Name (Last, First): ______________________________ **Date:** April 21, 2026

ASTR 201 — Midterm 2 Exam

Astronomy for Science Majors — Spring 2026

San Diego State University

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MC	Problem 1	Problem 2	Problem 3	TOTAL
________ / 14	________ / 12	________ / 12	________ / 12	________ **/ 50**

Instructions:

- There are **two parts** to this exam, worth **50 points** total. Answer all questions in the space provided.
- Show your work in a clear and orderly fashion, including all unit conversions, for full credit on calculation-based questions. **Circle your final answers clearly.**
- Partial credit will be awarded where appropriate.
- A formula sheet is provided; identify and use the appropriate equations where necessary. CGS units are used throughout.
- Use **proportional reasoning, ratio methods**, and scaling arguments wherever possible — full derivations are not required unless specifically requested.

Part I: Multiple Choice Questions

Please show your work in the space provided if necessary and provide your answer on the line provided. *(14 points, 2 points each)*

1. For a main-sequence star, which of the following is the correct ordering of the three fundamental stellar timescales from **shortest to longest**?

(a) $\tau_{\rm nuc} < \tau_{\rm KH} < \tau_{\rm dyn}$
(b) $\tau_{\rm KH} < \tau_{\rm dyn} < \tau_{\rm nuc}$
(c) $\tau_{\rm dyn} < \tau_{\rm KH} < \tau_{\rm nuc}$
(d) $\tau_{\rm dyn} < \tau_{\rm nuc} < \tau_{\rm KH}$
(e) All three are comparable on the main sequence.

Answer: ________

2. A 10 $M_{\rm sun}$ main-sequence star has a lifetime approximately how long compared to the Sun's?

(a) $10\times$ longer (100 Gyr).
(b) $\approx 3\times$ shorter (3 Gyr).
(c) $\approx 300\times$ shorter (30 Myr).
(d) $\approx 3\times10^5\times$ shorter (30 kyr).
(e) Its lifetime is independent of mass.

Answer: ________

3. If mass is gradually added to a main-sequence star (assume R stays roughly constant), how does the core respond to maintain hydrostatic equilibrium?

(a) Core expands; T_c decreases; P_c decreases.
(b) Core contracts; T_c decreases; P_c increases.
(c) Core expands; T_c increases; P_c decreases.
(d) Core contracts; T_c increases; P_c increases.
(e) Core properties remain unchanged.

Answer: ________

4. Quantum tunneling allows protons to fuse in the Sun's core, even though the classical thermal energy ($k_B T_c \approx 1 \text{ keV}$) is far below the Coulomb barrier ($E_C \approx 1 \text{ MeV}$). Why is this possible?

(a) Protons have zero size and so do not feel the Coulomb barrier.
(b) Gravity is strong enough at the core to push protons together.
(c) Protons behave as quantum waves, giving a nonzero probability of penetrating the Coulomb barrier.
(d) Magnetic fields in the core channel protons toward one another.
(e) The CNO cycle lowers the temperature threshold for fusion.

Answer: __________

5. Fusion of elements heavier than iron (^{56}Fe) does not release energy in stellar cores. Why?

(a) The Coulomb barrier becomes infinitely large for $Z > 26$.
(b) Nuclei heavier than iron have lower binding energy per nucleon, so fusing them absorbs rather than releases energy.
(c) All available fuel is locked up in iron.
(d) Neutrino losses prevent further reactions.
(e) Heavy nuclei spontaneously fission before they can fuse.

Answer: __________

6. Light travels from the Sun's core to its surface in roughly 100,000 years, even though light travels at speed c and $R_{\rm sun} \approx 7 \times 10^{10} \text{ cm}$ (a light-crossing time of $\sim 2 \text{ s}$). What is the physical reason?

(a) Photons slow down when passing through dense plasma.
(b) The photons lose energy and are recreated at each absorption.
(c) Photons undergo a random walk, being absorbed and re-emitted $\sim 10^{24}$ times, so energy diffuses outward rather than streaming.
(d) Gravitational time dilation slows photons near the core.
(e) Convection carries photons slowly from the core.

Answer: __________

7. Which is the correct evolutionary sequence for a $1 M_{\rm sun}$ star **after** it leaves the main sequence?

(a) Main-sequence turnoff → red giant branch → helium flash → horizontal branch → AGB → planetary nebula → white dwarf.
(b) Main-sequence turnoff → white dwarf → red giant → planetary nebula.
(c) Red giant → main sequence → horizontal branch → white dwarf.
(d) Main-sequence turnoff → AGB → red giant → helium flash → white dwarf.
(e) Main-sequence turnoff → supernova → neutron star.

Answer: __________

Part II: Problems

Tip: *Solve algebraically (using ratio/scaling methods) before plugging in numbers. This minimizes arithmetic errors and earns credit for correct setup even if the final number is off.*

1) Stellar Structure Under a Hypothetical Scenario. Suppose a main-sequence star doubles its mass while somehow keeping its central temperature T_c **fixed**. Assume the mean molecular weight μ and composition remain constant throughout.

(a) Determine how the star's radius R must change to keep T_c fixed. Express R_2 (after) in terms of R_1 (before). ***(4 pts)***

(b) How do the central pressure P_c and central density ρ_c change under this scenario? Express $P_{c,2}/P_{c,1}$ and $\rho_{c,2}/\rho_{c,1}$ as numerical ratios. ***(4 pts)***

(c) Is this scenario physically realistic for a main-sequence star? If not, describe what a real star **actually** does when mass is gradually added — how do R, T_c, P_c, and the fusion rate respond? Justify your reasoning. ***(4 pts)***

2) Fusion Sensitivity & The Radiation Limit. In this problem you will investigate two effects that together shape the upper end of the stellar mass distribution: the temperature sensitivity of hydrogen fusion and the limit set by radiation pressure.

(a) Consider the pp-chain hydrogen-fusion rate per unit mass, ε_{pp}, deep in a stellar core. Suppose the core density **doubles** and the core temperature increases by 50% (i.e., $T \to 1.5T$). By what factor does ε_{pp} change? ***(4 pts)***

(b) For a $M = 100 M_{\text{sun}}$ main-sequence star with a fully ionized hydrogen envelope, compute the ratio $L_{\text{MS}}/L_{\text{Edd}}$. Is this star super-Eddington ($L_{\text{MS}} > L_{\text{Edd}}$) or sub-Eddington ($L_{\text{MS}} < L_{\text{Edd}}$)? ***(4 pts)***

(c) Explain **why very massive stars ($M \gtrsim 100 M_{\text{sun}}$) are rare and short-lived.** Use your results from parts (a) and (b) to justify both claims quantitatively. ***(4 pts)***

3) The Chandrasekhar Mass & White Dwarf Structure. When gravity fully compresses the electrons in a white dwarf until they become relativistic, a fundamental mass scale emerges that can be built from only three fundamental constants — $\hbar$, c, G — together with the mass of a proton m_p.

(a) Using **dimensional analysis**, construct a combination of $\hbar$, c, G, and m_p that has the units of mass and is expected to yield the Chandrasekhar mass scale. Evaluate your expression numerically (in grams and in M_{sun}). Show that it yields a value of order $\sim 1 M_{\text{sun}}$. ***(4 pts)***

(b) Two (non-relativistic) white dwarfs have masses $M_1 = 0.6 M_{\text{sun}}$ and $M_2 = 1.2 M_{\text{sun}}$. Determine (i) which has the larger **radius** and by what factor, and (ii) which has the larger **average density** and by what factor. ***(4 pts)***

(c) The Chandrasekhar mass $M_{\text{Ch}} \approx 1.4 M_{\text{sun}}$ is an **upper limit** on white-dwarf masses: no stable WD can exceed it. Explain **why this limit exists** physically, and justify your reasoning quantitatively. ***(4 pts)***

— End of Exam —

Formula sheet provided separately.