ASTRONOMY QUALIFYING EXAM

January 2019

Possibly Useful Quantities

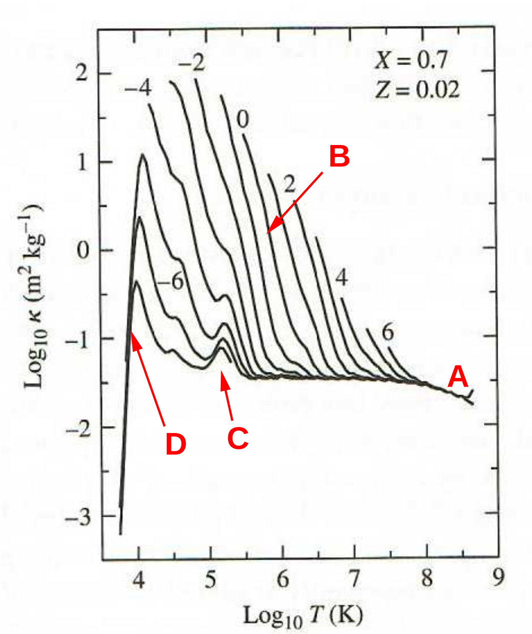
$L_\odot = 3.9 \times 10^{33}$ erg s^{-1}
$M_\odot = 2 \times 10^{33}$ g
$M_{bol\odot} = 4.74$
$R_\odot = 7 \times 10^{10}$ cm
1 AU = 1.5 $\times 10^{13}$ cm
1 pc = 3.26 Ly. = 3.1 $\times 10^{18}$ cm
1 radian = 206265 arcsec
a = 7.56 $\times 10^{-15}$ erg cm^{-3} K^{-4}
c = 3 $\times 10^{10}$ cm s^{-1}
$\sigma = ac/4 = 5.7 \times 10^{-5}$ erg cm^{-2} K^{-4} s^{-1}
k = 1.38 $\times 10^{-16}$ erg K^{-1}
e = 4.8 $\times 10^{-10}$ esu
1 fermi = 10^{-13} cm
$N_A = 6.02 \times 10^{23}$ moles g^{-1}
G = 6.67 $\times 10^{-8}$ g^{-1} cm^3 s^{-2}
$m_e = 9.1 \times 10^{-28}$ g
h = 6.63 $\times 10^{-27}$ erg s
1 amu = 1.66053886 $\times 10^{-24}$ g

PROBLEM 1

The opacity in the atmosphere of a star can be divided into four broad types: bound-bound transitions, bound-free absorption, free-free absorption, and electron scattering.

a) (2 points) Describe the physical process for each type of absorption.

b) (2 points) Figure below shows a plot of the Rosseland mean opacity. The curves are labeled by the logarithmic value of the density. Explain the physical origin of the opacity at the lettered points.



c) (2 points) Consider hydrogen; sketch the wavelength dependence of the bound-free opacity. Note: It is important to include the wavelength values on the wavelength axis, but relative intensity is OK for the y axis.

d) (2 points) Explain the phenomenon of limb darkening. It may help to draw a picture.

e) (2 points) The opacity of the solar photosphere at 500 nm is $\kappa = 0.03\,\mathrm{m^2\,kg^{-1}}$. Calculate how far you could see through the Earth's atmosphere if it had the opacity of the solar photosphere. You may use $\rho = 1.2\,\mathrm{kg\,m^{-3}}$ for the earth's atmosphere.

PROBLEM 2

a) (2 points) Estimate the pressure at the center of the sun. Note that $M_\odot$, $R_\odot$, and $L_\odot$ are given on page 1.

b) (2 points) Estimate the temperature at the center of the sun.

c) (2 points) How long could the sun shine assuming the energy is produced by gravitational collapse to its present size?

d) (2 points) How do we know that the power of the sun does not come from gravitational collapse?

e) (2 points) How long could the sun shine via hydrogen fusion?

PROBLEM 3

Define/explain 10 of the following and indicate their relevance in astronomy. Be sure to clearly indicate which of the 10 you would like graded (otherwise the first 10 items will automatically be graded).

a) Equation of State (1 point)
b) Bias and Flat Field Calibrations (1 point)
c) CNO cycle (1 point)
d) Cosmological Principle (1 point)
e) Hayashi Track (1 point)
f) Fundamental plane (1 point)
g) Malmquist Bias (1 point)
h) Olbers Paradox (1 point)
i) Wolf-Rayet Star (1 point)
j) Total Rosseland Mean Opacity (1 point)
k) Schwarzschild Criterion for Convection (1 point)
l) Eddington Limit (1 point)
m) Convective overshoot (1 point)

PROBLEM 4

Assume that a galaxy disk has an exponential surface brightness profile:

$$\mathsf{I(R) = I_0\ e^{-R/R_d}} \tag{1}$$

where R_d is the exponential scale length.

a) (6 points) What is the luminosity of the disk within R, expressed in terms of I_0 and R_d? Try to put as many terms into dimensionless ratios as possible, i.e. $R_d(1 + R/R_d)$ is easier to think about than $(R_d + R)$.

b) (4 points) Derive the conversion from I_0 (in units of $L_\odot$ per square parsec) to μ_0 (in units of magnitudes per square arc second). Hint: it is helpful to put the galaxy at 10 pc; and also recall that the absolute magnitude of the sun in the B−band is 5.5, and 1 radian = 206265 arcsec.

PROBLEM 5

In this problem, you will estimate the cooling timescale for dissipative collapse during the formation of protogalaxies. Assume that the collapsing protogalactic nebula has mass M, and radius R. To estimate this time scale, you must first determine the characteristic amount of thermal energy contained within each particle in the gas.

a) (2 points) Using the viral theorem, assume the gas is in quasi-static equilibrium, and relate the thermal kinetic energy of the gas to the potential energy. Assume the gas has a mean molecular weight μ, and contains N particles (mass of hydrogen is $\mathrm{m_H}$).

b) (2 points) Recall that σ, the velocity dispersion, is related to gas velocity as $\sigma = \sqrt{< \mathrm{v}^2 >}$. Solve for the velocity dispersion of the gas.

c) (2 points) Determine a characteristic temperature of the gas, known as the viral temperature, by equating the typical kinetic energy of the gas to its thermal energy.

d) (2 points) To estimate the cooling time, assume that the cooling rate for the gas (in units of ergs/s/cm^3) is $\mathrm{r_{cool}} = \mathrm{n}^2\Lambda(\mathrm{T})$, where n is the number density of particles in the gas and $\Lambda(\mathrm{T})$ is the quantum mechanical cooling function. Solve for $\mathrm{t_{cool}}$ assuming all the energy of the cloud is radiated in away in that amount of time. Your answer should be in terms of the virial temperature, Λ and n.

e) (2 points) Suppose that the freefall time ($\mathrm{t_{ff}}$) is less than the cooling time ($\mathrm{t_{cool}}$). Discuss what this means in terms of the collapse of the protogalactic nebula.

PROBLEM 6

If the source function inside a star is $S_\nu(\tau_\nu) = a_\nu + b_\nu \tau_\nu$, where a_ν and b_ν are functions of ν, calculate

a) (4 points) the specific intensity $I_\nu(0, u)$ at the surface for the outgoing directions $(u \geq 0)$.

b) (2.5 points) the average intensity J_ν.

c) (2.5 points) the Eddington Flux H_ν.

c) (1 point) the monochromatic Flux F_ν.