Assignment 3
Electrodynamics and Radiative Processes I

20 marks for each question

Due on 26th September 2019

1) $10^{11}\ M_{sun}$ of hydrogen occupies a sphere of radius 100 kpc at a temperature of 10^6 K (galaxy scale)
Calculate

a) the total thermal energy E
b) the rate of loss of this energy due to free-free emission dE/dt
c) the time scale for significant cooling
d) by what factor does dE/dt changes if the mass goes up by two orders of magnitude, radius by 10^2, and temperature by 10^2 (cluster scale)
e) what fraction of the incident radiation undergoes Thomson scattering in galaxy scale and cluster scale

2) An ultrarelativistic electron emits synchrotron radiation. Show that its energy decreases with time according to: $\gamma(t) = \gamma_0 /(1 + A\gamma_0 t)$, where $A = 2e^4 B^2/ (3m^3c^5)$.
Here γ_0 is the initial value of γ and $B_\perp = B \sin \alpha$.
Show that the time for the electron to lose half its energy is $t_{1/2} = 5.1 \times 10^8 /\gamma_0 B^2_\perp$

3) From the rate of energy loss due to synchrotron emission from a particle moving in a magnetic field with a pitch angle $\pi/2$, find the energy of the particle as a function of time. Consider that the particle has an energy E_0 at a time t_0. If an initial power law energy distribution of electrons is allowed to evolve by synchrotron

emission in a constant magnetic field B, without further energy or particle input, what will the spectrum look like after a time t?

(4) A fully ionized hydrogen plasma of mass density ρ at a temperature T cools by optically thin bremsstrahlung. Derive the expression for cooling time (time required to radiate away the thermal energy) assuming that the density remains constant and that the electrons and ions maintain a common temperature. For such a plasma with a density of 10 hydrogen atoms per cm^3 and a temperature of 2000 K ,how long will the cooling take.

(5) Orion nebula is one of the brightest HII regions on the sky. Its angular size is approximately 1 deg and we know that its distance is around 400 pc. This region emits thermal bremsstrahlung radiation with transition from optically thick to optically thin regime at 1 GHZ and cut-off frequency at 200 THz.

(a) In observations, the measure of the cutoff frequency is a way to determine the plasma temperature. Estimate the temperature of Orion nebula.

(b) Assuming that Orion nebula has a spherical shape, estimate the number density of the region.