Introduction to Astronomy

Stellar Evolution and Cosmology Quiz – Answer Key

1. **(C) Hydrogen fusion in the core.** Main-sequence stars convert hydrogen to helium via nuclear fusion (proton-proton chain or CNO cycle), releasing enormous energy through mass-energy conversion ($E = mc^2$).

2. **(C) Luminosity and surface temperature.** The H-R diagram plots luminosity (y-axis) versus temperature/spectral type (x-axis). Stars cluster in characteristic regions based on their evolutionary stage.

3. **(C) White dwarf.** Sun-like stars shed outer layers as planetary nebulae, leaving behind a degenerate carbon-oxygen core—a white dwarf supported by electron degeneracy pressure.

4. **(C) Galaxies recede at velocities proportional to their distance.** $v = H_0 \times d$ where H_0 is Hubble's constant (70 km/s/Mpc). This implies universal expansion.

5. **(B) The early hot, dense universe.** The CMB is relic radiation from 380,000 years after the Big Bang when the universe cooled enough for atoms to form and photons to travel freely.

6. **True.** When hydrogen exhausts in the core, shell burning expands the outer layers, increasing luminosity and radius while the surface cools (redder color).

7. **False.** Black holes don't emit light (nothing escapes the event horizon). They're detected indirectly through gravitational effects, accretion disk radiation, and gravitational waves.

8. **True.** Estimates suggest 10^{22}-10^{24} stars in the observable universe, comparable to estimates of sand grains on Earth (10^{22}-10^{24}).

9. **Massive Star Life Cycle:**

   Formation:

   - Gravitational collapse of giant molecular cloud
   - Protostar forms, heats up
   - Nuclear fusion ignites when core reaches 10 million K

   Main Sequence (Hydrogen Burning):

   - CNO cycle dominates (more efficient at high temperatures)
   - Duration: millions of years (shorter than low-mass stars)
   - Core converts H $\rightarrow$ He

   Post-Main Sequence Evolution:

   - Helium burning: He $\rightarrow$ C, O (triple-alpha process)
   - Carbon burning: C $\rightarrow$ Ne, Mg
   - Neon burning: Ne $\rightarrow$ O, Mg
   - Oxygen burning: O $\rightarrow$ Si, S

- Silicon burning: Si $\rightarrow$ Fe (iron)
- Onion-layer structure develops

Core Collapse and Supernova:

- Iron cannot fuse to release energy (endothermic)
- Core collapses in milliseconds
- Rebound creates Type II supernova
- Heavy elements (beyond iron) created via r-process

Final States:

- 8-25 $M_{\odot}$: Neutron star (supported by neutron degeneracy)
- $>$25 $M_{\odot}$: Black hole (gravity overcomes all pressure)

10. Evidence for Big Bang Theory:

1. Cosmic Microwave Background (CMB):

- Discovered 1965 by Penzias and Wilson
- Nearly uniform 2.725 K blackbody radiation in all directions
- Predicted by Big Bang: remnant heat from early universe
- Tiny fluctuations (1 part in 100,000) seed large-scale structure

2. Hubble's Law and Expansion:

- Galaxies exhibit redshift proportional to distance
- Universe is expanding; running time backward implies denser, hotter past
- Extrapolation gives age 13.8 billion years
- Accelerating expansion discovered 1998 (dark energy)

3. Primordial Nucleosynthesis:

- Big Bang predicts specific light element abundances
- 75% H, 25% He, traces of D, Li formed in first minutes
- Observed abundances match predictions precisely
- Cannot be explained by stellar nucleosynthesis alone

Additional evidence:

- Large-scale structure consistent with early density fluctuations
- Time dilation in distant supernovae
- No objects older than 13.8 billion years observed