozone molecules before it is removed from this stratospheric cycle.

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Elaborate on why the following measurements might be thought of as the "smoking gun" of evidence linking atmospheric chlorine monoxide to ozone depletion.

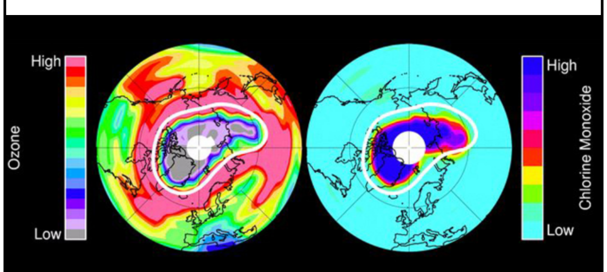

Image courtesy of NASA Jet Propulsion Laboratory at: https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA14824

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Antarctic Ozone, July - September 2010

- http://www.flickr.com/photos/gsfc/4995772362/
  - Animation provided by NASA Goddard Space Flight Center.

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Antarctic Winter/Spring

- Extreme cold of winter (-90 C) freezes atmospheric water into stratospheric clouds of ice crystals. Also condenses other species
- Otherwise safe molecules can be converted to more reactive species. When the sun comes out, the break down of these species may release chlorine radicals.

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1987 – Montreal Protocol

- Phaseout of production and use of certain CFC's, development of new compounds.
- Continually being refined, new compounds being added to ban (HCFC's).
  - Ex. 2005: CH_3Br phaseout begins.
  - Ex. 2013/2015: HCFC's phaseout begins.
- Many CFC's have a lifetime of ~ 100 years, however, some levelling off of effective [Cl] and [Br] has been observed.

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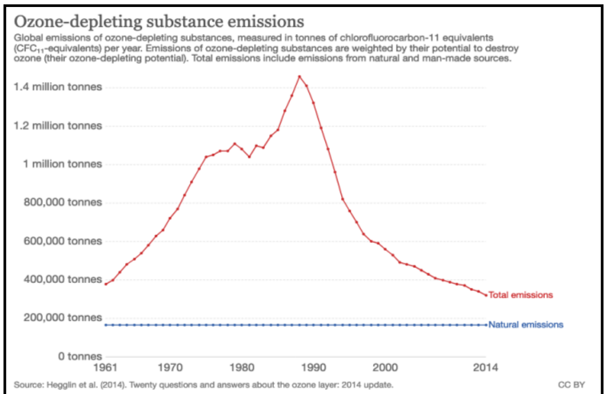
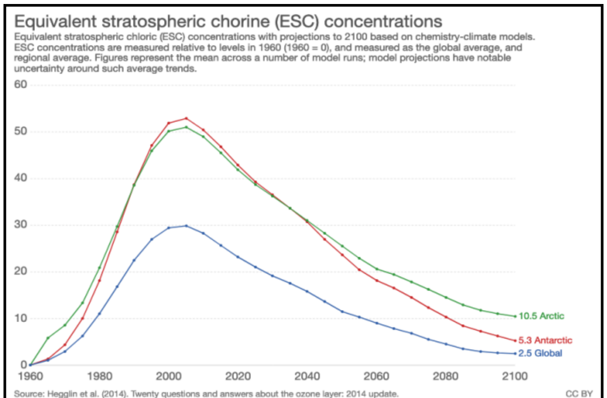
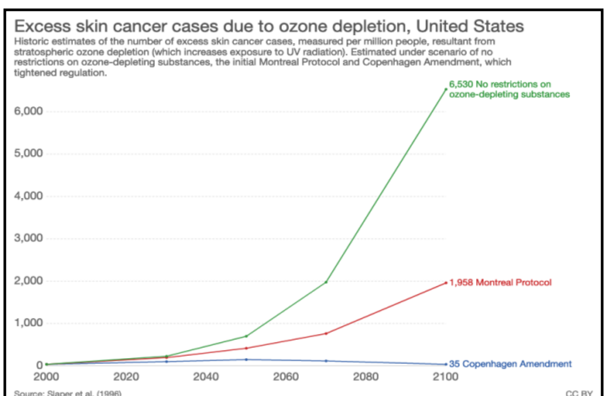


"File:Ozone-depleting substance emissions, OWID.svg" by Our World In Data is licensed under CC BY 3.0 49



"File:Equivalent stratospheric chorine (ESC) concentrations, OWID.svg" by Our World In Data is licensed under CC BY 3.0



"File:Excess skin cancer cases due to ozone depletion, OWID.svg" 51
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Ozone Watch

https://earthobservatory.nasa.gov/features/videos/the-ozone-hole

Video provided by NASA/Goddard Space Flight Center.

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Summary – Ozone/CFC's

- Chapman cycle
- Potentially catastrophic series of events.
- 'Smoking gun' of evidence.
- Montreal Protocol, and subsequent refinements.
  - Substitutes were (are) available.
  - Economic setback (but not devastating).
- The ozone 'holes' are shrinking

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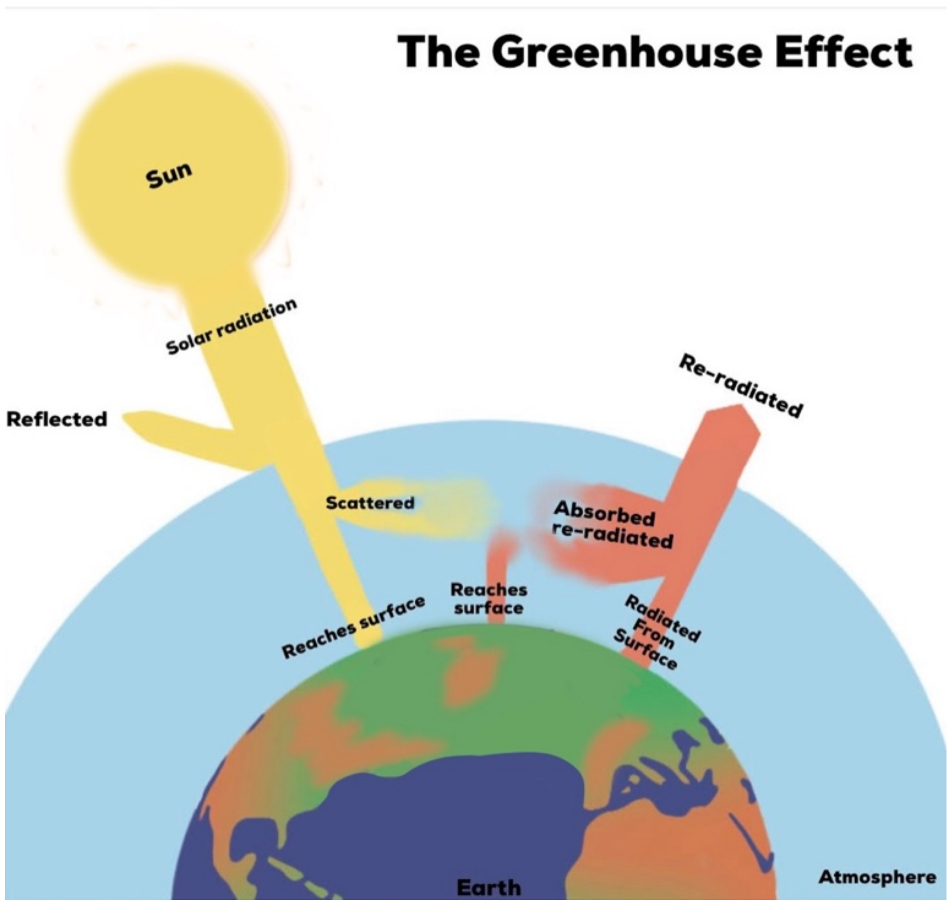
Focus on Climate Change

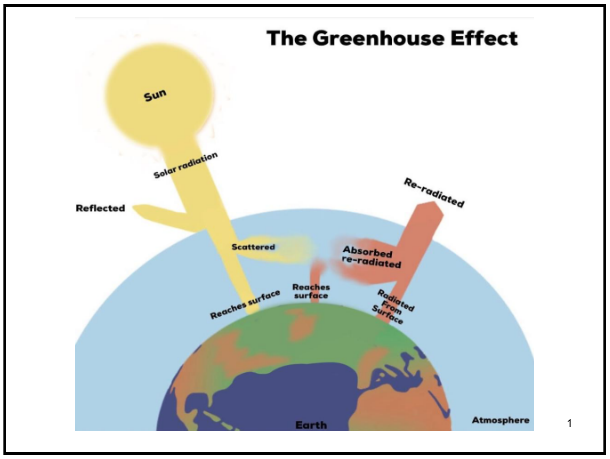
Molecular shape, polarity and a further look at the interaction of electromagnetic radiation and matter enable one to understand the fundamentals of the greenhouse effect.

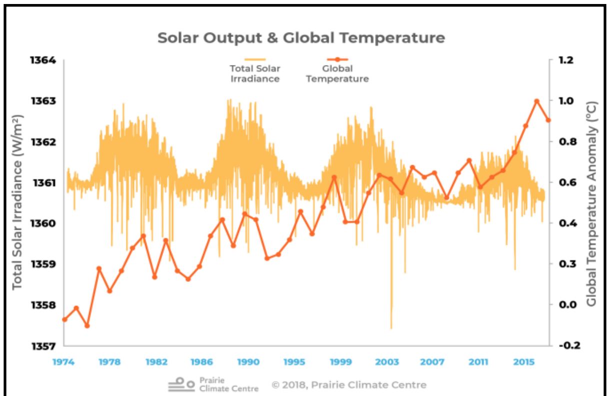


When the suns energy warms the atmosphere and surface of the earth, much of that heat is re-radiated back out into the atmosphere. Molecules in the atmosphere absorb some of that released heat and then re-release it, warming the atmosphere and surface of the earth further. Without this natural greenhouse effect, the earth's average global temperature would be approximately -18 ^{o}C, but instead it is +15 ^{o}C. This 33 ^{o}C temperature difference is crucial to the way that life and society have evolved and a stable average temperature is thought to be an important metric for many climate related issues such as weather and sea levels.

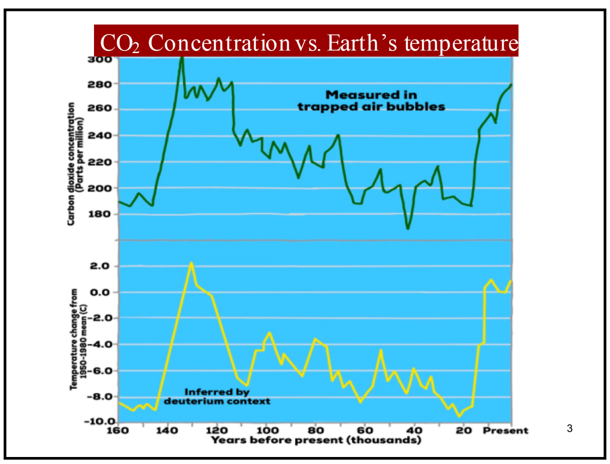
Anthropogenic release of extra greenhouse gases is being blamed for a measurable increase in recent global temperatures.

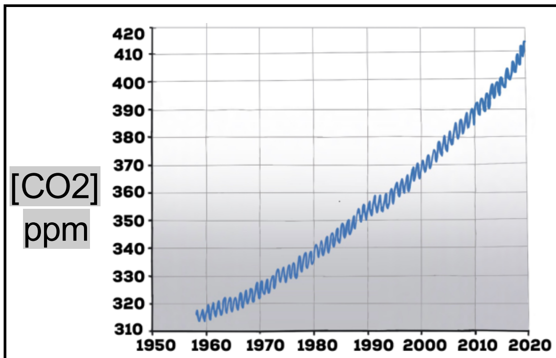
Refer to the information discussed in the previous Focus section and elaborate on the following focus boxes, solving the problems that appear. Use the information to frame the story of the climate change debate to where it stands today. It is quite useful to compare the story to that of the ozone layer.





Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca





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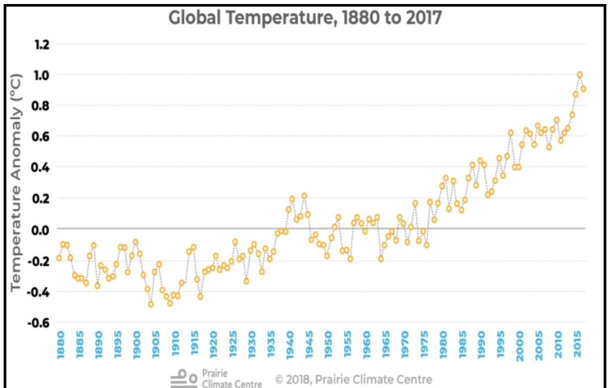

Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca

Climate Atlas - 1 °C and its impacts

- https://climateatlas.ca/video/one-degree-and-its-impacts

Rebroadcast with permission of the Climate Atlas, Prairie Climate Centre https://climateatlas.ca/

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Galileo Movement Australia- Axe the Tax

- https://www.youtube.com/watch?t=7&v=BC1l4geSTP8

Rebroadcast with permission of the Galileo Movement Australia
http://www.galileomovement.com.au/

7

Molecular Shape

- The 3-dimensional positions of bonded atoms in the molecule with respect to a central atom.
  - Valence Shell Electron Pair Repulsion (VSEPR)

8

non-bonding electrons

- VSEPR predicts the positions of all electrons around a central atom (electron pair geometry).
- Molecular geometry involves the 3-dimensional positions of atoms only.
- Further, lone pairs of electrons take up more room than bonding pairs of electrons.

9

Ex: Determine the molecular shape of the following molecules.

ie. consider the central atom and determine the number of 'groups of electrons' (symmetry number, SN), then determine the molecular shape.

Ex: CO_2 **Ex: H_2CO** **Ex: CH_4**

Ex: CF_2Cl_2 **Ex: NH_3** **Ex: H_2S**

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Electron groups	Examples	Shape
4 groups of bonding electrons	CH_4 CF_2Cl_2	Tetrahedral
3 bonding, 1 non-bonding	NH_3 PF_3	pyramidal
2 bonding, 2 non-bonding	H_2O SF_2	bent

What is the shape of the H_2S molecule?

- A. Linear
- B. Triangular planar
- C. Tetrahedral
- D. Triangular pyramid
- E. Bent

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What is the shape of the CHF_3 molecule?

- A. Linear
- B. Triangular planar
- C. Tetrahedral
- D. Triangular pyramid
- E. Bent

13

What is the shape of the SO_3 molecule (S is central)?

- A. Linear
- B. Triangular planar
- C. Tetrahedral
- D. Triangular pyramid
- E. Bent

14

What is the shape of the NF_3 molecule?

- A. Linear
- B. Triangular planar
- C. Tetrahedral
- D. Triangular pyramid
- E. Bent

15

Bond Polarity

- when two different atoms form a bond, one attracts the shared pair of electrons more strongly than the other.
- the displacement of the bonding pair causes a partially positive charge on one atom and a partially negative on the other.
- The bond is said to have electric poles and be a polar bond.

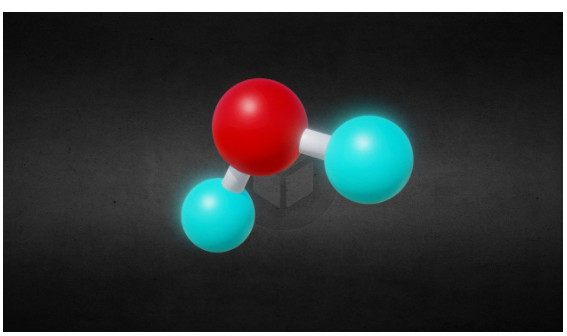
16

Molecular Polarity

- In a polar molecule, electron density accumulates toward one side of the molecule.
- Ex: Is the CO_2 molecule polar? What about H_2O?

17

Water



Is the CHF_3 molecule polar?

- A. yes
- B. no
- C. Not enough information given

19

Is the F_2 molecule polar?

- A. yes
- B. no
- C. Not enough information given

20

Is the SO_3 molecule (S is central) polar?

- A. yes
- B. no
- C. Not enough information given

21

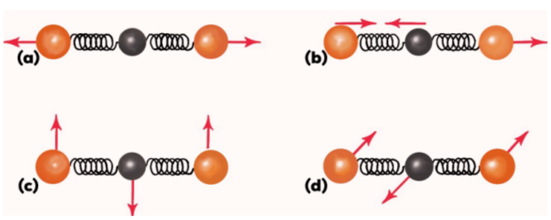
Is the Cl_2O molecule polar?

- A. yes
- B. no
- C. Not enough information given

22

Vibrational States of Molecules

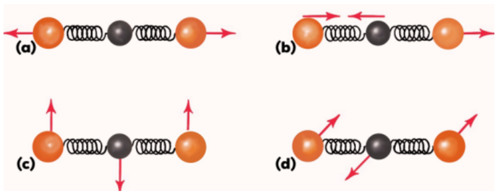
Based on its molecular geometry, a molecule's bonds are able to undergo certain vibrations. These are known as its 'fundamental modes of vibration'.



- Like electronic states, there are vibrational states which occur at certain 'fixed' or 'quantized' energy levels.
- Infrared radiation - is not of sufficient energy to break bonds (as in UV/ozone) but can be energetic enough to cause an increase in the amplitude of the ***'vibrating'***.
- The amount of energy that is absorbed depends on the type of vibration as well as the change in dipole moment as the bonded atoms vibrate.

24

Molecular geometry and absorption of IR radiation

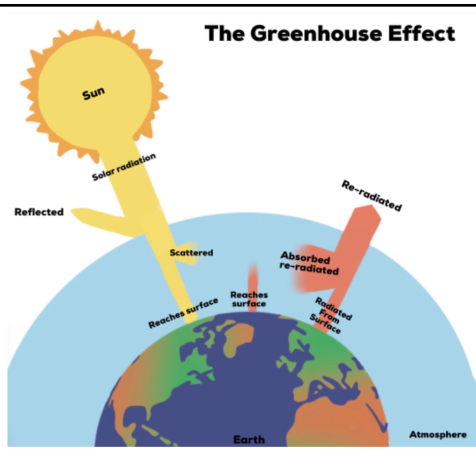


Molecular vibrations in CO_2. Each spring represents a C=O bond.

(a) = no change in dipole moment - no IR absorption.

(b, c, d) = these vibrations have a net change in dipole, so absorption/emission of IR can accompany a vibrational state transition.

25



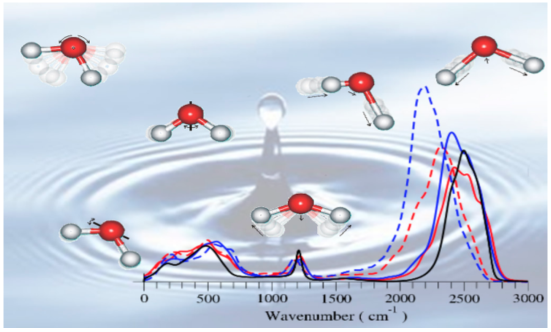
26

Choose all of the molecules which can absorb infrared radiation?

- A. N_2
- B. O_2
- C. Ar
- D. CO_2
- D. CH_4

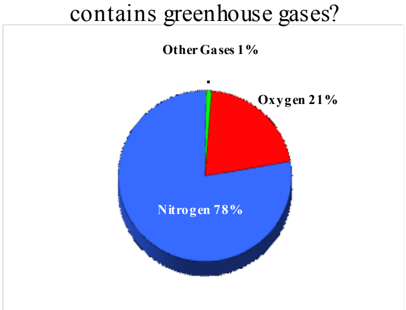
27

Infrared Spectroscopy



Note: The Composition of Dry Air

In addition to the pie chart below, 0.9 of the "1% other gases" is argon. Thus, what percentage of dry air contains greenhouse gases?



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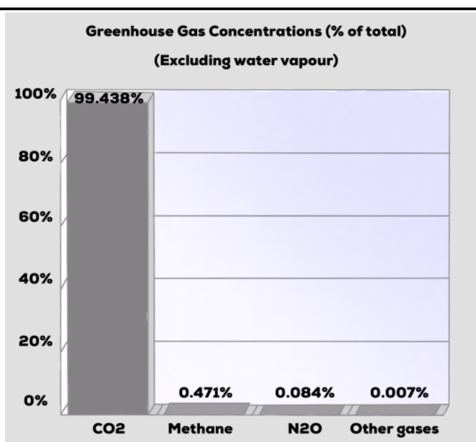


30

Global Warming Potential (GWP) represents the relative contribution of a molecule of an atmospheric gas to global warming.

Compound	Name	anthropogenic sources	GWP
CO_2	carbon dioxide	fossil fuel combustion, deforestation	1
CH_4	methane	fossil fuel production, livestock	21
N_2O	nitrous oxide	combustion, fertilizers	310
CCl_2F_2	CFC-12	refrigeration, aerosols	8100

31

Not considering average atmospheric lifetimes, which of the following would you expect to have the greatest global warming potential?

- A. N_2
- B. CH_2F_2
- C. CO_2
- D. CH_4
- E. F_2

32

Not considering average atmospheric lifetimes, which of the following would you expect to have the greatest global warming potential?

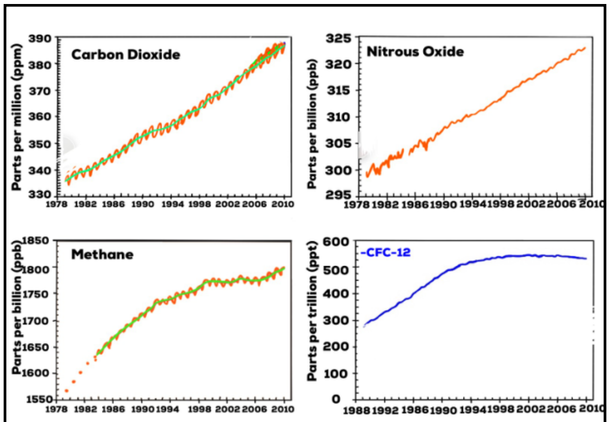
- A. CO_2
- B. CH_3F
- C. N_2
- D. CH_4
- E. CCl_2F_2

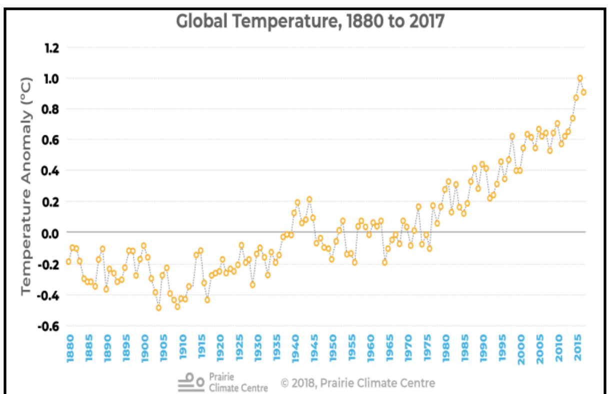
33

Compare the effectiveness of CFC-12 as a ghg to that of CO_2: multiply GWP by concentration.

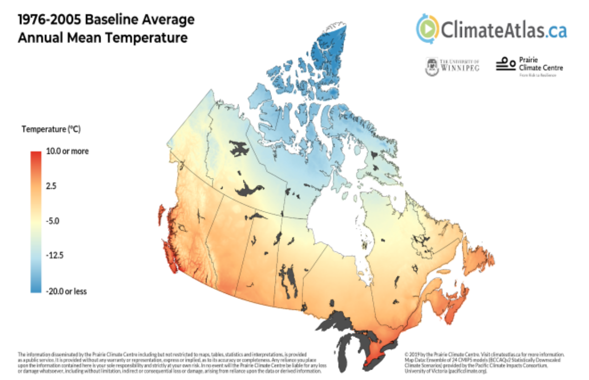
Compound	Name	anthropogenic sources	GWP	2020 atmospheric concentration
CO_2	carbon dioxide	fossil fuel combustion, deforestation	1	427 ppm
CH_4	methane	fossil fuel production, livestock	21	1875 ppb
N_2O	nitrous oxide	combustion, fertilizers	310	332 ppb
CCl_2F_2	CFC-12	refrigeration, aerosols	8100	498 ppt

34

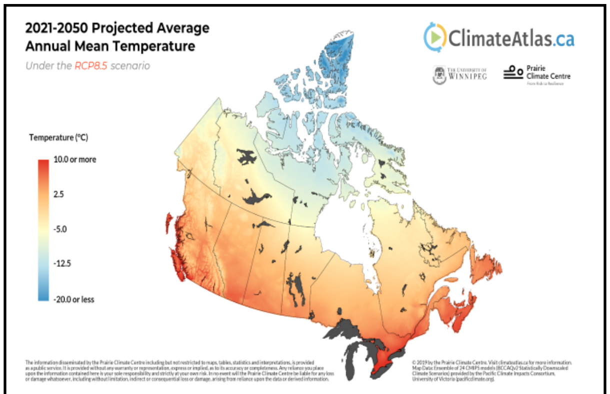




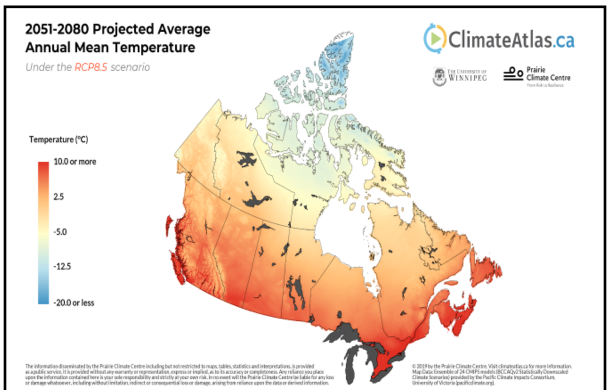
Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca



Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca

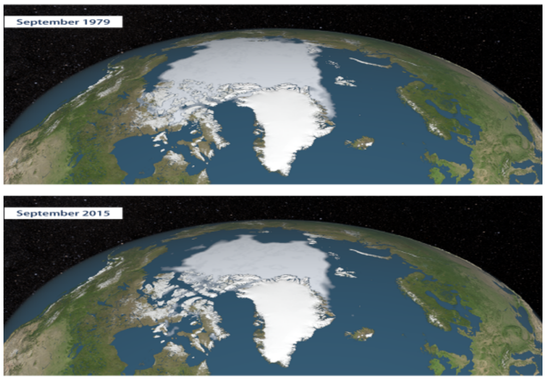


Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca



Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca

Dwindling Arctic Sea Ice



ce: NASA (National Aeronautics and Space Administration). 2016. NASA's Goddard Space Flight Center Scientific Visualiza
io. http://svs.gsfc.nasa.gov.

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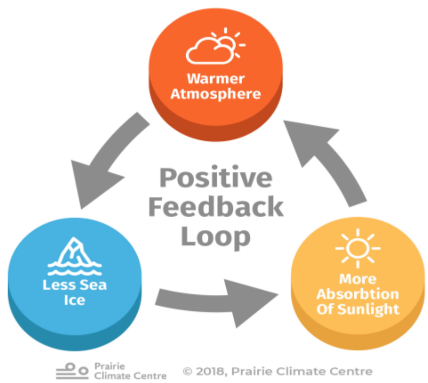
nore information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.



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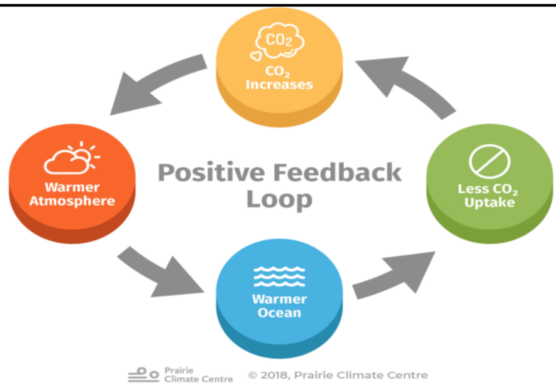


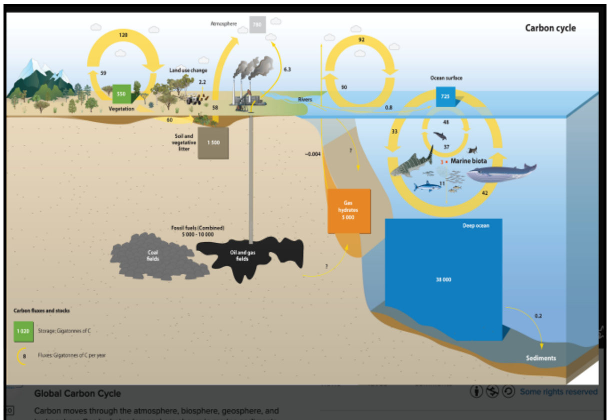
Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca

Possible Explanations

Observations	The Sun	Orbital Changes	El Niño	Volcanos	Natural GHGs	Human GHGs
Global CO_2 higher than any time in past 10-15 million years	✗	✗	✗	✗	✗	✓
Nights warming faster than days	✗	✗	✗	✗	✓	✓
Winters warming faster than summers	✗	✗	✗	✗	✓	✓
More CO_2 in the air with a fossil fuel signature	✗	✗	✗	✗	✗	✓
Less oxygen in the air	✗	✗	✗	✗	✗	✓
Long-term stratospheric cooling	✗	✗	✗	✗	✓	✓

Prairie Climate Centre © 2018, Prairie Climate Centre

Prairie Climate Centre. *The Climate Atlas of Canada* (version 2, July 10, 2019). https://climateatlas.ca



GRID-Arendal https://www.grida.no/resources/6614

Intergovernmental Panel on Climate Change (IPCC) 1988

Kyoto Protocol - 1997

- IPCC certified the scientific basis of the greenhouse effect.
- Emission targets set to reduce emissions of six greenhouse gases from 1990 levels.

  (CO_2, CH_4, N_2O, HFC's, PFC's, and SF_6)
- U.S.A. did not ratify
- Many members such as Canada did not meet targets. Canada has since withdrawn.

45

Kyoto successors

- 'Washington Declaration' - 16 February 2007
- Copenhagen 2009
- Cancun 2010
- South Africa 2011
- Qatar/South Korea 2012 (COP 18)
- Warsaw, 2013
- UN Climate Summit, 2014
- Paris, 2016

46

Remember: Ozone/CFC's summary

- Potentially catastrophic series of events.
- Smoking gun.
- Substitutes were (are) available.
- Economic setback (but not devastating).
- Montreal Protocol, and current refinements.

47

Compare: Climate change summary

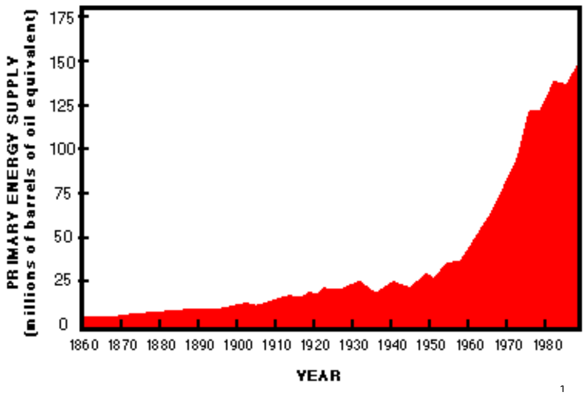
- Scientific events.
- Smoking gun?
- Substitutes available?
- Economic setback?
- Government, industry, personal action? Protocols?

48

Focus on Energy

What is energy? Where does the abundance of energy – electricity, gasoline, natural gas, etc. - that people have available today come from? Since the industrial revolution began in the 18th century, humankind have discovered a multitude of energy sources to help power our society. The average life expectancy has been extended and the world's population has grown, while our use of external energy sources has continued to grow even faster. With that, there have been rewards, consequences and challenges along the way.

Refer to the information discussed in the previous Focus section as well as Part V of this text and elaborate on the following focus boxes, solving any problems that appear. Make note of the important role that 'fossil' fuels have played and continue to play in meeting our energy demands. In order to determine the best route to meeting our future energy needs, one must understand the benefits and challenges of the processes that are currently in use.



1

Energy

- Energy can be defined as the capacity to supply heat or do work. One type of work (*w*) is the process of causing matter to move against an opposing force.

2

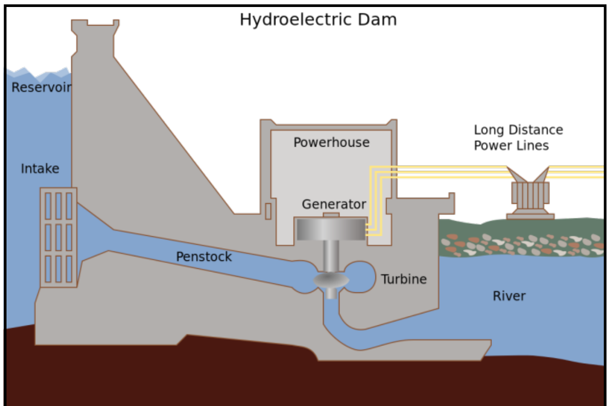
Two types of energy associated with objects can be defined

potential energy - the energy an object has because of its relative position, composition, or condition.

kinetic energy - the energy that an object possesses because of its motion.

Label the following hydroelectric dam with (i) potential energy, (ii) kinetic energy, (iii) work.

3



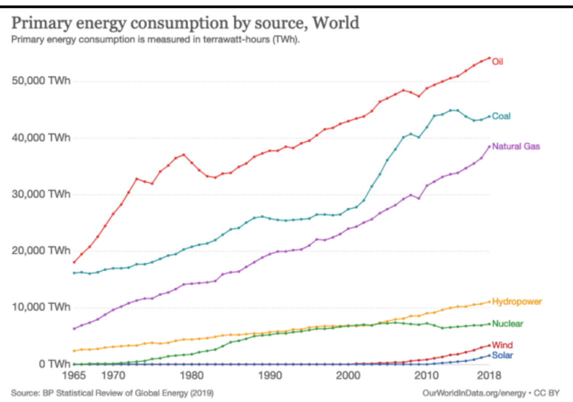
Tennessee Valley Authority; SVG version by [Tomia](). Licenced GFDL and CC-BY-2.5

4

Some sources of Energy

- Hydro Reservoirs
- Chemical Bonds
- Nuclear Transformations
- Solar Power

5



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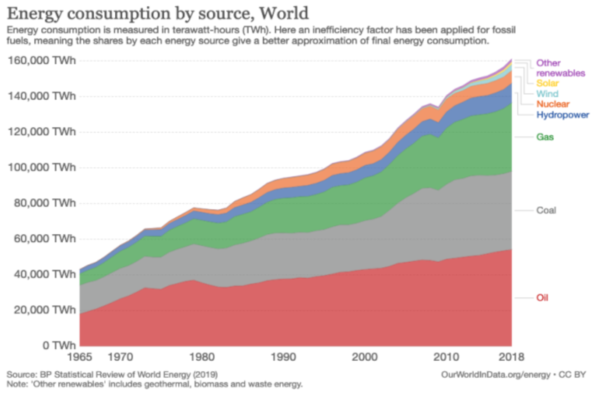

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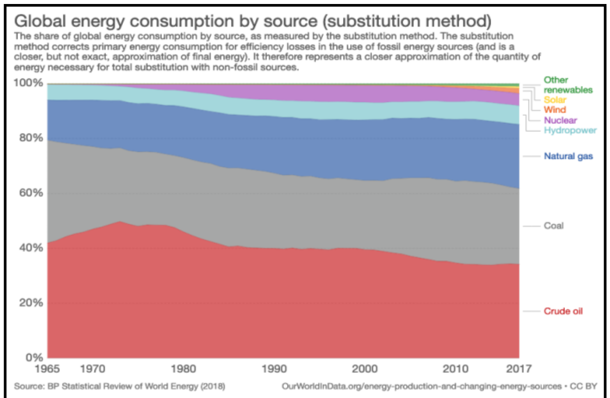

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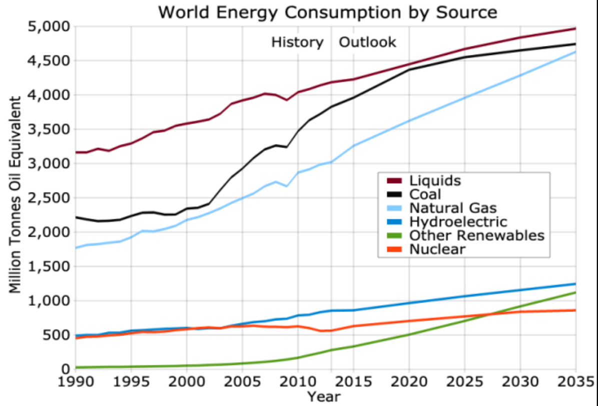


"File:World Energy Consumption Outlook 2014.svg" by Delphi234 is licensed under CC0 1.0

9

Chemical Bond Energy

The rearrangement of atoms in chemical reactions… breaking bonds and forming new bonds... may require energy, or it may release energy.

10

Bond energy - is the amount of energy that is required to break a chemical bond. Thus, it is also the amount of energy that is released when that same chemical bond is formed.

Exothermic - releases energy
Endothermic - requires energy

11

Show the balanced reaction for the combustion of hydrogen and determine the energy change for the reaction (per mole of H_2 combusted as well as per gram of H_2 combusted). Is this energy absorbed or released by the reaction?

12

Average Bond Lengths and Bond Energies for Some Common Bonds

Bond	Bond Length (Å)	Bond Energy (kJ/mol)
C–C	1.54	345
C = C	1.34	611
C ≡ C	1.20	837
C–N	1.43	290
C = N	1.38	615
C ≡ N	1.16	891
C–O	1.43	350
C = O	1.23	741
C ≡ O	1.13	1080

13

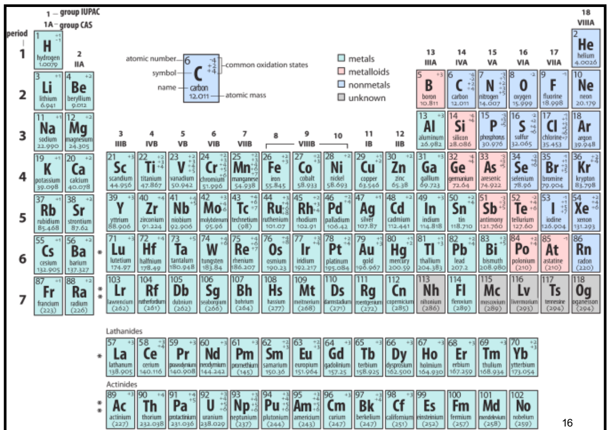
Bond Energies (kJ/mol)

Bond	Bond Energy	Bond	Bond Energy	Bond	Bond Energy
H–H	436	C–S	260	F–Cl	255
H–C	415	C–Cl	330	F–Br	235
H–N	390	C–Br	275	Si–Si	230
H–O	464	C–I	240	Si–P	215
H–F	569	N–N	160	Si–S	225
H–Si	395	N = N	418	Si–Cl	359
H–P	320	N ≡ N	946	Si–Br	290
H–S	340	N–O	200	Si–I	215
H–Cl	432	N–F	270	P–P	215
H–Br	370	N–P	210	P–S	230
H–I	295	N–Cl	200	P–Cl	330
C–C	345	N–Br	245	P–Br	270

14

C–C	345	N–Br	245	P–Br	270
C=C	611	O–O	140	P–I	215
C≡C	837	O=O	498	S–S	215
C–N	290	O–F	160	S–Cl	250
C=N	615	O–Si	370	S–Br	215
C≡N	891	O–P	350	Cl–Cl	243
C–O	350	O–Cl	205	Cl–Br	220
C=O	741	O–I	200	Cl–I	210
C≡O	1080	F–F	160	Br–Br	190
C–F	439	F–Si	540	Br–I	180
C–Si	360	F–P	489	I–I	150
C–P	265	F–S	285		

15



16

What is the approximate energy change associated with the combustion of methane (per mole of CH_4 combusted as well as per gram of CH_4 combusted)? Is this energy absorbed or released by the reaction? Do the same determination for ethane (C_2H_6)

17

Coal

- ~ $C_{135}H_{96}O_9NS$
- ~ 85 % Carbon
- ~ 30 kJ per gram
- solid
- various grades
- there's lots of it. (~ 400 years)

18

http://www.worldometers.info/

- Energy at:
  http://www.worldometers.info/

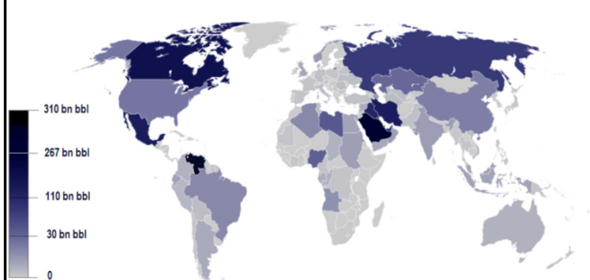
19

Petroleum

- Various Hydrocarbons
- ~ 48 kJ per gram
- liquid
- must first be refined (distillation)
- value captures/conversions
- there's less known reserves (< 50 years) and it's becoming harder to extract ("peak oil")
- 'Where oil is' *vs.* 'Where oil is used'

20

Oil reserves by country



21

Gasoline additives

- **Tetraethyl lead**
  - - used to be added to gasoline to minimize premature firing.
  - - Pb would be released to the environment
  - - Pb interferes with the function of certain enzymes

22

Elimination of octane enhancing tetraethyl lead (TEL) created a need to find substitutes.

MTBE (methyl tertiary-butyl ether)

Due to groundwater contamination concerns, MTBE is now banned in the U.S., Canada and Japan.

Ethanol (ethyl alcohol)

23

Natural Gas

- C_1-C_4 hydrocarbons
- gas
- approximately 55 kJ per gram
- Approximately 150 years remain of known reserves

24

Biomass

- Wood
- Biodiesel
- Ethanol

- Show the balanced chemical reaction for the combustion of ethanol (CH_3CH_2OH). Calculate the energy change per mole and per gram of ethanol combusted.

25

Ethanol

- Brazil, USA, Manitoba, others
  - corn, sugarcane
  - cellulosic ethanol

Alternative Combustibles

- For example:
- $C_{(s)} + H_2O$ ------> $CO + H_2$ (water gas)

--> Fisher-Tropsch synthesis of gasoline (Fe or Co catalyst)

27

Biogas

- The ferment of animal and vegetable wastes
- 60% methane

28

Garbage

- More than 1/3 is directly combustible, as little as 10% of the original volume may end up as landfill
- Japan, Germany, US

29

Fossil Fuels, Biofuels - Photosynthesis

- Note: the energy in all fossil fuels and biofuels originates from the same place - chlorophyll in plants captures solar energy and converts CO_2 and H_2O into carbohydrates, essentially storing the energy in the chemical bonds of the new molecule.
- $6\ CO_2 + 6\ H_2O$ + sunlight $\Rightarrow$ $C_6H_{12}O_6 + 6\ O_2$

30

Fossil Fuels – the reasons for Conservation and Alternatives

- Pollution
- Climate Change
- Finite Resources - ‘Peak oil’
- Political consequences
- Are practically non-renewable. Now is the time to ensure we have this important energy and feedstock source (for chemical synthesis) for the future.

31

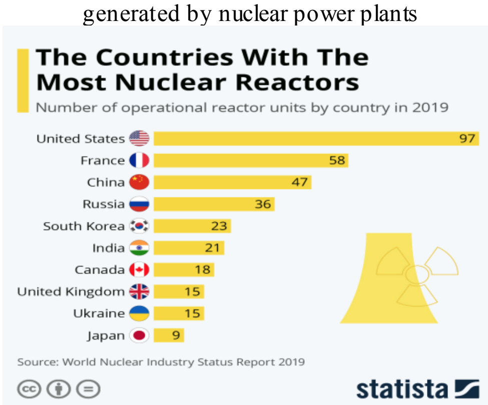
Focus on Nuclear Energy

"Cooling towers" by US Department of State is licensed under CC BY-NC 2.0

When nuclear energy came into the mainstream in the 1950's, it was envisioned, by then chairman of the U.S. Atomic Energy Commission Lewis L Strauss, to be such a cheap and powerful source of energy that "our children would enjoy in their homes electrical energy too cheap to meter." While some countries like France have since adopted and developed '*nuclear*' as the primary source of energy for electricity generation, in most countries the development of nuclear power has slowed considerably. While the energy potential might remain, accidents and other complications have led to considerable costs and political opposition to the development of nuclear power programs.

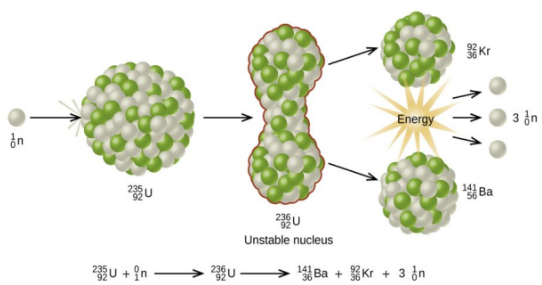
Refer to the information discussed in the previous Focus section as well as Part XIV of this text and elaborate on the following focus boxes, solving any problems that appear. While learning the basics of balanced nuclear reactions and radioactivity, make note of important distinctions between nuclear and other types of fuels in meeting our energy demands. In order to determine the best route to meeting our future energy needs, one must understand the benefits and challenges of the processes that are currently in use.

- Approximately 15% of the world's electricity is generated by nuclear power plants



1

Nuclear fission - the splitting of a large nucleus into smaller ones with the release of energy.



2

- Show the balanced nuclear reaction for U-235 absorbing a neutron and undergoing fission to produce Ba-141, Kr-92 and neutrons.

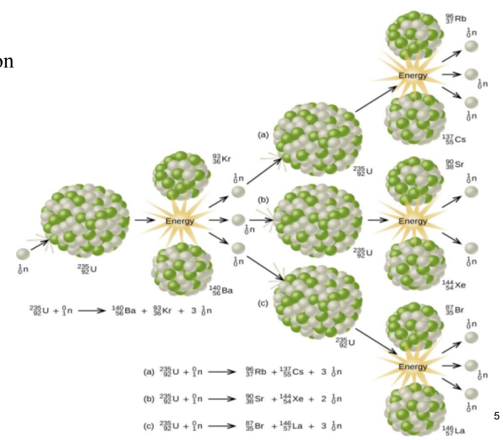
3

Energy is released because the sum of the masses of these fragments is less than the original mass, and this missing mass (about 0.1 percent of the original mass of U-235) has been converted into energy according to Einstein's equation:

$E=mc^2$

4

Chain Reaction



5

Using $E = mc^2$

Ex: Calculate the amount of energy that is released when 1.0 kg of U-235 undergoes nuclear fission.

0.1 % of the mass is converted to energy

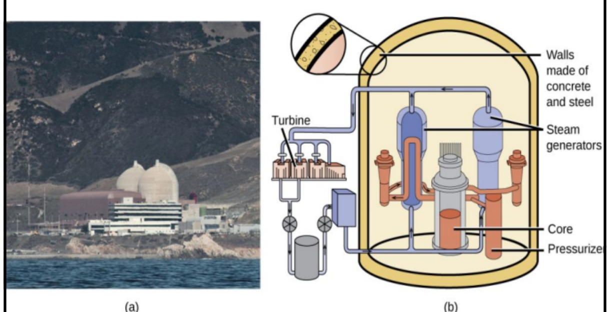
6

CANDU
(**CANada Deuterium Uranium**)
reactor

- natural U ---> UO_2
- ceramic pellets --> rods ---> bundles

7

Nuclear Reactor



8

For equivalent energy production

- ***3-400 tons coal***
- *emitting:*
  - 1400 tons CO2
  - 12 tons SOx
  - 4 tons NOx
- Expensive and becoming more so

- ***one CANDU bundle***
- no C, S or N oxides emitted into air
- Postulated to potentially be a very cheap source of energy

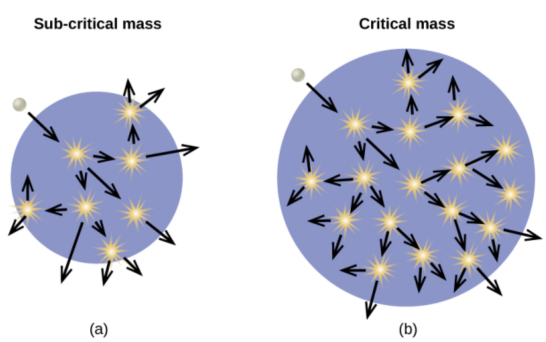
9

Could a nuclear power plant undergo a nuclear explosion?

Power plant (controlled fission)
= 0.7-5 % U-235

Nuclear explosion (critical mass)
= 90 % U-235

10



 11

Could nuclear power plant fuel be used to make weapons?

 12

The isotopes U-235 and U-238 behave essentially the same in all chemical reactions, so the separation/purification of either of these isotopes is *extremely* difficult.

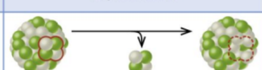
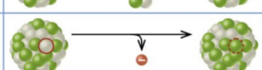
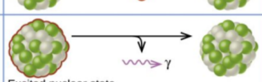
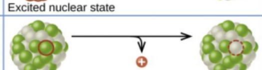
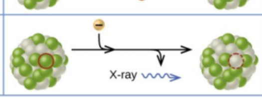
However, plutonium is a much more likely candidate. Show the balanced nuclear reaction of how U-238 absorbing neutrons can create Pu-239 via the release of beta particles.

13

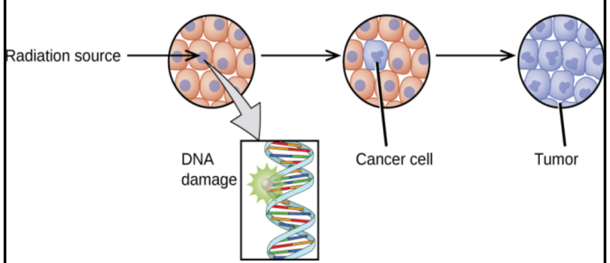
Accidents/Waste

- Large amounts of radioactivity can be very dangerous.
- Radioactivity - the spontaneous emission of radiation by certain elements

14

Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	${}^{A}_{Z}X$ ${}^{4}_{2}He + {}^{A-4}_{Z-2}Y$		A: decrease by 4 Z: decrease by 2
Beta decay	${}^{A}_{Z}X$ ${}^{0}_{-1}e + {}^{A}_{Z+1}Y$		A: unchanged Z: increase by 1
Gamma decay	${}^{A}_{Z}X$ ${}^{0}_{0}\gamma + {}^{A}_{Z}Y$		A: unchanged Z: unchanged
Positron emission	${}^{A}_{Z}X$ ${}^{0}_{+1}e + {}^{A}_{Y-1}Y$		A: unchanged Z: decrease by 1
Electron capture	${}^{A}_{Z}X$ ${}^{0}_{-1}e + {}^{A}_{Y-1}Y$		A: unchanged Z: decrease by 1

15



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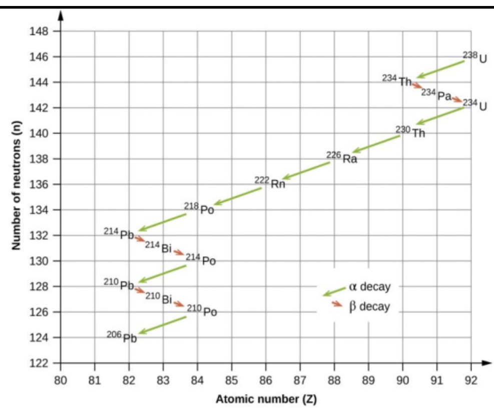

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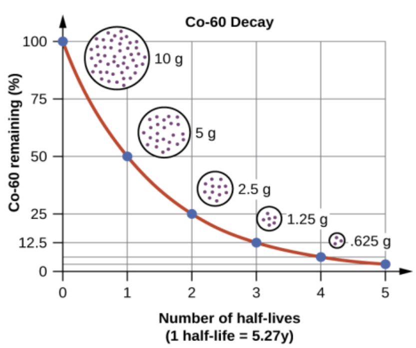
Half-life ($t_{1/2}$): the time required for a quantity to reduce to **half** of its initial value.



 18

Accidents

- *Chernobyl*
  - *design flaw, graphite moderator, fire/explosion*
- *Fukushima*
  - *earthquake/tsunami*

Nuclear Waste

20

Long-term geologic repository

21

22

Spent Nuclear Fuel: A Trash Heap Deadly for 250,000 Years or a Renewable Energy Source?

- http://www.scientificamerican.com/article.cfm?id=nuclear-waste-lethal-trash-or-renewable-energy-source

23

A sample of 10 Kg of Thorium-234 is allowed to radioactively decay for 96.4 days. Approximately, how much Th-234 remains?
[Th-234 $t_{1/2}$ = 24.1 days]

- A. 7.5 Kg
- B. 5 Kg
- C. 2.5 Kg
- D. 1.25 Kg
- E. 0.625 Kg

24

Carbon Dating

- A sample of fossilized remains is found to contain 6% of the original (living organism) ^{14}C. Approximately, how old are the remains? [C-14 $t_{1/2}$ = 5715 years]

25

Summary

- Fossil Fuels
- BioFuels
- Nuclear Fuels

26

Focus on Alternative Energy

"Alternative Energy Galore" by roliathBrickworx is licensed under CC BY-NC 2.0

There are a multitude of what one might call 'alternative' sources of energy - biofuels, wind, solar, solar-thermal, hydroelectric, fuel cells - simply because they supply a small portion of the world's total energy needs. In this text, we introduced biofuels in the 'Focus on Energy' section as an alternative combustible to the fossil fuels that we spent much of that section on. In this section we will introduce a few other fuels but limit our discussion to hydroelectric power, batteries and hydrogen based power as they all have significant chemistry-based fundamentals at the level of this text.

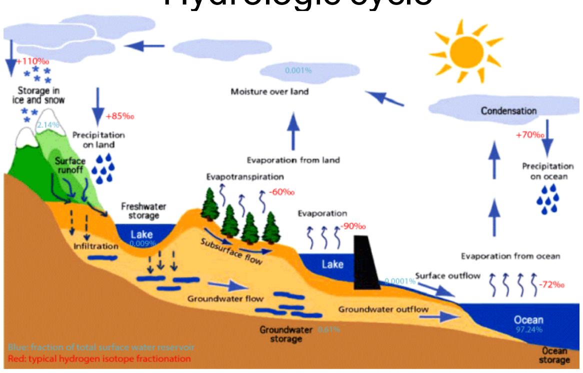
Refer to the information discussed in the previous Focus section as well as Part XII of this text and elaborate on the following focus boxes, solving any problems that appear. While learning the basics of electrochemistry and using hydrogen as a fuel source, make note of important distinctions between this and other types of fuels in meeting our energy demands. One must understand the benefits and challenges of the processes that are currently in use and those being proposed to meet our future energy demands in order to decide on the best route for moving forward.

Solar Power

- Direct Heat
- Wind
- Water - the hydrologic cycle.

1

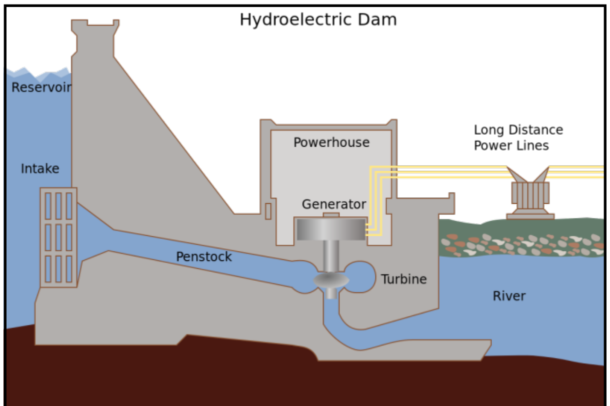
Hydrologic cycle



2

Hydroelectric generating station

3



Tennessee Valley Authority; SVG version by Tomia. Licenced GFDL and CC-BY-2.5 4

The creation of hydroelectric reservoirs can have a number of environmental consequences. Research and elaborate.

"Dam causes a 100km of devastation" by joellehernandez is licensed under CC BY-NC-ND 2.0 5

A **battery** (or galvanic cell) is a system for the direct conversion of chemical energy to electrical energy.

- convenient, transportable sources of stored energy.

"AJ Batteries001" by Curious Gregor is licensed under CC BY-NC-SA 2.0

Nickel-Cadmium battery

- a redox reaction between cadmium and nickel. Show the full redox reaction and identify the species that is being oxidized and that which is being reduced.

7

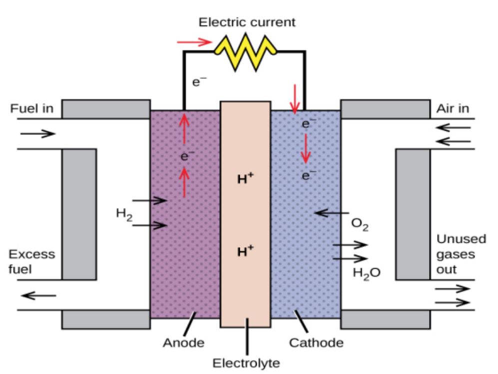
Fuel Cell

- chemical reaction corresponding to hydrogen combustion but the energy is released as electricity.
- combustion:

  $H_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow H_2O_{(l)}$

  yields 143 kJ/g and water
- fuel cell redox reaction: has the same overall reaction as combustion

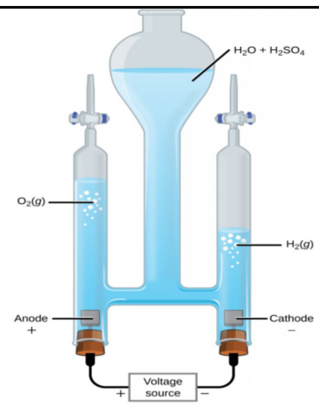
8



9

- Show the half-reactions and overall reaction involved in the release of energy from hydrogen in a fuel cell. Summarize how this compares with the combustion of hydrogen.
- To make the hydrogen economy a reality, where will we get the hydrogen?

10



Photovoltaics - involves the flow of electrons directly from the impact of the sun.
- normally using semiconductors

12

Solar Thermal - concentration of heat energy directly from the sun for use in heating or electricity generation

13

Fusion

- of nuclei can produce massive amounts of energy.
  - What is the fusion reaction involved in the sun? What are the conditions necessary for this reaction? Do you think this is a feasible route to power in the future?

14

Summary

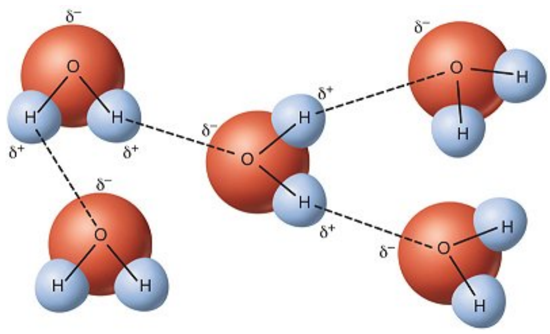
- Fossil Fuels
- BioFuels
- Nuclear Fuels
- Alternative Energy Sources

15

Focus on Water Quality

Water – one of the most important and plentiful resources on earth, yet it's availability and quality are lacking to many around the globe. From droughts to pollution, the lack of clean water is a question of health, and ultimately, survival, for millions of people. Water is known to chemists as the 'universal solvent' and in this section the role of solutes and solvents are examined in terms of interactions between molecules to give a glimpse of the field of environmental fate modelling – the prediction of where a chemical might end up in the environment. In order to make a proper assessment of a compound in the environment, there are a number of other factors that must be examined, such as persistence and toxicity, full discussions of which are beyond the scope of this text.

Refer to the information discussed in the previous Focus section as well as Part VIII and IX of this text and elaborate on the following focus boxes, solving any problems that appear. While the field is very complicated, a general ability to approximate the relative solubility of a compound and do rudimentary calculations in concentration terms can provide an important resource for the examination of contaminants in the aqueous environment.



1

Hydrogen bond

- an especially strong intermolecular force between an electronegative element (such as N, O or a halogen) and a hydrogen that is covalently bound to an electronegative element (such as N, O or a halogen).

Demonstrate the dominant intermolecular in the following solutions. Does the solution have hydrogen bonding?

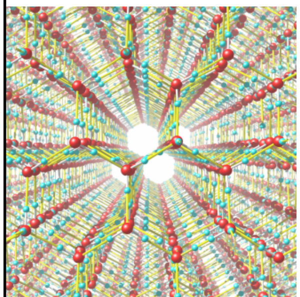
(i) H_2O, (ii) NH_3, (iii) CH_3-O-CH_3, (iv) NH_3 in CH_3-O-CH_3.

2

Surface Tension

3

Ice floats



"iceIh" by vitroid is licensed under CC BY 2.0

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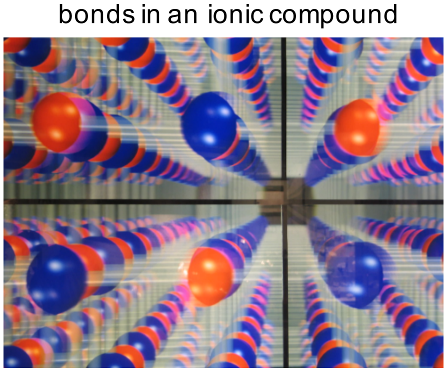
4

ion

- an atom or group of atoms that has lost or gained one or more electrons so that it is no longer electrically neutral
  - Will form based on the 'stable' electron configuration of the noble gases (Group 8)
- ex: show the reaction of elemental potassium and elemental chlorine to form potassium chloride

5

lattice energy - a measure of the strength of bonds in an ionic compound



"Structure of a Crystal lattice" by Fovea Centralis is licensed under CC BY-ND 2.0

6

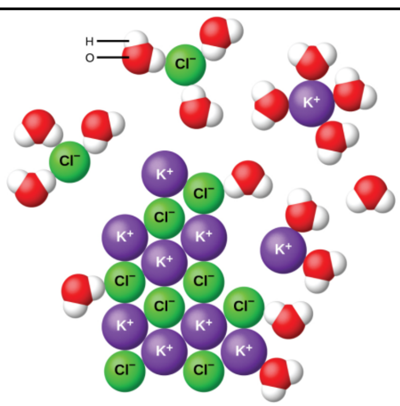
Second Law of Thermodynamics

Spontaneous processes involve an increase in the entropy (a measure of the disorder of the system) of the universe.

7

Show the reaction for the dissolution of solid KCl in water and summarize the interactions that must be overcome and the interactions that result after the dissolution.

8



9

Now consider the following mixtures. How soluble will they be in one another?

$CH_3CH_2CH_2CH_2CH_3$
+
H_2O

10

immiscible liquids

$CH_3CH_2CH_2CH_2CH_3$
+
$CH_3CH_2CH_2CH_3$

12

"Like dissolves like"

- Polar (hydrophilic) compounds normally dissolve other polar compounds, while non-polar (hydrophobic) dissolve non-polar.

13

$CH_3CH_2OH + H_2O$

$CH_3CH_2CH_2OH + H_2O$

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH + H_2O$

14

$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH + H_2O$

- Now, estimate/measure the differential solubility of a compound between these two solvents.
  - K_{ow}: octanol-water partition coefficient.
  - Environmental fate modelling

15

16

Would you expect MgCl2 to be more soluble in water or the long chain hydrocarbon, $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$?

- A. Water
- B. $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$
- C. Equal solubility.

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Would you expect $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2Cl$ to be more soluble in water or the long chain hydrocarbon, $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$?

- A. Water
- B. $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$
- C. Equal solubility.

18

Compared to CH_3CH_2OH, what would you expect the solubility properties of $CH_3CH_2CH_2CH_2OH$ to be?

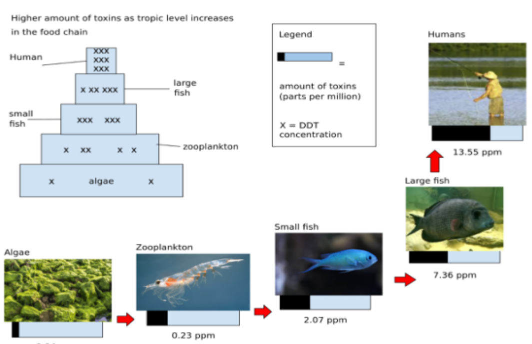
- A. More soluble in octanol, less soluble in water and organic matter.
- B. Less soluble in octanol, more soluble in water and organic matter.
- C. More soluble in octanol and organic matter, less soluble in water.
- D. Less soluble in octanol and organic matter, less soluble in water.

19

Bioconcentrate: from non-dietary (water) partitioning

20

Biomagnify: concentration up the foodchain

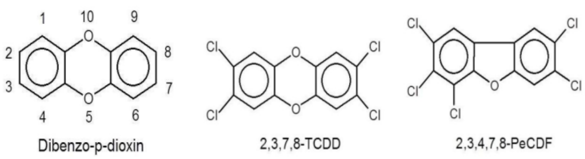


21

Bioaccumulate

22

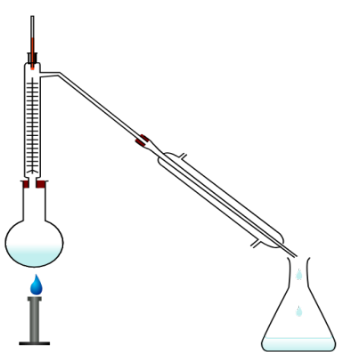
Ex: "dioxins"



- lipophilic, bioaccumulate
- teratogen, carcinogen, mutagen

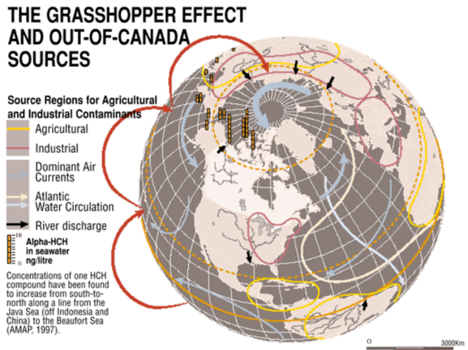
23

The Grasshopper Effect: Global Distillation



24

Figure 4.2: The Grasshopper Effect



Canada House of Commons government report
https://www.ourcommons.ca/DocumentViewer/en/36-2/ENVI/report-1/page-66

25

Concentration Terms

Mass % = [mass solute/mass solution] x 100

Molarity = moles solute/L of solution

Ex: What is the concentration (*in mass % and M)* of the resulting solution when you add 5 grams of NaOH to 95 mL of water?

26
5.4

Concentration Terms

Parts per hundred (percent)

1 g of NaCl as part of 100 g of solution is a 1% NaCl solution
1 in 100 = 1 in 1 x 10^2

Parts per million (ppm)

1 part solute in 1,000,000 parts solvent = 1 in 1 x 10^6

Parts per billion (ppb)

1 part solute in 1,000,000,000 parts solvent = 1 in 1 x 10^9

Ex: The maximum contaminant level [MCL] for dioxin in drinking water is set at 3 × 10^{-8} ppm. A sample of drinking water is found to contain 2 × 10^{-4} ppb. Is the sample of water safe to drink?

27
5.4

The 1 %

- For example, present carbon dioxide concentrations in air ~ 0.040 %
- Q - if the indoor CO_2 concentration in a building is measured at 4002 ppm, would this be considered normal?
  - ie. What is the 0.040 % concentration expressed as ppm?

28

The 1 %

- For example, carbon dioxide = 0.040 % or 400 ppm.

So, the measurement of 4002 ppm is 10 times the normal tropospheric [CO_2].
(most likely, more outside air would need to be introduced to the building)

29

- The permissible upper limit for concern for ground level carbon monoxide is given as 0.009 ppt. A researcher finds the level in Winnipeg one day to be measuring at 6 ppm. What is the measured value in ppt and is this permissible?
  - A. 0.06 ppt, this is not permissible
  - B. 0.06 ppt, this is permissible
  - C. 0.006 ppt, this is not permissible
  - D. 0.006 ppt, this is permissible
  - E. 0.0006 ppt, this not permissible

30

- The permissible upper limit for ground level ozone is 0.12 ppm. A researcher finds the level in Toronto one day to be measuring at 580 ppb. What is the measured value in ppm and is this of concern?
  - A. 58 ppm, this is of concern
  - B. 0.00058 ppm, this is of no concern
  - C. 0.58 ppm, this is of concern
  - D. 58 ppm, this is of no concern
  - E. 0.58 ppm, this is of no concern.

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Focus on Acid Precipitation

Photo by Steve Schlachter reproduced with permission

At many times, in many places, lakes and forests can experience a surge in acidity causing an unhealthy environment whereby the fish and trees in that ecosystem will die. What is an acid? Where does this extra acidity in the environment come from? Why are some places more prone to acidity than others? In many cases, it seems that the source of the acidity is found in one area, while the environmental effects of the acidity are observed in another. In this section, acids and bases will be introduced in the context of this 'extra acidity' and the source of what is referred to as 'acid precipitation' will be traced. While understanding whole ecosystems is quite complicated, a decent foundation in acid-base chemistry and the calculations involved with a number such as pH can enable a person to understand the data involved and take part in the discussions required to solve the problem.

Refer to the information discussed in the previous Focus section as well as Part XI of this text and elaborate on the following focus boxes, solving any problems that appear.

One way to define an acid is as a substance that releases hydrogen ions, H^+, in aqueous solution.

Since the hydrogen ion has no electron, and only one proton (hence the positive charge), the hydrogen ion sometimes is referred to as a proton.

Example:

$$HCl(g) \xrightarrow{H_2O} \underset{\text{(a proton)}}{H^+(aq)} + Cl^-(aq)$$

However, in aqueous solution, the H^+ will be associated with a water molecule to form the hydronium ion, H_3O^+

One way to define a base is as a substance that releases hydroxide ions, OH^-, in aqueous solution.

Show how each of these produce hydroxide in water:

NaOH

NH_3

When acids and bases react with each other, it is called a neutralization reaction.

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)$$

In neutralization reactions, hydrogen ions from an acid combine with the hydroxide ions from a base to form molecules of water.

The other product is a salt (an ionic compound) and will often be dissolved in the aqueous solution.

pH and pOH

- a measure of the concentration of H_3O^+ (pH) and OH^- (pOH) in solution.

$pH = -\log [H_3O^+]$

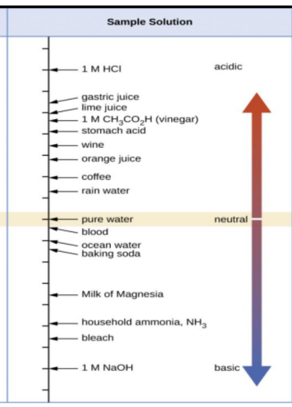
$pOH = -\log [OH^-]$

$pH + pOH = 14$

What is the pH of a solution with $[H_3O^+] = 1.0 \times 10^{-7}$ M ? What is the pOH

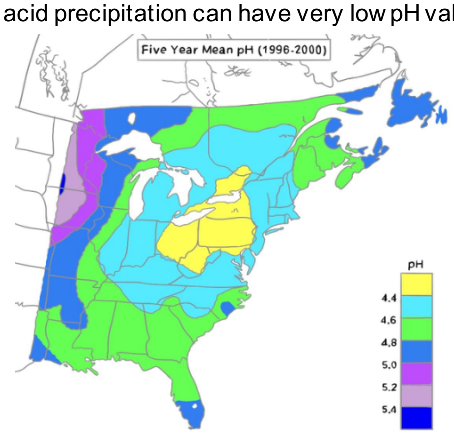
What is the pH of a solution with $[H_3O^+] = 2.0 \times 10^{-6}$ M ? What is the pOH

$[H_3O^+]$ (M)	$[OH^-]$ (M)	pH	pOH
10^1	10^{-15}	–1	15
10^0 or 1	10^{-14}	0	14
10^{-1}	10^{-13}	1	13
10^{-2}	10^{-12}	2	12
10^{-3}	10^{-11}	3	11
10^{-4}	10^{-10}	4	10
10^{-5}	10^{-9}	5	9
10^{-6}	10^{-8}	6	8
10^{-7}	10^{-7}	7	7
10^{-8}	10^{-6}	8	6
10^{-9}	10^{-5}	9	5
10^{-10}	10^{-4}	10	4
10^{-11}	10^{-3}	11	3
10^{-12}	10^{-2}	12	2
10^{-13}	10^{-1}	13	1
10^{-14}	10^0 or 1	14	0
10^{-15}	10^1	15	–1



Pure water has a pH of 7.0, while normal rain has a pH of around 5.7 because of dissolved CO_2. Show how the dissolution of CO_2 in water produces carbonic acid H_2CO_3 which then reacts with water to produce hydronium ions.

But acid precipitation can have very low pH values

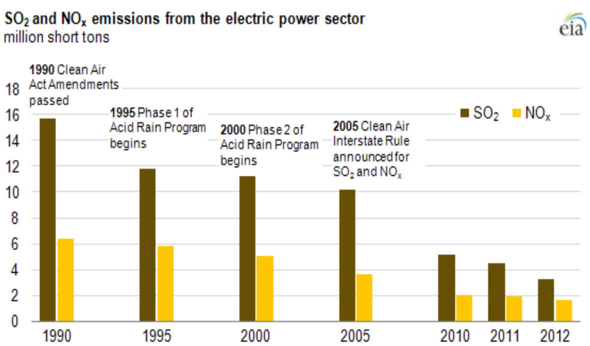


Remember: Because the pH scale is logarithmic, 1 unit of pH is a difference of 10 times in the amount of acidity.

Analysis of rain for specific compounds has indicated that the primary components responsible for the extra acidity are the ***oxides of sulfur and nitrogen***. Explain, using chemical reactions, how the combustion of coal can lead to oxides of sulfur and nitrogen, and to acidic aqueous solutions.

Acidic precipitation damages forests, aquatic life, monuments

"Smokey Mountain National Park - Acid Rain on Top" by You want it darker is licensed under CC BY-NC-ND 2.0



Source - U.S. Energy Information Administration

[BBC - The bittersweet story of how we stopped acid rain](https://www.bbc.com/future/article/20190823-can-lessons-from-acid-rain-help-stop-climate-change) (ELA)

https://www.bbc.com/future/article/20190823-can-lessons-from-acid-rain-help-stop-climate-change

Focus on Polymers

Synthetic polymers were developed in the early 20th century, and since that time have become ubiquitous in our world. The clothing, the helmet and the goggles on the people riding these snowmobiles and, indeed, even the material that makes up the housing of the snowmobiles, are all synthetic polymers.

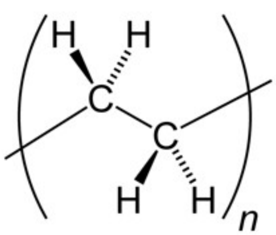
The computers we work on, our cell phones and much of the furniture around us all have a large number of different polymers involved in them. The success of these materials, however, is a double-edged sword – their variety continues to provide us with amazing and useful materials, but the fact that they are cheap, vast and persistent is also causing a unique environmental catastrophe. In this section, the basic reactions involved in producing the most common polymers will be examined along with a survey of associated environmental issues and current developments being made to address those issues.

Refer to the information discussed in the previous Focus section as well as Part XIII of this text and elaborate on the following focus boxes, solving any problems that appear.

A **monomer** is a molecule that forms the basic unit for **polymers**. Monomers bind to other monomers to form repeating chain molecules through a process known as **polymerization**.

Addition polymers

Ex: Show the initiation and beginning of chain growth for the formation of polyethylene



Show the general reaction for the formation of polypropylene

Show the general reaction for the formation of polystyrene

Show the general reaction for the formation of Polyvinyl chloride (PVC)

How many chloroethene (vinyl chloride) subunits are in a molecule of polyvinyl chloride with a molar mass of 3122.5 g/mole?

- A. 100
- B. 500
- C. 250
- D. 50
- E. 550

What is the molar mass of one molecule of polypropylene with 300 propylene subunits?

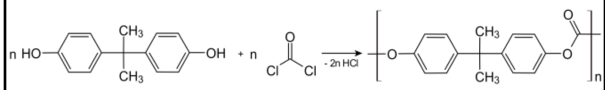
- A. 12,600
- B. 6,300
- C. 25,200
- D. 100,800
- E. 50,400

Condensation Polymers

- Monomer units join by eliminating (splitting out) a small molecule, often water.
- Ex: show the reaction for the formation of polyethylene terephthalate (PET)

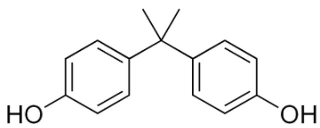
Polycarbonates

- The main polycarbonate material is produced by the reaction of bisphenol A and phosgene COCl2.



- strong, transparent
- Have a number of uses and were once used in the production of drinking bottles.

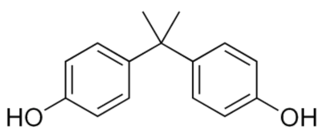
Polycarbonates and bisphenol A



- Bisphenol A: estrogen-mimicking, hormone-like properties

  Various studies have found a range of effects - from ‘significant’ to ‘none’

Polycarbonates and bisphenol A



- Bisphenol A: estrogen-mimicking, hormone-like properties
- Bisphenol A leachate low-dose effects (Saal and Hughes; https://ehp.niehs.nih.gov/doi/10.1289/ehp.7713)
  - Industry-funded studies tend to find no significant effects
  - government-funded studies tend to find significant effects

Commercial polymers also normally have a number of other additives and processing agents

- Antioxidants, blowing agents, colorants, coupling agents, flame retardants, heat stabilisers, impact modifiers, lubricants, plasticisers, preservatives, uv stabilisers, etc.

After Use?

- Re-use, Recycle, *Down*-cycle.
- Incineration
  - Produces CO2 and potentially other harmful compounds
- Trash - Landfill

"Plastic Beach" by ravi khemka is licensed under CC BY 2.0

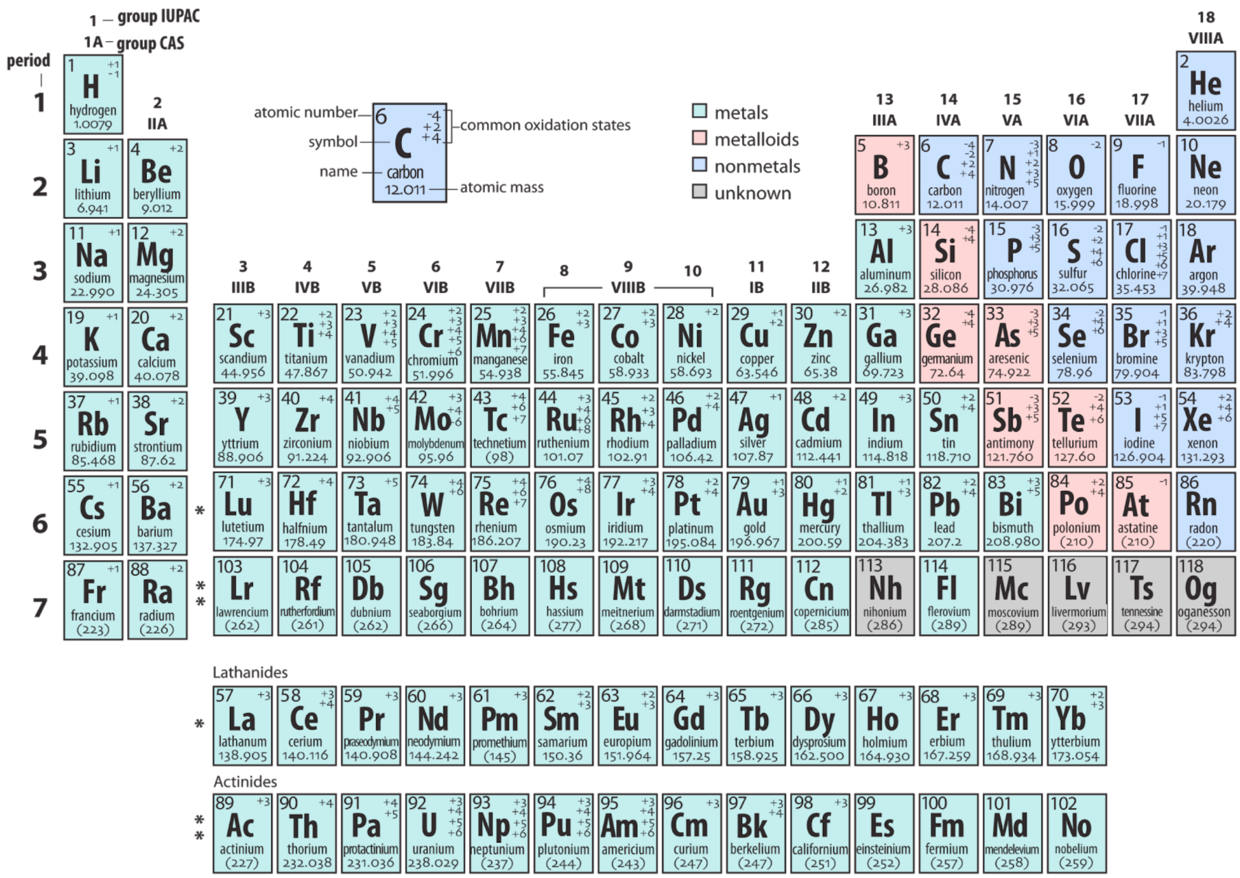
"Albatross at Midway Atoll Refuge" by USFWS Headquarters is licensed under CC BY 2.0

National Geographic - biodegradable polymers

https://www.nationalgeographic.com/environment/2018/11/are-bioplastics-made-from-plants-better-for-environment-ocean-plastic/#close

After Use?

- Re-use, Recycle, *Down*-cycle – ex: depolymerization
  - Energy intensive, low market value.
- Incineration – high energy content,
  - Produces CO2 and potentially other harmful compounds
- Trash/Landfill
- Biodegradation – some natural polymers are degraded by worms, bacteria and fungi.
  - must be designed into the polymer
  - disposal sites must be redesigned to allow this.


1 — group IUPAC
1A – group CAS
period
18
VIIIA
2
IIA
13 IIIA
14 IVA
15 VA
16 VIA
17 VIIA
3 IIIB
4 IVB
5 VB
6 VIB
7 VIIB
8
9 VIIIB
10
11 IB
12 IIB
atomic number
symbol
name
6 C carbon 12.011 -4 +2 +4
common oxidation states
atomic mass
metals
metalloids
nonmetals
unknown
1 H hydrogen 1.0079
2 He helium 4.0026
3 Li lithium 6.941
4 Be beryllium 9.012
5 B boron 10.811
6 C carbon 12.011
7 N nitrogen 14.007
8 O oxygen 15.999
9 F fluorine 18.998
10 Ne neon 20.179
11 Na sodium 22.990
12 Mg magnesium 24.305
13 Al aluminum 26.982
14 Si silicon 28.086
15 P phosphorus 30.976
16 S sulfur 32.065
17 Cl chlorine 35.453
18 Ar argon 39.948
19 K potassium 39.098
20 Ca calcium 40.078
21 Sc scandium 44.956
22 Ti titanium 47.867
23 V vanadium 50.942
24 Cr chromium 51.996
25 Mn manganese 54.938
26 Fe iron 55.845
27 Co cobalt 58.933
28 Ni nickel 58.693
29 Cu copper 63.546
30 Zn zinc 65.38
31 Ga gallium 69.723
32 Ge germanium 72.64
33 As aresenic 74.922
34 Se selenium 78.96
35 Br bromine 79.904
36 Kr krypton 83.798
37 Rb rubidium 85.468
38 Sr strontium 87.62
39 Y yttrium 88.906
40 Zr zirconium 91.224
41 Nb niobium 92.906
42 Mo molybdenum 95.96
43 Tc technetium (98)
44 Ru ruthenium 101.07
45 Rh rhodium 102.91
46 Pd palladium 106.42
47 Ag silver 107.87
48 Cd cadmium 112.441
49 In indium 114.818
50 Sn tin 118.710
51 Sb antimony 121.760
52 Te tellurium 127.60
53 I iodine 126.904
54 Xe xenon 131.293
55 Cs cesium 132.905
56 Ba barium 137.327
71 Lu lutetium 174.97
72 Hf halfnium 178.49
73 Ta tantalum 180.948
74 W tungsten 183.84
75 Re rhenium 186.207
76 Os osmium 190.23
77 Ir iridium 192.217
78 Pt platinum 195.084
79 Au gold 196.967
80 Hg mercury 200.59
81 Tl thallium 204.383
82 Pb lead 207.2
83 Bi bismuth 208.980
84 Po polonium (210)
85 At astatine (210)
86 Rn radon (220)
87 Fr francium (223)
88 Ra radium (226)
103 Lr lawrencium (262)
104 Rf rutherfordium (261)
105 Db dubnium (262)
106 Sg seaborgium (266)
107 Bh bohrium (264)
108 Hs hassium (277)
109 Mt meitnerium (268)
110 Ds darmstadium (271)
111 Rg roentgenium (272)
112 Cn copernicium (285)
113 Nh nihonium (286)
114 Fl flerovium (289)
115 Mc moscovium (289)
116 Lv livermorium (293)
117 Ts tennessine (294)
118 Og oganesson (294)
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57 La lathanum 138.905
58 Ce cerium 140.116
59 Pr praseodymium 140.908
60 Nd neodymium 144.242
61 Pm promethium (145)
62 Sm samarium 150.36
63 Eu europium 151.964
64 Gd gadolinium 157.25
65 Tb terbium 158.925
66 Dy dysprosium 162.500
67 Ho holmium 164.930
68 Er erbium 167.259
69 Tm thulium 168.934
70 Yb ytterbium 173.054
Actinides
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90 Th thorium 232.038
91 Pa protactinium 231.036
92 U uranium 238.029
93 Np neptunium (237)
94 Pu plutonium (244)
95 Am americium (243)
96 Cm curium (247)
97 Bk berkelium (247)
98 Cf californium (251)
99 Es einsteinium (252)
100 Fm fermium (257)
101 Md mendelevium (258)
102 No nobelium (259)