Student ID Number: ________

PRELIMINARY EXAMINATION

Department of Physics
University of Florida
Part D, January 5, 2019, 14:00–17:00

Instructions

1. You may use a calculator and CRC Math tables or equivalent. No other tables or aids are allowed or required. You may **NOT** use programmable calculators to store formulae.

   (a) All of the problems will be graded and will be tabulated to generate a final score. Therefore, you should submit work for all of the problems.

   (b) For convenience in grading please write legibly, use only one side of each sheet of paper, and work different problems on separate sheets of paper. The sheets for each problem will be stapled together but separately from the other two problems.

   (c) Your assigned student **ID Number**, the **Problem Number**, and the **Page Number** should appear in the upper right hand corner of each sheet. Do **NOT** use your name anywhere on the Exam.

   (d) All work must be shown to receive full credit. Work must be clear and unambiguous. Be sure that you hand your completed work to the Proctor.

   (e) Each problem is worth 10 points.

   (f) Following the UF Honor Code, your work on this examination must reflect your own independent effort, and you must not have given, nor received, any unauthorized help or assistance. If you have any questions, ask the Proctor.

University of Florida Honor Code: We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honesty and integrity. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: *"On my honor, I have neither given nor received unauthorized aid in doing this assignment."*

DO NOT OPEN EXAM UNTIL INSTRUCTED

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D1. (a) **[3 points]** Two masses with the same heat capacity c are isolated mechanically and thermally from their environment. They are initially at absolute temperatures T and rT respectively, where r is a dimensionless constant. The masses are brought into contact and reach thermal equilibrium with each other.

Find the entropy change ΔS of the universe, due to this equilibration. Express ΔS in terms of only c, T, r and fundamental constants.

(b) **[2 points]** Sketch ΔS versus r for $r \geq 0$ for (a) above. Your sketch should clearly show the sign of ΔS, and show how it behaves near $r \simeq 1$ and at very large and small r.

(c) **[3 points]** Now suppose that the two masses have very different heat capacities. One mass has heat capacity c and is initially at absolute temperature rT, where r is a dimensionless constant. The other mass is initially at temperature T and has such a large heat capacity C that it acts as a reservoir ($C \gg c$). The two masses are isolated from their environment.

Find the entropy change of the universe ΔS when these two masses come to thermal equilibrium.

(d) **[2 points]** Sketch ΔS versus r for $r \geq 0$ for (c) above. Your sketch should clearly show the sign of ΔS, and show how it behaves near $r \simeq 1$ and at very large and small r.

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D2. The deuteron is a bound state of a proton and a neutron (with nearly equal mass), where the strong nuclear force is responsible for the binding rather than the electromagnetic force. However, in this problem we will treat it as analogous to a hydrogen-like atom. If you don't recall or cannot derive any needed formulae, try dimensional analysis and the numbers given to determine the dependencies. Also try to reason how the requested parameters should scale with the relative strength of the force involved.

(a) **[2 points]** First, calculate the deuteron binding energy (in MeV) directly from the masses involved. For reference note that the masses for the deuteron, neutron, proton, and electron are 1875.63, 939.57, 938.28, and 0.511 MeV/c^2. (1 MeV = 10^6 eV, where 1 eV = 1.6×10^{-19} J)

(b) **[4 points]** Now approximate the nuclear potential of the deuteron as a Coulomb-like potential well but with the fine structure constant of electromagnetism, $\alpha = e^2/(4\pi\epsilon_0\hbar c) = 1/137$, replaced by that for the strong nuclear force, $\alpha_S \approx 0.1$. Calculate the binding energy of the deuteron (in MeV) in the lowest energy state for such a potential. Note that the ground-state energy for a hydrogen-like atom with an *infinite-mass* nucleus is -13.6 eV, and $\hbar = 6.58 \times 10^{-22}$ MeV$\cdot$s and $c = 3.0 \times 10^8$ m/s.

(c) **[4 points]** Calculate the Bohr radius of the deuteron. For a hydrogen atom with an *infinite-mass* nucleus it is 0.53×10^{-10} m.

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D3. A beam proton p of a total relativistic energy E collides with a target proton

(a) **[7 points]** What is the minimum total relativistic energy E_{min} in GeV of a beam proton to allow for creation of additional pair of two particles: anti-proton p^- and proton p? Assume that the target protons are stationary in a Hydrogen target

$$p + p \to p + p + p + p^-$$

Mass of a proton is ~ 0.94 GeV (in "natural" units $c = \hbar = 1$)

(b) **[3 points]** Will this minimum total relativistic energy increase, decrease or remain the same if a target proton is located inside a complex nucleus heavier than Hydrogen? Explain why.

(Hint: a target proton if inside a complex nucleus containing few protons and neutrons is localized within a nuclear size of $\sim 10^{-15}$ m.).