1. Balance the following nuclear reactions by filling in the missing particle and indicate the type of nuclear process:

a. \( ^{73}_{31}\text{Ga} \rightarrow ^{73}_{32}\text{Ge} + _{-1}^0\text{e} \quad \text{or} \quad _{-1}^0\beta \quad \text{beta emission} \)

b. \( ^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th} + _{4}^2\text{He} \quad \text{or} \quad _{4}^2\alpha \quad \text{alpha emission} \)

c. \( ^{201}_{80}\text{Hg} + _{-1}^0\text{e} \rightarrow ^{201}_{79}\text{Au} + _{0}^0\gamma \quad \text{beta capture} \)

d. \( ^{14}_{6}\text{C} + _{0}^{23}\text{U} \rightarrow ^{141}_{56}\text{Ba} + _{36}^{92}\text{Kr} + 3_0\text{He} \quad \text{fission} \)

e. \( ^{13}_{6}\text{C} \rightarrow ^{13}_{6}\text{C} + _{1}^0\text{e} \quad \text{positron emission} \)

2. Fill in the table:

<table>
<thead>
<tr>
<th>Type of decay</th>
<th>Effect on nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha (α)</td>
<td>↓p ↑n or ↓mass, happens for larger nuclei</td>
</tr>
<tr>
<td>beta (β)</td>
<td>↑p ↑n or n→p, n/p ratio is too large</td>
</tr>
<tr>
<td>positron</td>
<td>↓p ↑n or p→n n/p ratio is too small</td>
</tr>
<tr>
<td>electron capture</td>
<td>↓p ↑n or p→n n/p ratio is too small</td>
</tr>
<tr>
<td>gamma (γ)</td>
<td>no effect on nucleus, just emits energy</td>
</tr>
</tbody>
</table>

3. The only stable isotope of fluorine is fluorine-19. Predict possible modes of decay for \(^{18}\text{F}\) and \(^{21}\text{F}\).

\(^{19}\text{F} = \text{stable}\)

\(^{18}\text{F} = \text{unstable}\) 9n, 9p  n/p ratio is too small

so predict \underline{positron emission} or \underline{beta capture}

\(^{21}\text{F} = \text{unstable}\) 12n, 9p  n/p ratio is too large

so predict \underline{beta emission}

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4. The isotope $^{247}\text{Bk}$ decays by a series of $\alpha$-particle and $\beta$-particle emissions, eventually ending up as $^{207}\text{Pb}$. In the complete decay series, how many $\alpha$ and $\beta$-particles are produced?

$$^{247}_{94}\text{Bk} \rightarrow ^{207}_{82}\text{Pb} + ^{10}_{4}\alpha + ^{5}_{-1}\beta$$

5. Phosphorous-32 is used in biochemical research, particularly in studies of nucleic acids. The half-life of $^{32}\text{P}$ is 14.3 days.

a. What mass of $^{32}\text{P}$ is left from an original sample of 175 mg after 35 days?

$$k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{14.3 \text{ d}} = 0.0485 \text{ d}^{-1}$$

$$A = A_0 e^{-kt} = (175 \text{ mg}) e^{-0.0485 \times 35} = 32 \text{ mg}$$

b. How long will it take for 15% of a sample of $^{32}\text{P}$ to decay?

$$\ln \frac{A}{A_0} = -kt$$

$$\ln 0.85 = - (0.0485) t$$

$$t = 3.4 \text{ days}$$

6. The easiest fusion reaction to initiate is $^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} + ^1\text{n}$

Calculate the energy released per mole of helium produced given the following atomic masses:

$^2\text{H} = 2.01410 \text{ amu}, ^3\text{H} = 3.01605 \text{ amu}, ^4\text{He} = 4.00260 \text{ amu}, \text{ neutron} = 1.00866 \text{ amu}$

$$\Delta E = \Delta m c^2$$

$$\Delta m = (4.0026 + 1.00866) - (2.0141 + 3.01605) = -0.01889 \text{ amu} = -0.01889 \text{ g/mol}$$

$$\Delta E = \left(-0.01889 \frac{g}{\text{mol}} \times \frac{1 \text{ kg}}{1000 \text{ g}}\right) (3 \times 10^3 \text{ m/s})^2 = \frac{-1.7 \times 10^{12} \text{ J/mol}}{(\text{ J} = \text{ kg m}^2/\text{s}^2)}$$

7. The most stable nucleus in terms of binding energy is $^{56}\text{Fe}$. If the atomic mass of iron-56 is 55.9349 amu, calculate the binding energy per nucleon for $^{56}\text{Fe}$.

$m_p = 5.486 \times 10^{-4} \text{ amu}, m_n = 1.00728 \text{ amu}, m_{\alpha} = 1.00866 \text{ amu}$

$$26p + 30n \rightarrow ^{56}\text{Fe} + 26 e^-$$

mass of $^{56}\text{Fe}$ nucleus = $55.9349 - 26 (5.486 \times 10^{-4})$

= $55.9206 \text{ amu}$

$$\Delta m = 55.9206 - (26 (1.00728) + 30 (1.00866))$$

= $-0.5285 \text{ amu}$

$$\Delta E = \Delta mc^2 = \left(-0.5285 \frac{\text{ amu}}{\text{ nucl}} \times \frac{1 \text{ kg}}{1000 \text{ amu}}\right) (3 \times 10^3 \text{ m/s})^2 = -7.89 \times 10^{-11} \text{ J}$$

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$$\Delta E = -7.89 \times 10^{-11} \text{ J/56 nucleons} = \frac{1.41 \times 10^{-12} \text{ J/nucleon}}{26p + 30n}$$