Astrophysics

Questions for the final exam on Friday, April 24, 2026

The exam will consist of two **large** questions requiring a detailed answer, and a few questions requiring a short answer (a couple of sentences), plus two problems which will be similar to those solved at home or at class. The answers to the first two questions should contain, e.g., the derivation of some formulae (if that is asked for) and a short physical description of what the formula and its different terms mean. There is no need to write a long essay on the topic of the question.

Large questions will cover the second part of the course (starting from **question 29** from the list below), whereas small questions will cover the **entire** syllabus. Some questions from the list below will possibly be combined, separated, or rephrased.

You can bring one A4 page with formulae. A calculator may be needed for getting numerical results for the problems.

Questions:

1. Derivation of the equation of hydrostatic equilibrium.
2. The dynamical, thermal and nuclear timescales (Estimation for the Sun).
3. Derivation of the virial theorem for a spherically symmetric star.
4. Lower limit on the stellar central pressure for density not increasing outwards.
5. Minimum mean stellar temperature. Corresponding values for the Sun.
6. Equation of energy production.
7. Convection. Derivation of Schwarzschild criterion for convective instability.
8. Derivation of the mean molecular weight. Mean molecular weight of ionized hydrogen, ionized helium, and ionized solar composition matter. Mean molecular weight per electron.
9. Estimations of the energy generation rate per unit mass for the Sun and main sequence stars.
10. Nuclear binding energy and its dependence on the masses of nucleus and nucleons. Binding energy per nucleon, its approximate dependence on the nucleon number. Efficiency of energy generation for fusion of H to He in terms of the rest mass.
11. Coulomb barrier. Temperature required for fusion of two protons if quantum effects are absent. Concept of quantum tunneling and Gamov peak.
12. pp-chain.
13. CNO-cycle.
14. He burning. Triple-α reaction.

15. Carbon, oxygen and silicon burning. Formation of the iron-group elements. s- and r-process.
16. Polytropic models of stars. Derivation of the Lane-Emden equation from the equations of hydrostatic equilibrium, mass conservation and the polytropic relation.
17. Lane-Emden equation and its solution for polytropic index $n = 0$.
18. Mass-Radius relationship for polytropic stars.
19. Eddington standard model.
20. Electron gas degeneracy (non-relativistic and relativistic). Chandrasekhar mass, physical reasons for the existence of the maximum stable mass.
21. The equations of stellar structure.
22. Basic physics of star formation. The Jeans instability, mass, density, length.
23. Protostars and pre-main-sequence stars.
24. The Hayashi track and the Henyey track.
25. Approximate evolutionary tracks of stars of various masses on H-R diagram. Main phases of evolution.
26. Main stages of evolution of solar-mass stars.
27. Approximate description of different evolutionary stages of massive stars and the timescales of nuclear burning.
28. Concept and derivation of Eddington luminosity. The existence of maximum stellar mass and its physical nature.
29. Definition of a Stellar atmosphere.
30. Spectral Types, Luminosity Classes, Magnitudes, Bolometric Flux and Bolometric Correction.
31. Specific and mean intensity, Flux & luminosity, Black body radiation, Effective temperature (Stefan-Boltzmann law), Brightness and Colour temperatures. Radiation density and pressure.
32. Describe what is meant by Local Thermodynamic Equilibrium (LTE). List the relevant microscopic physical processes obeyed by the gas and the radiation field in an LTE environment. State, with a brief explanation, for which types of stellar atmosphere LTE is a good or a poor approximation
33. Definitions and units of absorption coefficient, cross-section, optical depth, emission coefficient, source function. Source function in thermodynamic equilibrium (TE) and in the local thermodynamic equilibrium (LTE). What is the intensity of radiation in TE and LTE?
34. A simple form of the (parallel-ray) radiative transfer equation and its formal solution. Optically thin and optically thick cases. Origin of absorption and emission lines. Relation to the temperature gradient.
35. Radiative transfer equation in plane-parallel atmosphere. A formal solution. A case of source function as a linear function of optical depth, emergent intensity and flux. The Eddington-Barbier relation.
36. Explanation of Limb darkening. How limb darkening observations can be used to obtain the optical depth dependence of the temperature of a stellar photosphere?

37. A concept of the radiative equilibrium. Radiative equilibrium (radiative balance) in the grey atmosphere. Temperature profile of the grey atmosphere in the Eddington approximation, the surface temperature.
38. LTE. Maxwellian distribution, Boltzmann and Saha formulae.
39. The structure of a hydrogen atom. Ionization potentials from different energy levels. Definition of bound-bound, bound-free (free-bound) and free-free transitions. Sources of opacity.
40. Continuous absorption coefficient of a hydrogen-like atom. Dependence on n, λ, and Z. Absorption coefficient per hydrogen atom (cross-section) at Lyman limit. Impossibility of observing distant objects at $\lambda < 912$Å. Make a sketch of dependence of the hydrogen continuous absorption coefficient on photon wavelength (or frequency) for different temperatures. Explain using Boltzmann formula.
41. The Saha equation. Ionization of hydrogen and characteristic temperature of ionization. Negative ion of hydrogen, its ionization potential (in eV and Å). Explain qualitatively why H^- absorption is more important than absorption by neutral hydrogen at temperatures $T \sim 4500 - 8000$ K. What is the difference relative to the earlier class stars?
42. The Thomson cross-section and the role of electron scattering.
43. Effect of non-greyness of the absorption coefficient on the emergent stellar radiation. Explain qualitatively using the Eddington-Barbier relation. Determining temperature (or density) from the Balmer jump.
44. The Rosseland mean absorption coefficient. Its physical interpretation. Temperature profile of the atmosphere.
45. The equation of hydrostatic equilibrium. The scale-height of an (isothermal) atmosphere.
46. The line absorption coefficient. Dumping profile, natural width. Thermal motions and the Doppler profile. The Voigt profile.
47. The line equivalent width, W_λ. W_λ for optically thin lines in LTE. Optically thick lines. The line intensity in the centre of deep lines. Schuster-Schwarzschild atmosphere model.
48. The curve of growth. Explain qualitatively its general behaviour.
49. Scattering in lines. Transfer Equation including lines. The Milne-Eddington model. Residual flux of the line. Absorption and scattering lines. Schuster Mechanism for Line Emission
50. Einstein coefficients and relations between them.
51. Non-LTE. Statistical equilibrium equations. Radiative and collisional rates. Relation between excitation and de-excitation collisional coefficients. When non-LTE effects are important?
52. Spectral type sequence.
53. Direct measurement of radii. Determining T_{eff} and surface gravity, Model-independent methods, Model-dependent methods, Atmospheric models, Photometric methods, Spectroscopic methods.
54. Basic properties of the interstellar medium (ISM). Phases of ISM.
55. Interstellar Absorption Lines. How can they be used to study the properties of ISM?
56. A concept of the Strömgren Sphere.