UNIVERSITY OF OTTAWA
Principles of Physics II
PHY1322 Winter2014
Dr. A. Czajkowski

STUDENT #: ______________

NAME: ____________________

Assignment 2:
Mass- Energy Equivalence, Bohr's Atom, Stellar Evolution, Particle Physics Cosmology

Assigned: Jan 17 14:30 *Due: Jan 24 14:00*

1 a) Using E=mc^2 find the energy difference in MeV between the mass of 4 hydrogen atoms and mass of one helium atom. Find the energy in Joules obtained if one mole of the hydrogen atoms is converted into helium
b) Express this energy in as TNT equivalent .

$$\Delta M = 4M(H) - M(He) = 4(1.00794u) - 4.002602u = 0.029158u$$
$$\Delta E = \Delta Mc^2 = (0.029158)(931.494061MeV) = 27.2MeV$$
$$0.25\times 6.02\times 10^{23}\times 4MeV = 4.095$$
$$0 = 0.25\times 6.02\times 10^{23}\times 4MeV = 4.095\times 10^{24}MeV = 6.55\times 10^{11}J$$
$$1ton\ TNT = 4.184\times 10\times 10^{9}J \Rightarrow \Delta E = 157tonnesTNT$$

2 To better grasp the energy mass equivalence (E=mc^2) fill the following table (use the textbook and internet resources to find the relevant information

Hint :
Δ^+ has exactly same quark configuration as proton and is in fact the excited state of |uud> configuration
Δ^0 has exactly same quark configuration as neutron and is in fact the excited state of |udd> configuration

Bound System	Ground state mass (u)	Ground State Energy (eV)	First Excited state mass (u)	First Excited State Energy (eV)
Hydrogen	1.00794u	938.890MeV	1.00794u	938.890MeV +3.4eV
Helium				
Proton	1.007276466812	938.272046	1,232	
Neutron	1.00866491600	939.565378	1,232	

3. a) How much total kinetic energy will an electron–positron pair have if produced by a 2.67-MeV photon?
b) What is the longest wavelength photon that could produce a proton–antiproton pair? (Each has a mass of $1.67 3\ 10^{2\ 27}$ kg.)

The photon energy must be equal to the kinetic energy of the products plus the mass energy of the products. The mass of the positron is equal to the mass of the electron.

$$E_{\text{photon}} = K_{\text{products}} + m_{\text{products}}c^2 \quad \rightarrow$$

$$K_{\text{products}} = E_{\text{photon}} - m_{\text{products}}c^2 = E_{\text{photon}} - 2m_{\text{electron}}c^2 = 2.67\,\text{MeV} - 2\left(0.511\,\text{MeV}\right) = \boxed{1.65\,\text{MeV}}$$

The photon with the longest wavelength has the minimum energy in order to create the masses with no additional kinetic energy. Use Eq. 37-5.

$$\lambda_{\max} = \frac{hc}{E_{\min}} = \frac{hc}{2mc^2} = \frac{h}{2mc} = \frac{\left(6.63\times 10^{-34}\,\text{J}\cdot\text{s}\right)}{2\left(1.67\times 10^{-27}\,\text{kg}\right)\left(3.00\times 10^{8}\,\text{m/s}\right)} = \boxed{6.62\times 10^{-16}\,\text{m}}$$

4 Using Bohr's Postulates for Hydrogen atom and the classical mechanics arguments obtain the expressions for
a) the Radius nth State Radius
b) the nth State Energy.
USE THE OPPOSITE PAGE FOR THESE DERIVATIONS:

See the details of my lecture notes

5 (I) *a*) Determine the wavelength of the second Balmer line ($n = 4$ to $n = 2$ transition)

b) Determine the wavelength of the third Lyman line and (*c*) the wavelength of the first Balmer line.

c (I) Calculate the ionization energy of doubly ionized lithium, Li^{21} , which has $Z = 3$.

(*a*) The second Balmer line is the transition from $n = 4$ to $n = 2$.

$$\frac{1}{\lambda} = \frac{f}{c} = \frac{k_e e^2}{2a_o hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = R_H\left(\frac{1}{2^2} - \frac{1}{4^2}\right) \Rightarrow \boxed{\lambda = 490\,\text{nm}}$$

(*b*) The third Lyman line is the transition from $n = 4$ to $n = 1$.

$$\frac{1}{\lambda} = \frac{f}{c} = \frac{k_e e^2}{2a_o hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = R_H\left(\frac{1}{1^2} - \frac{1}{4^2}\right) \Rightarrow \boxed{\lambda = 97.3\,\text{nm}}$$

(*c*) The first Balmer line is the transition from $n = 3$ to $n = 2$.
For the jump from $n = 5$ to $n = 2$, we have

$$\frac{1}{\lambda} = \frac{f}{c} = \frac{k_e e^2}{2a_o hc}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = R_H\left(\frac{1}{2^2} - \frac{1}{3^2}\right) \Rightarrow \boxed{\lambda = 650\,\text{nm}}$$

Doubly ionized lithium is similar to hydrogen, except that there are three positive charges ($Z = 3$) in the nucleus. The square of the product of the positive and negative charges appears in the energy term for the energy levels. We can use the results for hydrogen, if we replace e^2 by Ze^2:

$$E_n = -\frac{Z^2(13.6\,\text{eV})}{n^2} = -\frac{3^2(13.6\,\text{eV})}{n^2} = -\frac{(122\,\text{eV})}{n^2} \qquad E_{\text{ionization}} = 0 - E_1 = 0 - \left[-\frac{(122\,\text{eV})}{(1)^2}\right] = \boxed{122\,\text{eV}}$$

6. An excited hydrogen atom could, in principle, have a diameter of 0.10 mm. What would be the value of *n* for a Bohr orbit of this size? What would its energy be?

The value of *n* is found from $r_n = n^2 r_1$, and then find the energy from Eq. 37-14b.

$$r_n = n^2 r_1 \quad \rightarrow \quad n = \sqrt{\frac{r_n}{r_1}} = \sqrt{\frac{\frac{1}{2}(0.10\times10^{-3}\,\text{m})}{0.529\times10^{-10}\,\text{m}}} = \boxed{972}$$

$$E = -\frac{(13.6\text{ eV})}{n^2} = -\frac{(13.6\text{ eV})}{972^2} = -\frac{(13.6\text{ eV})}{1375^2} = \boxed{-1.4\times10^{-5}\text{eV}}$$

7 The position of the star on the Herzprung-Russel Diagram (H-R):

a) is determined by the star spectral type and its luminosity
b) is independent of the star mass
c) allows to classify the star and predict its evolution
d) all of the above are true
e) a and c are true
f) none of the above is true

8. Identify the particles corresponding to the quark combinations

(a) suu, $\text{suu} = \boxed{\Sigma^+}$ (c) $\text{s}\bar{\text{d}}$, $\bar{\text{s}}\text{d} = \boxed{\text{K}^0}$

(b) $\bar{\text{u}}\text{d}$, $\bar{\text{u}}\text{d} = \boxed{\pi^-}$ (d) ssd $\text{ssd} = \boxed{\Xi^-}$

9. What is the electrical charge of the baryons with the quark compositions (a) $\bar{\text{u}}\,\bar{\text{u}}\,\bar{\text{d}}$ and (b) $\bar{\text{u}}\,\bar{\text{d}}\,\bar{\text{d}}$ What are these baryons called?

(a) $\bar{\text{u}}\bar{\text{u}}\bar{\text{d}}$: charge $= \left(-\frac{2}{3}e\right) + \left(-\frac{2}{3}e\right) + \left(\frac{1}{3}e\right) = \boxed{-e}$. This is the $\boxed{\text{antiproton}}$.

(b) $\bar{\text{u}}\bar{\text{d}}\bar{\text{d}}$: charge $= \left(-\frac{2}{3}e\right) + \left(\frac{1}{3}e\right) + \left(\frac{1}{3}e\right) = \boxed{0}$. This is the $\boxed{\text{antineutron}}$.

10. Supernova Shelton 1987A, located about 170 000 ly from the Earth, is estimated to have emitted a burst of neutrinos carrying energy $\sim 10^{46}$ J. Suppose the average neutrino energy was 6 MeV and your body presented cross-sectional area 5 000 cm^2. To an order of magnitude, how many of these neutrinos passed through you?

We find the number N of neutrinos: $10^{46}\ \text{J} = N(6\ \text{MeV}) = N\left(6\times 1.60\times 10^{-13}\ \text{J}\right)$

$N = 1.0\times 10^{58}$ neutrinos

The intensity at our location (number of neutrinos per m^2) is given by

$$\frac{N}{A} = \frac{N}{4\pi r^2} = \frac{1.0\times 10^{58}}{4\pi\left(1.7\times 10^{5}\ \text{ly}\right)^2}\left(\frac{1\ \text{ly}}{\left(3.00\times 10^{8}\ \text{m/s}\right)\left(3.16\times 10^{7}\ \text{s}\right)}\right)^2 = 3.1\times 10^{14}\ \text{m}^{-2}.$$

The number passing through a body presenting $5\,000\ \text{cm}^2 = 0.50\ \text{m}^2$ is then

$$\left(3.1\times 10^{14}\ \frac{1}{\text{m}^2}\right)\left(0.50\ \text{m}^2\right) = 1.5\times 10^{14} \quad \text{or} \quad \boxed{\sim 10^{14}}.$$