Cosmology Name:

Homework 1: History of Cosmology

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000 qmult 00100 1 4 1 easy deducto-memory: reading and done

1. Did you complete reading for this cosmology lecture before it was lectured/bypassed on in class and the corresponding homework by the day after?

   a) YYYessss! b) Jawohl! c) Da! d) Sí, sí. e) OMG no!

   SUGGESTED ANSWER: (a),(b),(c),(d)

   Wrong answers:
   e) As Lurch would say AAAARGH.

   Redaction: Jeffery, 2008jan01

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004 qmult 00010 1 1 1 easy memory: astronomy oldest science

2. Astronomy is often cited as the:

   a) oldest exact, empirical science. b) youngest exact, empirical science. c) oldest inexact, empirical science. d) youngest, inexact, colonial science. e) oldest form of folklore.

   SUGGESTED ANSWER: (a)

   Calling astronomy this actual requires careful definition of terms to be exactly right—but who cares about being exactly right: the way we usually talk, it is more right than saying anything else.

   Wrong answers:
   b) Never ever.
   e) I'm just not accepting this answer.

   Redaction: Jeffery, 2001jan01

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004 qmult 00020 1 1 5 easy deducto-memory: neolithic astronomy

3. Moon-shaped cut marks on bones in groupings of order 30 from paleolithic times (as long ago as 36,000 BCE) suggest that people then were doing astronomy by:

   a) whiling away the time. b) counting sheep. c) whittling. d) counting fingers and toes. e) counting days of the lunar month.

   SUGGESTED ANSWER: (e) See No-xxiv and Cox-16.

   Wrong answers:
   a) As Lurch would say: "Aaaarh."

   Redaction: Jeffery, 2001jan01

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004 qmult 00090 1 4 3 easy deducto-memory: alignment astronomy

4. "Let's play *Jeopardy*! For $100, the answer is: Stonehenge and many other prehistoric monuments suggest that the makers were doing this."

   What is/are ____________, Alex?

   a) special relativity calculations b) orbital physics c) simple alignment astronomy d) casting horoscopes e) receiving alien visitors from outer space

   SUGGESTED ANSWER: (c)

   Wrong answers:
   e) As Lurch would say: "Aaaarhhh."

   Redaction: Jeffery, 2001jan01

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004 qmult 00100 1 4 2 easy deducto-memory: Stonehenge midsummer sunrise

5. Stonehenge demonstrates that some prehistoric people:

   a) could predict eclipses.

b) knew the northernmost rising location of the Sun.
c) knew nothing of astronomy.
d) knew more than the ancient Greeks about the universe.
e) suffered from back pain.

SUGGESTED ANSWER: (b) The answer can be confined by minimal knowledge. It is often said, even by yours truly, that the Sun rises over the Heel Stone on the summer solstice. Actually, this is only approximately true. In fact, the Heel Stone may have had a companion stone. The two stones framed the point where Sun actually rose. The line from the center of Stonehenge to that point has been called the Solar Corridor.

Wrong answers:
a) Not the best answer since the theory that Stonehengers could predict eclipses is very unlikely to be true.
c) Most people know now of the Stonehenge-astronomy connection.
d) Not likely after all one can say about Greek astronomy
e) A nonsense answer although probably true of some of them—maybe all of them some of the time.

Redaction: Jeffery, 2001jan01

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004 qmult 00300 1 1 5 easy memory: sexagesimal angular units
6. Sexagesimal angular units were introduced in astronomy insofar as we know by:

a) the Mayans. b) the Pueblo Indians. c) Isaac Newton (1642/3–1727).
d) Renaissance astronomers. e) the ancient Babylonians.

SUGGESTED ANSWER: (e)

I believe this is correct. The Babylonians used degrees (i.e., 360 degrees in a circle) (No-39) which are at least sort of sexagesimal. They certainly had sexagesimal arithmetic and Neugebauer (Ne-17) confirms they used sexagesimal math in astronomy. But did they use arcminutes and arcseconds? Everything implies that they did at least in computation. I think that the use of degrees suffices to make the question correct, but I wish someone would confirm if they had or had not arcminutes and arcseconds as explicit units.

The Sumerians invented sexagesimal in the 3rd millennium BCE, but I don't think there is any evidence that they used it in astronomy. Wikipedia: Sexagesimal fails to elucidate this fine point, but relying on my fading memory of Neugebauer, I the Babylonians are the first recorded astronomers to use it in astronomy.

Wrong answers:
a) Sexagesimal angular units were used in the Old World long before the New was contacted.
b) It doesn't seem likely.
c) They are older than him.
d) Could be plausible.

Redaction: Jeffery, 2001jan01

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004 qmult 00400 3 2 2 tough math: sexagesimal subtraction
7. The ancient Babylonians were using a sexagesimal (number) system as early as circa 1800 BCE. We do not know why, but it may well have been to save labor in division. The many whole number factors of 60 (1 2, 3, 4, 5, 6, 10, 12, 15, 20, 30, and 60 for a total of 12 factors) simplifies many division problems. The sexagesimal system seems to have been used consistently only for mathematical and astronomical purposes. For everyday use, the Babylonians often or maybe mainly used other systems including the ubiquitous decimal system: counting on fingers is as old as the hills so to say. In the last centuries BCE the sexagesimal system was taken over into astronomy. Using a large base number with a lot of factors has advantages. But one needs a lot of symbols for all the numerals unless one uses some subsidiary base which is what the Babylonians did: 10. In any case 10 as a base has nothing very special to recommend it, except for the old (very old) finger exercise.

As a non-finger exercise, subtract $61^\circ 43' 14''$ from $120^\circ 41' 03''$. Recall that $'$ stands for arcminutes and $''$ for arcseconds. **HINT:** If sexagesimal subtraction seems too tricky, you can try sexagesimal addition to recover $120^\circ 41' 03''$.

a) 182°24′17″. b) 58°57′49″. c) 58°31′14″. d) 59°51′49″. e) 58°51′14″.

SUGGESTED ANSWER: (b)

Recall single prime is for arcminutes; double prime is for arcseconds. The sexagesimal arithmetic is:

```
   120 41 03   which changes to  119 100 63
-   61 43 14                  -   61  43 14
    --------                      ---------
     ?  ?  ?                      58  57 49      .
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Wrong answers:
a) This subtraction wouldn't lead to a bigger number.

Redaction: Jeffery, 2001jan01

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004 qmult 00500 2 4 4 easy deducto-memory: 3 early Greeks

8. The earliest 6th century BCE names in ancient Greek science include:

a) Thales, Copernicus, and Aristotle. b) Thales, Caesar, and Aristotle. c) Eratosthenes, Thales, and Kepler. d) Thales, Anaximander, and Pythagoras. e) Aristotle, Eratosthenes, and Ptolemy.

SUGGESTED ANSWER: (d)

Wrong answers:
a) Copernicus was not an ancient Greek.
b) Caesar important for his calendar, but definitely a Roman of the 1st century BCE.
c) Kepler, nope.
e) Tricky, but Aristotle and Ptolemy came later.

Redaction: Jeffery, 2001jan01

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004 qmult 00600 1 4 5 easy deducto-memory: Parmenides round Earth

9. The spherical Earth theory may have been first proposed by Parmenides of Elea. Parmenides was:

a) Mayan, but he lived in southern California. b) Babylonian, but he lived in Ur. c) Roman, but he lived in Alexandria. d) Icelandic. e) Greek, but he lived in what in what is now Italy.

SUGGESTED ANSWER: (e)

The students know the spherical Earth theory came from the Greeks: elimination allows them to reach the answer.

Wrong answers:
a) The Mayans were good, but not that good.
d) Oh, c'mon.

Redaction: Jeffery, 2001jan01

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004 qmult 00610 3 4 5 tough deducto-memory: round Earth reasons

10. The ancient Greek Presocratic philosophers:

a) may have hypothesized a spherical Earth in order to explain the daily rotation of the celestial sphere. But it is equally likely that they thought that a spherical Earth was proven by the axioms of geometry.
b) may have hypothesized a spherical Earth in order to explain the daily rotation of the celestial sphere. Thales of Miletus then used the spherical Earth theory to predict a solar eclipse.
c) may have hypothesized a spherical Earth because they thought the Earth needed to be spherical in order to be in balance at the center of the cosmos. Aristotle (384–322) later summarized empirical arguments for the spherical Earth. These included the varying celestial locations of the stars and planets relative to the horizon as one moved north-south and the fact that the Earth's shadow on

the Moon in a lunar eclipse was always round. However, **ARISTOTLE** went on to affirm that Greece must be on top of the spherical Earth because the ground in Greece was nearly level.

d) may have hypothesized a spherical Earth because they thought the Earth needed to be spherical in order to be in balance at the center of the cosmos. Aristotle (384–322) later summarized empirical arguments for the spherical Earth. These included the varying celestial locations of the stars and planets relative to the horizon as one moved north-south and the fact that the Earth's shadow on the Moon in a lunar eclipse was always round. However, **PTOLEMY** went on to affirm that Greece must be on top of the spherical Earth because the ground in Greece was nearly level.

e) may have hypothesized a spherical Earth because they thought the Earth needed to be spherical in order to be in balance at the center of the cosmos. Aristotle (384–322) later summarized empirical arguments for the spherical Earth. These included the varying celestial locations of the stars and planets relative to the horizon as one moved north-south and the fact that the Earth's shadow on the Moon in a lunar eclipse was always round.

SUGGESTED ANSWER: (e)

According to Wik: Spherical Earth, Aristotle did not get the ship-at-sea argument. That was added later by Strabo.

Wrong answers:

a) One doesn't need a spherical Earth in order to have a rotating celestial sphere. Also pure geometry has no necessary connection to the actual physical world.

b) Thales did not use the spherical world theory for this and he did not think the world was round. He hypothesized that it was a disk.

c) If the Greeks moved north and south far enough to know the altitudes of stars, etc. varied then they knew that down was always to the center of the Earth, and thus ground is approximately "level" everywhere on Earth.

d) Same as (c).

Redaction: Jeffery, 2001jan01

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004 qmult 00620 2 4 4 easy deducto-memory: Eratosthenes

11. A determination of the radius of the Earth was:

a) made by **ERATOSTHENES** in the **15TH CENTURY CE**. This measurement proved the Earth was spherical and was the inspiration for Columbus's voyage.

b) made by **ARISTOTLE** in the **15TH CENTURY CE**. This measurement proved the Earth was spherical and was the inspiration for Columbus's voyage.

c) made by **ERATOSTHENES** in the **3rd CENTURY BCE**. This measurement was based on the assumption that the Earth was **SPHERICAL** and the Sun was very distant from the Earth. If the Earth was not spherical, the measurement would have required the **SAME** interpretation.

d) made by **ERATOSTHENES** in the **3rd CENTURY BCE**. This measurement was based on the assumption that the Earth was **SPHERICAL** and the Sun was very distant from the Earth. If the Earth was not spherical, the measurement would have required a **DIFFERENT** interpretation.

e) made by **ERATOSTHENES** in the **3rd CENTURY BCE**. This measurement was based on the assumption that the Earth was an **OVAL SHAPE**. When the result came out spherical, Eratosthenes was surprised.

SUGGESTED ANSWER: (d)

Wrong answers:

a) As Lurch would say: "Aaaaah."

Redaction: Jeffery, 2001jan01

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004 qmult 00700 2 4 3 moderate deducto-memory: Greek distances

12. A major obstacle that ancient Greek astronomers had in trying to determine the nature of the Solar System was:

a) the eastward motion of the planets.

b) the inability to measure any distances beyond Pluto.

c) the inability to measure any distances beyond the Moon.

d) the lack of all theoretical biases.

e) the lack of geometrical skills.

SUGGESTED ANSWER: (c)

Wrong answers:

a) It was the westward retrograde motions that were hard to explain. Even I had said westward, the lack of ability to measure distances (other than to the Moon) is the more fundamental problem.
b) If they could have measured to Pluto (of which they had never heard), they would have known the basic structure of the Solar System.
d) They certainly didn't lack theoretical biases. The lack of biases is often an aid rather than an obstacle and in more than this.
e) Everyone one knows the Greeks were geometers down to their toes.

Redaction: Jeffery, 2001jan01

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004 qmult 00800 1 4 3 easy deducto-memory: time sequence Greek astronomers

13. Which of the following sequences is correctly ordered in time?

a) Aristotle, Ptolemy, Kepler, Copernicus, Thales.
b) Aristotle, Ptolemy, Galileo, Copernicus, Thales.
c) Thales, Aristotle, Ptolemy, Copernicus, Galileo.
d) Ptolemy, Aristotle, Thales, Copernicus, Galileo.
e) Kepler, Aristotle, Thales, Copernicus, Galileo.

SUGGESTED ANSWER: (c) Thales and maybe Ptolemy could be hard to recognize.

Wrong answers:

e) Kepler before Aristotle!

Redaction: Jeffery, 2001jan01

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004 qmult 00910 3 5 5 tough thinking: days of the week

14. The ancient Babylonians of the 5th century BCE probably invented horoscopic astronomy (No-41), but its main structure as passed down to the present probably evolved in the Greco-Roman world from the 2nd century BCE onward (Ne-170–171).

This Greco-Roman astrology has left some unusual imprints on modern conventions. For example, each hour of the 24-hour day—which itself came from the ancient Egyptians of the 2nd millennium BCE by no very logical process (Ne-86)—has a ruler (Ne169). The rulers are the seven moving stars which are ordered in decreasing order by their sidereal periods: Saturn, Jupiter, Mars, Sun, Venus, Mercury, and Moon. The Greco-Roman astronomers (including Ptolemy) believed this was the order of decreasing distance from the Earth: actually it is the order of decreasing distance from the Sun if Earth replaces Sun in the list and you eliminate the Moon.

The rulers of each hour are assigned using the ordered sequence of moving stars. The assignment of rulers starts with the 1st hour of Saturday being Saturn. The next hour is assigned Jupiter as its ruler and so on. When one completes assigning the sequence of 7 stars, then one starts the sequence over again.

Each day of the week has a ruler too: its ruler is the ruler of that day's first hour. A little calculation—or knowing that Jupiter's day got assigned to Thor in English—shows that the day rulers starting from Saturday's ruler Saturn are:

a) Saturn, Sun, Moon, Mars, Saturn, Sun, and Moon.
b) Saturn, Saturn, Saturn, Saturn, Saturn, Saturn, and Saturn.
c) Saturn, Sun, Saturn, Mars, Saturn, Mercury, and Saturn.
d) Saturn, Sun, Moon, Mars, Jupiter, Mercury, and Venus.
e) Saturn, Sun, Moon, Mars, Mercury, Jupiter, and Venus.

SUGGESTED ANSWER: (e)

You probably guessed the answer without doing the calculation. The resulting rulers are the moving stars (or gods) who provide the names of the week days. Of course, in English the guessed solution is a bit obscured by the fact that all but one of the Latin day names got replaced by

Germanic/Norse-god-derived names. Sun and Moon replaced the Latin Sol and Luna. The not-very-well-remembered-Germanic/Norse god Tiw replaced Mars; Woden replaced Mercury; Thor replaced Jupiter; and the old English goddess Frige (equivalent to Norse goddess Frigg) replaced Venus. Saturday is the only Latin-derived name that made it into English.

In Spanish things are at bit clearer: sabados, domingo, lunes, martes, miericoles, juebes, vernes.

Of course, one should do the calculation to confirm your guess. If you are math-minded, the following formula comes to mind after some thought:

$$J = \text{mod}[24 \times (I - 1), 7] + 1 ,$$

where I is the day number assigning 1 to Saturday, 2 to Sunday, 3 to Monday, etc., J is the ruler number assigning 1 to Saturn, 2 to Jupiter, 3 to Mars, etc., and mod is the modulus function. Using the function one finds arrives at the following table.

Table: Day Rulers

Day	I	J	Ruler
Saturday	1	1	Saturn
Sunday	2	4	Sun
Monday	3	7	Moon
Tuesday	4	3	Mars
Wednesday	5	6	Mercury
Thursday	6	2	Jupiter
Friday	7	5	Venus

Well after all this, you can see why we've given up on astrology. It's not that it's not true: it's just too tricky.

Wrong answers:
b) Not very likely.

Redaction: Jeffery, 2001jan01

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004 qmult 01000 3 5 3 tough thinking: Aristotelian cosmology

15. Aristotelian cosmology:

a) consisted of perfect eternal cubes rotating about the Earth.
b) put the Earth at the center of the cosmos. The planets and fixed stars were located on sets of solid spheres that rotated about the Earth. The celestial phenomena were eternal exactly repeating motions. Beyond the sphere of the fixed stars was a **CHAOS** of primordial material in which were embedded other finite cosmoses.
c) put the Earth at the center of the cosmos. The planets and fixed stars were located on sets of solid spheres that rotated about the Earth. The celestial phenomena were eternal exactly repeating motions. Beyond the sphere of the fixed stars was **NOTHING**, not even empty space. The universe was finite.
d) was **DISCARDED** by everyone in the medieval Islamic period. It put the Earth at the center of the cosmos. The planets and fixed stars were located on sets of solid spheres that rotated about the Earth. The celestial phenomena were eternal exactly repeating motions. Beyond the sphere of the fixed stars was **NOTHING**, not even empty space. The universe was finite.
e) was never seriously considered again after Ptolemy's time.

SUGGESTED ANSWER: (c)

Wrong answers:
a) Cubes?

Redaction: Jeffery, 2001jan01

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004 qmult 01300 1 1 4 easy memory: stellar parallax defined 1

Extra keywords: the other definition is in ch-38

16. Stellar parallax is:

a) the westward motion of the planets.
b) the daily westward motion of the fixed stars.
c) an optical illusion.
d) the change in angular position of a star relative to background stars due to the Earth's yearly motion around the Sun.
e) the change in magnitude of a star due to the Earth's year motion around the Sun.

SUGGESTED ANSWER: (d)

Wrong answers:
a) That's retrograde motion.

Redaction: Jeffery, 2001jan01

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004 qmult 01310 2 5 2 moderate thinking memory: stellar parallax historical

17. Take a pencil (or pen or finger). Hold it upright at arm's length in front of some distant object of smallish angular size such as a wall clock. Center the pencil on the object. Then keeping your hand steady (rock steady) shift your head until the object is just out of eclipse. Neither the pencil nor the object has moved in space, but they have shifted in relative angular position because of the movement of the observer. This change in angular position of objects due the shift in the spatial position of the observer is called **PARALLAX**. (Note the term **PARALLAX** is used both for the phenomena of shift in general [e.g., "we know this from parallax"] and for particular angular shifts [e.g., "the parallax" caused by this motion is 10°].) Try the experiment again but this time with the pencil right in front of your eye: move your head as much as before. Is the angular shift between the pencil and object larger than before? Yes/No? Well maybe after you've tried it carefully a few times it will be clear that parallax effects are bigger for closer objects since the same head movement (the same observational baseline) gives a larger angular shift or parallax. If the Earth were moving in space, would the stars show parallaxes relative to each other?

a) Yes, unless they were so distant that we couldn't detect parallax or unless they were all flying in formation with the Earth. The latter exception was so obviously **REASONABLE** that the ancient Greeks decided the Earth must be moving around the Sun.
b) Yes, unless they were so distant that we couldn't detect parallax or unless they were all flying in formation with the Earth. The latter exception was so obviously **CONTRIVED** that it doesn't seem to have been discussed in history as a means of accounting for the lack of stellar parallax in moving-Earth theories. Stellar parallax was, in fact, first observed in **1838**.
c) Yes, unless they were so distant that we couldn't detect parallax or unless they were all flying in formation with the Earth. The latter exception was so obviously **CONTRIVED** that it doesn't seem to have been discussed in history as a means of accounting for the lack of stellar parallax in moving-Earth theories. Stellar parallax was, in fact, first observed in **2008**.
d) No, never, no matter how close or far they were. Stars unlike any other object just cannot show parallax.
e) Parallax is the change in angular position of an object due to the change in spatial position of the observer.

SUGGESTED ANSWER: (b)

See North p. 419 for Bessel's 1838 discovery of stellar parallax. A really easy question, but under test pressure, trying to think is always tedious.

Wrong answers:
a) It doesn't seem to reasonable to me and most people know the ancient Greeks (with a few immortal exceptions) concluded the Earth was at rest and the Sun and stars moved around us.
c) I think people should know stellar parallax was discovered long ago.
d) Why should stars be an absolute in-principle exception.
e) True, but not answer.

Redaction: Jeffery, 2001jan01

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004 qmult 02010 1 4 5 easy deducto-memory: Aristotelian cosmology dogma

18. "Let's play *Jeopardy*! For \$100, the answer is: A cosmology became something of a philosophical dogma in Greco-Roman Antiquity, the Medieval Islamic and European societies, and in Europe up until the

17th century."

What is ____________, Alex?

a) Democritean cosmology b) Newtonian cosmology c) Big Bang cosmology
d) inflation cosmology e) Aristotelian cosmology

SUGGESTED ANSWER: (e)

Wrong answers:

a) Democritus (460?–370? BCE) had an interesting atomist cosmology that unfortunately was still flat-Earth.

Redaction: Jeffery, 2001jan01

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004 qmult 02100 1 1 1 easy memory: Copernicus's model

19. In modern times (which here we mean to be after circa 1450), who first proposed the heliocentric theory of the solar system?

a) Nicolaus Copernicus (1473–1543). b) Thomas Digges (c. 1546–1595).
c) Tycho Brahe (1546–1601). d) Galileo Galilei (1564–1642).
e) Isaac Newton (1643–1727).

SUGGESTED ANSWER: (a)

Wrong answers:

c) Tycho proposed the Tychonic system which was geocentric, but with the Sun as a secondary center.

e) Newton was born 1642 Dec25 on the Julian calendar used in England all of this life. This 1643 Jan04 on the modern Gregorian calendar that was used in most of the rest of Europe at that time.

Redaction: Jeffery, 2001jan01

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004 qmult 02110 2 5 3 moderate thinking: Aristotelian/Ptolemaic

Extra keywords: Needs work: Ptolemy had a size scale and ordering

20. The Aristotelian and Ptolemaic cosmologies were:

a) mutually **COMPLETELY CONSISTENT**. Together they gave a reasonable explanation of celestial phenomena. In the Medieval Islamic and European cultures, they were regarded as totally satisfactory. The heliocentric model of Copernicus was introduce only due to Copernicus' personal eccentricity. He merely made a lucky guess.

b) **ABANDONED** almost as soon as they were proposed. In the Medieval Islamic and European cultures, no theoretical interpretation was put on celestial phenomena at all. The prediction of celestial events was done entirely using Babylonian cycles.

c) were largely accepted during in the Medieval Islamic and European cultures despite their **PARTIAL INCONSISTENCY** and their lack of any definite size scale or ordering for the planets. Occasional attempts to improve these cosmologies came to little. The Copernican theory was a **RADICAL ALTERNATIVE**.

d) were largely accepted during in the Medieval Islamic and European cultures despite their **PARTIAL INCONSISTENCY** and their lack of any definite size scale or ordering for the planets. Occasional attempts to improve these cosmologies came to little. The Copernican theory was **NOT A RADICAL ALTERNATIVE**. It was completely consistent with Aristotelean physics and even kept epicycles.

e) were largely accepted during in the Medieval Islamic and European cultures despite their **PARTIAL INCONSISTENCY** and their lack of any definite size scale or ordering for the planets. Occasional attempts to improve these cosmologies **ALWAYS SUCCEEDED** in making their quantitative predictions much more accurate. The Copernican theory was only the lucky last of these attempts. Sheer bias kept the Aristotelean and Ptolemaic cosmologies dominant until then.

SUGGESTED ANSWER: (c)

Wrong answers:

e) Well no: they could be made a little more accurate than Ptolemy but not much more accurate. In fact, they were usually less accurate I believe.

Redaction: Jeffery, 2001jan01

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004 qmult 02020 1 4 4 easy deducto-memory: Copernicus reason for heliocentrism

21. A key reason (perhaps the most important reason) that led Copernicus to propose the heliocentric Solar System was to:

a) get rid of uniform circular motion.
b) appease the Sun god.
c) answer Galileo's insult.
d) get a prediction of the relative positions of the planets.
e) prove that the universe was infinite.

SUGGESTED ANSWER: (d)

Wrong answers:
a) Ah, but he kept uniform circular motion.
b) C'mon.
c) Copernicus lived before Galileo and the answer sounds nonsensical anyway.
e) Actually, he was sort of against the infinite universe, but he was forced to conclude it was very big.

Redaction: Jeffery, 2001jan01

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004 qmult 02030 2 1 2 moderate memory: apparrent retrograde motion

22. Apparent retrograde motion is:

a) the **westward** motion of a **star** on the sky.
b) the **westward** motion of a **planet** on the sky.
c) the **eastward** motion of a **planet** on the sky.
d) the **eastward** motion of a **star** on the sky.
e) the result of an inter-planetary collision.

SUGGESTED ANSWER: (b) Of course, retrograde motion applies to planets, not stars and eastward motion is the usual motion of Solar System objects relative to the fixed stars, therefore (b) follows by elimination.

Wrong answers:
e) This is a red herring.

Redaction: Jeffery, 2001jan01

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004 qmult 02150 1 4 4 easy deducto-memory: elliptical orbit discoverer

23. "Let's play *Jeopardy*! For $100, the answer is: He/she discovered that the planets orbited the Sun in elliptical orbits."

Who is ____________, Alex?

a) Apollonios of Perga (circa 3rd century BCE) b) Nicolaus Copernicus (1473–1543)
c) Galileo Galilei (1564–1642) d) Johannes Kepler (1571–1630)
e) Caroline Herschel (1750–1848)

SUGGESTED ANSWER: (d)

Wrong answers:
a) Ah, the irony. Apollonios was the one who apparently first proposed epicycle models for the planets. But he was also the great ancient expert on ellipses. Of course, he would have had to adopt a heliocentric or Tychonic system of the Solar System in order to really suggest ellipses as good for orbits. That is not impossible given that he was a near contemporary at least of Aristarchos of Samos, the first proposer of the heliocentric model. True with the inferior data available to Apollonios, epicyclic models would have given probably equally good fits and would have been simpler to employ.
b) Famously, Copernicus stuck with epicycle models for his heliocentric system.

c) Famously, Galileo never appreciated Kepler's epicycle models though he had heard of them.
e) She was the sister of the William Herschel the greatest observational astronomer of the 18th century. She was a significant astronomer in her own right. She was also a professional singer—a soprano.

Redaction: Jeffery, 2001jan01

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004 qmult 02200 2 5 3 moderate thinking: Kepler's 3 laws

24. Kepler's three laws of planetary motion:

a) **PROVED** the Copernican theory. But this was not immediately realized because it was difficult to master the mathematical techniques and data needed to verify the three laws.
b) were partially empirical discoveries made by analyzing Tycho's data. The laws were inconsistent with the Tychonic model, and hence **PROVED** the Copernican model.
c) were partially empirical discoveries made by analyzing Tycho's data. The laws were consistent geometrically with both the Tychonic and Copernican theories. Thus they were **INSUFFICIENT** by themselves to prove the Copernican theory. Nevertheless, since the Earth fit so well as a planet obeying the three laws and was so exceptional as the center of the Solar System (given the three laws), an unbiased person might well have said that the three laws strongly favored the Copernican theory.
d) were partially empirical discoveries made by analyzing Tycho's data. The laws were consistent geometrically with both the Tychonic and Copernican theories. Thus they were **SUFFICIENT** by themselves to prove the Copernican theory.
e) were partially empirical discoveries made by analyzing Tycho's data. The laws were consistent geometrically with both the Tychonic and Copernican theories. Thus they were **SUFFICIENT** by themselves to prove the Copernican theory. Realizing this Kepler **SUPPRESSED** them for term of his life.

SUGGESTED ANSWER: (c)

Note that "partially empirical". Kepler had a strong theoretical principle guiding his search for the laws of planetary motion. That principle was that the Sun-Planet distance was a key variable in determining planetary motion.

Wrong answers:
e) There is a logical error here.

Redaction: Jeffery, 2001jan01

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004 qmult 02202 1 1 3 easy memory: Kepler's 3rd law
Extra keywords: physci KB-24-12

25. According to Kepler's 3rd law, the orbital period of a planet (i.e., the planet's year) depends on planet:

a) mass. b) diameter. c) distance from Sun. d) color. e) axis tilt.

SUGGESTED ANSWER: (c)

Wrong answers:
d) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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004 qmult 02204 2 3 3 mod. math: Kepler's 3rd law calculation 1
Extra keywords: physci KB-25-13

26. Kepler's 3rd law for the Solar System planets can be conveniently written

$$P_{\rm year} = A_{\rm AU}^{3/2} \qquad \text{or, less conveniently,} \qquad P_{\rm year}^2 = A_{\rm AU}^3 \ ,$$

where $P_{\rm year}$ is the orbital period in Earth years and $A_{\rm AU}$ is the mean Sun-planet distance in astronomical units (AU) (i.e., in mean Sun-Earth distances). If an asteroid is 9 AU from the Sun, what is its orbital period in years?

a) 9. b) 3. c) 27. d) 729. e) 1.

SUGGESTED ANSWER: (c)

Wrong answers:
e) This would mean the asteroid was in the Earth's orbital location.

Redaction: Jeffery, 2001jan01

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004 qmult 02210 3 3 5 hard math: Kepler's 3rd law calculation 2

27. If a planet has a mean distance from the Sun of 9 astronomical units, what is its orbital period in years?

a) 28 years. b) 3 years. c) 9 years. d) 81 years. e) 27 years.

SUGGESTED ANSWER: (e)

The student must know Kepler's 3rd law in the reduced form:

$$p = a^{3/2} ,$$

where p is in years and a is astronomical units. and know how to use it. In this case,

$$9^{3/2} = 9 \times \sqrt{9} = 9 \times 3 = 27 .$$

Wrong answers:
a) Close.

Redaction: Jeffery, 2001jan01

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004 qmult 02420 1 4 3 easy deducto-memory: Galileo, fll phases of Venus

28. Galileo's discovered that Venus showed a full set of phases like the Moon. But it was already known since Antiquity that Venus is never opposite the Sun on the sky and in fact is never further than 46° from the Sun. Thus, Galileo's discovery proved:

a) Venus orbited the Earth.
b) Venus orbited the Moon.
c) Venus orbited the Sun.
d) Venus executed an orbit about an empty point in space that always lies between the Earth and Sun on the Sun-Earth line.
e) Venus is falling into the Sun perpetually.

SUGGESTED ANSWER: (c) Venus does orbit the Sun and if Galileo's proof was valid, then it must be the right answer. A little thought shows his answer is right.

Wrong answers:
a) It would show full phases if it orbited the Earth, but then it would also move far from the Sun and have oppositions.
d) This is the Ptolemaic model which Galileo disproved.

Redaction: Jeffery, 2001jan01

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004 qmult 02430 2 4 3 moderate deducto-memory: Galileo's discoveries

29. Galileo did **NOT** discover:

a) the four largest moons of Jupiter. b) the full phases of Venus. c) the moons of Mars. d) sunspots. e) the mountainous surface of the Moon.

SUGGESTED ANSWER: (c) See Se-65. The answer can be deduced from what Galileo could have seen with a small telescope. This is a combination Chapter 4 and 23 question, but mostly 4.

Wrong answers:
e) All things are wrong.

Redaction: Jeffery, 2001jan01

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004 qmult 02440 2 5 5 moderate thinking: Galileo, moons of Jupiter

30. Galileo's discovery of the moons of Jupiter:

a) had no bearing on the debate over the Copernican theory.
b) meant that the Earth was the center of Jupiter's orbit.
c) explained the full phases of Venus.
d) meant that the Earth was not the physical center of all motion in the Solar System, and that Earth could have a moon and still be on an **EPICYCLE**.
e) meant that the Earth was not the physical center of all motion in the Solar System, and that Earth could have a moon and still be a **PLANET**.

SUGGESTED ANSWER: (e) A moderate thinking question although it could be just a fact one for some. If one understood the nature of the Copernican debate, (e) seems best.

Wrong answers:
a) A very implausible opinion.
b) A false conclusion.
c) A red herring.
d) The first part is a true conclusion and the second is true (in the context of the Copernican debate), but is not a conclusion from the moons of Jupiter.

Redaction: Jeffery, 2001jan01

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004 qmult 02450 2 4 2 moderate deducto-memory: Galileo, Saturn's rings
31. From his observations of Saturn in 1610, Galileo's discovered:

a) that Saturn had an obvious ring.
b) that Saturn had odd protuberances, but he couldn't make out what they were. Christiaan Huygens later in the **17TH CENTURY** concluded that Saturn had a ring.
c) that Saturn had odd protuberances, but he couldn't make out what they were. Christiaan Huygens later in the **20TH CENTURY** concluded that Saturn had a ring.
d) that Saturn had 3 obvious rings that he labled A, B, and C.
e) that Saturn's rings, which are visible to the naked eye were green.

SUGGESTED ANSWER: (b) See No-335,344.

Wrong answers:
c) The 20th century is pretty late for this fairly easy telescopic discovery.
d) Saturn does have 3 main rings labeled A, B, and C, but did discover or label them.

Redaction: Jeffery, 2001jan01

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004 qmult 02500 1 5 3 easy thinking: Galileo and Copernicanism
32. Galileo's telescopic discoveries:

a) **PROVED** Copernicanism absolutely. Resistance to this proof was simply irrational.
b) proved that the ancients had been wrong about the cosmos and that they had not had all the evidence. But Kepler's laws had already **PROVEN** Copernicanism to all the mathematically-minded including Galileo. Not everyone had accepted these proofs, of course. Soon—but not soon enough for Galileo—they would.
c) proved that the ancients had been wrong about the cosmos and that they had not had all the evidence. Now Tycho's demonstrations that the heavens were mutable and the crystalline spheres had no existence in a strong sense had already proved some of the ancient beliefs wrong. And Kepler's first two laws, published 1609 just a year before the telescopic discoveries were published in 1610, were so much better descriptions—that is they were more accurate, more unique, and simpler (with a certain interpretation of "simpler" of course)—that they made the ancient descriptions seem implausible. But Tycho's work and Kepler's work (at least prior to the publication of the *Rudolphine Tables* [1627]) was **NOT EASILY VERIFIABLE** by anyone else. The telescopic discoveries could be verified fairly easily (some very easily) by anyone and no expertise with mathematical astronomy was needed. Thus, the telescopic discoveries tore the mask from the cosmos (well a bit anyway) and opened minds to new ideas, even Copernicanism.
d) proved that the ancients had been wrong about the cosmos and that they had not had all the evidence. Now Tycho's demonstrations that the heavens were mutable and the crystalline spheres had no existence in a strong sense had already proved some of the ancient beliefs wrong. And Kepler's first two laws, published 1609 just a year before the telescopic discoveries were published in

1610, were so much better descriptions—that is they were more accurate, more unique, and simpler (with a certain interpretation of "simpler" of course)—that they made the ancient descriptions seem implausible. But Tycho's work and Kepler's work had been mostly ignored because they were **BOTH COPERNICANS** when Copernicanism was still considered to be **COMPLETELY DISCREDITING**. The telescopic discoveries, on the other hand had been made by a Copernican whose Copernicanism was still secret (a closet Copernican), and therefore were generally taken as being well founded. Thus, the telescopic discoveries tore the mask from the cosmos (well a bit anyway) and opened minds to new ideas, even Copernicanism.

e) were completely irrelevant to the debate over Copernicanism. The fact that they were made at about the same time that Copernicanism became a hot topic is a historical coincidence.

SUGGESTED ANSWER: (c) Ah poor old mathematical astronomy—a bizarre endeavor tolerated for its utility in astrology one supposes.

Wrong answers:
e) C'mon.

Redaction: Jeffery, 2001jan01

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004 qmult 03000 1 4 2 easy deducto-memory: unified terrestrial/celestial 1

33. Newtonian physics unified:

a) thermodynamics and special relativity. b) terrestrial and celestial physics. c) terrestrial and substantial physics. d) terrestrial and Martian physics. e) talking and walking physics.

SUGGESTED ANSWER: (b)

Wrong answers:
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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026 qmult 00100 1 4 4 easy deducto-memory: galaxy defined
Extra keywords: CK-370

34. "Let's play *Jeopardy*! For $100, the answer is: They are large, gravitationally-bound systems of stars that range from dwarf versions that are kiloparsec in size scale to the large ones that are tens of kiloparsecs or even a couple hundred kiloparsecs in size scale."

What are ____________, Alex?

a) binaries b) open clusters c) globular clusters d) galaxies e) universes

SUGGESTED ANSWER: (d) See FK-582.

Wrong answers:
a) Now does this sound likely?

Redaction: Jeffery, 2001jan01

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026 qmult 00110 1 1 3 easy memory: Irregular galaxies

35. Galaxies come in five main types: ellipticals, lenticular, unbarred spirals, barred spirals, and:

a) globulars. b) regulars. c) irregulars. d) Cepheids. e) Vermeers.

SUGGESTED ANSWER: (c)

Wrong answers:
a) These are a kind of star cluster.
d) These are luminous variable stars used as distance indicators.
e) These are paintings by Vermeer. Very pricy.

Redaction: Jeffery, 2001jan01

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026 qmult 00200 1 4 4 easy deducto-memory: traditional Milky Way
Extra keywords: CK-370

36. "Let's play *Jeopardy*! For \$100, the answer is: In the celestial-sphere picture of the sky, this object is luminous band on celestial sphere that straddles a great circle that is at an angle of about 60° to the celestial equator."

What is the ____________, Alex?

a) Zodiac b) celestial axis c) ecliptic d) Milky Way e) Andromeda Nebula

SUGGESTED ANSWER: (d) See CM-366 for the angle of the Milky Way band on the celestial sphere.

Wrong answers:
a) The Zodiac constellations straddle the ecliptic.

Redaction: Jeffery, 2001jan01

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026 qmult 00210 2 1 2 moderate memory: center of Milky Way

37. The center of the Milky Way is in:

a) Orion. b) Sagittarius. c) Virgo. d) Cassiopeia. e) Pegasus.

SUGGESTED ANSWER: (b)

Wrong answers:
a) Nope.

Redaction: Jeffery, 2001jan01

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026 qmult 00320 1 4 5 easy deducto memory: Milky Way structure speculators

38. The first three recorded persons, all living in the 18th century, to speculate about the structure of the Milky Way in the context of Newtonian physics were:

a) Larry, Curly, and Moe. b) Voltaire, Talleyrand, and Robespierre. c) Ben Franklin, Thomas Jefferson, and George Washington. d) Thomas Wright, Goethe, and Frederick the Great. e) Thomas Wright, Immanuel Kant, and J. H. Lambert.

SUGGESTED ANSWER: (e)

Wrong answers:
a) I don't think so.
c) Ben Franklin is plausible. He was a considerable scientist with broad interests.
d) Goethe also had broad interests and dabbled in science.

Redaction: Jeffery, 2001jan01

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026 qmult 00330 1 4 4 easy deducto-memory: Herschel maps the Milky Way

39. "Let's play *Jeopardy*! For \$100, the answer is: He/she attempted to map the Milky Way using star counts (or star gauges)."

Who is ____________, Alex?

a) Nicolaus Copernicus (1473–1543) b) Galileo Galilei (1564–1642)
c) Isaac Newton (1642/3–1727) d) William Herschel (1738–1822)
e) Caroline Herschel (1750–1848)

SUGGESTED ANSWER: (d) Caroline probably helped out.

Wrong answers:
c) Newton was born 1642 Dec25 on the Julian calendar used in England all of this life. This 1643 Jan04 on the modern Gregorian calendar that was used in most of the rest of Europe at that time.
e) She was probably nearby making coffee or something. Actually, she helped her brother a lot.

Redaction: Jeffery, 2001jan01

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026 qmult 00350 1 4 3 easy deducto-memory: Shapley and Milky Way

40. "Let's play *Jeopardy*! For $100, the answer is: He/she obtained a roughly correct size estimate for the Milky Way and was the first to roughly correctly locate the center of the Milky Way using Cepheid variable stars in globular clusters in the halo of the Milky Way."

    Who is ____________, Alex?

    a) Henrietta Swan Leavitt (1868–1921) b) Heber Curtis (1872–1942)
    c) Harlow Shapley (1885–1972) d) Edwin Hubble (1889–1953)
    e) Stephen Hawking (1942–2018)

    SUGGESTED ANSWER: (c)

    Wrong answers:
    a) She was the discoverer of the period-luminosity relation for Cepheid variable stars (No-488) while working at Harvard College Observatory. Distance determinations by Hubble using this relation established the extragalactic nature of the galaxies.

    Redaction: Jeffery, 2001jan01

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026 qmult 00400 1 4 4 easy deducto-memory: nebulae
Extra keywords: CK-366,370

41. Clouds in space or, when speaking historically, those objects regarded as cloud-like are called:

    a) shapleys. b) stars. c) galaxies. d) nebulae. e) curtises.

    SUGGESTED ANSWER: (d)

    Wrong answers:
    e) As Lurch would say: "Aaaarh."

    Redaction: Jeffery, 2001jan01

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026 qmult 00460 1 4 2 easy deducto-memory: Rosse discovers spirals
Extra keywords: CK-366, super-easy deduction question

42. The spiral nature of some nebulae was discovered using visual astronomy and the largest telescope of its time: the 183-cm diameter Leviathan of Parsonstown located at Birr Castle, Parsonstown, Ireland. Because the spiral nebula are rather faint, it takes are large telescope to make out the spiral arms visually. With long-exposure photography it is relatively easy to discover spirals. But visual astronomy beat the recently invented photography by some years in this case: the discovery was made in 1845 April by the builder of the Leviathan:

    a) Caroline Herschel (1750–1848). b) the Earl of Rosse (1800–1867).
    c) Henrietta Swan Leavitt (1868–1921). d) Harlow Shapley (1885–1972).
    e) Edwin Hubble (1889–1953).

    SUGGESTED ANSWER: (b)

    Wrong answers:
    a) Yes, 95-year old Caroline Herschel still going strong in Ireland ...

    Redaction: Jeffery, 2001jan01

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026 qmult 00500 1 1 4 easy memory: Shapley-Curtis debate
Extra keywords: CK-370

43. On 1920 April 26, a debate about the nature of the spiral nebulae was held at a meeting of the National Academy of Sciences in Washington, D.C. The debaters both made sound points in the printed presentations that they later made if not on the day of. This debate is called the Great Debate or the:

    a) Einstein-de Sitter debate. b) Rosse-Hubble debate. c) Shapley-Hubble debate.
    d) Shapley-Curtis debate. e) Kant-Einstein debate.

    SUGGESTED ANSWER: (d)

    Curtis is generally considered to have won on actual points on the day of since Shapley was aiming at impressing people who could hire him to be director of the Harvard College Observatory rather than on winning the debate. Curtis also won historically: he argued the spiral nebulae were other galaxies and he was right. See Hoskin, M. A. 1976, *Journal for the History of Astronomy,* vii, 169.

Wrong answers:

e) It might have been interesting to have Immanuel Kant (1724–1804) square of with Albert Einstein (1879–1955).

Redaction: Jeffery, 2001jan01

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026 qmult 00600 1 1 4 easy memory: Hubble proves galaxies exist

Extra keywords: CK-370-2

44. Using Cepheid variable stars as distance indicators and the inverse square law for electromagnetic radiation flux, this famous astronomer was able to prove that M31 (the Andromeda spiral nebulae) was a giant star system (i.e., a galaxy) outside of the Milky Way. His/her name is:

a) Caroline Herschel (1750–1848). b) Henrietta Swan Leavitt (1868–1921). c) Harlow Shapley (1885–1972). d) Edwin Hubble (1889–1953). e) Knut Lundmark (1889–1958).

SUGGESTED ANSWER: (d)

Wrong answers:

a) Caroline Herschel was a noted comet and nebula discoverer in her own right (No-399), but is most noted as helpmeet (eek!) to her brother William Herschel (1738–1822), the foremost observational astronomer of his time (No-398).
b) She was the discoverer of the period-luminosity relation for Cepheid variable stars (No-488) while working at Harvard College Observatory. Distance determinations by Hubble using this relation established the extragalactic nature of the galaxies.
c) Shapley was the first person to achieve a good estimate for the size of the Galaxy and the location of its center using Cepheid variables (No-493, 497).
e) Lundmark played around with rules connecting distances and velocities of galaxies in 1924, but my didn't come to a solid conclusion (Trimble 2013).

Redaction: Jeffery, 2001jan01

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026 qmult 00610 1 4 2 easy memory: Hubble and the 100-inch

45. Edwin Hubble (1889–1953) was able to prove the extragalactic nature of the spiral nebulae because, among other things, he had available the world's:

a) largest telescope of our day. b) largest telescope of his day. c) smallest telescope of his day. d) smallest telescope of our day. e) largest telescope of Newton's day.

SUGGESTED ANSWER: (b)

Wrong answers:

a) The Hooker 100-inch (2.54 m) telescope is a significant, but not large, telescope by modern standards.
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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030 qmult 00100 1 1 5 easy memory: cosmology defined

Extra keywords: physci

46. The science of the universe as a whole is called:

a) proctology. b) universology. c) cosmetology. d) inflation. e) cosmology.

SUGGESTED ANSWER: (e)

Wrong answers:

a) A very important science which is difficult to discuss in polite society.
d) Inflation is an idea in modern cosmology; we stole the word from economics.
c) Many people say this. Actually, both cosmetics and cosmos are derived from the same Greek word meaning something like ornamentation.

Redaction: Jeffery, 2001jan01

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030 qmult 00450 1 1 3 easy memory: Hubble's law
Extra keywords: physci

47. Given v as recession velocity and r as cosmological physical distance, Hubble's law is:

a) $r = Hv$. b) $r = H/v$. c) $v = Hr$. d) $v = H/r$. e) $v = Hr^2$.

SUGGESTED ANSWER: (c)

Wrong answers:

e) As Lurch would say: "Aaaarh." But someone if I recall correctly thought they had found evidence for such a law.

Redaction: Jeffery, 2001jan01

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030 qmult 00460 1 4 3 easy deducto-memory: discoverer of Hubble's law
Extra keywords: physci

48. "Let's play *Jeopardy*! For $100, the answer is: He/she is the person who observationally discovered Hubble's law."

Who is ____________, Alex?

a) Henrietta Swan Leavitt (1868–1921) b) Knut Lundmark (1889–1958)
c) Edwin Hubble (1889–1953) d) Georges Lemaître (1894–1966)
e) Adriaan van Maanen (1884–1946)

SUGGESTED ANSWER: (c)

The story of the discovery of the expansion of the universe and Hubble's law (which is the form of the expansion) is complex. Some form of universal expansion was gradually becoming apparent to astronomers from 1912 on, starting from Vesto Slipher's work on the redshifts of galaxies.

But convincing observational evidence of the expansion of the universe and Hubble's law came with Hubble in 1929. Knut Lundmark deserves some credit for getting partway to it. Theoretically, the expansion was first suggested by Willem de Sitter (1872–1934) in 1917 and Lemaître first demonstrated Hubble's law as a theoretical consequence of the Friedmann-equation models of the expanding universe in 1927 though it was little known till some years later. Lemaître, using published data in the literature, even obtained a value of Hubble's constant that was not much worse than Hubble's own value which was about 7 times too large due an overall calibration error. Note Lemaître did not observationally discover Hubble's law, but only showed that if did apply observationally then his value of Hubble's constant may have applied.

Wrong answers:

a) She was the discoverer of the period-luminosity relation for Cepheid variable stars (No-488) while working at Harvard College Observatory. Distance determinations by Hubble using this relation established the extragalactic nature of the galaxies.
e) His mistaken observations of movement of the spiral arms of the spiral nebulae worked against the acceptance of the extragalactic nature of these objects (No-495).

Redaction: Jeffery, 2001jan01

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030 qmult 00470 1 4 1 easy deducto-memory: Hubble time
Extra keywords: physci KB-668-26

49. The current value of the Hubble time and the Λ-CDM model (AKA the concordance model) value for the age of the universe are both about:

a) 14 Gyr. b) 10^{100} yr. c) 10 years. d) 4.6 Gyr. e) 0.

SUGGESTED ANSWER: (a)

Wrong answers:

d) This is the age of the Solar System as determined by radioactive dating.
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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030 qmult 00480 1 1 4 easy memory: Hubble length observable universe
Extra keywords: physci KB-670-22

50. The Hubble length is $4.283h_{70}^{-1}$ Gpc (where h_{70} is the reduced Hubble constant: it is equal to 1 to within a few percent). It is a characteristic size scale for the:

    a) quantum of the inflaton. b) Milky Way. c) total universe. d) observable universe. e) Solar System.

    SUGGESTED ANSWER: (d)

    Wrong answers:
    a) As Lurch would say: "Aaaarh."

    Fortran-95 Code

```
          print*
          print*,'Hubble quantities, Hubble values'
          ckms=2.99792458d5                  ! speed of light in km/s
          yearsec=365.25d0*86400.d0          ! Jyr in seconds
          gly=ckms*yearsec*1.d9              ! Gly in km
          au=1.49597870700d8  ! https://en.wikipedia.org/wiki/Astronomical_unit in
km
          con=2.*acos(-1.)/(3600.d0*360.d0) ! Arcseconds to radians
          parsec=au/con                      ! Parsec in km
          xmpc=parsec*1.d6                   ! Mpc in km
          gpc=parsec*1.d9                    ! Gpc in km
          pclyr=gpc/gly                      ! pc in ly
          gyr=1.d9*yearsec                   ! Gyr in seconds
          h0=70.d0                           ! Fiducial value
          t=(xmpc/h0)/gyr                    ! Hubble time in Gyr
          dly=t                              ! Hubble length in Gly
          dgpc=dly/pclyr                     ! Hubble length in Gpc
          print*,'pclyr,t,dly,dgpc'
          print*,pclyr,t,dly,dgpc
    !    3.2615636864061552       13.968459921017748       13.968459921017748
4.2827493999999993
```

Redaction: Jeffery, 2001jan01

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030 qmult 00500 1 1 3 easy memory: Einstein universe defined

51. The Einstein universe presented by Einstein in 1917 is a/an ____________ universe model.

    a) contracting, hyperspherical b) expanding, hyperspherical c) static, hyperspherical d) static, hypercritical e) expanding, hypercritical

    SUGGESTED ANSWER: (c) See No-520.

    Wrong answers:
    e) As Lurch would say: "Aaaarh."

    Redaction: Jeffery, 2001jan01

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030 qmult 00700 1 4 4 easy deducto-memory: Friedmann-equation models

52. "Let's play *Jeopardy*! For $100, the answer is: These models were the first plausible universe models (in that they contained mass-energy) to predict the expansion of the universe."

    What are the ____________ models, Alex?

    a) Alpher-Behte-Gamow b) Einstein-Lemaître c) Einstein d) Friedmann-equation e) Gamow

    SUGGESTED ANSWER: (d)

    Wrong answers:
    a) There was a famous Alpher-Behte-Gamow paper in the development of Big Bang cosmology.

Redaction: Jeffery, 2001jan01

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030 qmult 00730 1 4 5 easy deducto-memory: Omega in Friedmann-equation models

53. "Let's play *Jeopardy*! For $100, the answer is: In the Friedmann-equation models, it is the symbol for density parameter which is the parameter that that specifies the geometry of the universe: if less than 1, the universe is hyperbolic and infinite; if equal to 1, the universe is flat and infinite; if greater than 1, the universe is hyperspherical and finite. The symbol name is often used as synonym for density parameter."

    What is ____________, Alex?

    a) Λ (spelt Lambda) b) Ψ (spelt Psi) c) Δ (spelt Delta) d) Γ (spelt Gamma) e) Ω (spelt Omega)

    SUGGESTED ANSWER: (e)

    Wrong answers:
    a) This is the symbol for the cosmological constant.
    b) This is the symbol for the wave function in quantum mechanics.
    c) This is the symbol for change in.
    d) I don't think Γ has a standard use in physics, although we do use it for various things.

    Redaction: Jeffery, 2001jan01

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030 qmult 00800 1 1 5 easy memory: accelerating universe

Extra keywords: physci KB-668-28 but note their answer is wrong.

54. According to observations of several kinds beginning in 1998, it is almost certain that the universal expansion is currently:

    a) decelerating. b) stopped. c) negative: i.e., the universe is contracting. d) in doubt. e) accelerating.

    SUGGESTED ANSWER: (e)

    Wrong answers:
    a) Exactly wrong, but this is what was believed to be the case before 1998.

    Redaction: Jeffery, 2001jan01

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030 qmult 00810 2 4 5 mod. deducto memory: cosmological constant

Extra keywords: physci

55. The simplest explanation considered for the accelerating expansion of the universe is:

    a) planet explosions. b) supernovae. c) stellar winds. d) green energy. e) a cosmological constant.

    SUGGESTED ANSWER: (e)

    Wrong answers:
    a) As Lurch would say: "Aaaarh."

    Redaction: Jeffery, 2001jan01

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030 qmult 01000 1 1 1 easy memory: Lambda-CDM or concordance model defined

56. The Friedmann-equation Λ model (i.e., the Friedmann-equation model with a nonzero cosmological constant Λ or nonzero dark energy but still using the letter Λ since one knows what one means) with parameters adjusted to fit current observations was once often called the concordance model, but nowadays is more usually nowadays called the:

    a) Λ-CDM model. b) Ω-CDM model. c) Λ-HDM model. d) Ω-HDM model. e) discord model.

    SUGGESTED ANSWER: (a)

    Wrong answers:
    e) Exactly wrong.

Redaction: Jeffery, 2001jan01

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030 qmult 01030 1 4 2 easy deducto-memory: dark matter
Extra keywords: physci KB-669-34

57. After the dark energy (whatever that is and assuming it's not just an effect of a true cosmological constant), the most abundant form of mass-energy in the universe is apparently some form of matter known only (at least to circa 2020) through its gravitational effects. We call this matter:

a) luminous matter. b) dark matter. c) baryonic matter. d) invisible matter. e) mirror matter.

SUGGESTED ANSWER: (b)

Wrong answers:
e) There is something called mirror matter, but I forget what and it probably doesn't exist anyway.

Redaction: Jeffery, 2001jan01

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030 qmult 01300 1 1 3 easy memory: Big Bang in brief defined
Extra keywords: physci KB-668-27

58. The Big Bang, in brief, is the:

a) explosion of a supernova. b) explosion of a star. c) origin of the observable universe. d) explosion of a quasar. e) end of the observable universe or our pocket universe.

SUGGESTED ANSWER: (c)

Wrong answers:
e) Exactly wrong. The big crunch (which is a sort of big bang in revese) is one of the theoretical ends of the universe.

Redaction: Jeffery, 2001jan01

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030 qmult 01330 1 1 2 easy memory: H and He from Big Bang
Extra keywords: physci KB-669-29

59. In Big Bang nucleosynthesis, the two most abundant products are:

a) hydrogen and iron in about a 1:1 mass ratio. b) hydrogen and helium in about a 3:1 mass ratio. c) hydrogen and helium in about a 1:1 mass ratio. d) hydrogen and iron in about a 3:1 mass ratio. e) helium and iron in equal amounts by mass.

SUGGESTED ANSWER: (b)

Wrong answers:
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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030 qmult 01332 1 4 1 easy deducto-memory: origin of the heavy elements
Extra keywords: physci KB-669-30

60. Most of the elements in the observable universe heavier than lithium were formed in:

a) stars and supernovae. b) black holes. c) the Big Bang. d) nuclear reactors. e) planets.

SUGGESTED ANSWER: (a)

Wrong answers:
c) Exactly wrong.
e) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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030 qmult 01370 1 4 4 easy deducto memory: CMB defined
Extra keywords: physci KB-669-33

61. The relic primordial electromagnetic radiation field which decoupled from matter in the recombination era circa 400,000 years after the Big Bang when hydrogen became neutral making the observable universe transparent and which has since free streamed through space and cooled off because of the expansion of the universe is called the:

a) Cosmic Gamma-ray Background (CGB). b) Cosmic X-ray Bare Ground (CXBG).
c) Cosmic X-ray Foreground (CXF). d) Cosmic Microwave Background (CMB).
e) Cosmic X-ray Background (CXB).

SUGGESTED ANSWER: (d)

Wrong answers:
b) As Lurch would say: "Aaaarh."

Redaction: Jeffery, 2001jan01

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030 qmult 01390 1 4 1 easy deducto memory: 5 evidences for Big Bang
Extra keywords: physci-670-28

62. Five observational evidences are:

1. the expansion of the universe.
2. the abundances of the light elements: H, D, He, and Li.
3. the existence of the cosmic microwave background (CMB).
4. that the fluctuations in the CMB are accounted for by primordial density fluctuations that account adequately so far for the initial conditions for the large-scale structure of the universe.
5. that the oldest stars ($\gtrsim 13.6\,\text{Gyr}$) are not older than the observable universe.

These evidences strongly support:

a) Big Bang cosmology. b) the steady-state universe. c) little bang cosmology.
d) the hierarchical universe. e) Democritean cosmology.

SUGGESTED ANSWER: (a)

Wrong answers:
b) Actually, 2–5 are evidence against the steady-state model of the universe.
c) This was proposed by Gary Larsen in a cartoon which is an unusual location for a scientific theory.
d) The hierarchical universe was a possibility at one time but seems ruled out by observations of the large-scale structure (CL-55).
e) Democritus (460?–370? BCE) was the 2nd proponent of the atom theory in ancient Greece. He, or he and his older colleague Leucippus, had a very interesting cosmology that in some respects anticipates the eternal inflation cosmology model of our own time.

Redaction: Jeffery, 2001jan01

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030 qmult 01500 1 4 5 easy deducto-memory: inflation defined
Extra keywords: CK-446

63. "Let's play *Jeopardy*! For $100, the answer is: It is name for the super-rapid expansion that the observable universe and maybe beyond may have undergone at very early times.

What is ____________, Alex?

a) inoculation b) infestation c) hybridization d) hydration e) inflation

SUGGESTED ANSWER: (e)

Wrong answers:
d) Hydration is to chemically combine with water (Ba-591).

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001 qfull 00230 1 3 0 easy math: Pythagorean theorem III with area rule with Euclid's 5th postulate

64. Can we prove the Pythagorean theorem semi-rigorously? Yes.

a) Assume an homogeneous, isotropic (homist) 2-dimensional space. Assume there is a geodesic rule: i.e., there is a rule for measuring distance and for measuring the stationary distance between two points. Draw intersecting equal length geodesics that intersect at their midpoints and that have 4-fold rotational symmetry about their intersection point. A full rotation about the intersection point is measured as 360°. How would you describe size of the angles subtended at the intersection point separating the crossed geodesic arms and why would you say this? Note draw the geodesics vertical and horizontal, so that the descriptions in the following parts are consistent with the diagram.

b) Now draw geodesics between the endpoints of your crossed geodesics, but note we are not assuming Euclidean (i.e., flat space) so that these geodesics could bend outward/inward from intersection point in some projection or another. You now have a square (but not necessarily a Euclidean square). Call it square 1. Now copy square 1 to square 2 and translate square 2 to the upper right so that the lower left corner endpoints of square 2 lie on the upper right corner endpoints of square 1. Is there a space between geodesics of the two squares joining common endpoints? Why or why not?

c) Now copy square 2 to square 3 and translate square 3 to the lower right, but otherwise with the same intructions as in part (b). Now copy square 3 to square 4 and translate square 4 to the lower left, but otherwise with the same intructions as in part (b). Does square 4 necessarily share a common geodesic with the original square 1? Why or why not?

d) The answer to part (c) was no. However, if there is a common geodesic then the space is a Euclidean plane and, at the common corner of the 4 squares, the angles between the geodesics that meet there are all 90°. Postulating that they are 90° is equivalent to Euclid's 5th postulate. For long ages mathematicians wondered if 5th postulate was derivable from Euclid's first 4 postulates. The answer is no. Even somewhat obviously no since, among other things, geodesics that are parallel on a sphere at the equator (i.e., separated by a mutually perpendicular geodesic there) meet at the poles.

   Assuming a Euclidean plane, prove that ines (as we now call geodesics) parallel at one location (i.e., separated by a mutually perpendicular line) stay the same perpendicular distance apart no matter how extended. There are probably many ways of proving this, but one path is to start by noting that equal squares of any size can tile the whole Euclidean plane without overlap which actually is an immediate consequence of our considerations above.

e) The fact that one can tile the Euclidean plane completely with squares without overlap suggests an area concept. Consider differential rectangles of side lengths dx and dy. Define their area to be $dx\,dy$. We define area to be countable in the sense that the area of N rectangles is $N\,dx\,dy$. You can tile completely any region surrounded by a closed curve with equal differential rectangles with no rectangles wholly out of the region. We define the area of the region by

$$A = \lim_{N\to\infty,\, dx\,dy\to 0} N\,dx\,dy \ .$$

   That such limit exists in general requires a rigorous proof that we will not do here. However, one can prove the limit exists in special cases easily and those special cases they also show why defining the area of the differential rectangles in terms of the lengths of their sides is reasonable since finite regions of sufficient symmetry also have areas specified by their defining lengths. An important point is that area is independent of the ordering of the adding up the differentials areas. As a nonce expression, we call this independence the area principle.

   Determine the area of a large rectangle of sides a and b in terms of differential rectangles and take the limit so that the properties of the differential rectangles vanish.

f) Prove that the area of a right triangle with sides forming the right angle being of length a and b is $ab/2$. **Hint:** You do need to use the area principle.

g) Draw a diagram of a square with sides of length $a + b$ and an inscribed square with side of length c with corners touching the sides of the first square (which is the circumscribed square) at points a from each corner of the first square.

h) Use the area principle to prove the Pythagorean theorem: i.e., $c^2 = a^2 + b^2$.

i) Prove the metric $ds^2 = dx^2 + dy^2$ holds for a Euclidean plane. **Hint:** This is easy.

SUGGESTED ANSWER:

a) Imagine the diagram and the angles would be described as 90° since the 4-fold symmetry implies they are equal and each a quarter of 360°.

b) There is no gap, because the corners of the original and copy are joined by geodesics in our homist 2-dimensional space and those two geodesics must the same geodesic by the homist properties of the space.

c) Square 4 and square 1 do not necessarily share a common geodesic. They share a common corner point with each other and the other squares, but angles between the geodesics meeting at this corner do not have to be 90° in general.

d) If you can tile the whole plane without overlap by squares of any size, then you can tile one square by four smaller squares. Consider one side of the big square. It is a line between the corners of the big square. The two small squares that fill between those both have sides that are lines coincident with the line of the big square. Thus, in general squares arranged in a row have sides that form two lines because any two points on one of those lines have their shortest distance apart along those lines and the squares can have any size we like and this must still be true. Those lines are parallel at every point no matter how extended the row and they are always the same perpendicular distance apart.

What about the converse? If two lines are not perpendicular at some location (i.e., there is a location where they are not separated by a mutually perpendicular line), must they intersect? The answer is yes, but I cannot think of a concise proof at the moment.

e) We make the differential rectangles similar to the large rectangle such that N differential rectangles span the x direction and N span the y direction. In fact, N is just an integer scaling factor. The area of the large rectangle is

$$A = N^2\,dx\,dy = N^2\left(\frac{a}{N}\right)\left(\frac{b}{N}\right) = ab\ .$$

Thus, the area of the large rectangle does not, in fact, depend on the size or number of the little rectangles, but just on its own lengths and, in fact, the product of those lengths. This suggests that defining differential area by a product of lengths is rational for the reason given in the question.

f) Just bisect a rectangle of sides a and b by a diagonal to get two triangles fitting the specifications. The two parts must have equal area by symmetry. The area principle then implies that those areas must be the rectangle area divided by 2 since that area is independent of how the differential areas are ordered in adding process to get area. Thus, the area of each triangle is $ab/2$.

g) You will have to imagine the diagram or view it at Wikipedia: Pythagorean theorem: Pythagorean proof.

h) Behold:

$$\begin{aligned} 4(ab/2) + c^2 &= (a+b)^2 \\ 2ab + c^2 &= a^2 + b^2 + 2ab \\ c^2 &= a^2 + b^2\ , \end{aligned}$$

with the last line being the Pythagorean theorem itself: QED.

i) If Pythagorean theorem $c^2 = a^2 + b^2$ holds for finite perpendicular distances a and b, then it must hold for differential coordinate differences dx and dy. Thus, $ds^2 = dx^2 + dy^2$ is the metric for the Euclidean plane, QED.

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