22.01 Fall 2015, Problem Set 1

Due: September 18, 11:59PM on Stellar

September 16, 2015

Complete all the assigned problems, and do make sure to show your intermediate work. Please upload your full problem set in PDF form on the Stellar site. Make sure to upload your work at least 15 minutes early, to account for computer/network issues.

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1 (50 points) Retracing Chadwick's Discovery of the Neutron

In thess questions, you will recreate some of James Chadwick's logic as he hypothesized and proved the existence of the neutron. Read the two papers on the Stellar site, "Possible Existence of a Neutron" and "The Existence of a Neutron," and answer the following questions.

1. What made James first hypothesize an uncharged particle with the mass of a proton?
2. What was the competing hypothesis to explain the observed results?
3. Write the nuclear reaction of alpha particles (helium nuclei) bombarding beryllium. You may want to look up the stable isotope of Be here: http://atom.kaeri.re.kr/
4. Why would a neutron have greater "penetrating power" (range) through matter compared to charged particles? What does a neutron not interact with?
5. On p. 694 of the second paper, Chadwick states that "The source of polonium was prepared from a solution of radium by deposition on a disc of silver." How could polonium be produced directly from radium?
6. On p. 698 of the second paper, Chadwick states that "the mass of the neutron is equal to that of the proton..." Is this true? What are the masses of the proton, neutron, and electron? Is the mass of Rutherford's "neutron," consisting of a proton and an electron, equal to the neutron's mass? Why or why not (where does the energy discrepancy come from)? Why couldn't Chadwick discern between the masses of these two particles?
7. On pp. 701-702, why is the kinetic energy of ^{11}B not accounted for, and what does it mean for kinetic energies to be given in "mass units?" Convert these "mass unit" energies to energies in electron volts (eV). What is the approximate kinetic energy of ^{11}B in eV at room temperature?

2 (50 points) Getting Used to Nuclear Quantities

In these questions, you will calculate a number of quantities related to nuclear reactions and power generation. You will have to look up certain reactions and values from *primary sources* in the literature (books, papers, databases). Make sure to state which values you look up or assume, and *cite your sources* using proper citation methods.

These calculations are useful, especially when arguing the benefits and costs of nuclear power. If you can derive them quickly and by yourselves, you don't have to rely on as many other sources of information to make your point.

2.1 Relative Power Densities

Calculate the energy released from burning 1kg of coal, natural gas, uranium, and deuterium. Now repeat this calculation for the nuclear fission of uranium, and the nuclear fusion of deuterium.

2.2 Accelerator Energetics

A common tool to provide data on nuclear reactions is the electrostatic accelerator. These work by accelerating charged particles through a large, static electric field. We consider here an accelerator that provides a 2MV potential drop over 2m for double charged nickel ions $\left(Ni^{+2}\right)$, which enter the accelerator at ˜zero kinetic energy into the accelerator from an ion source.

2.2.1 What will be the kinetic energy of a nickel ion in eV, as it exits the accelerator?

2.2.2 What will be its *total mass* (not its rest mass) as it exits the accelerator?

2.2.3 If the ion source injects 2mA of current, what is the total number of particles leaving the accelerator per second?

2.2.4 What is the total power, in Watts, associated with pulling 2mA of current through 2MV of electrostatic potential? Where does this power go?

2.3 Mass-Energy Equivalence

From general relativity, the mass (m) of a moving particle can be expressed as follows:

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{1}$$

where m_0 is its rest mass, v is its velocity, and c is the speed of light.

2.3.1 What is the particle's mass at the following speeds: 1 $\frac{m}{s}$, 1 $\frac{km}{s}$, 1 $\frac{Mm}{s}$, 0.9c, 0.99c, c?

2.3.2 Derive an expression for the particle's kinetic energy (T) in terms of its total and rest masses.

2.3.3 Show that the particle's momentum (p) can be described in terms of its kinetic energy and rest mass as follows:

$$p = \frac{1}{c}\sqrt{T^2 + 2Tm_0c^2} \tag{2}$$

2.3.4 At what ratio of kinetic energy to rest mass energy is the classical (non-relativistic) expression for momentum accurate to one part per thousand?