Problems of High Energy Astrophysics (Ebisawa), August 1, 2016

full score: 100

1. In high energy plasmas, heavy elements are ionized, and both continuum emission and many emission lines are observed in the X-ray energy band. (**15**)
   (a) Derive formula of the binding energy of the *hydrogenic ion*, which has only a single electron, of the atomic number Z, using m_e (electron mass), $\hbar$, e and Z. (5)
   (b) What is the binding energy of the hydrogenic iron ion (in keV)? (5)
   (c) Estimate the plasma temperature (in K), where iron is ionized up to hydrogenic ion? (5)
2. Let's consider a spherically radiating star with the mass M. (**20**)
   (a) Derive the formula of *Eddington luminosity* using c, G, M and κ (mass-absorption coefficient due to Thomson scattering). (10)
   (b) Estimate typical temperatures (in keV) of "X-ray bursts" and "Super-soft Sources" assuming the blackbody radiation from the neutron star or white-dwarf surfaces, respectively, at Eddington luminosity. (10)
3. Let's consider mass accretion to non-spinning black holes (a=0) or maximally spinning black holes ($a = 1$). (**20**)
   (a) What is the Innermost Stable Circular Orbit (ISCO) for each case? (10)
   (b) Using Newtonian approximation, estimate energy conversion efficiency for each case when materials fall from infinity to ISCO. (Note, the precise values are $1 - \sqrt{8/9}$ ($a = 0$) and $1 - \sqrt{1/3}$ ($a = 1$) according to the general relativity.) (10)
4. Let's consider standard accretion disks around black holes. (**20**)
   (a) Estimate innermost temperature (in keV) of the standard accretion disk around a black hole with the mass M, assuming that the disk is radiating with blackbody at Eddington luminosity, and the black hole is not spinning. (10)
   (b) Estimate the innermost disk temperature of the standard disk around the black holes with $M = 10M_\odot$ and $M = 10^9 M_\odot$. Which wave-length would be most appropriate to observe these targets? (10)
5. Let's consider X-ray satellites by JAXA/ISAS (ASCA, Suzaku, Hitomi) which have the telescope in the direction of the satellite Z-axis and the solar-panel in the direction of the Y-axis. The satellite attitude is described with the Z-Y-Z Euler angle. What are the Euler angles to observe North Ecliptic Pole (NEP) region in spring-equinox, summer-solstice, autumun-equinox and winter solstice? (**15**)
6. Let's consider synchrotron radition or non-thermal inverse-Comptonized radition from the relativistic electrons whose number density is given as $\propto \gamma^{-p}\ d\gamma$ in a wide-energy band, where $mc^2\gamma \equiv mc^2/\sqrt{1-(v/c)^2}$ is the electron energy. In both cases, the following conditions are satisfied;
   (a) Characteristic photon energy ($\equiv h\nu_c$) emitted from a single electron is proportional to the electron energy ($\propto \gamma^2$).
   (b) Energy spectrum of photons emitted from a single electron is represented as a function of ν/ν_c.

   Show that the expected synchrotron radiation and the inverse-Compton radiation have the power-law energy spectra, $\propto \nu^{-s}$, and derive the relation between s and p. (**10**)