Short Answer Questions

Many are qualitative and require a specific sentence or two. Starred questions have 3 times the weight of the unmarked questions and require some calculating.

When an answers mentions “scaling” drop all extraneous factors and focus on the main variables of interest. For an “estimate” try to work to one power of 10. For numerical questions, 1 digit accuracy is fine. For a “picture” draw and label a schematic representation.

1. What is meant by retrograde motion? Give an example.

2. Starting from Newton’s laws of motion and gravity derive the scaling of Kepler’s Third Law.

3. Draw a picture which explains in a qualitative manner why the gravitational force exerted by a thin, spherical shell of matter vanishes at points interior to the shell. What is the analogous result for points exterior to the shell?

4. *Assume two stars of unequal mass make up a circular binary. Let stellar evolution cause mass to be slowly transferred from the heavy star to the light one over many orbits and in a conservative fashion (total mass and total angular momentum preserved). Is energy conserved? Work out whether the semi-major axis shrinks, expands or stays constant. What happens to the eccentricity of the orbit? What happens to the orientation of the orbital plane?

5. In a geosynchronous orbit the satellite remains fixed over a specific point on the Earth’s surface. Determine (symbolically) the altitude of the orbit.

6. Relate the parsec to the method of trigonometric parallax.

7. What is the name of the function which describes the frequency-dependent energy density for thermal radiation? What fundamental physical constants (not mathematical ones) enter and why? Based solely on the consideration of the dimensions, express the total energy density in terms of the fundamental constants (ignore all numerical constants).

8. *The photon clock oscillator: in frame S’ a photon bounces back and forth between two mirrors at rest (see picture, photon velocity in y’
direction, mirrors lie along x’). The round trip takes time Δt’ in S’. An
observer in frame S sees both mirrors move at constant velocity v in x
direction (the x axis is parallel to the x’ axis and to the mirror surface);
the y separation is fixed; the round trip takes time Δt. Infer the form
of the special relativistic time-dilation from geometrical considerations
and the constancy of the speed of light.

9. *Find the wavelength change suffered by a photon which backscatters
off an electron. The electron is initially at rest. The photon energy
is assumed to be very small compared to mec² so work to lowest non-
vanishing order in this ratio.

10. Draw a schematic energy level diagram for hydrogen showing bound
and continuum states. Illustrate bound-bound, bound-free and free-
free transitions. Identify the Lyman-alpha and Lyman continuum
transitions.

11. Draw and label a picture explaining the meaning of ”focal length”
for a simple converging lens. If an object and its image are located at
distances p and q from the optical axis of the lens show that 1/p+1/q =
1/f where f is the focal length.

12. Estimate the angular resolution of Arecibo, Keck, Hubble and JWST
(use the usual criterion for distinguishing two point sources).

13. *Draw a diagram which shows (precisely) how the intensity I of a
radiation field is defined by judicious measurements of energy flux. A
cloud emits radiation with intensity I in a particular direction. How
does I vary along the ray (in a vacuum, no absorption, no emission)?

14. A binary with two individually resolved stars is observed over several
full orbital periods. Unfortunately neither star has any measureable
line with which to determine a radial velocity. What steps would you
take to determine the individual masses of the two stars?

15. What is the binary mass function?

16. Give the Boltzmann and Saha equations (omit pure numerical factors
like 2π but the results should be dimensionally correct; do include
symbols for degeneracy of levels). In the context of a pure hydrogen
gas explain what physical property each equation directly describes.

17. What’s the partition function and what’s it used for? Explain how
you would calculate it for an atom like hydrogen.
18. What are the primary physical and astronomical differences between stellar luminosity classes and stellar types?

19. What physical properties do the following temperatures refer to: ionization temperature, kinetic temperature, color temperature, spin temperature?

20. Estimate the mean free path of a molecule in this room.

21. What is an eigenstate? If an electron is in an eigenstate corresponding to an excited bound state of the hydrogen atom (i.e. an electron plus proton with Coulomb forces) then WHY does the electron eventually make a transition to a lower energy state?

If the excited eigenstate survives a time $\Delta t$ before jumping to a lower energy eigenstate what is the natural width of the emitted line? For a sample of atoms at temperature $T$, list two other effects that commonly contribute to the observed spectral width.

22. *Estimate the particle energy in eV at the center of the Sun given its mass and radius. Estimate the particle energy necessary to get two nuclei to touch (for simplicity, assume two protons). Explain qualitatively how fusion takes place.

23. *Imagine that the nuclear reactions at the Sun’s center suddenly ceased. Describe how the Sun would behave for the first $10^6$ years after that moment.

24. Make an estimate of how long the Sun can burn hydrogen based on its observed luminosity, mass and a very rough estimate of energies released by fusion.

25. The binding energy/nucleon of $\text{H}$ is 0. What is the binding energy/nucleon for $\text{He}$ (estimate it if you don’t know the specific number). What is the element with the maximum binding energy/nucleon and quote a value (ditto).

26. What physical effect gives rise to 21 cm radiation?

27. The 21 cm optical depth at line center depends upon column density of hydrogen $N_H$, temperature $T$ and velocity width $\delta v$. Give a qualitative explanation for the form of $\tau_H$.

28. *What is the Jean’s mass? Estimate the Jean’s mass as a function of the characteristic temperature and mass density of a gas.
29. Consider a star in pressure equilibrium. What does the dynamical timescale refer to? Estimate it in terms of the star’s fundamental properties.

30. What is the Eddington limit?

31. What is the name and location on the HR diagram of the hydrogen burning phase of stellar evolution? Where on that diagram does a star with a mass like the Sun begin to burn Helium?

32. Roughly speaking: what is the minimum mass of a hydrogen burning star? what mass range leads to supernovae? which stars become white dwarfs? which ones live longer than the age of the universe?

33. In qualitative terms: why do some stars pulse? Name three types of variable stars.

34. What type of pressure supports white dwarfs against gravity?

35. Estimate the moment of inertia of a neutron star.

36. *Estimate the energy loss by a pulsar due to magnetic dipole radiation – do not worry about constants or geometric factors of order unity – just deal with the fundamental constants and pulsar’s macroscopic properties (e.g. size).

37. What is the Schwarzschild radius of an object of mass M? Do not worry about constants; focus on the way in which the fundamental constants enter the answer.

38. What is Einstein’s elevator thought experiment?

39. Imagine a blackbody of temperature T produced at the inner edge of an accretion disk located at radius R close to a compact object of mass M. The radiation escapes to without further absorption or emission. What is the character of this radiation field seen by an observer at infinity?

40. Explain what Lagrange points (L1, L2, etc.) are; show where they lie in a schematic diagram.

41. *The moon exerts a tidal force on the Earth. Give the lowest order approximation (just get the dimensions right and omit constants of order unity); supplement your schematic formula with a picture of the tidal forces as seen by an Earth-centered observer.
42. *In the plane parallel limit, how does the density of an isothermal atmosphere vary with height? What is the pressure scale height? Estimate the location of the exosphere, the point in the atmosphere from which a particle can escape without running into another atmospheric particle.

43. State the basic physical idea behind Hadley circulation; provide two pictures, one for a non-rotating Earth, and the other for the circulation when Coriolis force play a role.

44. Mercury has an eccentric (e=0.206) orbit and a rotation period of 2/3 its orbital period. Draw a picture of how its tidal bulge behaves during the orbit and briefly explain how the system might have reached this state.

45. What is the physics that keeps Venus’ surface temperature so much higher than that which an airless planet in the same orbit would have?

46. Where would you go to seek present day evidence of tectonic activity on the Earth?

47. Qualitatively describe the mass-radius relation for cold objects with mass ranging from Jupiter to that of a brown dwarf. Comment briefly on the source of pressure support at the extremes.

48. Very briefly: what sort of evidence for water on Mars has been discovered by the rovers?

49. Currently, what is the most distant man-made object?

50. What is a planetesimal and how does its growth differ from that of a dust grain in a protoplanetary disk?

51. *Show in a few lines of math how Olber’s paradox arises. Briefly, what physical effects resolve the paradox?

52. What are the length scales for the distance between stars, for the size of the galaxy, for the spacing between galaxies and for the size of the universe?

53. *Derive the scaling of density with radius needed to explain a flat rotation curve in a spherical galaxy.

54. What are the fundamental units of the Hubble constant? of the Oort constants? How are the values of these constants usually phrased?
55. Consider a star on a nearly circular orbit in the disk of the galaxy. Are the orbital periods about the center of the galaxy and about the center of its epicycle comparable – say within a factor of 3 – or not?

56. What is an L* galaxy?

57. How is a standard candle used to determine distance? Give 3 examples. What technique is used for the measuring distances to the most distant galaxies?

58. Very briefly: what is the unified model of AGN?

59. What do homogeneity and isotropy mean in the context of cosmology?

60. *What does critical density mean in cosmology? Consider a uniform distribution of expanding matter with Newtonian gravity and derive an expression in terms of the Hubble parameter.

61. What are comoving coordinates?

62. *What is the maximum distance light can travel in a universe with scale factor $a(t) = a_0(t_0/t)^{2/3}$?

63. What is the amplitude of the small-scale perturbations in the CMB? What role do they play in our universe?

64. To what do the epochs of recombination and decoupling refer?

65. Briefly: contrast the notion of luminosity distance in static Euclidean space and in cosmology.

66. Briefly: describe how the scale factor varies during inflation. Mention one problem in cosmology that might be mitigated if the universe underwent a very early phase of inflation.
USEFUL CONSTANTS:

\[ R_\odot = 6.96 \times 10^{10} \text{ cm} \]
\[ L_\odot = 3.90 \times 10^{33} \text{ erg s}^{-1} \]
\[ M_\odot = 5.974 \times 10^{27} \text{ g} \]
\[ G = 6.67 \times 10^{-8} \text{ cm}^3 \text{ s}^{-2} \text{ g}^{-1} \]
\[ k = 1.3806 \times 10^{-16} \text{ erg K}^{-1} \]
\[ \text{barn} = 10^{-24} \text{ cm}^2 \]
\[ eV = 1.602 \times 10^{-12} \text{ erg} \]
\[ m_H = 1.6605 \times 10^{-24} \text{ g} \]
\[ R_{\text{gas}} = kN_A = 8.314 \times 10^7 \text{ erg mole}^{-1} \text{ K}^{-1} \]
\[ 1 \text{ light yr} = 9.46 \times 10^{17} \text{ cm} \]
\[ m_V(\text{sun}) = -26.74 \]
\[ M_{\text{bol}}(\text{sun}) = 4.72 \]

\[ M_\odot = 1.99 \times 10^{33} \text{ g} \]
\[ F_\odot = 1.36 \times 10^6 \text{ erg s}^{-1} \text{ cm}^{-2} \]
\[ R_\odot = 6.378 \times 10^8 \text{ cm} \]
\[ c = 2.99793 \times 10^{10} \text{ cm s}^{-1} \]
\[ h = 6.625 \times 10^{-27} \text{ erg s} \]
\[ fm = 10^{-13} \text{ cm} \]
\[ m_e = 9.1096 \times 10^{-28} \text{ g} \]
\[ \sigma = 5.67 \times 10^{-5} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ K}^{-4} \]
\[ 1 \text{ AU} = 1.496 \times 10^{13} \text{ cm} \]
\[ 1 \text{ pc} = 3.086 \times 10^{18} \text{ cm} \]
\[ M_V(\text{sun}) = 4.79 \]