Chapter 21

Nuclear Energy

Practice Problem Solutions

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1. **Conceptualize the Problem**
   - *Mass defect* is the *difference* between the total *mass* of the *reactants* and the total *mass* of the *fission products*.
   - The *energy* released is the *energy equivalent* of the *mass defect*.

   Identify the Goal
   The mass loss, Δm, and the amount of energy released, E, in the reaction

   Data
   $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{90}_{38}Sr + ^{135}_{54}Xe + 11^{1}_{0}n$

Particle	Mass (u)
$^{1}_{0}n$	1.008 665
$^{235}_{92}U$	234.993
$^{90}_{38}Sr$	89.886
$^{135}_{54}Xe$	134.879

   Identify the Variables

Known	Implied	Unknown
A, Z and m for all particles	$c = 2.998 \times 10^8$ m/s	Δm E

   Develop a Strategy

   Find the total mass of reactants.

   Calculations

   $m_{neutron} = 1.008665$ u
   $m\left(^{235}_{92}U\right) = 234.993$ u
   $m_{reactants} = 1.008665$ u $+ 234.993$ u
   $m_{reactants} = 236.002$ u

   Find the total mass of the products.

   $m\left(^{90}_{38}Sr\right) = 89.886$ u
   $m\left(^{135}_{54}Xe\right) = 134.879$ u
   $m_{11\ neutrons} = 11 \times 1.008665$ u
   $m_{11\ neutrons} = 11.095$ u
   $m_{products} = 89.886 + 134.879$ u $+ 11.095$ u
   $m_{products} = 235.8603$ u

Find the mass defect, or mass lost, by subtraction.

$\Delta m = m_{\text{reactants}} - m_{\text{products}}$
$\Delta m = 236.002 \text{ u} - 235.860 \text{ u}$
$\Delta m = 0.141685 \text{ u}$
$\Delta m \cong 0.14168\text{u}$

Convert the mass defect into kilograms.

$\Delta m = (0.141685 \text{ u})(1.6605 \times 10^{-27}\text{kg/u})$
$\Delta m = 2.35268 \times 10^{-28} \text{ kg}$
$\Delta m \cong 2.3527 \times 10^{-28} \text{ kg}$

The mass lost in the reaction is 0.14168 u, or 2.3527×10^{-28} kg.

Convert the mass into energy, using $\Delta E = \Delta mc^2$.

$\Delta E = \Delta mc^2$
$\Delta E = (2.3527 \times 10^{-28} \text{ kg})(2.998 \times 10^8 \text{ m/s})^2$
$\Delta E = 2.11459 \times 10^{-11} \text{ J}$
$\Delta E \cong 2.114 \times 10^{-11} \text{ J}$

The energy released in the reaction is 2.114×10^{-11} J.

Validate the Solution
The amount of energy released in this fission reaction is similar to the amount released in the reaction in the sample problem, so the solution is reasonable.

2. Conceptualize the Problem
- *Mass defect* is the *difference* between the total *mass* of the *reactants* and the total *mass* of the *fission products*.
- The *energy* released is the *energy equivalent* of the *mass defect*.

Identify the Goal
The amount of energy released, *E*, in the reaction

Data
${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$

Particle	Mass (u)
${}^{2}_{1}\text{H}$	2.013 553
${}^{3}_{1}\text{H}$	3.015 500
${}^{4}_{2}\text{He}$	4.001 506
${}^{1}_{0}\text{n}$	1.008 665

Identify the Variables

Known	Implied	Unknown
A, *Z* and *m* for all particles	$c = 2.998 \times 10^8$ m/s	Δm
		E

Develop a Strategy
Find the total mass of reactants.

Calculations
$m({}^{2}_{1}\text{H}) = 2.013553 \text{ u}$
$m({}^{3}_{1}\text{H}) = 3.015500 \text{ u}$
$m_{\text{reactants}} = 2.013553 \text{ u} + 3.015500 \text{ u}$
$m_{\text{reactants}} = 5.029053 \text{ u}$

Find the total mass of the products. $m\left({}^{4}_{2}\text{He}\right) = 4.001506\text{ u}$

$m_{\text{neutron}} = 1.008665\text{ u}$

$m_{\text{products}} = 4.001506\text{ u} + 1.008665\text{ u}$

$m_{\text{products}} = 5.010171\text{ u}$

Find the mass defect, or mass lost, by subtraction.

$\Delta m = m_{\text{reactants}} - m_{\text{products}}$

$\Delta m = 5.029053\text{ u} - 5.010171\text{ u}$

$\Delta m = 0.018882\text{ u}$

Convert the mass defect into kilograms.

$\Delta m = (0.018882\text{ u})(1.6605 \times 10^{-27}\text{ kg/u})$

$\Delta m = 3.13535 \times 10^{-29}\text{ kg}$

Convert the mass into energy, using $\Delta E = \Delta mc^2$.

$\Delta E = \Delta mc^2$

$\Delta E = (3.13535 \times 10^{-29}\text{ kg})(2.998 \times 10^{8}\text{ m/s})^2$

$\Delta E = 2.818059 \times 10^{-12}\text{ J}$

$\Delta E \cong 2.818 \times 10^{-12}\text{ J}$

The energy released in the reaction is 2.818×10^{-12} J.

Validate the Solution

The mass defect is positive, indicating an energy release.

3. Conceptualize the Problem

- *Mass defect* is the *difference* between the total *mass* of the *reactants* and the total *mass* of the *fission products*.
- The *energy* released is the *energy equivalent* of the *mass defect*.

Identify the Goal

(a) The mass defect, Δm, for the reaction and the energy produced, E

(b) The energy released, E, by the production of 1.00 g of helium

Data

$4{}^{1}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + 2{}^{0}_{1}\text{e}$

Particle	Mass (u)
${}^{1}_{1}\text{H}$	1.007 276
${}^{4}_{2}\text{He}$	4.001 506
${}^{0}_{1}\text{e}$	0.000 549

Identify the Variables

Known	Implied	Unknown
A, Z and m for all particles	$c = 2.998 \times 10^{8}$ m/s	Δm
		E

Develop a Strategy / **Calculations**

Find the total mass of reactants.

$m\left(4{}^{1}_{1}\text{H}\right) = (4)(1.007\ 276\text{ u})$

$m_{\text{reactants}} = m\left(4{}^{1}_{1}\text{H}\right) = 4.029104\text{ u}$

Find the total mass of the products.

$m\left({}^{4}_{2}\text{He}\right) = 4.001506\text{ u}$

$m_{2\text{ electrons}} = (2)(0.000549\text{ u})$

$m_{2\text{ electrons}} = 0.001098\text{ u}$

$m_{\text{products}} = 4.001506\text{ u} + 0.001098\text{ u}$

$m_{\text{products}} = 4.002604\text{ u}$

Find the mass defect, or mass lost, by subtraction.

$$\Delta m = m_{\text{reactants}} - m_{\text{products}}$$
$$\Delta m = 4.029104\ \text{u} - 4.002604\ \text{u}$$
$$\Delta m = 0.0265\ \text{u}$$

Convert the mass defect into kilograms.

$$\Delta m = (0.0265\ \text{u})(1.6605 \times 10^{-27}\ \text{kg/u})$$
$$\Delta m = 4.40 \times 10^{-29}\ \text{kg}$$

Convert the mass into energy, using $\Delta E = \Delta mc^2$.

$$\Delta E = \Delta mc^2$$
$$\Delta E = (4.40 \times 10^{-29}\ \text{kg})(2.998 \times 10^{8}\ \text{m/s})^2$$
$$\Delta E = 3.9550 \times 10^{-12}\ \text{J}$$
$$\Delta E \cong 3.96 \times 10^{-12}\ \text{J}$$

(a) The mass defect is 0.0265 u and the energy produced in this fusion is 3.96×10^{-12} J.

The energy released in the creation of 1.00 g of helium involves a conversion of units: the above is in J/reaction and the goal is J/g.

$$\Delta E_{1.00\,\text{g}} = \Delta E \times \frac{1\ \text{reaction}}{1\ (\text{He nucleus})} \times \frac{6.02 \times 10^{23}\ (\text{He nuclei})}{4.00\ \text{g}}$$
$$\Delta E_{1.00\,\text{g}} = 3.96 \times 10^{-12} \frac{\text{J}}{\text{reaction}} \times \frac{1\ \text{reaction}}{1\ (\text{He nucleus})} \times \frac{6.02 \times 10^{23}\ (\text{He nuclei})}{4.00\ \text{g}}$$
$$\Delta E_{1.00\,\text{g}} = 5.96 \times 10^{11}\ \text{J}$$

Note that 1 reaction (more correctly, series of reactions) consumes 4 H nuclei.

(b) The production of 1.00 g of He will release 5.96×10^{11} J (or, the amount of energy released in the production of He is 5.96×10^{11} J/g).

Validate the Solution

The mass defect is positive, indicating an energy release.

Comparing the results of 8 and 9, it's noted that similar amounts of energy are released in the production of helium from the two different fusion reactions, so the answer here is reasonable.

Chapter 21 Review

Answers to Problems for Understanding

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20. The energy change is 6.72×10^{-14} J.

$$m_{\text{reactants}} = 2m({}^{1}_{1}H) = 2 \times 1.007276\ \text{u} = 2.014552\ \text{u}$$
$$m_{\text{products}} = m({}^{2}_{1}H) + m({}^{1}_{0}e) = 2.013553\ \text{u} + 0.000549\ \text{u} = 2.014102\ \text{u}$$
$$\Delta m = m_{\text{reactants}} - m_{\text{products}}$$
$$\Delta m = (2.014552\ \text{u} - 2.014102\ \text{u}) \times (1.6605 \times 10^{-27}\ \frac{\text{kg}}{\text{u}})$$
$$\Delta m = 7.47225 \times 10^{-31}\ \text{kg}$$
$$\Delta E = \Delta mc^2$$
$$\Delta E = (7.47225 \times 10^{-31}\ \text{kg})(2.998 \times 10^{-14}\ \text{m/s})^2$$
$$\Delta E = 6.7161 \times 10^{-14}\ \text{J}$$
$$\Delta E \cong 6.72 \times 10^{-14}\ \text{J}$$

21. The unknown nuclide is 144-cesium, ${}^{144}_{55}Cs$.

The atomic number and the numbers of protons must balance on each side of the equation:

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{90}_{37}Rb + 2{}^{1}_{0}n + {}^{144}_{55}Cs$$