ASTRONOMY 8300 – Fall 2024
Midterm – Due 10/30/24 at 9:30 am

1. a. (5 pts) Write the equation of radiative transfer for an absorption line in the cold interstellar medium. Define the optical depth (at a particular frequency or wavelength) from this equation. What is the optical depth in terms of the observed and continuum flux? If the ratio of observed to continuum flux at that frequency or wavelength is 0.01, what is the optical depth?

   b. (5 pts) Suppose that you observe a C IV λ1548 absorption line with an intrinsic width of FWHM = 200 km/sec, using a spectrograph with a resolution of FWHM = 0.2 Å. What technique would you use to determine the column density? What technique would you use if the spectrograph had a resolution of only 5.0 Å?

   c. (5 pts) How do we determine the abundances of elements in diffuse interstellar gas? How do these abundances differ from solar abundances? Why are they different?

2.a. (5 pts) What is a basic property that all reddening curves have in common? How do the reddening curves for the Galaxy, SMC, and LMC differ? What are the likely physical causes of the differences?

   b. (5 pts) For a star that is reddened by E(B-V) = 0.25, what is the extinction (in magnitudes) in the V and B bands (assuming a standard Galactic reddening curve)? How much brighter (in flux) would the star be in the V and B bands if the dust were removed from our line of sight?

3.a. (5 pts) Write down an expression for the ionization balance at a particular location in a photoionized hydrogen nebula. Define each term. What does each side of the equation represent?

   b. (5 pts) Consider an optically thick (to ionizing radiation) H nebula around a single star. Write down a modified version of this equation to account for this specific situation.

   c. (5 pts) Consider the ionization balance on a global scale, and derive an expression for the radius of a Stromgren sphere.

4.a. (5 pts) Consider an H II region consisting of pure H and He at low density ($n_H = 10^2$ cm^{-3}). List the basic physical processes by which the region is heated and cooled in order of decreasing importance.

   b. (5 pts) If elements heavier than H and He are added to the above gas (at the level of solar abundances), what happens to its temperature? Why?

   c. (5 pts) If the density is increased to $n_H = 10^8$ cm^{-3} what happens to its temperature? Why?

5. (5 pts) Given a photoionized nebula with a temperature of T = 10,000K and a density of $n_H = 10^2$ cm^{-3}, which of the following would you see in emission? Which would you see in absorption, given a suitably hot background source? If the answer is "yes", give the physical process. If "no", give a reason why not.
   a. Lyα λ1216
   b. Hβ λ4861
   c. [O III] λ5007
   d. Ga I λ2874
   e. O I λ1302

6.a. (5 pts) Based on the atomic energy levels of [O III], why is the [O III] λ5007/ λ4363 ratio a good temperature diagnostic? How does this ratio change with temperature?

   b. (5 pts) Based on the atomic energy levels of [O II], why is the [O II] λ3729/ λ3726 ratio a good density diagnostic? How does this ratio change with density?

   c. (5 pts) Explain how we can obtain temperatures of H II regions by comparing recombination lines and recombination continua.

7. Give a brief description or explanation of the following terms (include an equation or diagram if needed). (1 pt each)
   a. Column density
   b. Equivalent width
   c. Curve-of-growth
   d. PDR
   e. PAHs
   f. Parahelium vs. orthohelium
   g. On-the-spot approximation
   h. Grotrian diagram
   i. Critical density
   j. Bowen resonance-fluorescence
   k. Bremsstrahlung
   l. Auger effect
   m. Dielectronic recombination
   n. Charge exchange
   o. Paschen continuum
   p. Two-photon continuum
   q. Photoionization model input parameters
   r. Resonance transition
   s. Mid-IR dust features
   t. HI 21-cm emission
   u. Quantum-mechanical rule for permitted transitions
   v. Shock front
   w. Ionization parameter
   x. Nebula energy conservation equation
   y. Five phases of the diffuse interstellar medium