Investigating Stars Name:____Block:____________

FYI: Nuclear Fusion **E1:R4**

1. Read FYI: *Nuclear Fusion* **and** FYI: *Conservation of Mass and Energy*

   As you read use the spaces below to write down any information you find especially interesting. Also define the bold terms used in the text. If you run across any other words that you don't know the meaning of, write those down and ask your teacher to help you with them.

Word/Term	Definition
Binding Energy	The energy necessary for ___________ the ___________ and neutrons together in the ____________ of an atom is called **binding energy.**
Nuclear Fusion	The process of combining ________ nuclei into ___________ nuclei is called **nuclear fusion.**
Atomic Mass Units	A small unit of mass used in nuclear calculations that is approximately equal to the mass of a single __________ or ___________ (both particles in the nucleus) is called an **atomic mass unit.**
Electric Force	The **electric force** is what makes positively charged protons _______ each other.
Nuclear Force	The **strong nuclear force** is responsible for holding atomic __________ together when they fuse.
Conservation of Mass-Energy	Einstein showed that mass isn't necessarily conserved on its own, but that in any reaction, the _______ of mass and ___________ is conserved (stays the same before and after).
Extra space for additional words or interesting information.	

1. How is helium formed inside a star?

2. How does nuclear fusion produce the light and heat we receive from the Sun?

3. Why don't fusion reactions occur naturally on Earth?

4. What was Einstein's great insight into matter and energy?

Name:____ Block:______________

FYI Nuclear Fusion

The energy necessary for holding the protons and neutrons together in the nucleus of an atom is called **binding energy**. The binding energy of a nucleus differs in strength from atom to atom. Below is a graph that shows the binding energy per nucleon (a proton or neutron) for each atom with increasing atomic mass (A).

The greater the forces that hold the particles of a nucleus together, the more difficult it is to tear the nucleus apart. Thus, the greater the binding energy per nucleon, the more stable a nucleus is. Binding energy can also be thought of as nuclear potential energy. Everything in nature will become more stable if it can. This is the reason water flows downhill, the reason gasoline burns in your car engine, and also the reason that most nuclear reactions occur. Small nuclei can become more stable if they combine with each other to create nuclei that have a greater mass and a greater binding energy. The process of small nuclei combining to form larger ones is called **nuclear fusion**.

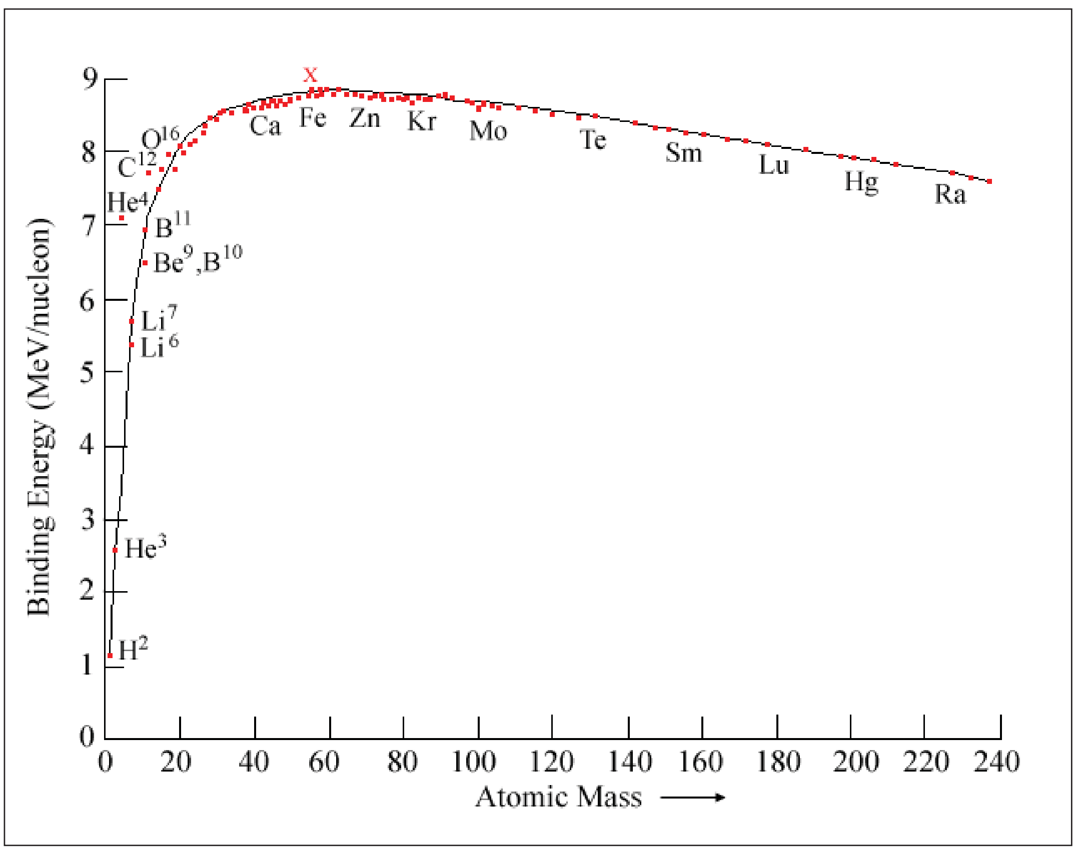

Figure 1-8: Graph of the binding energy per nucleon for the elements by atomic mass

When atoms fuse to form larger atoms, there is often a mass difference between the input atoms and the output. For example:

Two ^{2}H atoms can combine to form one ^{4}He.

The mass of two ^{2}H atoms is 2 x 2.01 **atomic mass units** = 4.02 atomic mass units.

The mass of one ^{4}He is 4.00 atomic mass units.

The resulting loss in mass (0.02 atomic mass units) is converted directly to energy. This energy is released in the form of electromagnetic radiation, such as the visible light and infrared radiation (heat) that are emitted by a star.

Fusion reactions need high pressure and temperature conditions to occur, and each stage of fusion inside the core of a star requires more and more energy as the force of repulsion between nuclei increases dramatically. All stars begin the fusion process by combining 4 hydrogen atoms to produce a single nucleus of helium. The core needs to be at least 10 million degrees C for fusion to proceed. For three helium atoms to fuse and produce a single carbon nucleus requires a temperature of 100 million degrees to proceed. For larger nuclei to fuse, temperatures in the billions of degrees may be necessary. If the internal temperature in the core of a star does not reach a temperature level necessary to initiate the next fusion reaction in the star, the fusion reactions in the core will cease. This leads to a slow and quiet death for most smaller stars, and to a more violent death for massive stars.

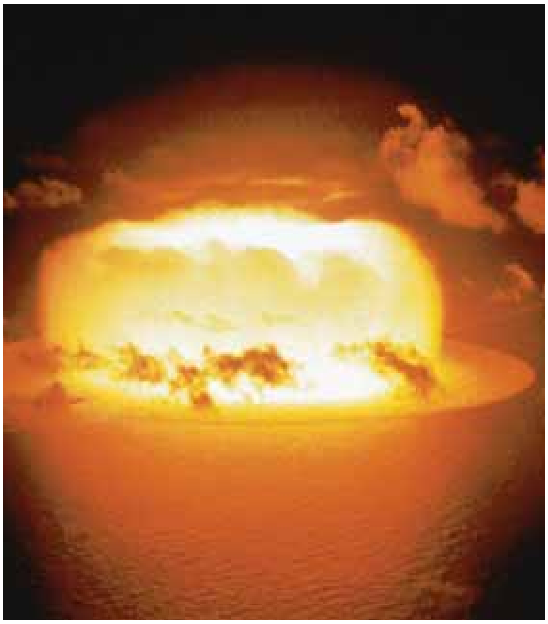

Figure 1-9: A hydrogen bomb explosion. An H-bomb is an example of an uncontrolled fusion reaction

As seen in Figure 1-8, the element that is at the peak of the binding energy curve, iron, has the most binding energy per nucleon. That means that iron cannot become more stable by combining with other nuclei. This fact will be of great importance later in this unit as you investigate how stars form, live their lives, and evolve through time.

FYI Conservation of Mass and Energy

The interior of stars is one of the only places in the universe where elements form naturally. The tremendous mass of the star's material generates a gravitational pull that constantly crushes down on the inner core, heating it to millions of degrees.

The heat and pressure resulting from the colossal gravitational force drive atoms and individual protons and neutrons close together. When particles are forced together under great pressure with a temperature of least 10 million degrees C, the **electric force**, which typically causes protons to repel one another, is overcome. Once this happens, the **nuclear force** takes over, and atoms fuse together, forming heavier atoms. Because the new atoms have more protons than either of the original atoms did, a new element has been created. This process, called nuclear fusion, is how many elements heavier than hydrogen and helium formed. When massive stars die, these materials become dispersed throughout space and may be incorporated into new stars, planets, and moons.

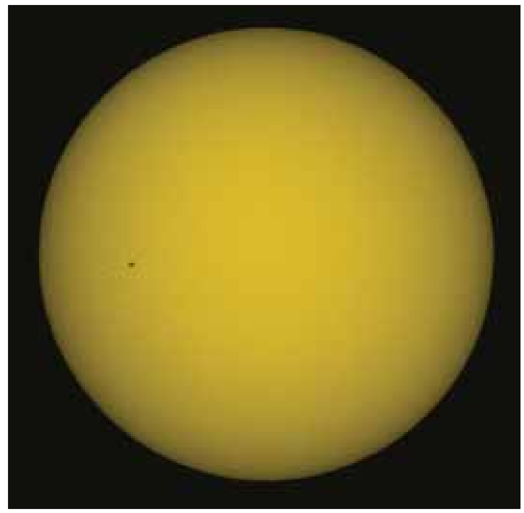

Figure 1-10: Image of the sun. The sun converts 600 million tons of hydrogen to helium every second and releases enormous amounts of energy in the process. Fusion only takes place in or near the core of stars where temperatures are high enough. During the conversion of hydrogen to helium, the sun loses 4 million tons of mass that is converted directly to energy.

In nuclear reactions, some mass is always converted to energy, so though it appears as if mass has been lost, the combination of mass and energy is ALWAYS conserved. The amount of energy that is released through a fusion reaction can be calculated by using Einstein's famous equation:

$$E = mc^2$$

where E is the energy released, m is the mass difference between the input and output, and c is the speed of light. So, Einstein changed the old conservation of mass law to a new principle: **The Conservation of Mass-Energy**. In any reaction, the sum of mass and energy is conserved.

The amount of energy created when two atoms fuse is very small. However, inside a star there are trillions and trillions of such reactions taking place simultaneously. Hence, stars release vast amounts of energy. Some of this energy feeds other fusion reactions. Some of it escapes to space. This energy is what sustains life on Earth.