

PHYS160

SOLUTIONS

Spring 2009

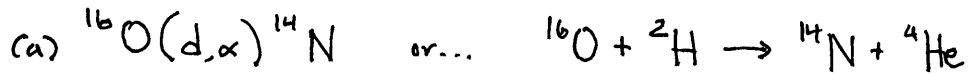
Problem Set #7: Due in class on Fri. 6/5

Problems from Chapter 13 of Thornton & Rex: 8, 14, 26, 38

Problems from Chapter 14 of Thornton & Rex: 1, 8, 13, 14, 17

13-8

Calculate the ground state Q values for the following reactions. Are the reactions endothermic or exothermic?



Use Eq. 13.7 $Q = M_{^{16}\text{O}}c^2 + M_{^2\text{H}}c^2 - M_{^{14}\text{N}}c^2 - M_{^4\text{He}}c^2$

$M_{^{16}\text{O}} = 15.994915\text{u}$ $M_{^2\text{H}} = 2.014102\text{u}$

$M_{^{14}\text{N}} = 14.003074\text{u}$ $M_{^4\text{He}} = 4.002603\text{u}$

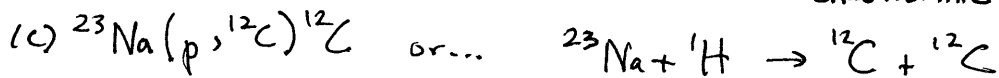
$Q = 0.00334\text{u} \times 931.49 \text{ MeV}/c^2 \cdot \text{u} \cdot c^2 = \boxed{+3.11 \text{ MeV}}$ exothermic



$Q = 2M_{^{12}\text{C}}c^2 - M_{^{22}\text{Na}}c^2 - M_{^2\text{H}}c^2$

$M_{^{12}\text{C}} = 12.000\text{u}$ $M_{^{22}\text{Na}} = 21.994437\text{u}$ $M_{^2\text{H}} = 2.014102\text{u}$

$Q = \cancel{2} - 0.008539 \times 931.49 \text{ MeV} = \boxed{-7.954 \text{ MeV}}$
 \uparrow endothermic



$M_{^{23}\text{Na}} = 22.989770\text{u}$ $M_{^1\text{H}} = 1.007825\text{u}$ $M_{^{12}\text{C}} = 12.000\text{u}$

$Q = M_{^{23}\text{Na}}c^2 + M_{^1\text{H}}c^2 - 2M_{^{12}\text{C}}c^2$

$Q = -0.002405\text{u} \times 931.49 \text{ MeV}/\text{u} = \boxed{-2.240 \text{ MeV}}$
 endothermic

8-14

A slow neutron is absorbed by ^{10}B in the reaction $^{10}\text{B}(n, \gamma)^{11}\text{B}$. What is the energy of the γ ray?

The reaction energy Q is... $Q = M_{^{10}\text{B}}c^2 + M_n c^2 - M_{^{11}\text{B}}c^2$

$$M_{^{10}\text{B}} = 10.012937 \text{ u} \quad M_{^{11}\text{B}} = 11.009305 \text{ u} \quad M_n = 1.008665 \text{ u}$$

$$Q = +0.012297 \text{ u} \times 931.49 \text{ MeV/u} = \boxed{11.45 \text{ MeV}}$$

↑ The γ -ray will have slightly less energy than this as the ^{11}B nucleus will recoil.

To estimate the Doppler shift of the γ -ray due to recoil of the ^{11}B nucleus, calculate the momentum of the photon...

$$p_\gamma = \frac{E_\gamma}{c} \approx 11.45 \text{ MeV}/c$$

To conserve momentum the ^{11}B nucleus must have the same momentum in the opposite direction. The kinetic energy of the ^{11}B nucleus is therefore,

$$K = \frac{p_\gamma^2}{2M} \left(\frac{c^2}{c^2} \right)$$

We can use non-relativistic equations since $Q \ll M c^2$

$$M_{^{11}\text{B}}c^2 = 11.009305 \text{ u} \times 931.49 \frac{\text{MeV}}{c^2} = 10255 \text{ MeV}$$

less 5 electrons worth... 10,253 MeV

$$K = \frac{(11.45 \text{ MeV})^2}{2 \cdot 10253 \text{ MeV}} = 0.0064 \text{ MeV}$$

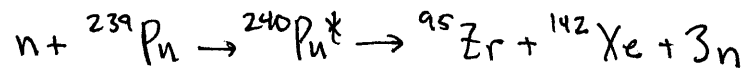
↑ negligible compared to Q

So...

$$\boxed{E_\gamma = 11.45 \text{ MeV}}$$

18-26

Calculate how much energy is released when ^{239}Pu absorbs a thermal neutron and fissions in the reaction



$$Q = M_{{}^{239}\text{Pu}}c^2 + M_n c^2 - M_{{}^{95}\text{Zr}}c^2 - M_{{}^{142}\text{Xe}}c^2 - 3M_n c^2$$

↑
combine ... $-2M_n c^2$

$$M_{{}^{239}\text{Pu}} = 239.052156 \text{ u}$$

$$M_{{}^{95}\text{Zr}} = 94.908043 \text{ u}$$

$$M_n = 1.008665 \text{ u}$$

$$M_{{}^{142}\text{Xe}} = 141.929710 \text{ u}$$

$$Q = 0.197073 \text{ u} \times 931.49 \text{ MeV/u} = \boxed{183.6 \text{ MeV}}$$

13-38

Assume that $\frac{2}{3}$ of the earth's surface is covered with water to an average depth of 3 km. Calculate how many nuclei of ^2H exist (0.015% abundance). Estimate how many joules of energy this represents?

First estimate the total mass of H_2O :

$$M = \text{density} \times \text{volume} = 1 \frac{\text{g}}{\text{cm}^3} \times \frac{2}{3} \cdot 4\pi R_{\oplus}^2 \times \text{depth}$$

$$R_{\oplus} = 6.4 \times 10^3 \text{ m} = 6.4 \times 10^5 \text{ cm}$$

$$\text{depth} = 3 \text{ km} = 3 \times 10^5 \text{ cm}$$

$$M = \frac{8}{3} \pi (6.4 \times 10^5 \text{ cm})^2 \cdot 3 \times 10^5 \text{ cm} \cdot 1 \frac{\text{g}}{\text{cm}^3}$$

$$M \approx 10^{18} \text{ g}$$

The molar mass of H_2O is $\sim 18 \frac{\text{g}}{\text{mol}}$ so there are

$$N_{\text{H}_2\text{O}} \approx \frac{10^{18} \text{ g}}{18 \frac{\text{g}}{\text{mol}}} \sim 5 \times 10^{16} \text{ moles of } \text{H}_2\text{O} \text{ or about } \dots$$

$$5 \times 10^{16} \times 2 \times N_A \approx 7 \times 10^{40} \text{ hydrogen atoms}$$

Multiply by the % abundance... ($\div 100$) to get the number of deuterons...
 Δ Avogadro's number $6.02 \times 10^{23} \text{ atoms/mol}$

$$N_{\text{deuterons}} \approx 10^{37}$$

The reactions listed in Eqs. 13.21 and 13.22 require 2 deuterons each... and result in an average energy release of 3.65 MeV, so the total energy potential of all the deuterium on earth is...

$$\frac{N_{\text{deuterons}}}{2} \times 3.65 \text{ MeV} \approx 2 \times 10^{37} \text{ MeV} \times 10^6 \frac{\text{eV}}{\text{MeV}} \times 1.6 \times 10^{-19} \text{ J}$$

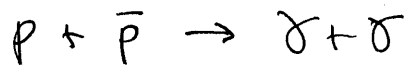
$$E_{\text{Total}} = 3 \times 10^{24} \text{ J}$$

The current annual ~~over~~ global energy demand is $5 \times 10^{20} \text{ J}$ (wikipedia)

So that gives us ~ 6000 years of fuel at current rates of consumption.

14-1

What are the frequencies of the two photons produced when a proton and an anti-proton annihilate?



If the proton and anti-proton are at rest then each photon has an energy equal to the rest mass energy of the proton

$$E_\gamma = 938.27 \text{ MeV}$$

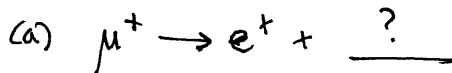
The frequency is...

$$f = \frac{E}{h} = \frac{938.27 \text{ MeV} \cdot 10^6 \text{ eV/MeV}}{4.1357 \cdot 10^{-15} \text{ eV}\cdot\text{s}}$$

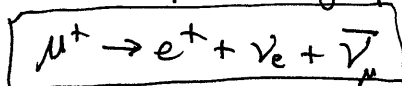
$$f = 2.27 \cdot 10^{17} \text{ Hz}$$

14-8

Supply the missing neutrinos in the following reactions or decays.

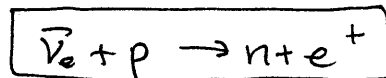


To conserve L_e and L_μ this decay requires 2 neutrinos

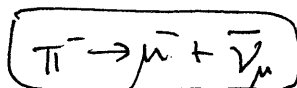


$$L_e \quad 0 = -1 + 1 \quad 0$$

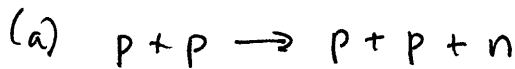
$$L_\mu \quad -1 = 0 + 0 \quad -1$$



$$L_e \quad -1 \quad 0 = 0 \quad -1$$

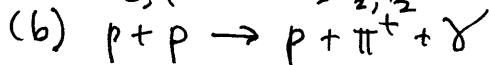


14-13 Explain why each of the following reactions is forbidden.



$B = +1 +1 \neq +1 +1 +1$
 $S = \frac{1}{2} \frac{1}{2} \neq \frac{1}{2} \frac{1}{2} \frac{1}{2}$ ←

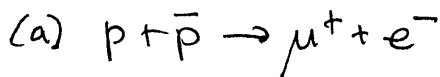
This does not conserve baryon number
 or spin/angular momentum



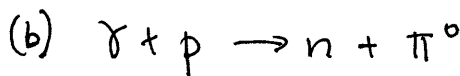
$B = +1 +1 \neq +1 + 0 + 0$
 $S = \frac{1}{2} \frac{1}{2} \neq \frac{1}{2} + 0 + 1$
 $0, 1 \qquad \frac{1}{2}, \frac{3}{2}$

This reaction does not conserve baryon number
~~or angular mo~~
 or angular momentum

14-14 Explain why each of the following reactions is forbidden.



This does not conserve lepton numbers L_μ, L_e



$Q = 0 + 1 \neq 0 + 0$

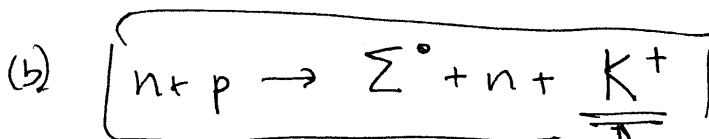
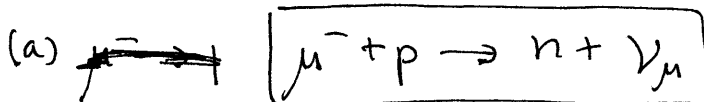
This does not conserve charge or angular momentum



$S = 1 \neq 0 + 0$

This does not conserve angular momentum

14-17 Complete the following reactions:



↑ need \oplus charge
 and $S = +1, B = 0$ to complete this reaction.