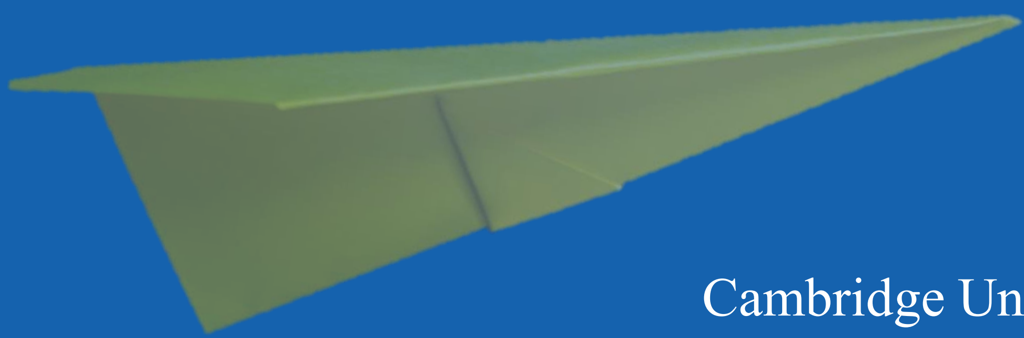
Clicker Questions

Modern Physics

by Gary Felder and Kenny Felder



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Instructions

- These questions are offered in two formats: a deck of PowerPoint slides, and a PDF file. The two files contain identical contents. There are similar files for each of the 14 chapters in the book, for a total of 28 files.
- Each question is marked as a "Quick Check" or "ConcepTest."
  - Quick Checks are questions that most students should be able to answer correctly if they have done the reading or followed the lecture. You can use them to make sure students are where you think they are before you move on.
  - ConcepTests (a term coined by Eric Mazur) are intended to stimulate debate, so you don't want to prep the class too explicitly before asking them. Ideally you want between 30% and 80% of the class to answer correctly.
- Either way, if a strong majority answers correctly, you can briefly discuss the answer and move on. If many students do not answer correctly, consider having them talk briefly in pairs or small groups and then vote again. You may be surprised at how much a minute of unguided discussion improves the hit rate.
- Each question is shown on two slides: the first shows only the question, and the second adds the correct answer.
- Some of these questions are also included in the book under "Conceptual Questions and ConcepTests," but this file contains additional questions that are not in the book.
- Some of the pages contain multiple questions with the same set of options. These questions are numbered as separate questions on the page.
- Some questions can have multiple answers. (These are all clearly marked with the phrase "Choose all that apply.") If you are using a clicker system that doesn't allow multiple responses, you can ask each part separately as a yes-or-no question.

14 Cosmology

14.1 The History of the Universe

Which of the following represents an example of the expansion of the universe? (Choose the best answer.)

A. The total length of the universe, from end to end, is bigger now than it was a billion years ago.

B. The distance from the Earth to the sun is bigger than it was a million years ago.

C. The distance from the Earth to Phi Ceti, a star currently about 50 light-years away from us, is bigger now than it was a billion years ago.

D. The distance from the Earth to GN-z11, the most distant known galaxy as of a few years ago, is bigger now than it was a billion years ago.

E. That little rip in the knee of my pants gets bigger every time I wash them.

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D. The distance from the Earth to GN-z11, the most distant known galaxy as of a few years ago, is bigger now than it was a billion years ago.

E. That little rip in the knee of my pants gets bigger every time I wash them.

Solution: D

The moment when the universe was at Planck density is important because . . . (Choose one.)

A. It's impossible for matter to be above that density.

B. The universe began at that moment.

C. That's the earliest moment we can describe with our current theories.

D. The universe existed before that, but nothing particularly interesting happened until that moment.

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C. That's the earliest moment we can describe with our current theories.

D. The universe existed before that, but nothing particularly interesting happened until that moment.

Solution: C

For the first few hundred years after the Big Bang, nuclei and electrons existed separately. Then, during the period called "re-combination," those electrons bound with those nuclei to create atoms. What change in the universe led to this change in particle behavior? (Choose one.)

A. The temperature.

B. The density.

C. The ratio of nuclei to electrons.

D. The types of nuclei.

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A. The temperature.

B. The density.

C. The ratio of nuclei to electrons.

D. The types of nuclei.

Solution: A

How did the temperature of the universe one second after the Big Bang compare to the temperature one minute after? (Choose one.)

A. The temperature at one second was higher.

B. The temperature at one minute was higher.

C. The temperature at both times was about the same.

D. No one knows.

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C. The temperature at both times was about the same.

D. No one knows.

Solution: A

Why don't we detect radiation emitted by the universe before recombination? (Choose one.)

A. No radiation was emitted at that time.

B. The radiation emitted at that time hasn't reached us yet.

C. The radiation emitted at that time is now at a frequency that our instruments cannot detect.

D. The radiation emitted at that time was immediately reabsorbed.

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C. The radiation emitted at that time is now at a frequency that our instruments cannot detect.

D. The radiation emitted at that time was immediately reabsorbed.

Solution: D

The universe of the early dark ages had an almost uniform density, but not perfectly uniform. Choose one of the following to describe how such a universe should evolve.

A. The density distribution should stay statistically the same, although the specific regions of higher and lower density will move around.

B. Over time the variations in density will smooth out, leading to a more even density.

C. Over time the variations in density will be exaggerated, leading to a more uneven density.

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C. Over time the variations in density will be exaggerated, leading to a more uneven density.

Solution: C. Denser regions exert greater gravity, so over time the densest regions pull in more matter and get even more dense.

14.2 How Do We Know All That?

Measuring the redshift of a galaxy is a way of determining . . . (Choose one)

A. its velocity

B. its distance

C. the dominant color it emits

D. its size

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D. its size

Solution: A

What makes a type of object a “standard candle”? (Choose one)

A. It doesn’t change its brightness over time.

B. It looks equally bright no matter how far away it is.

C. All objects of that type are equally bright.

What makes a type of object a “standard candle”? (Choose one)

A. It doesn’t change its brightness over time.

B. It looks equally bright no matter how far away it is.

C. All objects of that type are equally bright.

Solution: C

14.3 Infinite Universe, Finite Universe, Observable Universe

The Hubble-Lemaître law applies … (Choose one.)

A. only in finite universes

B. only in infinite universes

C. in both finite and infinite universes

The Hubble-Lemaître law applies . . . (Choose one.)

A. only in finite universes

B. only in infinite universes

C. in both finite and infinite universes

Solution: C

If we say that an infinite universe is expanding, we mean which of the following? (Choose all that apply.)

A. The total volume of the universe is getting bigger.

B. Average distances between objects is getting bigger.

C. The universe began at infinite density a finite time ago.

D. The average density of galaxies is getting smaller.

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D. The average density of galaxies is getting smaller.

Solution: B

Why can't we see beyond our observable universe? (Choose one.)

A. There is nothing but empty space beyond the observable universe.

B. There is matter beyond our observable universe, but it hasn't yet emitted any light.

C. There is matter beyond our observable universe and it has emitted light, but that light hasn't had time to reach us yet.

D. Our current telescopes aren't powerful enough to see that far.

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C. There is matter beyond our observable universe and it has emitted light, but that light hasn't had time to reach us yet.

D. Our current telescopes aren't powerful enough to see that far.

Solution: C

A team of astronomers announces that they have found the location in space where the Big Bang occurred. Which of the following reactions would be most appropriate? (Choose one.)

A. You don't believe them because the Hubble-Lemaître law says that expansion looks the same no matter where you are, so there's no way to tell where the Big Bang occurred.

B. You don't believe them because the Big Bang probably occurred outside our observable universe, so we wouldn't be able to see it.

C. You don't believe them because there is no particular place where the Big Bang occurred.

D. You believe them.

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B. You don't believe them because the Big Bang probably occurred outside our observable universe, so we wouldn't be able to see it.

C. You don't believe them because there is no particular place where the Big Bang occurred.

D. You believe them.

Solution: C

Would it be possible for an infinite one-dimensional universe to expand in a way that would *not* obey the Hubble-Lemaître law?

Would it be possible for an infinite one-dimensional universe to expand in a way that would *not* obey the Hubble-Lemaître law?

Solution: Yes. For example, if everything within an inch of Galaxy 0 doubled its distance from Galaxy 0, while everything else moved outward by exactly one inch. But any expansion other than Hubble-Lemaître expansion would violate homogeneity, meaning the expansion would look different in different places.

14.4 The Friedmann Equations

The equation $a = 2$ tells us… (Choose one.)

A. The distance to a distant galaxy is twice what that distance was at some arbitrarily chosen $a = 1$ moment.

B. The radius of the observable universe is twice what that distance was at some arbitrarily chosen $a = 1$ moment.

C. The universe is expanding twice as fast as it was at some arbitrarily chosen $a = 1$ moment.

D. The density of the universe is twice the critical density.

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D. The density of the universe is twice the critical density.

Solution: A

For a matter-dominated universe, the sign of k in Equation 14.1 (p. 672) determines which of the following? (Choose all that apply.)

A. whether the universe is infinite or finite

B. whether the angles of a triangle add up to more or less than 180°

C. whether the universe will someday recollapse

D. whether radiation or matter density decreases faster as the universe expands

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C. whether the universe will someday recollapse

D. whether radiation or matter density decreases faster as the universe expands

Solution: A, B, C

In a universe with matter and radiation, and positive curvature ($k > 0$), which of the following decreases the fastest? (Choose one.)

A. the energy density of matter

B. the energy density of radiation

C. the curvature term in the first Friedmann equation (p. 672)

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A. the energy density of matter

B. the energy density of radiation

C. the curvature term in the first Friedmann equation (p. 672)

Solution: B. The density of radiation decreases faster than the density of matter, which is why matter eventually comes to dominate radiation. The curvature term decreases slowest of all, which is why a universe with any non-zero curvature will evolve toward being less flat.

Suppose the universe 13 billion years ago was determined to be open ($\Omega < 1$, where $\Omega = \rho/\rho_c$). Which of the following would be true about the universe today? (Choose one.)

A. It might be open, flat, or closed, depending on how it evolved over that time.

B. It would definitely still be open, but Ω might not have the same value as it did then.

C. Ω would be the same today as it was then.

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C. Ω would be the same today as it was then.

Solution: B

Can the curvature term in Equation 14.1 (p. 672) ever be bigger in magnitude than the density term? (Choose one.)

A. Yes, but only for a closed universe

B. Yes, but only for an open universe

C. Yes, regardless of the type of universe

D. No, regardless of the type of universe

Can the curvature term in Equation 14.1 (p. 672) ever be bigger in magnitude than the density term? (Choose one.)

A. Yes, but only for a closed universe

B. Yes, but only for an open universe

C. Yes, regardless of the type of universe

D. No, regardless of the type of universe

Solution: B. If the curvature term is positive, then that term having a larger magnitude than the density term would lead to the impossible conclusion that H^2 is negative. But if the curvature term is negative, then its magnitude can be as big as you like, and H^2 still comes out positive.

We argued that for matter or radiation domination an open universe will expand forever and a closed one will eventually recollapse. What will happen to a flat universe ($k = 0$)? (Choose one.)

A. It will expand forever.

B. It will eventually recollapse.

C. It could do either one, depending on other factors.

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Solution: A. If $k = 0$, the equation puts H^2 proportional to ρ. Since ρ is never zero, $\dot{a}$ is never zero. So if the universe is expanding ($\dot{a} > 0$), then it will keep expanding forever. But as ρ decreases (which is, remember, the definition of expansion), $\dot{a}$ will decrease.

14.5 Dark Matter and Dark Energy

We know dark energy exists because … (Choose one.)

A. The observed rotation curves of galaxies don't match what we would expect from visible matter.

B. The universe is currently expanding faster than we would have otherwise predicted.

C. The expansion of the universe is accelerating.

D. We observe the effects of dark energy via gravitational lensing.

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C. The expansion of the universe is accelerating.

D. We observe the effects of dark energy via gravitational lensing.

Solution: C

What happens over time to the energy in an expanding region of space? (Choose one.)

A. The energy of dark matter decreases and the energy of dark energy remains the same.

B. The energy of dark matter remains the same and the energy of dark energy decreases.

C. The energy of dark matter increases and the energy of dark energy remains the same.

D. The energy of dark matter remains the same and the energy of dark energy increases.

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C. The energy of dark matter increases and the energy of dark energy remains the same.

D. The energy of dark matter remains the same and the energy of dark energy increases.

Solution: D

The effects of dark energy include… (Choose all that apply.)

A. to make H increase over time.

B. to make galaxies accelerate away from us.

C. to increase the total energy in the observable universe (not counting potential energy of expansion).

D. to change the rotation curves of galaxies.

E. to enable Sith Lords to shoot lightning bolts from their hands.

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E. to enable Sith Lords to shoot lightning bolts from their hands.

Solution: B, C

Suppose Galaxy A is currently 8 billion light-years away from us, and Galaxy B is going to be 8 billion light-years away from us in 3 billion years. Which of the following are true about these galaxies in a universe dominated by dark energy (such as ours)? (Choose all that apply.)

A. In 3 billion years, Galaxy A will be receding from us faster than it is now.

B. In 3 billion years, Galaxy A will be receding from us more slowly than it is now.

C. In 3 billion years, Galaxy B will be receding from us faster than Galaxy A is currently receding from us.

D. In 3 billion years, Galaxy B will be receding from us more slowly than Galaxy A is currently receding from us.

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A. In 3 billion years, Galaxy A will be receding from us faster than it is now.

B. In 3 billion years, Galaxy A will be receding from us more slowly than it is now.

C. In 3 billion years, Galaxy B will be receding from us faster than Galaxy A is currently receding from us.

D. In 3 billion years, Galaxy B will be receding from us more slowly than Galaxy A is currently receding from us.

Solution: A, D

What is the equation of state $P(\rho)$ for dark matter? (Choose one.)

$A.\ P = 0$

$B.\ P = \rho/3$

$C.\ P = -\rho$

$D.\ P = \rho$

E. We don't have enough information to know.

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$A. P = 0$

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$C. P = -\rho$

$D. P = \rho$

E. We don't have enough information to know.

Solution: A

Shortly after antimatter finished annihilating, the energy in radiation was much greater than the energy in matter. At that time was the density of dark energy . . . (Choose one)

A. much smaller than the density of matter

B. comparable to the density of matter

C. much larger than the density of matter

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Solution: A. Remember that over time the density of matter and radiation are decreasing, while the density of dark energy stays the same. Projecting backward, dark energy must have been a negligibly small (but not zero) contributor to the energy budget of the early universe.

14.6 Problems with the Big Bang Model

The "flatness problem" is … (Choose one.)

A. We measure the universe to have very high curvature, but such a universe violates general relativity.

B. We measure the universe to have very low curvature, but such a universe violates general relativity.

C. A universe as flat as we measure ours to be should have recollapsed almost instantly after the Big Bang.

D. The measured curvature of the universe isn't impossible, but seems too outrageous a coincidence to have occurred without some explanation.

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Solution: D

Which of the following best describes the theoretical predictions of magnetic monopoles? (Choose one.)

A. Magnetic monopoles should not be able to exist.

B. Magnetic monopoles could exist in principle, but they would quickly decay.

C. Magnetic monopoles could exist, and would be stable, but the right conditions to create them have never occurred.

D. Magnetic monopoles could exist, and would be stable, and the right conditions to create them *have* occurred, so some completely different explanation is needed for why we never see them.

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D. Magnetic monopoles could exist, and would be stable, and the right conditions to create them *have* occurred, so some completely different explanation is needed for why we never see them.

Solution: D

Guth's calculations showed that the lack of magnetic monopoles in the world around us was a mystery that needed to be explained. But the lack of tauons, Higgs bosons, and many other parts of the standard model was *not* considered a mystery that needed to be solved. Why not? (Choose one.)

A. Grand Unified Theories (GUTs) predict that those particles cannot exist.

B. Those particles, like neutrinos, interact so little with matter that they are almost impossible to detect.

C. Those particles decay almost immediately after being created.

D. Those particles can exist only in conditions of extreme temperature and pressure.

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D. Those particles can exist only in conditions of extreme temperature and pressure.

Solution: C

14.7 Inflation and the Very Early Universe

Immediately after inflation, we would expect… (Choose all that apply.)

A. The universe would have no magnetic monopoles.

B. The *observable* universe would have no magnetic monopoles.

C. The universe would have no protons.

D. The *observable* universe would have no protons.

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C. The universe would have no protons.

D. The *observable* universe would have no protons.

Solution: B and D

Consider the ratio of the curvature term to the density term in the first Friedmann equation. Since the end of inflation, that ratio has . . . (Choose one.)

A. decreased, so it is now close to zero.

B. stayed the same (close to zero).

C. increased, but it started out so close to zero that it's still pretty close to zero today.

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Solution: C

A scalar field trapped in a local minimum of its potential energy function has . . . (Choose one.)

A. constant energy

B. constant energy density

C. constant scale factor

D. constant curvature

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A. constant energy

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C. constant scale factor

D. constant curvature

Solution: B