PHYS 331 and 580 exam 1

Spring 2012 semester

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You are expected to observe the GMU Honor Code. ***You may use the book and notes. Exam is due in class Thursday Pleasebe sure to show formulas, before plugging numbers in!***

Question 1. Fossil Fuels

(a) According to Carnot, what is the highest possible efficiency of a heat engine that inputs heat from a reservoir at 323 C and expels it to the environment at 23 C?

(b) Derive the formula for overall efficiency for a ***triple*** cycle plant in terms of the efficiencies of each the three cycles.

(c) Show that if the efficiency of a power plant were to increase from 33% to 50% the amount of rejected heat per MW generated is halved.

(d) The U.S. consumes about 400 million gallons of gasoline per day. Suppose that the nation's entire fleet of 2 million 18-wheeler tractor trailer trucks were converted to natural gas, by what amount would the fraction of U.S. oil imports decrease? Assume that the U.S. imports are 67% of all the oil it consumes and that the average 18-wheeler gets 6 mpg, and drives 60,000 miles per year.

Question 2. Nuclear

(a) It requires 2.2 MeV to separate the neutron & proton in a deuterium nucleus. Use this number to calculate the percentage difference between the mass of a deuterium nucleus and that of its constituents, and be sure to state whether the nucleus is heavier or lighter than its constituents by this amount.

(b) Suppose you are inadvertently in the presence of a radioactive source whose half-life is 3 hours for a two hour interval. Calculate your total exposure in rads over the 4 hours if the initial dose rate was 5 rad/hr.

(c) If the dose to double your cancer risk is 2000 mSv, estimate the percentage increase in your long-term risk of cancer from a medical exposure equal to five times the average background radiation (2.5 mSv) – assuming the linear no-threshold hypothesis is true.

(d) Based on Fig. 3.6, estimate how many times greater the energy released per kg in fusion is than that released in fission. Explain your reasoning.

Question 3. Geothermal. A certain geothermal field used to power a 100 MW plant has a temperature gradient G. Assume that the minimum depth is based on the rocks being hot enough (T > 175 C) to be useful in generating electricity, and the maximum depth that can be drilled is based on the greatest depth for which the rock remains below 500 C. Also assume the rock has a specific heat of 0.84 kJ/kg.K, a thermal conductivity of 2 W/m.K, a density of 3000 kg/m^3 , and that the power plant extracts heat over a surface area of 5 km^2 ,

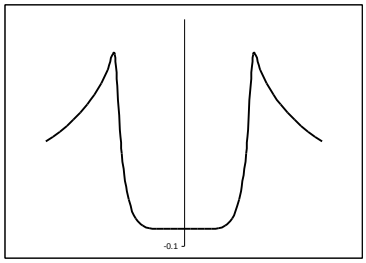
(a) Derive an expression for the useful thermal energy contained in this field above the ambient air temperature (25 C), and evaluate it for the specific case of G = 50 K/km.

(b) The energy calculated in (a) is extracted by pumping water initially at the ambient air temperature through the rocks. What is the minimum thermal power the rocks need to supply in order to produce an electrical power output of 100 MW, based on the Carnot efficiency? (For simplicity assume here that the entire field has a single temperature equal to its average value.)

(c) What is the minimum volume flow rate of the water that is needed to produce the thermal power you found in (b)?

(d) If the flow rate of the water is constant over time, find the initial rate of decline of the average temperature of the geothermal field, and also find how long will it be before the power of the plant becomes 35% less than its initial value? (Do not assume a constant rate of decline.)

Question4. Nuclear



(a) Explain how these 3 specific properties of the strong and Coulomb forces follow from the above graph of the potential energy versus separation r for a pair of protons:

1. Strong force is attractive while Coulomb force is repulsive
2. Strong force is much stronger than Coulomb force
3. Strong force only present at very short distances

(a) Explain why there is a heaviest nucleus.

(b) Explain why the concept of a critical mass applies to fission but not fusion where no critical mass is needed.

(c) Explain why the first generation fusion reactor is likely to be built using the d-t reaction, where d and t refer to the two isotopes of hydrogen H^2 and H^3 .

Question 5 Biofuels

(a) The total amount of energy trapped by photosynthesis each second is approximately 100 TJ. Estimate how many tons of CO2 photosynthesis removes from the atmosphere each second, assuming that the absorbed energy consists of visible photons whose energy is about 2 eV each, and that absorption of one photon is sufficient to induce the basic photosynthesis reaction:

: $CO_2 + H_2O + \text{Energy} \rightarrow CH_2O + O_2$.

(b) Explain why the ***net*** effect on atmospheric CO2 levels from plants over the course of a year is actually zero.

(c) If 100 TJ per second is in fact 6x larger than the power consumed by all humans, what does that imply about the average power consumed per person?

(d) Explain how it might make sense to produce a biofuel that had an energy content that was lower than the energy required to produce it or a NER less than one?