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First Midterm Exam

- This is a 50 min, closed book exam. While taking the exam, the only materials you can use are your calculator and one page of hand-written notes.
- There are FOUR problems, and you have to solve all of them to get full credit.
- The problems are *not* arranged in the order of difficulty, so make sure you try them all! Even if you cannot do part (a) of some problem, you might be able to do other parts, so do not give up too easily.
- Do not try to get answers exact to many significant digits. *Estimate* whenever possible. This will save you a lot of calculation time.
- In some problems it might be necessary for you to make assumptions. Please state these clearly in your solutions.
- Please write your name at the top of each page, just in case...

Good Luck!

Physical Constants

$G = 6.67259 \times 10^{-11}\,\mathrm{m^3\,kg^{-1}\,s^{-2}}$
$c = 2.99792 \times 10^{8}\,\mathrm{m\,s^{-2}}$
$h = 6.62608 \times 10^{-34}\,\mathrm{J\,s}$
$k = 1.38066 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
$\sigma = 5.67 \times 10^{-8}\,\mathrm{J\,m^{-2}\,s^{-1}\,K^{-4}}$
$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
$1\,\mathrm{eV} = 1.60218 \times 10^{-19}\,\mathrm{J}$
$1\dot{\mathrm{A}} = 10^{-10}\,\mathrm{m}$

Astronomical Constants

$M_\odot = 1.99 \times 10^{30}\,\mathrm{kg}$
$R_\odot = 6.96 \times 10^{8}\,\mathrm{m}$
$L_\odot = 3.826 \times 10^{-26}\,\mathrm{J\,s^{-1}}$
$T_{\odot,\mathrm{eff}} = 5800\,\mathrm{K}$
$1\,\mathrm{AU} = 1.4960 \times 10^{11}\,\mathrm{m}$
$1\,\mathrm{pc} = 3.0857 \times 10^{16}\,\mathrm{m}$
$1\,\mathrm{rad} = 2.06 \times 10^{5}$ arcsec

These Equations Might Be Useful

$$P^2 = \frac{4\pi^2}{G(M_1+M_2)}a^3; \quad r = \frac{a(1-\epsilon^2)}{1+\epsilon\cos\theta}; \quad E = -\frac{GM\mu}{2a}; \quad L = \frac{M_1 M_2}{M_1+M_2}\sqrt{G(M_1+M_2)a(1-\epsilon^2)}$$

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT}-1}; \quad B_\nu(T) = \frac{2h\nu^3/c^2}{e^{h\nu/kT}-1}; \quad \lambda_{\max} = \frac{0.29\,\mathrm{cm\,K}}{T}$$

$$L = 4\pi R^2 \sigma T^4; \quad \int_0^\infty B_\nu(T)d\nu = \frac{\sigma T^4}{\pi}$$

$$F_\lambda = \int I_\lambda \cos\theta d\omega; \quad d\omega = d\phi\,\sin\theta\,d\theta$$

$$dI_\lambda = I_\lambda\ d\tau_\lambda - S_\lambda\ d\tau_\lambda; \quad I_\lambda(0) = I_\lambda(\tau_{\lambda,0})\,e^{-\tau_{\lambda,0}} + \int_0^{\tau_{\lambda,0}} S_\lambda(\tau_\lambda)\,e^{-\tau_\lambda}d\tau_\lambda$$

$$m_1 - m_2 = 2.5\log_{10}\left(\frac{F_2}{F_1}\right); \quad m - M = 5\log_{10}\left(\frac{d}{10\,\mathrm{pc}}\right)$$

$$\frac{N_b}{N_a} = \frac{g_b}{g_a}e^{-(E_b-E_a)/kT}$$

$$\frac{N_{i+1}}{N_i} = \frac{2}{n_e}\frac{Z_{i+1}}{Z_i}\left(\frac{2\pi m_e kT}{h^2}\right)^{3/2} e^{-\chi_i/kT}; \quad Z = \sum_{i=1}^{\infty} g_i e^{-(E_i-E_1)/kT}$$

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1. **Martian Astronomer** [25 points]

(a) Suppose an astronomer on Mars observes trigonometric parallax of a nearby star to be $0.5''$. Calculate the distance to this star if the distance from Mars to the Sun is about 1.5 AU.

(b) The same astronomer observed a nova outburst, during which a star brightens by ~ 10 magnitudes. What is the corresponding increase in the observed flux?

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2. **Shoemaker-Levy Comet** [25 points]

The famous Shoemaker-Levi comet that crashed into Jupiter in 1994 is believed to have started out in a typical, highly elliptical orbit with a perihelion distance smaller than 1 AU and aphelion distance of about 50 AU from the Sun. A close encounter with Jupiter resulted in the comet being captured into an orbit around it, before smashing into Jupiter's atmosphere.

(a) Estimate the original orbital period of Shoemaker-Levy comet.

(b) Did the total energy of the comet increased or decreased after its capture by Jupiter? (*Hint*: Don't forget that Jupiter orbits the Sun.) How is your result consistent with energy conservation?

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3. **Stars and Clouds** [25 points]

A Sun-like star is located inside a gas cloud of radius R and $\tau_\lambda \simeq 100$.

(a) Calculate the equilibrium temperature of the cloud in terms of R, $R_\odot$ and $T_\odot$.

(b) What is the characteristic wavelength of the observed emission from the cloud if $R = 100\,\mathrm{AU}$?

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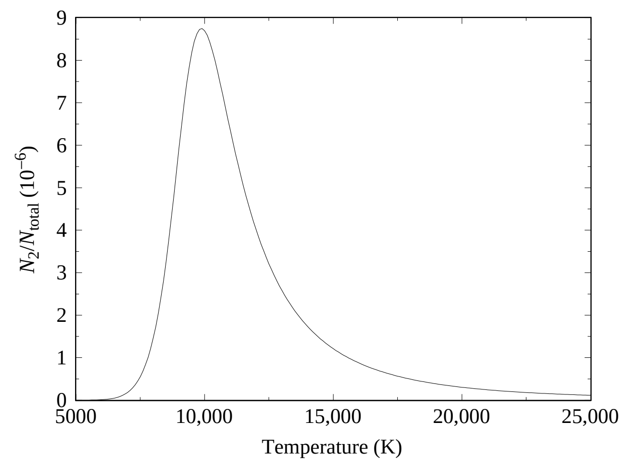
4. **Formation of Spectral Lines** [25 points]

The figure below shows how the ratio N_2/N_{total} evolves with temperature of the gas. N_2 is the number density of hydrogen atoms in the first excited state (with $n = 2$) and N_{total} is the total number density of hydrogen atoms. The number density of electrons is assumed to be constant with temperature.

(a) Explain qualitatively what physical processes determine the shape of this curve.



(b) Briefly describe how this diagram explains the relative strengths of hydrogen Balmer lines in the spectra of stars of different spectral types.