It then took several hundred thousand years before the universe was cool enough for electrons to combine with nuclei to form atoms. The background radiation had expanded and cooled so much that its total energy became less than the energy in matter, and matter dominated increasingly over radiation. Then stars and galaxies formed, producing a universe not much different than it is today—some 13 billion years later.

Recent observations indicate that the universe is flat, that it contains an as-yet unknown type of **dark matter**, and that it is dominated by a mysterious **dark energy** which exerts a sort of negative gravity causing the expansion of the universe to accelerate.

Today the evidence suggests that the universe is flat and will continue to expand indefinitely. The total contributions of baryonic (normal) matter, dark matter, and dark energy sum up to the **critical density**.

Questions

1. The Milky Way was once thought to be "murky" or "milky" but is now considered to be made up of point sources. Explain.
2. A star is in equilibrium when it radiates at its surface all the energy generated at its core. What happens when it begins to generate more energy than it radiates? Less energy? Explain.
3. Describe a red giant star. List some of its properties.
4. Select a point on the H–R diagram. Mark several directions away from this point. Now describe the changes that would take place in a star moving in each of these directions.
5. Does the H–R diagram reveal anything about the core of a star?
6. Why do some stars end up as white dwarfs, and others as neutron stars or black holes?
7. Can we tell, by looking at the population on the H–R diagram, that hotter main-sequence stars have shorter lives? Explain.
8. If you were measuring star parallaxes from the Moon instead of Earth, what corrections would you have to make? What changes would occur if you were measuring parallaxes from Mars?
9. *Cepheid variable* stars change in luminosity with a typical period of several days. The period has been found to have a definite relationship with the absolute luminosity of the star. How could these stars be used to measure the distance to galaxies?
10. What is a geodesic? What is its role in General Relativity?
11. If it were discovered that the redshift of spectral lines of galaxies was due to something other than expansion, how might our view of the universe change? Would there be conflicting evidence? Discuss.
12. All galaxies appear to be moving away from us. Are we therefore at the center of the universe? Explain.
13. If you were located in a galaxy near the boundary of our observable universe, would galaxies in the direction of the Milky Way appear to be approaching you or receding from you? Explain.
14. Compare an explosion on Earth to the Big Bang. Consider such questions as: Would the debris spread at a higher speed for more distant particles, as in the Big Bang? Would the debris come to rest? What type of universe would this correspond to, open or closed?
15. If nothing, not even light, escapes from a black hole, then how can we tell if one is there?
16. What mass will give a Schwarzschild radius equal to that of the hydrogen atom in its ground state?
17. The Earth's age is often given as about 4 billion years. Find that time on Fig. 33–25. People have lived on Earth on the order of a million years. Where is that on Fig. 33–25?
18. Explain what the 2.7-K cosmic microwave background radiation is. Where does it come from? Why is its temperature now so low?
19. Why were atoms, as opposed to bare nuclei, unable to exist until hundreds of thousands of years after the Big Bang?
20. Under what circumstances would the universe eventually collapse in on itself?

Problems

33–1 to 33–3 Stars, Galaxies, Stellar Evolution, Distances

1. (I) Using the definitions of the parsec and the light-year, show that $1\text{ pc} = 3.26\text{ ly}$.
2. (I) A star exhibits a parallax of 0.38 seconds of arc. How far away is it?
3. (I) The parallax angle of a star is 0.00019°. How far away is the star?
4. (I) A star is 36 pc away. What is its parallax angle? State (*a*) in seconds of arc, and (*b*) in degrees.
5. (I) What is the parallax angle for a star that is 55 ly away? How many parsecs is this?
6. (I) If one star is twice as far away from us as a second star, will the parallax angle of the farther star be greater or less than that of the nearer star? By what factor?
7. (II) A star is 35 pc away. How long does it take for its light to reach us?
8. (II) We saw earlier (Chapter 14) that the rate energy reaches the Earth from the Sun (the "solar constant") is about $1.3 \times 10^3\text{ W/m}^2$. What is (*a*) the apparent brightness l of the Sun, and (*b*) the absolute luminosity L of the Sun?
9. (II) What is the relative brightness of the Sun as seen from Jupiter as compared to its brightness from Earth? (Jupiter is 5.2 times farther from the Sun than the Earth.)
10. (II) Estimate the angular width that our Galaxy would subtend if observed from the nearest galaxy to us (Table 33–1). Compare to the angular width of the Moon from Earth.
11. (II) When our Sun becomes a red giant, what will be its average density if it expands out to the orbit of Earth (1.5×10^{11} m from the Sun)?