Preview of Period 8: Energy and Mass

8.1 Einstein’s Equation, $E = Mc^2$ Compounds

What happens to the mass of a substance that gains or loses energy?

8.2 Nuclear Processes

How can an atom’s nucleus change?

What is the difference between physical, chemical, and nuclear changes?

8.3 Nuclear Forces

What holds nuclei together?

8.4 Nuclear Stability

Which nuclei are stable?
Einstein’s Equation relates mass and energy

The amount of energy contained in matter equals the mass times $C^2$ ($C=$ the speed of light)

$$E = M C^2$$

- $E =$ energy (joules)
- $M =$ mass (kilograms)
- $c =$ the speed of light $= 3 \times 10^8 \text{ m/s}$

As we will see, this is probably the most important equation of the 20th century.
Act. 8.1 Einstein’s Equation applied to stored potential energy

Does the mass of the radio change when energy is added to its spring?

The weight of an object equals the object’s mass times the acceleration of gravity \((g)\)

\[
\text{Weight} = F = M \times g
\]

- \(F\) = force (newtons)
- \(M\) = mass of object (kilograms)
- \(g\) = acceleration of gravity = 9.8 m/s\(^2\)

Work is done when a force moves an object over some distance in the direction of the force.

\[
W = F \times D
\]

- \(W\) = work (joules)
- \(F\) = force applied (newtons)
- \(D\) = distance moved in the direction of the force (meters)
Act. 8.1 Einstein's Equation applied to phase changes

Does the mass of the water change when thermal energy is removed?

**Specific heat of a substance:** The amount of energy needed to raise the temperature of 1 gram of a substance by 1 degree C.

\[ Q = s_{\text{heat}} \times M \times \Delta T \]

- \( Q \) = heat added or subtracted (calories or joules)
- \( s_{\text{heat}} \) = specific heat (calories/gram °C or joules/kilogram °C)
- \( M \) = mass (grams or kilograms)
- \( \Delta T \) = change in temperature = \( T_{\text{final}} - T_{\text{initial}} \) (°C)

**Latent heat:** The amount of energy needed to change the phase of 1 gram of a substance.

\[ Q = L_{\text{heat}} \times M \]

- \( Q \) = heat (calories or joules)
- \( L_{\text{heat}} \) = latent heat (calories/gram or j/kg)
- \( M \) = mass (grams or kilograms)
Act 8.3 What holds an atom together?

What Holds Electrons in Orbit about a Nucleus?

**Electromagnetic force** - The electromagnetic attraction between negatively charged electrons and the positively charged nucleus binds the electrons to the nucleus.

What Holds Nucleons together in a Nucleus?

**Strong nuclear force** - holds nucleons (protons and neutrons) together in atomic nuclei. It is the strongest force, but it acts over only very short distances \((10^{-15} \text{ meters})\). At even shorter distances, the strong force is repulsive, which keeps the separation between adjacent nucleons nearly the same.
**Binding Energy**

*Chemical changes* involve making and breaking chemical bonds to create new molecules. The *binding energy of a molecule* is the energy you must supply to break the molecule up into its constituent atoms.

*Nuclear reactions* involve changes to the nuclei of atoms that result in the formation of atoms of new elements. The *binding energy of a nucleus* is the energy you must supply to break the nucleus up into free protons and neutrons.
Which Nuclei are Stable?

Stable nuclei have

♦ 82 or fewer protons.
♦ the same number of protons and neutrons for light elements with 20 or fewer protons.
♦ more neutrons than protons for elements with more than 20 protons.

Unstable nuclei become more stable by changing protons into neutrons or neutrons into protons.
Graph of neutron number $N$ vs proton number $Z$ for stable nuclei
Period 8 Summary

8.1: Atoms consist of a nucleus of nucleons - positively charged protons and neutrons with no charge. Surrounding the nucleus is a cloud of electrons. The number of protons (Z) determines which element an atom is.

8.2: Chemical changes involve making and breaking chemical bonds to create new molecules. Nuclear reactions involve changes to the nuclei of atoms that result in the formation of atoms of new elements.

8.3: The strong nuclear force binds nucleons into a nucleus by overcoming the electromagnetic repulsion of the positively charged protons.

8.4: Isotopes are nuclei of the same element (same number of protons, Z) that have different numbers of neutrons (N). Nuclei with more than 82 protons are unstable. Stable nuclei of smaller atoms tend to have the same number of neutrons and protons. Stable nuclei of large atoms that contain many protons have more neutrons than protons.
Period 8 Review Questions

**R.1** Suppose that the size of an atom were represented by the diameter of the OSU oval (about 250 meters). On this scale, how large would the nucleus of the atom be? What sort of object could represent it?

**R.2** Why does an H\(_2\) molecule have very nearly the same mass as a deuterium atom?

**R.3** What is the difference between a chemical change and a nuclear process? Why is the energy released when H atoms combine to form H\(_2\) molecules so much less than the energy released when protons and neutrons combine to form deuterium molecules?

**R.4** What is an isotope of an element? Which of the following isotopes of carbon – \( ^{12}_6 \text{C} \) or \( ^{14}_6 \text{C} \) – is stable? Why?

**R.5** Why do stable nuclei of large atoms that contain many protons have more neutrons than protons?