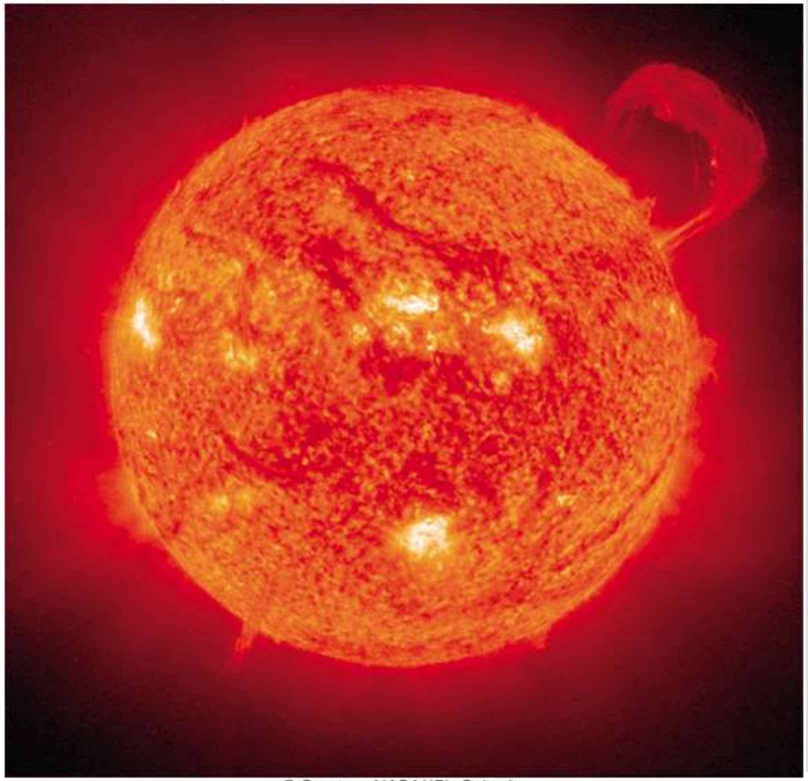
2 THE LAWS OF MATTER AND ENERGY

PowerPoint® Lecture prepared by Gary A. Beluzo

STUDENT LEARNING OUTCOMES

After reading this chapter, students will be able to

- Explain the importance of the law of conservation of matter for environmental science.
- Describe the limits that the laws of thermodynamics place on energy conversion.
- Distinguish the important differences between chemical, physical, and nuclear changes in matter.
- Provide examples of the entropy law in nature and in their everyday lives.
- Define and describe the major forms of energy they use in their everyday lives.



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Lead: Industrial Marvel and Environmental Villain

- Soft, extremely dense, bluish element
- Body paint and ceremonial powders (Native Americans)
- Romans had lead aqueducts
- Paint, batteries, water pipes, gasoline in 20th century
- Nervous system and hearing problems, and kidney damage in children
- High blood pressure, digestive problems, and nerve disorders in adults

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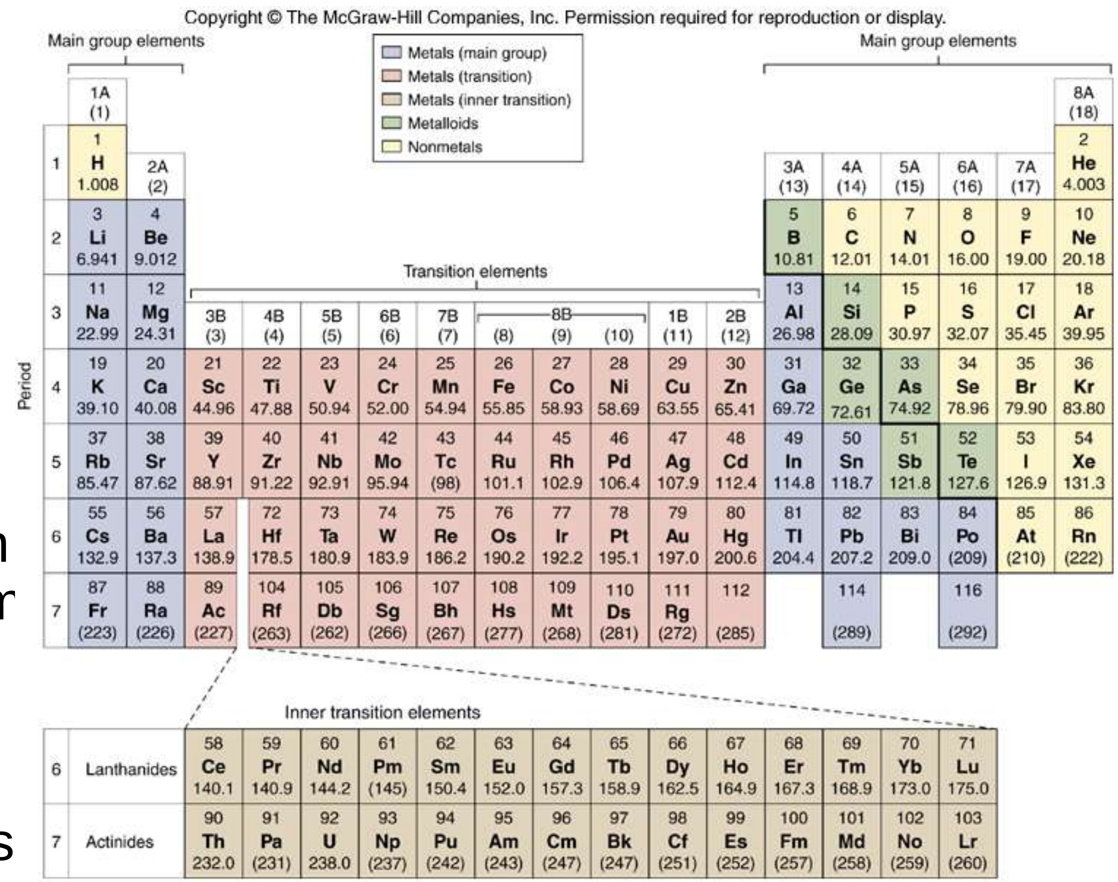
Matter: Elements and Compounds

- Matter
  - Solid, liquid, gas
- Elements
  - Cannot be broken down by chemical means
  - **92** naturally occurring
  - Carbon (C), Hydrogen (H), Sulfur (S), Sodium (Na)
- Compounds
  - Two or more elements in combination
  - $\mathbf{H_2O}$, NaCl, CO_2, NH_3



Elements Essential for Life

- 25 elements are essential for life
- Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, and Sulfur (**CHONPS**) are macronutrients
- Carbon makes up 2/3 of the dry weight of an organism
- Trace elements include manganese, iodine, selenium
- Toxic metals include lead, cadmium, aluminum, copper, and zinc

TABLE 2.1 Naturally Occurring Elements in the Human Body

Symbol	Element	Atomic Number	Percent Weight of Human Body
O	Oxygen	8	65.0%
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.5
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

Trace elements (less than 0.01%): boron(B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

Source: Data from Campbell, *Biology, Third Edition*, Benjamin Cummings.

Elements in the Earth's Crust

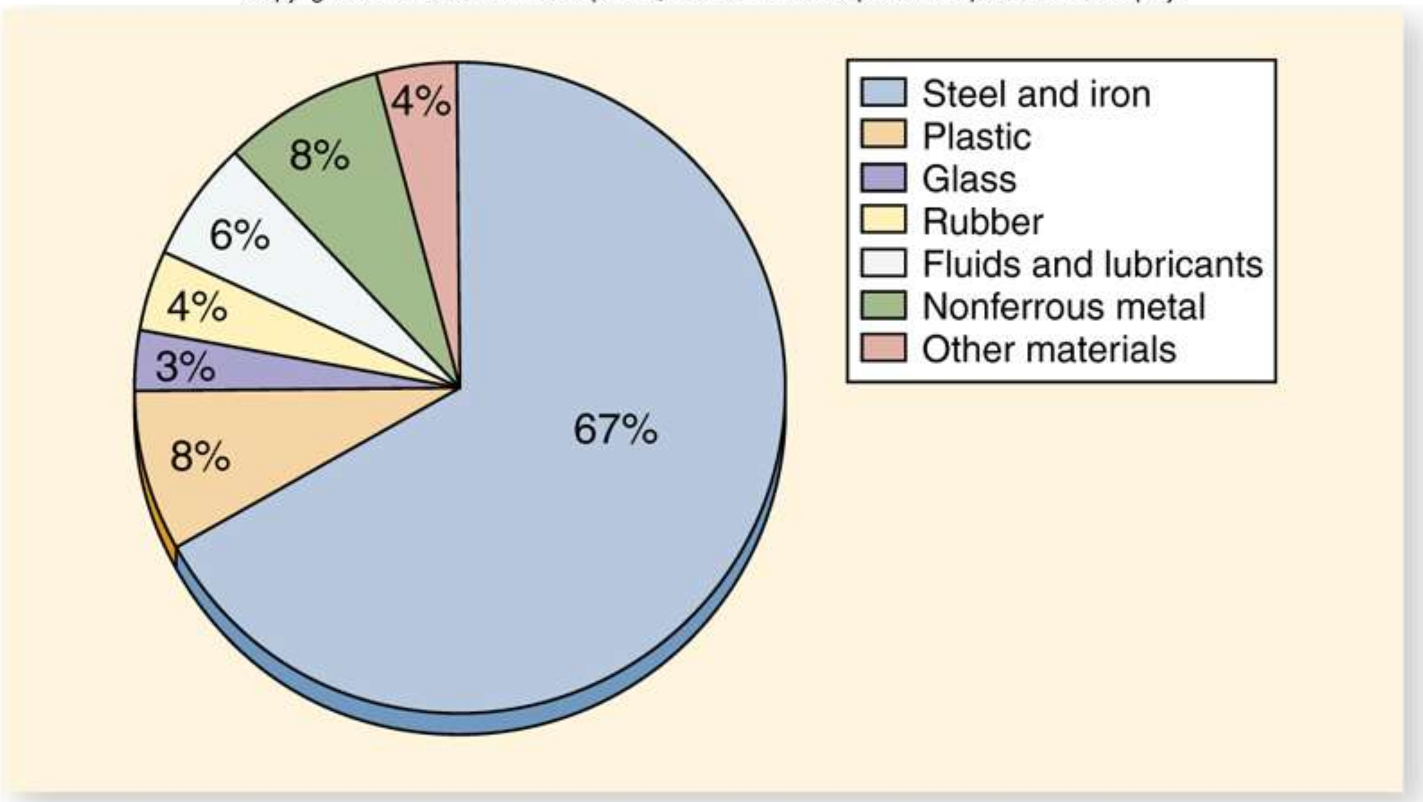
- **10** elements make up more than 99% of the Earth's crust.
- Material Resources include copper, iron, uranium, nickel, phosphorus, sulfur, and silicon.
- Energy Resources include hydrocarbons (C and H) such as coal, oil, and natural gas.

TABLE 2.2 Average Composition of Earth's Crust

Symbol	Element	Atomic Number	Percent Weight of Earth's Crust
O	Oxygen	8	46.60%
Si	Silicon	14	27.72
Al	Aluminum	13	8.13
Fe	Iron	26	5.00
Ca	Calcium	20	3.63
Na	Sodium	11	2.83
K	Potassium	19	2.59
Mg	Magnesium	12	2.09
Ti	Titanium	22	0.44
H	Hydrogen	1	0.14
		Total	99.17
		All other elements	0.83
			100.00%

Source: Data from B. Mason, *Principles of Geochemistry*, Wiley.

Elements and the U.S. Automobile



Atoms: The Building Blocks of Elements

- **Atoms** are units of matter; the smallest units having the chemical and physical properties of its element.
- **Subatomic particles**
  - Protons (atomic number)
  - Neutrons (isotope)
  - Electrons (chemical bonds)
- A **molecule** is an assembly of two or more tightly bound atoms behaving as a single object.

$^{12}_{6}C$

$^{235}_{92}U$ $^{238}_{92}U$

H_2O

Chemical Reactions

- A substance is transformed into a different substance by changing its chemical composition.

$$2H_2 + O_2 \rightarrow 2H_2O$$

reactants products

Matter is conserved in a chemical reaction

Reactions cannot create or destroy matter but only **rearrange the atoms**

Combustion to Release Energy

- In this reaction the energy contained within the chemical bonds of methane (natural gas) is released during combustion

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + 210.8\ \text{kcals}$$

reactants products

The release of CO2 is of concern to many scientists because of the link to climate change

Nuclear Changes

- 1898 radioactivity was identified by Marie Curie, a French scientist
- Alpha particles, beta particles, gamma rays
- More than 50 such radioactive isotopes or radioisotopes have been identified. **All elements with greater than 83 protons are radioactive.**

$$^{239}_{94}\mathrm{Pu} \longrightarrow \,^{235}_{92}\mathrm{U} + \,^{4}_{2}\text{Alpha particle} + \text{Energy}$$

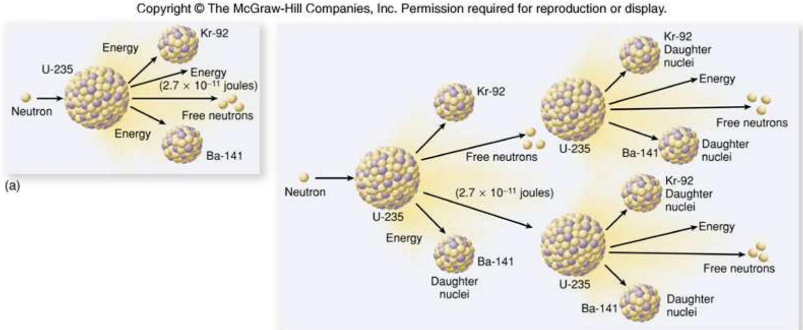
Radioactivity and Half-Lives

- A **half-live** is the time it takes for the process of radioactive decay to convert one-half of the atoms of one element to atoms of the second element.
- Each isotope has a characteristic half-life, ranging from millionths of a second to billions of years.

TABLE 2.3	The Half-Lives of Some Radioactive Isotopes
Isotope	**Half-Life**
^{238}U	4.5×10^9 years (4.5 billion years)
^{40}P	1.3×10^9 years
^{239}Pu	24,000 years
^{14}C	5,730 years
^{137}Cs	30 years
^{230}U	20.8 days
^{222}Ac	5 seconds
^{212}Po	0.3 microseconds (0.3 one-thousandth of a second)

Fission and Fusion

- Fission occurs when a large isotope splits into lighter isotopes
- Fusion occurs when nuclei of two light elements are combined together to form a heavier nucleus



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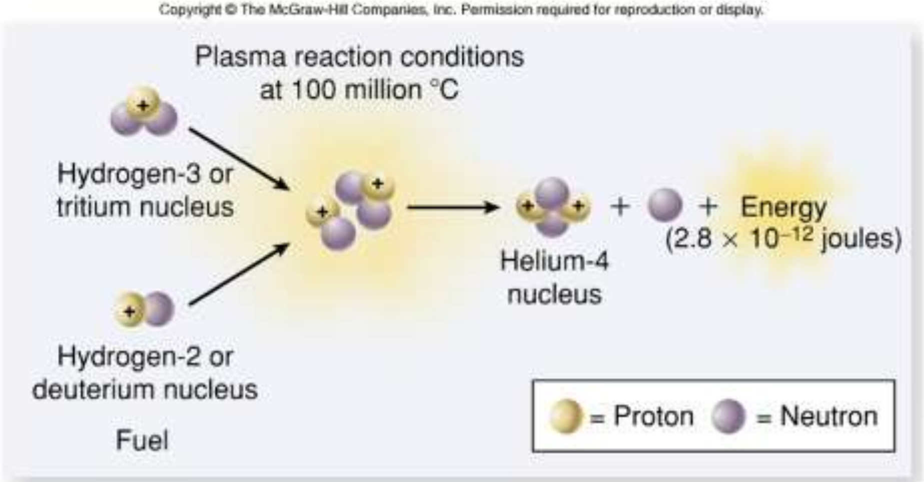
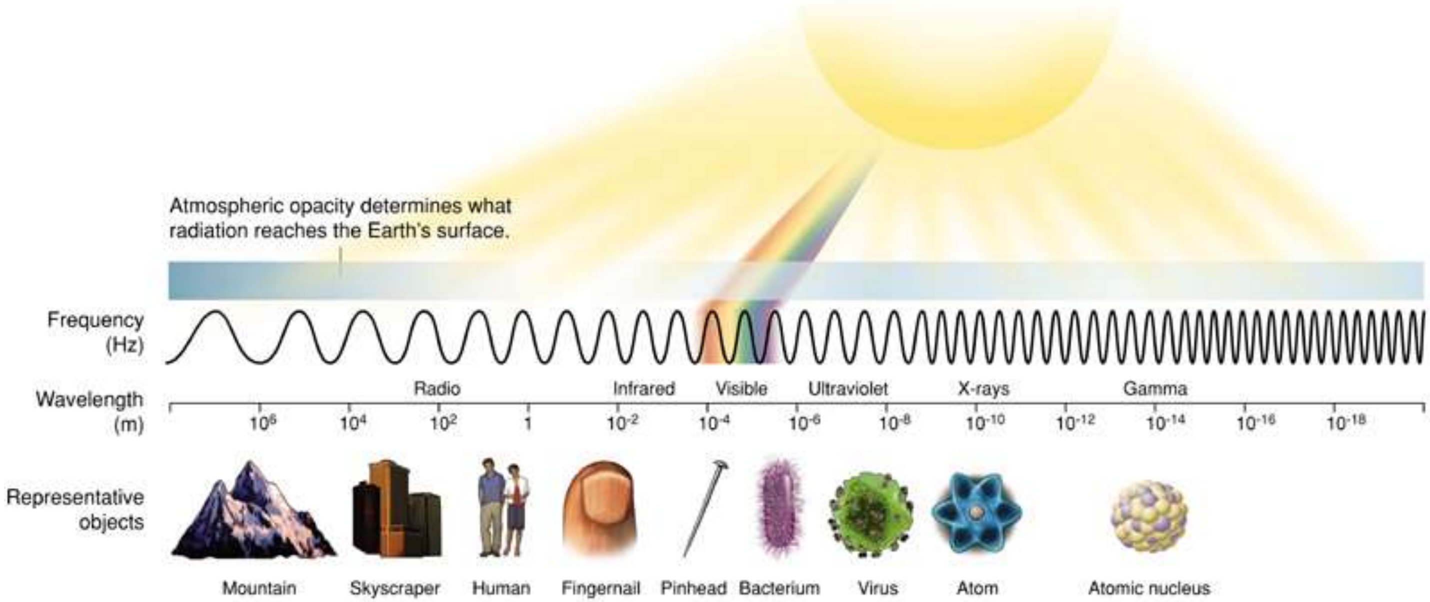


Law of Conservation of Matter

Importance of Energy

- Aristotle first used the term *energeia* (at + work)
- Energy is the ability to do work
- Used to organize materials into goods, provides heat, light, and other useful services
- In natural environment, energy evaporates water, makes plants grow, moves the large plates of the crust

Electromagnetic Radiation



Mechanical Energy

- Energy of organized motion
- Potential and kinetic energy

Potential Energy

- Energy of position
- Water stored behind dam, gallon of gasoline

Kinetic Energy

- Energy of Motion
- Flowing Water, moving car, person walking up stairs

Chemical Energy

- Energy stored in the arrangement of elements, such as energy stored in fossil fuels or carbohydrates
- Energy stored in the chemical bonds between the atoms
- Potential energy as chemical bonds until released

Nuclear Energy

- Energy that binds the protons and neutrons together in the nuclei of atoms.
- **$E = MC^2$** Einstein’s famous equation which relates matter to energy. A very small mass is converted to very large amount of energy
- Release of this energy is used to generate electricity in nuclear power plants

Electrical Energy

- The force of charged particles acting on one another. An electric current, is caused by the flow of electric charges.
- In electrical wires and appliances, the flow of energy is caused by the back and forth flow of electrons.

Heat

- Kinetic energy associated with the random motion of atoms and molecules.
- Temperature measures the average speed of atoms or molecules
- Heat is an important form of energy because all forms of energy can be expressed in their **heat equivalent**.

Gasoline is a form of potential energy, one liter of gasoline releases 32,500 kcals of heat when burned

Uranium is a form of nuclear fuel, one kilogram of uranium releases 4 billion kcals of heat when used

Work and Force

- Energy is the capacity to do work
- **Work = Force x Distance**
- Heat of fusion (80 calories/gram)
- Heat of vaporization (539 calories/gram)
- Solar energy also creates wind
- Society uses fossil fuels to do work in the manufacture of goods and services.
- **What is an energy converter?**

Solar energy→ Chemical Energy →Kinetic Energy→Heat

Energy and Power

- Power is the rate at which work is done or more generally, the rate at which energy is used.
- Power = Quantity of Work/Time to do Work
- 1 Horse can do work at 11kcals/minute (1 HP)
- Average power of 2005 car in the U.S. is 170 Horsepower

TABLE 2.4 Power of Various Events in Nature and Society

Event	Power	(Watts)
Flight of hummingbird	10^{-1}	(.1)
CD player spinning U2's latest song	10^{1}	(10)
Running a 100-meter dash	10^{3}	(1000)
Intercity truck trip	10^{5}	(100,000)
Avalanche with 500-meter drop	10^{7}	(10,000,000)
Tornado	10^{9}	(1,000,000,000)
Lightning	10^{13}	(10,000,000,000,000)
Richter magnitude 8 earthquake	10^{15}	(1,000,000,000,000,000)

Source: Data from V. Smil, *General Energetics: Energy in the Biosphere and Civilization*, Wiley.

First Law of Thermodynamics

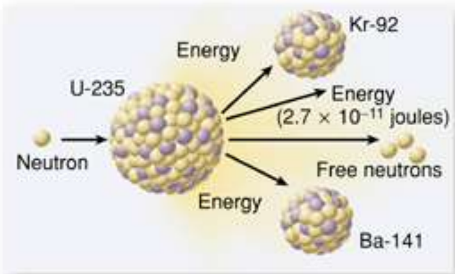
- There is no increase or decrease in the quantity of energy in any energy conversion.
- The QUANTITY of energy remains constant in every conversion process.

Second Law of Thermodynamics

- In all energy conversion processes energy loses its ability to do work and is degraded in quality.
- The QUALITY of the energy decreases with each energy conversion (i.e. more and more energy in the form of heat)
- **Energy Conversion Efficiency:**

$$\text{Efficiency} = \frac{\text{kcals of work out}}{\text{kcals of total energy converted}}$$

Efficiency of Energy Conversions



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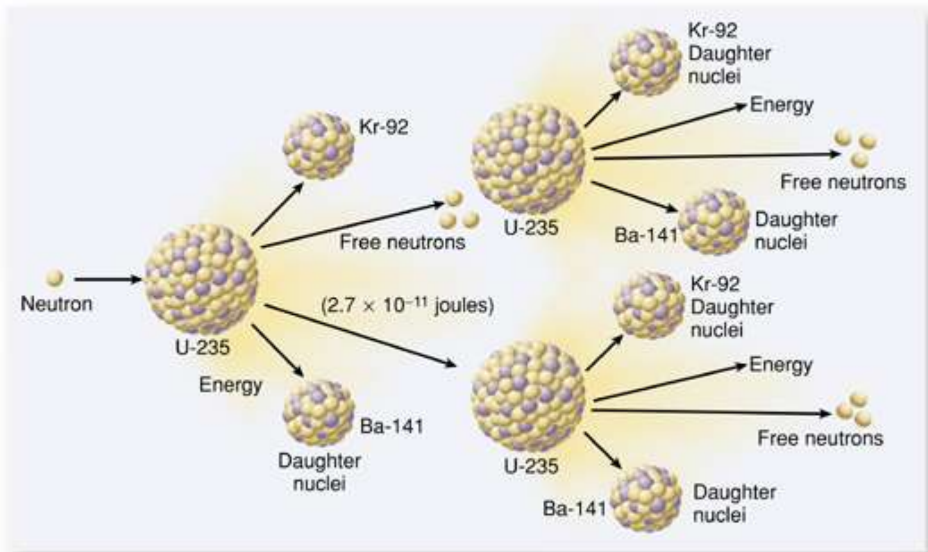

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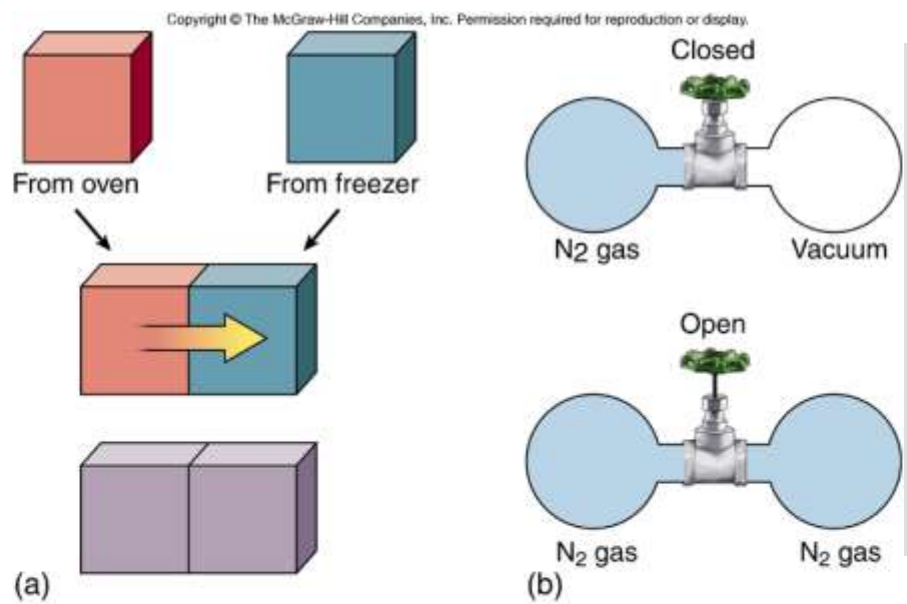
Entropy

- Conversion of energy from a highly organized state to a disorganized state
- It is the degree of order or organization in a system.
- Clausius' work applied the concept to energy, but scientists since then have found the same principle applies to all changes in materials.
- **Spontaneous process**



Energy and Materials Balance

- The law of conservation of matter, laws of thermodynamics, and the entropy law provide a foundation for the study of environmental problems.
- Pollution, Resource Depletion, Waste Assimilation are examples
- **Energy and Materials Balance**

Coal Burning Power Plant