Energy in Nuclear Processes

① A. $240\,mg \times \left(\frac{1\,g}{1000\,mg}\right) = 0.24\,g$

B. $3.9\times10^{-6}\,kg \times \left(\frac{1\,u}{1.66\times10^{-27}\,kg}\right) = 2.3\times10^{21}\,u$

C. $0.0067\,u \times \left(\frac{1.66\times10^{-27}\,kg}{1\,u}\right) = 1.1\times10^{-29}\,kg$

D. $8.8\,u \times \left(\frac{930\,MeV/c^2}{1\,u}\right) = 8200\,MeV/c^2$

E. $0.0045\,mg \times \left(\frac{1000\,mg}{1\,g}\right) \times \left(\frac{1\,g}{1000\,g}\right) \times \left(\frac{1\,u}{1.66\times10^{-27}\,kg}\right) = 2.7\times10^{18}\,u$

F. $2.2\times10^{-14}\,kg \times \left(\frac{1\,u}{1.66\times10^{-27}\,kg}\right) \times \left(\frac{930\,MeV/c^2}{1\,u}\right) = 1.2\times10^{16}\,MeV/c^2$

G. $17\,MeV \times \left(\frac{1.6\times10^{-13}\,J}{1\,MeV}\right) = 2.7\times10^{-12}\,J$

H. $9.0\times10^{7}\,eV \times \left(\frac{1\,MeV}{1\,000\,000\,eV}\right) = 90\,MeV$

I. $7.11\times10^{-11}\,J \times \left(\frac{1\,MeV}{1.6\times10^{-13}\,J}\right) = 444\,MeV$

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② A. $\mathcal{E} = \Delta mc^2 = 1.0\,kg\,(3.0\times10^{8}\,m/s)^2 = 9.0\times10^{16}\,J$

B. $\mathcal{E} = \Delta mc^2 = 4.0\times10^{-6}\,kg\,(3.0\times10^{8}\,m/s)^2 = 3.6\times10^{11}\,J$

C. $\mathcal{E} = \Delta mc^2 = 1.3\times10^{-15}\,kg\,(3.0\times10^{8}\,m/s)^2 = 120\,J$

D. $\mathcal{E} = \Delta mc^2 = 285\,kg\,(3.0\times10^{8}\,m/s)^2 = 2.57\times10^{19}\,J$

E. $\mathcal{E} = \Delta mc^2 = 7.2\times10^{-7}\,kg\,(3.0\times10^{8}\,m/s)^2 = 6.5\times10^{10}\,J$

F. $\mathcal{E} = \Delta mc^2 = 3.44\times10^{-17}\,kg\,(3.0\times10^{8}\,m/s)^2 = 3.10\,J$

G. $\Delta m = 9.0\,g \times \left(\frac{1\,kg}{1000\,g}\right) = 9.0\times10^{-3}\,kg$

$\mathcal{E} = \Delta mc^2 = 9.0\times10^{-3}\,kg\,(3.0\times10^{8}\,m/s)^2 = 8.1\times10^{14}\,J$

(2) H. $\Delta m = 14\text{mg} \times \left(\frac{1\text{g}}{1000\text{mg}}\right) \times \left(\frac{1\text{kg}}{1000\text{g}}\right) = 1.4\times10^{-5}\text{kg}$

$E = \Delta mc^2 = 1.4\times10^{-5}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{1.3\times10^{12}\text{ J}}$

I. $\Delta m = 14u \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = 2.324\times10^{-26}\text{kg}$

$E = \Delta mc^2 = 2.324\times10^{-26}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{2.1\times10^{-9}\text{ J}}$

J. $\Delta m = 0.0037u \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = 6.142\times10^{-30}\text{kg}$

$E = \Delta mc^2 = 6.142\times10^{-30}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{5.5\times10^{-13}\text{ J}}$

K. $2.31\times10^{-2}u \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = 3.8346\times10^{-29}\text{kg} = \Delta m$

$E = \Delta mc^2 = 3.8346\times10^{-29}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{3.45\times10^{-12}\text{ J}}$

L. $\Delta m = 6.2\times10^{5}u \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = 1.0292\times10^{-21}\text{kg}$

$E = \Delta mc^2 = 1.0292\times10^{-21}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{9.3\times10^{-5}\text{ J}}$

M. $\Delta m = 35\text{MeV/c}^2 \times \left(\frac{1u}{930\text{MeV/c}^2}\right) \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = 6.24731183\times10^{-29}\text{kg}$

$E = \Delta mc^2 = 6.24731183\times10^{-29}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{5.6\times10^{-12}\text{ J}}$

N. $\Delta m = 99\text{MeV/c}^2 \times \left(\frac{1u}{930\text{MeV/c}^2}\right) \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = 1.76709677\times10^{-28}\text{kg}$

$E = \Delta mc^2 = 1.76709677\times10^{-28}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{1.6\times10^{-11}\text{ J}}$

O. $0.04\text{MeV/c}^2 \times \left(\frac{1u}{930\text{MeV/c}^2}\right) \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = \Delta m = 7.13978495\times10^{-32}\text{kg}$

$E = \Delta mc^2 = 7.13978495\times10^{-32}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{6\times10^{-15}\text{ J}}$

P. $930\text{MeV/c}^2 \times \left(\frac{1u}{930\text{MeV/c}^2}\right) \times \left(\frac{1.66\times10^{-27}\text{kg}}{1u}\right) = \Delta m = 1.66\times10^{-27}\text{kg}$

$E = \Delta mc^2 = 1.66\times10^{-27}\text{kg}\,(3.0\times10^{8}\text{m/s})^2 = \boxed{1.5\times10^{-10}\text{ J}}$

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(3) A. $\Delta m = 1.0\text{kg} \times \left(\frac{1u}{1.66\times10^{-27}\text{kg}}\right) \times \left(\frac{930\text{MeV/c}^2}{1u}\right) = 5.60240964\times10^{29}\text{MeV/c}^2$

$E = \Delta mc^2 = 5.60240964\times10^{29}\text{MeV/c}^2\,c^2 = \boxed{5.6\times10^{29}\text{ MeV}}$

(3) B. $3.2\times10^{-24}\,kg \times \left(\frac{1u}{1.66\times10^{-27}\,kg}\right) \times \left(\frac{930\,MeV/c^2}{1u}\right) = 1.79277108\times10^{4}\,MeV/c^2 = \Delta m$

$E = \Delta mc^2 = 1.79277108\times10^{4}\,MeV/c^2 \times c^2 = \boxed{1.8\times10^{4}\,MeV}$

C. $\Delta m = 0.00077\,kg \times \left(\frac{1u}{1.66\times10^{-27}\,kg}\right) \times \left(\frac{930\,MeV/c^2}{1u}\right) = 4.475625\times10^{26}\,MeV/c^2$

$E = \Delta mc^2 = 4.475625\times10^{26}\,MeV/c^2 \times c^2 = \boxed{4.5\times10^{26}\,MeV}$

D. $2.004g \times \left(\frac{1kg}{1000g}\right) \times \left(\frac{1u}{1.66\times10^{-27}\,kg}\right) \times \left(\frac{930\,MeV/c^2}{1u}\right) = \Delta m = 1.12272289\times10^{27}\,MeV/c^2$

$E = \Delta mc^2 = 1.12272289\times10^{27}\,MeV/c^2 \times c^2 = \boxed{1.123\times10^{27}\,MeV}$

E. $\Delta m = 0.0064u \times \left(\frac{930\,MeV/c^2}{1u}\right) = 5.952\,MeV/c^2$

$E = \Delta mc^2 = 5.952\,MeV/c^2 \times c^2 = 5.952\,MeV \simeq \boxed{6.0\,MeV}$

F. $\Delta m = 4.733u \times \left(\frac{930\,MeV/c^2}{1u}\right) = 4.40169\times10^{3}\,MeV/c^2$

$E = \Delta mc^2 = 4401.69\,MeV/c^2 \times c^2 = \boxed{4402\,MeV}$

G. $1.0u \times \left(\frac{930\,MeV/c^2}{1u}\right) = 930\,MeV/c^2 = \Delta m$

$E = \Delta mc^2 = 930\,MeV/c^2 \times c^2 = \boxed{930\,MeV}$

H. $\Delta m = 122u \times \left(\frac{930\,MeV/c^2}{1u}\right) = 11\,346\,MeV/c^2$

$E = \Delta mc^2 = 11\,346\,MeV/c^2 \times c^2 = 11\,346\,MeV \simeq \boxed{11\,300\,MeV}$

I. $E = \Delta mc^2 = 17\,MeV/c^2 \times c^2 = \boxed{17\,MeV}$

J. $E = \Delta mc^2 = 1.0\,MeV/c^2 \times c^2 = \boxed{1.0\,MeV}$

K. $E = \Delta mc^2 = 228\,MeV/c^2 \times c^2 = \boxed{228\,MeV}$

L. $E = \Delta mc^2 = 99\,MeV/c^2 \times c^2 = \boxed{99\,MeV}$

see how easy? This is why MeV/c^2 is the preferred mass unit for atomic and nuclear physics!

(4) A. $\Delta m = 2.001\,kg - 2.0\,kg = 0.001\,kg$

$\mathcal{E} = \Delta m c^2 = 0.001\,kg\,(3.00\times10^{8}\,m/s)^2 = \boxed{9\times10^{13}\,J}$

$m_{products} > m_{reactants} \Rightarrow$ Energy Absorbed / Endothermic

B. $\Delta m = 24\,kg - 23.4\,kg = 0.6\,kg$

$\mathcal{E} = \Delta m c^2 = 0.6\,kg\,(3.0\times10^{8}\,m/s)^2 = \boxed{5.4\times10^{16}\,J}$

$m_{products} < m_{reactants} \Rightarrow$ Energy Released / Exothermic

C. $\Delta m = 23.0034u - 23.0032u = 0.0002u$

⇒ Either Joules of MeV are appropriate, I'll do both, You just pick one!

Joules: $\Delta m = 0.0002u \times \left(\frac{1.66\times10^{-27}\,kg}{1u}\right) = 3.32\times10^{-31}\,kg$

$\mathcal{E} = \Delta m c^2 = 3.32\times10^{-31}\,kg \times (3.00\times10^{8}\,m/s)^2 = \boxed{2.988\times10^{-14}\,J}$ (2.988×10⁻¹⁴ J)

OR MeV: $\Delta m = 0.0002u \times \frac{930\ MeV/c^2}{u} = 0.186\ MeV/c^2$

$\mathcal{E} = \Delta m c^2 = 0.186\,MeV/c^2 \times c^2 = \boxed{0.186\,MeV}$

$m_{products} < m_{reactants} \Rightarrow$ Energy Released / Exothermic

D. $m_{reactants} = m_{parent} = 167.078452u$

$m_{products} = m_{daughter} + m_{\alpha} = 163.076337u + 4.001567u = 167.077904u$

so $m_{products} < m_{reactants} \Rightarrow$ Energy Released / Exothermic

I think MeV is easiest so ...

$\Delta m = 167.078452u - 167.077904 = 0.000548u \times \left(\frac{930\,MeV/c^2}{1u}\right) = 0.5096$

$\mathcal{E} = \Delta m c^2 = 0.50964\,MeV/c^2 \times c^2 = \boxed{0.50964\,MeV}$

⑤ $E = \Delta m c^2$

$$\Delta m = \frac{E}{c^2} = \frac{26\,MeV}{c^2}$$

$$26\,\frac{MeV}{c^2} \times \left(\frac{1\,u}{930\,\frac{MeV}{c^2}}\right) = 0.027956989\overline{25}\,u$$

Endothermic ⇒ mass of products > mass of reactants

$$m_{product} = m_{reactant} + \Delta m = 77.890226u + 0.027956989\overline{25}\,u$$

$$m_{product} = \boxed{77.918183\,u}$$