PHYS 390 Final Examination

Time: 3 hours — Name_____
8 April, 2002 — Student number_____

Calculator and one formula sheet allowed

Some useful constants, data, ...

$L_{Sun} = 3.9 \times 10^{26}$ J/s
$M_{Sun} = 2.0 \times 10^{30}$ kg
$m_{proton} = 1.67 \times 10^{-27}$ kg
$M_{Earth} = 5.97 \times 10^{24}$ kg
$R_{Sun} = 6.96 \times 10^{8}$ m
$R_{Earth} = 6.38 \times 10^{6}$ m
$\sigma = 5.67 \times 10^{-8}$ watts•K^{-4}•m^{-2}
$k = 1/(4\pi\varepsilon_o) = 8.99 \times 10^{9}$ N•m^2/C^2
$e = 1.6 \times 10^{-19}$ C
$G = 6.67 \times 10^{-11}$ N•m^2/kg^2
$k_B = 1.38 \times 10^{-23}$ J/K
AU $= 1.50 \times 10^{11}$ m
pc = 3.26 ly
ly $= 9.46 \times 10^{15}$ m
$c = 3.0 \times 10^{8}$ m/s
$U_\gamma = 7.565 \times 10^{-16}\ T^4$ J/m^3.

Show complete solutions to questions 4 to 8.

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1. For each of the following questions, circle one correct answer. (15 marks)

(i) For a pair of objects orbiting each other under gravity, which of the following statements is false? The period of the orbital motion
- (a) depends on the semi-major axis
- (b) is independent of the radii of the objects if their mass is fixed
- (c) depends on the reduced mass
- (d) depends on the gravitational constant *G*.
- (e) depends on the total mass.

(ii) A seen by an observer on Earth, a Jupiter-like planet of radius R_{planet} passes in front of a star of radius R_{star}. If the apparent luminosity of the star decreases by a maximum of 1%, what is R_{planet}/R_{star}?
(a) 10^{-4} (b) 10^{-2} (c) 10^{-1} (d) $10^{-2}/\sqrt{\pi}$ (e) $10^{-1}/\sqrt{\pi}$.

(iii) Two members of a binary pair of stars called Alpha and Beta have apparent magnitudes $m_{alpha} = 4$ and $m_{beta} = 6.5$. What is the ratio of their luminosity L_{alpha}/L_{beta}? Assume that the separation between the binaries is much less than their distance from Earth.
(a) 0.1 (b) 1 / 2.5 (c) $10^{2.5}$ (d) 10 (e) $1 / 10^{2.5}$

(iv) If the surface temperature of a star suddenly doubles, leaving its mass and mean density unchanged, by what factor does its luminosity change?
(a) 1/2 (b) 2 (c) 4 (d) 8 (e) 16

(v) A particular hydrogen cloud of mass *M*, density ρ and temperature *T* barely possesses enough mass to collapse under gravity. If the density were doubled at fixed temperature, what would be the minimum mass for collapse?
(a) $\sqrt{2}\,M$ (b) $2M$ (c) $4M$ (d) $M/\sqrt{2}$ (e) $M/4$.

2. For each of the following questions, circle one correct answer. (15 marks)

(i) In a thermonuclear reaction at temperature T, the optimal energy for tunneling through the Coulomb barrier is E_o. If the temperature is increased by a factor of 8, what is the optimal energy in terms of the original E_o?
(a) $2E_o$ (b) $4E_o$ (c) $8E_0$ (d) $16\ E_o$ (e) none of [a-d]

(ii) Considering only their electromagnetic interactions, which of the following pairs of nuclei would have the slowest thermonuclear reaction rate? In all cases, the reaction produces an excited state of ^{8}Be.
(a) $\gamma + {}^8$Be (b) $p + {}^7$Li (c) ^{4}He + ^{4}He (d) $n + {}^7$Be (e) ^{2}H + ^{6}Li

(iii) Which of the following statements regarding the three PP reaction sequences (*i.e.* PP-I to PP-III) is false?
(a) The energy released through neutrinos is the same for each complete sequence.
(b) The total energy released per ^{4}He produced is the same.
(c) Two neutrinos are produced for each ^{4}He.
(d) All reactions can proceed even if there are no neutrons present.
(e) More than one of the above statements is false.

(iv) If the binding energy of the nucleus were described solely by $BE = C_{vol}A - C_{surf}A^{2/3}$, which of the following statements is false?
(a) The binding energy is independent of charge.
(b) Fusion of light nuclei releases energy.
(c) Fission of heavy nuclei releases energy.
(d) The most deeply bound nucleus is not ^{56}Fe.
(e) More than one of the above statements is false.

(v) For a white dwarf with a mass well below the Chandrasekhar limit, the radius is proportional to (approximately) what power of the mass?
(a) $1/M^{1/3}$ (b) $1/M^{2/3}$ (c) $1/M$ (d) $1/M^{3/2}$ (e) R is independent of M.

3. For each of the following questions, circle one correct answer. (15 marks)

(i) Consider a system composed only of electrons, positrons and photons at such a high temperature that $k_B T >> m_e c^2$. In terms of the photon number density N_γ, what is the total number density?
(a) $2N_\gamma$. (b) $(3/2)N_\gamma$. (c) $(7/4)N_\gamma$. (d) $(1/2)N_\gamma$. (e) none of [a-d]

(ii) Consider a system composed only of electron-neutrinos, anti-neutrinos and photons at a temperature T. In terms of the photon energy density U_γ, what is the total energy density?
(a) $(15/8)U_\gamma$. (b) $(11/4)U_\gamma$. (c) $(7/8)U_\gamma$. (d) $2U_\gamma$. (e) none of [a-d]

(iii) How has the net baryon density changed with respect to the photon number density in the time period since the first few minutes of the Big Bang? The ratio of the number densities varies as:
(a) T^3 (b) T^4 (c) $1/T^3$ (d) $1/T^4$ (e) unchanged

(iv) If the capture of neutrons to form ^{4}He in the early universe occurred when the neutron abundance was 5% by number, what would be the resulting percentage weight of ^{4}He?
(a) 2.5 (b) 20 (c) 10 (d) 5 (e) 25

(v) Which of the following conditions is NOT required to produce the asymmetry between matter and antimatter of the magnitude and type observed in the universe today?
(a) violation of B-L_e
(b) violation of B+L_e
(c) no equilibration after asymmetry created
(d) an excursion from equilibrium that removes baryon number symmetry
(e) all of the above condition are required.

4. Suppose that the Earth bore a slight excess charge Q.
(a) What is the maximum value of Q such that the gravitational interaction cannot bind the planet together? Quote your answer in C.
(b) What is the net charge per nucleon? Quote your answer in electron charges per nucleon. (8 marks)

5. Light from a distant star passes through a giant molecular cloud on its way to an observer on Earth. The cloud has a mean density of 10^9 atoms per cubic meter and a radius of 0.5 parsec. If the absorption cross section of the atoms is 10^{-26} m^2, what is the maximum decrease in the flux of light from the star compared to its true value? (7 marks)

6. Two identical stars, each with mass equal to the Sun, form a binary pair. The stars are separated by a constant distance of 1 AU. Although very far removed, Earth lies in the same orbital plane as the stars.
(a) What is the period of their motion?
(b) Consider the emission of light of a specific wavelength λ simultaneously from each star? What will be the wavelength λ' of this light as seen by an observer on the Earth, and how will this wavelength change with time (make a rough sketch)? What will be the maximum difference in wavelength in light emitted from the two stars as observed on Earth? (18 marks)

...more

7. Starting from initial nuclei A and B, a two-step reaction produces nucleus D *via* an intermediate nucleus C:

$A + B \rightarrow C$ Λ_{AB}

$C + C \rightarrow D$ Λ_{CC}.

Take the initial concentrations of A and B to be equal ([A] = [B]). Once a steady state regime has been reached, what is the rate of production of D per unit volume in terms of Λ_{AB}, Λ_{CC} and [A]? (12 marks)

8. The white dwarf Sirius B has a radius of 5500 km and a mass of 1.05 solar masses. Treated (incorrectly) as a classical ideal gas with constant density, what is the pressure of its core? State any further assumptions that you make to solve this problem by approximations no worse than what we did in class! (10 marks)

Ans:
1. c, c, d, e, d.
2. b, c, a, c, a.
3. e, a, e, c, b.
4. (a) 5.14×10^{14} C; (b) 9×10^{-19} *e* per nucleon.
5. 30% of the light is absorbed.
6. (a) 7.9×10^{6} seconds; (b) 2.0×10^{-6} for single, 4.0×10^{-4} for pair
7. $d[D]/dt = \Lambda_{AB} [A]^2/2$.
8. 7.7×10^{22} J/m^3.