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RADIATION PROCESSES – AST1440F

Review Questions for Section 1

1. Compton scattering is coherent (no change in ν) at low frequencies but noncoherent at high frequencies. Why the difference?
2. Why should the bremsstrahlung spectrum require quantum corrections at high frequencies and high temperatures?
3. A bound electron obviously violates Maxwell's equations. Explain.
4. In astrophysics, we usually set $\epsilon = \mu = 1$. Why can we do this?
5. The phase of an EM wave involves the factor $\boldsymbol{k} \cdot \boldsymbol{r}$. What is $\boldsymbol{r}$? Does the phase of a wave really depend on the position of the origin of our coordinate system?
6. In a vacuum, the group velocity is equal to c just like the phase velocity. How would you prove this?
7. If an EM pulse passes by an observer in 10μs, can she distinguish or measure the amplitude of two components whose frequencies differ by only 10 MHz? Why or why not?
8. Can you prove that $\hat{E}(-\nu) = \hat{E}^*(\nu)$? Does it matter if $E(t)$ is real or complex?
9. Demonstrate geometrically that the specific intensity I_ν is independent of distance from a source (ignoring absorption or emission along the line of sight).
10. The concept of a specific intensity (smooth continuum of radiation which does not interact with itself) is not always a viable one. But in astrophysics, it generally works fine. Why?
11. Show in one line that the flux from a source (a star, say) falls off like r^{-2}. Do the same for U_ν.
12. Demonstrate that the flux in an isotropic radiation field is zero. That is, evaluate the integral of $\boldsymbol{n}\, d\Omega$ over all solid angles and show that it is identically zero.
13. Demonstrate that the radiation pressure tensor has *nine* elements or components in general. But, if I_ν is isotropic, there are only *three* nonzero elements (the diagonal ones) and they are all equal. Show this explicitly by calculating the elements.
14. If a star has a mean density of $1\,\mathrm{gm\,cm^{-3}}$ and a mass absorption coefficient ($k_\nu = \alpha_\nu/\rho$) of $1\,\mathrm{cm^2\,gm^{-1}}$, what is the total optical depth of the body given that its radius is 10^{11} cm? What is the probability of a photon passing through the star without being absorbed?
15. If a photon is released at the photosphere of a star, what is the probability that it will escape without being absorbed?
16. If we assume that a photon is scattered on average after every optical depth ($d\tau \sim 1$), then how many scatterings would be required for a photon released in the core of a star to get out to the surface?

17. If a gaseous nebula had a source function $S_\nu = B_\nu$, then an observer would see a black body at frequencies where the object is opaque. But at frequencies where it is partially transparent, it wouldn't be a black body. Why?

18. For an optically thin nebula, an observer sees $I_\nu \simeq S_\nu \tau_\nu$ which goes to zero with decreasing optical depth. But, as pointed out in the lecture notes, this expression is equivalent to $j_\nu L$ which doesn't appear to vanish with decreasing absorption. Explain.

19. When the temperature of a gas changes by only a "small amount" over one optical depth or photon mean free path, the gas is said to be in LTE. This is a "fuzzy" concept because "small amount" is never quantified. To get some feel for how small "small" is, estimate ΔT over one optical depth in a stellar interior. Use the opacity given in question 14 on the preceding page.

20. The gas at the photosphere of a star can radiate like a black body (how?) but the radiation field itself is definitely not blackbody or Planckian (why?).

21. How can the mean energy in photon states remain constant (kT) as $\nu \to 0$?

22. The Sun's effective temperature is about 5600 °K. At what wavelength does $B_\nu(5600)$ peak? At what λ does $B_\lambda(5600)$ peak? Which $\lambda_{\max}$ do you think the human eye is most sensitive to?

23. Wien's Law does does not predict $B_\nu \to \infty$ as $T \to \infty$. Why?

24. Note that the flux radiated from the surface of a blackbody is $\pi B(T)$ but the total energy radiated into 2π steradians is obviously $2\pi B(T)$. What's going on here?

25. Explain why T_b and T_{eff} require a knowledge of a star's distance but T_c does not. A related question is the following: can we measure I_ν for a star and then equate this to the I_ν actually radiated at the stellar surface (ignoring absorption along the line of sight)? If we could, then it would be possible to infer T_b and, hence, the absolute magnitude (and distance) of any star just from I_ν!!!

26. Why is the IR peak in the figure on p18 higher than the optical peak? After all, the total mass of the dust is much smaller than that in the form of stars. Also, grain temperatures are much lower than the effective temperatures of stars. So, what's going on here?

27. Why don't stars radiate like black bodies? (There are at least *two* reasons!)

28. Under what conditions will the Boltzmann distribution of energy states break down? Consider LTE, non-LTE, leptons, and photons.

29. Name three basic physical laws which govern the state of matter in thermodynamic equilibrium and which have their roots in the Boltzmann Law.

30. Give several examples of astrophysical situations where the gas is radiating thermally but the radiation field is not Planckian (that is, $I_\nu \neq B_\nu$). Explain in each case why the gas is radiating like a blackbody but the region is not in thermodynamic equilibrium.

31. What mechanisms are responsible for keeping dust grains in galaxies warm and radiating infrared thermal radiation?

32. Why should long wavelength radiation ($\lambda \gg a_g$) interact more weakly with dust grains than short wavelength radiation?
33. Einstein concluded that stimulated emission was necessary in principle even before it was demonstrated experimentally. What do you think his reasoning was?
34. Is the absorption (or emission) profile $\phi(\nu)$ a fixed function dependent only on the properties of the absorbing (or emitting) atom or will it depend on local physical conditions?
35. Why should stimulated emission be important in the radio but not in the ultraviolet?
36. In class, we recovered Kirchoff's Law by including only spontaneous emission in j_ν and using the *net* absorption for α_ν. Would we get the right result ($S_\nu = B_\nu$ in thermodynamic equilibrium) if we moved stimulated emission from α_ν to j_ν?
37. Explain why and under what circumstances the source function for scattering can be different than the source function for thermal emission.
38. Can you explain why scattering can be much more important at *small* optical depths (i.e., low densities) than thermal absorption. Also, why should this fact lead to completely *black* absorption lines ($J_\nu = 0$)?
39. Why are most astrophysical sources of radiation unpolarized?
40. Give three scenarios where the radiation might be polarized.
41. What does the convention $\boldsymbol{E} = \boldsymbol{E}_0 \, \mathrm{e}^{i\omega t}$ really mean? Is $\boldsymbol{E}_0$ real or complex? Do we in the final analysis work with real or complex $\boldsymbol{E}$?
42. Why does $\beta = \pi/4$ correspond to "left-handed" circular polarization?
43. Explain why for monochromatic waves there are only *three* independent Stokes parameters but, in general, there are *four*.
44. Consider a beam of radiation with constant intensity but completely random polarization properties. What region in Stokes parameter space would be traced out by this beam?