2.3 Consider the quasar SDSS J162057.65+062546.1 contained in the Sloan Digital Sky Survey (http://www.sdss.org). The decimal coordinates, often used by SDSS, are ra=245.24022971 and dec=6.42948537. The SDSS spectrum is labeled as spSpec-53501-1732-007 in the MJD-plate-fiber terminology. Use the SDSS DR6 Explore tool to retrieve data on this quasar (http://cas.sdss.org/dr6/en/tools/quicklook/quickobj.asp) by means of a Plate-MJD-Fiber search. (Note the different order of the plate number and MJD; omit leading zeros. In some browsers you may need to manually zoom the window to see the full display.) Click on the spectrum to get an enlarged view and save it (you will get a .gif file). Click on "FITS" under "SpecObj" to download the digital spectrum in FITS format. When spectral measurements are required below, make approximate measurements by hand on the gif spectrum. Then measure more accurately from the .fit file using using the IRAF routine SPLOT or another program such as IDL that can handle FITS files. (Note that the spectrum is in HDU 1 of the .fit file.) Assume a cosmology with $H_o = 70$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$.

(a) Verify that the observed wavelength of the narrow [O III] λ5007 emission line agrees with the redshift of the QSO given by SDSS. (Consult figures in Osterbrock & Ferland or Peterson (1997) "Active Galactic Nuclei" to identify the [O III] doublet, the Hβ line, and other features of the spectrum.)

(b) Measure the observed continuum flux F_λ (SDSS's F_λ is Osterbrock's πF_λ) in units of erg s^{-1} cm^{-2} Å^{-1} at the redshifted wavelength corresponding to a rest wavelength of 5100 Å. Find the "luminosity distance" d_L to the quasar using Ned Wright's Cosmology Calculator (http://www.astro.ucla.edu/∼wright/CosmoCalc.html) , for the above cosmological parameters (flat universe). This is defined such that $(\lambda L_\lambda)_{rest} = 4\pi d_L^2 (\lambda F_\lambda)_{obs}$, where L_λ is the specific luminosity (erg s^{-1} Å^{-1}) in the rest frame of the object and F_λ is the specific flux in the observed frame at the redshifted wavelength. Find the value of $\lambda L_\lambda(5100)$ for the QSO.

(c) From the result of part (d), find the specific luminosity of the QSO per unit frequency, L_ν, using the relationship $\nu L_\nu = \lambda L_\lambda$. Assume a power-law spectrum $L_\nu = L_0(\nu/\nu_H)^{-1.5}$ for all frequencies above the frequency corresponding to λ5100. Calculate the ionizing luminosity L_i (erg s^{-1}) integrated over all ionizing frequencies ($\nu > \nu_H$) and the ionizing photon luminosity $Q(\mathrm{H}^0)$ in photons s^{-1}. What is the mean energy of the ionizing photons?

(d) Use equation 2 of Kaspi et al. (2005, ApJ 629, 61) to estimate the radius of the broad line region in the QSO. Use this radius to calculate the ionizing photon flux ϕ_i incident on a cloud in the BLR. If the cloud consists of pure hydrogen with a density of 10^{10} atoms per cm^3 and a temperature of 15,000 K, what is the ionization ratio $n(H^0)/n(H^+)$ at the front face of the cloud? For a plane-parallel cloud of large column density, what is the expected depth in the cloud to which hydrogen remains highly ionized (photon counting argument)?

(e) Run a simple plane-parallel photoionization model with CLOUDY to find the degree of ionization of hydrogen at the front face of the cloud and the depth in the cloud at which hydrogen is 50% ionized. Compare with your hand calculation in part (d) above.

(f) For the Hβ broad emission line, measure the equivalent width (EW) in Å, the flux (πF) in erg s^{-1} cm^{-2} , and the full width at half-max (FWHM) in km s^{-1}. Restate the EW of the line in the rest frame of the QSO.

(g) Assuming a power-law continuum $L_\nu = L_0/,(\nu/\nu_H)^{-1.5}$ as before, calculate the expected equivalent width of the Hβ line. Assume that the BLR completely surrounds the continuum source and absorbs all the ionizing photons. Assume that the Hβ line is formed by radiative recombination, with one photon in Hβ emitted for every 12 recombinations to $n = 2$ or higher. Make the on-the-spot approximation regarding the hydrogen diffuse Lyman continuum. If your result does not agree with the measured value, discuss possible explanations.

(h) Assuming that the BLR consists of clouds orbiting the central black hole at a velocity equal to the FWHM of Hβ. calculate the mass of the central black hole using the radius found in part (d).

3.1 Consider the cooling curves in Figure 3.2 and 3.3 of Osterbrock & Ferland.

(a) Using the atomic data in the book, calculate the normalized cooling rate $\epsilon(O^+) = L_C/n_e n_{O^+}$ for [O II] $^4S - ^2D$ (see Figure 5.7) at 10,000 K in the low density limit (ignoring collisional de-excitation). Verify your result using Shaw & Dufour's nebular analysis package at http://stsdas.stsci.edu/nebular/ionic.html. Using $n(O)/n(H) = 7 \times 10^{-4}$, calculate the cooling coefficient $\Lambda = L_C/n_e n_p$ and compare with Figure 3.2. (Treat O$^+$ as a two level system, ignoring the splitting of the ^2D term.)

(b) Repeat for $n_e = 10^4$ cm^{-3} using Figure 3.3 for comparison.

(c) Suppose a small gas cloud is ionized in equilibrium by monochromatic radiation at $h\nu = 1.5h\nu_H$. The gas has only hydrogen and oxygen with $n(O)/n(H) = 6 \times 10^{-4}$. The H is almost all H$^+$ and the O is almost all O$^+$. What is the equilibrium temperature (analytic solution)? Why is it not necessary to specify the flux of ionizing radiation, provided that it is sufficient to give the prescribed degree of ionization? (Do the calculation for an infinitesimal cloud, i.e., a single point in the gas, but assume on-the-spot for the diffuse radiation.)