LPP#9. A meteor contains 0.556 g of Pb-206 to every 1.00g U-238. Determine the age of the meteor.

Step 1: Calculate the moles of each nuclide present.

\[
\begin{align*}
0.566 \text{g Pb-206} & \times \\
1.00 \text{g U-238} & \times
\end{align*}
\]

Step 2: Calculate the total amount of U-238 present at time=0.

Step 3: Calculate fraction remaining.

Step 4: Calculate the rate constant for the decay process.

\[
k = \frac{0.693}{t_{\frac{1}{2}}}
\]

Step 5: Plug into

\[
t = \frac{\ln (N_t/N_0)}{-k}
\]

7. Nuclear Energy Reactions

Mass/Energy Relationships

Law of Conservation of Mass Plus Energy
In nuclear reactions, we must combine the laws of conservation of mass and energy.

Mass + Energy (before rxn) =

Conversion Between Mass and Energy

\[
E = m \cdot c^2
\]

energy (J) mass (kg) (speed of light = 2.998 \times 10^8 \text{ m/s})

Very ________ amounts of mass convert to very ________ amounts of energy.
**Atomic Mass Units**

1 amu = 1/12 the mass of one C-12 atom
1 amu = $1.66054 \times 10^{-24}$ g

$6.02214 \times 10^{23}$ amu = 1 g

**Rest Mass of Particles**

<table>
<thead>
<tr>
<th>Particle</th>
<th>amu/atom OR g/mol</th>
<th>amu/atom OR g/mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>$5.486 \times 10^{-4}$</td>
<td>p + e-</td>
</tr>
<tr>
<td>proton</td>
<td>1.00728</td>
<td></td>
</tr>
<tr>
<td>neutron</td>
<td>1.00866</td>
<td></td>
</tr>
</tbody>
</table>

**Binding Energy**

- The energy that holds nucleons together
- The higher the binding energy, ______________ - the loss in mass (that is converted to energy) that occurs when protons and neutrons combine to form a nucleus.

1. Lost mass is converted into energy.

   **Binding Energy** is usually expressed on a ______________ using the electron volts as the energy unit

   (1 eV = $1.60 \times 10^{-19}$ J) OR (1 MeV = $1.60 \times 10^{-13}$ J)

**EXAMPLE:** (shortened process)

Calculate the nuclear binding energy in MeV/nucleon for $^{194}_{77}$Ir, atomic mass = 193.965 0784 amu.

(Mass of e⁻ + p = 1.00783 amu; n = 1.00866 amu)

SOLUTION: First calculate the total mass of the individual particles

Mass of 77 (p) + (e⁻) =

Mass of 117 (n) =

__________________________

Mass of individual particles combined =

---
Next, solve for the **mass defect** by subtracting the mass of the $^{194}$Ir nucleus from the rest mass of the individual free particles.

Mass defect = mass of particles - mass of atom

We could use Einstein’s $E=mc^2$ to calculate the energy associated with this mass (converted to kg), then convert the J to MeV.

OR

We can use the convenient factor that 1 amu = 931.5 MeV

We now convert to MeV/nucleon

**Fission & Fusion**

The greater the binding energy/nucleon the more __________ the nucleus. The most stable nucleus is _________

1. Heavy nuclei - gain stability and release energy if they fragment to yield mid-mass elements in a process known as ____________________.
2. Light nuclei can gain stability and release energy if they fuse together in a process known as ________________.
**Fission**

The fragmentation of heavy nuclei.

1. Nuclei break into fragments when struck by neutrons.
2. Doesn't occur in exactly the same way each time.
3. Uranium-235 - more than 100 different fission pathways.

   a. One frequently occurring pathway is

   b. Released neutrons can induce further fission reactions, possibly resulting in a ________________

**Chain Reactions**

____________________ - a reaction that continues to occur even if the supply of neutrons from outside is cut off

____________________ - a sufficient amount of radioactive nuclide that allows the chain reaction to become self-sustaining
Critical Mass Considerations:

- Many of the neutrons escape before initiating additional fission events if the sample is too small.

Material that can sustain a nuclear fission chain reaction is said to be __________ or ________________. (Technically, fissile material can undergo fission with neutrons of any energy, whereas fissionable material requires high-energy neutrons.)

Enormous amounts of heat are generated during nuclear fission.

a. Fission of 1.0g of U-235 can produce

b. Some countries generate as much as of their power through nuclear fission

c. Products of fission reaction are themselves still radioactive with very long half-lives.

LP#10. According to the following reaction, what other isotope besides tellurium-137 is produced by nuclear fission of uranium-235

\[
\begin{align*}
^{238}_{92}U + \ ^{1}_{0}n & \rightarrow \ ^{137}_{52}Te + \ ^{1}_{0}n + ?
\end{align*}
\]
Uses of Fission Technology

Nuclear Reactors (for Energy)

Heat from a nuclear decay reaction is used to heat water to steam to drive turbines. Steam must be cooled before being released, so usually located

---

Nuclear Reactor Schematic

Heat produced in the reactor core is transferred by coolant circulating in a closed loop to a steam generator. The steam then drives a turbine to generate electricity.

---

Nuclear Fuels

Natural uranium ore contains about 0.05-0.3% uranium oxide U₃O₈, which consists of about __________ non-fissionable U-238 with only __________ fissionable U-235.

Nuclear reactors require a fuel with a higher concentration of U-235 than is found in nature. It is normally enriched to have about __________ of the uranium mass as U-235.

At this concentration, it is __________ possible to achieve the supercritical mass necessary for a nuclear explosion.
Each fuel assembly consists of fuel rods that contain many thimble-sized, ceramic-encased, enriched uranium (usually UO₂) fuel pellets.

Modern nuclear reactors may contain as many as __________ fuel pellets. These will be encased in Zr or steel rods. The amount of energy in each of these pellets is equal to that in almost a ton of coal or 150 gallons of oil.

**Control Rods**

Nuclear reactors use control rods to control the fission rate of the nuclear fuel by adjusting the number of slow neutrons present to keep the rate of the chain reaction at a safe level. Control rods are made of boron, cadmium, hafnium, or other elements that are able to ________________

i.e., boron absorbs neutrons by

**Atomic Bomb**

An atomic bomb contains several pounds of fissionable U-235 or Pu-239, a source of neutrons, and an explosive device for compressing it quickly into a small volume.

When fissionable material is in small pieces, the proportion of neutrons that escape through the relatively large surface area is great, and a chain reaction does not take place.

When the small pieces of fissionable material are brought together quickly to form a body with a mass larger than the critical mass, the relative number of escaping neutrons decreases, and a chain reaction and explosion result.

(a) The nuclear fission bomb that destroyed Hiroshima on August 6, 1945, consisted of two subcritical masses of U-235, where conventional explosives were used to fire one of the subcritical masses into the other, creating the critical mass for the nuclear explosion.
Nuclear Fusion

The joining together of light nuclei.

1. Release enormous amounts of energy.

2. This is how the sun produces energy.

   The sun contains $73\%$ H, and $26\%$ He, $1\%$ of other

   \begin{align*}
   ^1_1H + ^1_1H & \rightarrow ^2_1H + ^0_1e \\
   ^1_1H + ^2_1H & \rightarrow ^3_2He \\
   ^3_2He + ^3_2He & \rightarrow ^4_2He + 2^1_1H \\
   ^3_2He + ^1_1H & \rightarrow ^4_2He + ^0_1e
   \end{align*}

   The net result (or sum) of these reaction is the formation of a helium atom (and 2 positrons) from 4 hydrogen atoms

3. Fusion of hydrogen nuclei - a potential power source.
   a. hydrogen isotopes are cheap and plentiful
   b. fusion products are non-radioactive and nonpolluting (helium)

4. Technical problems to achieving a practical and controllable fusion.
   a. to initiate the process,

      Hence the name

   b. What type of container do you do it in?

We have not yet overcome all these limitations to put fusion technology to work on the positive front for energy generation.

Mankind has accomplished it on a very limited scale in the laboratory with reactions such as:
Mankind has made much further strides in utilizing this technology on the military front.

This is the technology of the ________________

Where does the required temperature of reaction come from?

The very first test of a fusion H-bomb was known as ________________ in ________________

The largest H-bomb ever detonated was the ________________ in ________________ by the Soviet Union.