

Part II: A Brief History of Time, Stephen Hawking

6. READ:

- Foreword in *A Brief History of Time*, Stephen Hawking.
- “Our Picture of the Universe,” Chapter 1 in *A Brief History of Time*, Stephen Hawking.

EXPLAIN:

- Olber’s paradox

ANSWER:

- Who won the Nobel Prize (and when) for the COBE observations? What does COBE stand for?
- Can you think of any other simple observations (besides Aristotle’s three) that indicate a spherical Earth?
- Look up Immanuel Kant. What was his book *Critique of Pure Reason* (1781) about?
- The question “Did time exist before the beginning of the universe?” is interesting. How does your religion answer it?

7. READ:

- “Space and Time,” Chapter 2 in *A Brief History of Time*, Stephen Hawking.

DEFINE:

- epistemology
- geodesic
- gravity and levity (as used by Aristotle)
- luminiferous aether

ANSWER:

- What were Einstein’s original statements of his two postulates of special relativity?
- What is the current (exact) value of the speed of light?
- Does the geodesic between Austin, TX, and Moscow, Russia, pass over Iceland or Paris?

8. READ:

- “The Expanding Universe,” Chapter 3 in *A Brief History of Time*, Stephen Hawking.

DEFINE:

- isotropic
- homogeneous (uniform)

ANSWER:

- Calculate the distance of a “light year” in km, miles, and A.U.
- Who (and when) first deduced the shape of the Milky Way?
- What is the inverse square law of light?
- What are the current best values for Hubble’s constant and the age of the universe?

9. READ:

- “The Uncertainty Principle,” Chapter 4 in *A Brief History of Time*, Stephen Hawking.

DEFINE:

- Newton’s clockwork universe
- ensemble, in the sense used in statistical mechanics
- wave-particle duality

EXPLAIN:

- the energy-time version of Heisenberg’s uncertainty principle.

10. READ:

- “Elementary Particles and the Forces of Nature,” Chapter 5 in *A Brief History of Time*, Stephen Hawking.

COLLATERAL READING:

- Selections from “Twentieth Century Physics,” M. A. Reynolds, 2009.

DEFINE:

- glueball

ANSWER:

- How do Aristotle’s four elements correspond to the four “phases” of matter?
- What does QCD stand for? What does it describe?
- Can you think of any macroscopic physical object that must be turned through two complete revolutions in order to look the same?
- Describe the exchange of virtual particles as an application of the energy-time version of Heisenberg’s uncertainty principle.

- List the twelve elementary particles (six quarks and six leptons) along with their electric charge and spin. List the four fundamental forces.

11. READ:

- “Cosmic Asymmetry between Matter and Antimatter,” Frank Wilczek, *Scientific American*, December 1980, pp. 82-90. Reprinted in “Particle Physics in the Cosmos,” *Scientific American*, (ERAU: QB464 .P37 1989).

In our copy, pages 169-176 are optional. That is, you must read the “Postscript,” but the section beginning “How could improved understanding of these forces ...” can be skipped. If you are interested in the weak force, however, please read them.

- *Cosmic Rays* from “Twentieth Century Physics,” M. A. Reynolds, 2009.

DEFINE:

- the “no hair” theorem (of black holes)
- “attractive speculations”

ANSWER:

- Build a cosmic “ladder” by looking up the distances from the Earth to the following objects. List them in order, from nearest to farthest, and express their distance in light years (or light days/hours/minutes, if necessary).
 - the Crab Nebula
 - the Coma cluster
 - the Sun
 - the Moon
 - Cygnus X-1
 - M 81 (Messier 81)
 - M 87 (Messier 87)
 - JKCS 041
 - the Virgo cluster
 - the center of the Milky Way
 - the Andromeda Galaxy
 - Pluto
 - α Cen (alpha Centauri)
- What is the current experimental lower bound for the lifetime of a proton?

12. READ:

- “Black Holes,” Chapter 6 in *A Brief History of Time*, Stephen Hawking.

CALCULATE:

- your event horizon distance, if you were to collapse into a black hole.

ANSWER:

- Numerically, what is the value of the “Chandrasekhar limit”? Explain what it means.
- Who said, “Nature abhors a vacuum,”? And why?
- Write a paragraph on Hulse and Taylor, and their Nobel-prize winning research.
- What is the current estimate of the distance to 3C273?

13. READ:

- “Black Holes Ain’t So Black,” Chapter 7 in *A Brief History of Time*, Stephen Hawking.

CALCULATE:

- On page 105, Hawking claims, “if two black holes collided and merged together to form a single black hole, the area of the event horizon of the final black hole would be greater than or equal to the sum of the areas of the event horizons of the original black holes.” Prove this. That is, prove that $A \geq A_1 + A_2$, where A is the final area and A_1 and A_2 are the original areas.

First calculate the area of the event horizon ($A = 4\pi R^2$) when R is the Schwarzschild radius, $R = 2GM/c^2$. Then add $A_1 + A_2$, knowing that the final mass is the sum of the masses, $M = M_1 + M_2$.

What would this fact imply about the arrow of time?

- Hawking suggests that there might be 300 black holes per cubic light year. Given that the nearest star to the Sun is 4.4 ly away, estimate the density of stars in the solar neighborhood (in units of stars per cubic light year). Which are more common, stars or black holes? (HINT: assume that stars are packed in a cubic lattice whose edges are 4.4 ly. They certainly don’t have this geometry, but it allows us to make a reasonable estimate of the density.)

ANSWER:

- Hawking explains a particle/antiparticle pair creation as one having positive energy and the other negative energy. Explain it, rather, in terms of Heisenberg’s energy-time uncertainty principle. Is this consistent with Hawking’s ideas of black hole radiation?

14. READ:

- “The Search for Black Holes,” Chapter 5 in *Black Holes, Quasars, and the Universe*, Harry Shipman.
- “ ϵ Aurigae,” *Burnham’s Celestial Handbook*, Robert Burnham, Jr.

ANSWER:

- Create the next column in the table on page 272 of Burnham. That is, when will the next eclipse of ϵ Aur take place? Be sure to list all five dates: partial phase, total phase, mid-eclipse, etc.
- List some of the discoveries of the Uhuru satellite.
- Write a paragraph about the scientific method, specifically as it applies to black holes and Cyg X-1 (as Shipman has presented the changing ideas regarding this object).

15. READ:

- “Journey into a Black Hole,” Chapter 4 in *Black Holes, Quasars, and the Universe*, Harry Shipman.

DEFINE:

- Doppler shift (for light)
- gravitational redshift
- cosmological redshift
- frame-dragging

ANSWER:

- List the three classic tests of general relativity.
- How strong is the tidal force of the Sun on the Earth, compared with the tidal force of the Moon on the Earth?
- Sketch a picture of the Earth (assuming that it’s a smooth sphere covered with water) indicating the tidal effects of the Moon on the water.
- From the point of view of the rocket ship watching the probe fall into the black hole, was Zeno right? Explain.
- On page 17, Shipman writes, “The progress of science involves both theory and observation. It is often possible for theorists to forget that they are only model-builders. The models become so fascinating that they become real, like the statue of Pygmalion. [J. L.] Synge, a theorist himself, calls fascination with models the Pygmalion syndrome. You get caught up in your work and become oblivious to the fact that you’re only dealing with pencil marks on paper (or ten-foot-high piles of computer output) and not real stars.” Who was Pygmalion? What is the classic Pygmalion effect? How does it compare with Synge’s Pygmalion syndrome?

EXTRA CREDIT:

- How massive must a black hole be so that the acceleration due to gravity, “ g ,” at its event horizon is equal to 9.8 m/s^2 ? (First, derive the formula for g on the surface of a planet of mass M and radius R . Then, substitute in the Schwarzschild radius so that you have g as a function of only M . You should obtain $g \sim 1/M$.)

16. READ:

- “Frontiers and Fringes,” Chapter 6 in *Black Holes, Quasars, and the Universe*, Harry Shipman.
- “Summaries,” in *Black Holes, Quasars, and the Universe*, Harry Shipman.

ANSWER:

- Explain the difference between chemical burning and chemical explosion. Pay special attention to the time scales of each.
- What is the current accepted model (if there is one) for the source of X-rays from globular clusters?
- Do you like Shipman’s explanation of black hole evaporation better than Hawking’s? Why or why not? Write a one paragraph explanation of black hole evaporation (using your own words) that you could use to explain this phenomenon to your grandfather.

EXTRA CREDIT:

- How massive must a (virtual) particle be to escape from a black hole of mass M ? Assume that a particle of mass m (and energy $E = mc^2$) just barely satisfies Heisenberg’s energy-time uncertainty principle (i.e., $\Delta E = mc^2 = \hbar/2\Delta t$), and that it can travel at speed c from the singularity to the event horizon, a distance of R_S . (Answer: $m = M$ when $M \approx 10^{-8}$ kg, which means that when the black hole gets this small, it can evaporate in one fell swoop, i.e., explode!)

17. READ:

- “The Relativity of Space and Time,” Chapter 1 in *Black Holes and Time Warps*, Kip Thorne.

DEFINE:

- inertial reference frame
- metaprinciple
- metacognition

CALCULATE:

- the relativistic factor

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

for the following: (a) $v = 60$ mph, (b) orbital velocity $v = 7$ km/s, (c) $v = \frac{1}{2}c$, and (d) the protons in the LHC.

ANSWER:

- In addition to Special Relativity, what two other major contributions did Einstein make with his publications in 1905, his “*annus mirabilis*”?

18. READ:

- start “The Origin and Fate of the Universe,” Chapter 8 in *A Brief History of Time*, Stephen Hawking.
- “Does Dark Matter Really Exist?” Mordehai Milgrom, *Scientific American*, August 2002, pp. 42-52.
- “Introduction to Nuclear Physics,” Chapter 3 in *Twentieth Century Physics*, Reynolds. Only read pages 45-49 and 60-68.

ANSWER:

- Since this chapter brings up a number of issues that need some background in order to fully understand, there will be no assignments for today. I will actually *lecture* (!) on dark matter and nuclear physics.

19. READ:

- finish “The Origin and Fate of the Universe,” Chapter 8 in *A Brief History of Time*, Stephen Hawking.

DEFINE:

- imaginary time

ANSWER:

- It is clear to see how *space* can be finite but with no boundary (e.g., the surface of a sphere), but can you envision *time* as finite with no boundary? Can you think of any analogies to assist the human mind?
- Draw Hubble’s tuning fork diagram. Does this classification say anything about the *age* of a particular galaxy?
- Write a paragraph on the history of the anthropic principle.

EXTRA CREDIT:

- What is the typical energy of a primordial neutrino today? Back up your answer with a calculation.

20. READ:

- “The Arrow of Time,” Chapter 9 in *A Brief History of Time*, Stephen Hawking.

WRITE:

- a paragraph on the research of *one* of the following pairs of Nobel prize winners (all related to CPT symmetry).
A good resource is http://nobelprize.org/nobel_prizes/physics/laureates/
 - 1957 — Yang & Lee
 - 1980 — Cronin & Fitch
 - 2008 — Kobayashi & Maskawa

ANSWER:

- How many arrows of time are there? Can you name any others besides those listed by Hawking?
- Hawking argues that the psychological arrow of time and the thermodynamic arrow of time are in the same direction by making an analogy between human memory and computer memory. Do you find his argument convincing? Why or why not?

21. READ:

- “Wormholes and Time Travel,” Chapter 10 in *A Brief History of Time*, Stephen Hawking.

DEFINE:

- spacetime interval
- Einstein’s train paradox
- Einstein-Rosen bridge
- the chronology protection conjecture

ANSWER:

- Do you believe that UFOs are evidence of aliens? Do you believe that UFOs are evidence of time travel? Why or why not?

EXTRA CREDIT:

- Calculate the speed necessary to travel to α Cen and return if you wish to age only one year. Do the same for travel to the center of the Milky Way (26,000 light years away).

22. READ:

- “The Unification of Physics,” Chapter 11 in *A Brief History of Time*, Stephen Hawking.
- “Conclusion,” Chapter 12 in *A Brief History of Time*, Stephen Hawking.

ANSWER:

- List all the problems you can think of with two-dimensional life forms.
- Which of the three possibilities on page 183 do you favor? Why?
- What do you think it means when a theory predicts an infinite value for something that is easily measurable?
- Must a unified theory be mathematically consistent, as Hawking assumes on page 185?
- Rate the book on a scale from 1-10, with 10 being the best book you’ve ever read, and 1 the worst. Base your rating on the writing style, the subject matter, your enjoyment of the subject matter, and any other criteria you wish.
- Rate our discussions of the book on a scale from 1-10. What did you especially like about the discussions? What did you especially dislike about them?

EXTRA CREDIT:

- What is St Augustine’s proof of the existence of God? Do you agree with it?