Teaching
Investigating Astronomy
with Peer Instruction

*Implementing Think-Pair-Share
or Intellectual Engagement*

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You've got to love your students.

-   *Paul G. Hewitt*

Becoming an Engaging Professor

Most professors spend a lot of time in class lecturing. Not just a little time lecturing, but lecturing a whole lot.[1] Yet, many professors have a tacit feeling that lecture alone is probably not the best way to teach students. Perhaps their ill at ease feeling hints at a deep truth—the information-download lecture has often been described as…the process by which the teacher's notes get transferred into students' notebooks with-out passing through the brains of either. Lecturing about science and technology has a distinct advantage over other disciplines in that demonstrations can be provocative, provide illustrative clarification, and excite the learner with unexpected phenomena. But, what else can one do?

As a first step, becoming aware that there are ready-to-go teaching tools at your disposal is key. That brilliant set of lecture materials that you thought would be perfect might need to be adjusted to meet the learning styles of a more diverse group of students to actively engage them in developing conceptual understanding. We believe that the pathway toward refocusing the teacher-centered lecture to a learner-centered classroom is to accept that much of the responsibility for learning resides squarely on the listener—not on the lecturer. Lecturers can motivate, inspire, and build a series of experiences that make astronomy more accessible; but professors cannot do the learning for the students. This notion is based on the idea that, *"It's not what the teacher does that matters; rather, it is what the students do."* In a learner-centered teaching environment, the role of lecture is radically shifted to a focus on guiding students through meaningful learning experiences. The pathway to giving great lectures is to say less and change listener behavior from passive to active! Teachers who have navigated the road to student engagement rarely go back to teaching mostly by telling. For students themselves, it seems that being a critical participant in a conversation is far more important than passively listening to a lecture. Students in the most basic of learner-centered learning environments do more than mindlessly recopy notes projected by the lecturer-students engaged in active learning are engaged in a conversation with their professor during class.

The key part of a learner-centered approach is to ask questions[2]. The questions posed should be nonrhetorical questions and should be at a cognitive level requiring more thought than just relying on preexisting

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[1] Smith, M. K., Jones, F. H., Gilbert, S. L., & Wieman, C. E. (2013). The Classroom Observation Protocol for Undergraduate STEM (COPUS): a new instrument to characterize university STEM classroom practices. *CBE—Life Sciences Education*, *12*(4), 618-627.

[2] Many of these ideas have been previously published in Slater, T. F. (2008). First steps toward increasing student engagement during lecture. *The Physics Teacher, 46*(5), 317-318.

declarative knowledge. Classrooms of students responding quickly, and in unison, can be mistaken for meaningful dialogue. Questions should be intellectually challenging and be carefully crafted to lead the students to deeper levels of understanding. Questions such as "does everyone understand?" and "do you have any questions?" provide the lecturer little insight into whether or not the audience actually comprehends the ideas being presented.

 An easy-to-understand yet difficult-to-implement teaching skill is to ask meaningful questions and then patiently WAIT. Researchers that care-fully track classroom dynamics have found that an instructor who too quickly provides clarifying information or responds to the first person who answers a question completely squashes further discussion and diver-gent thinking. The common advice is to wait at least 10 seconds before saying anything after posing a question. If everyone in the audience can answer your question in less than 10 seconds, then the question isn't conceptually challenging enough. One useful strategy to help fidgety lecturers be certain that 10 seconds elapses before accepting responses is to turn away from the class, taking a sip of coffee, or flip through lecture notes without looking at the students. It is equally important to ask responders to explain the reasoning behind their answers and to avoid affirming the correctness of a response before accepting several other answers.

 At the same time, a diligent professor must avoid holding a discussion with only the students in the first few front rows. After just a few sessions the students farther back in the classroom realize that questions without accountability systems don't actually need to be contemplated because only the first few rows are required to respond. To be effective, a system that holds all the students accountable needs to be implemented. Some lecturers draw names at random from a hat to ask specific students questions. Others write students' names on ice cream sticks using a color code that distinguishes male names from female names to easily alternate between males and females.

 What about *Peer Instruction* and *Think-Pair-Share* (Green, 2003; Duncan, 2006; Mazur, 1997)? To capitalize on the innate social nature of students, pose a multiple-choice question to students in a think-pair-share format. Students are asked to THINK about the ques-ion and individually commit to and vote on an answer. It is crucial that people actually commit to an initial idea so that they can actively compare their initial thinking with any new understandings that might result after discussion with a peer. The second step is to PAIR with another student and to SHARE their answer, articulate the reasoning, and convince their neighbor "why their answer is correct." After a short collaborative discussion, they are asked to respond to the question a second time. We ask the audience to vote anonymously perhaps by holding one, two, three, or four fingers close to their chest to

indicate their answers, using colored or lettered index cards to indicate a choice, or even use electronic peer-response systems. The outcome of the voting allows the lecturer to monitor the audience's conceptual growth. The underlying hope is that through social conversations with peers, the audience will develop a more complete understanding.

Asking students questions in a way that really works no matter how small or how large your class is—that's what this book is about. As teachers, we make countless decisions about our classrooms every day. Some of them are obvious: "Am I going to talk about planets before stars today, or the other way around?" Other decisions are so subtle, they might go unnoticed: "Am I going to carefully grade every aspect of this assignment, like spelling and grammar, or am I just going to skim to see if this student has acquired the general idea?" With so many decisions to be made every day, you might think we'd be exhausted before we ever talked to a single student. And, we would, if it were not for the underlying philosophies about teaching and theories about learning that we carry with us to help us make these decisions. All too often, these philosophies and theories are completely unexamined, tacit if you will. Most importantly, if you want to improve your teaching effectiveness, understanding which philosophies and theories of learning you have adopted will allow you to make improvements in your students' learning. Let's consider some of the more prevalent theories and practices in teaching astronomy and see if you can gain some insight into how you are making decisions about your classroom.

Underlying these ideas are at least two contrasting philosophies that people use when teaching astronomy. One is called positivism and the other is called constructivism. Let's talk about positivism first.

Undoubtedly, the dominant philosophy driving most of teaching is one based in positivism. In brief, and with sincere apologies to philosophers who have spent lifetimes eloquently describing the aspects of this philosophical position, positivism is based on a notion that we only learn what we have been told or directly experienced. An astronomy teacher who devises instruction based on a positivist philosophy of teaching expends considerable effort on delivering precisely articulated lectures with cleverly illustrated graphics and illustrations.

Professors subscribing to a positivist viewpoint believe that students do not know anything about the Universe before entering their classroom and it is their task to clearly describe the nature and mechanics of the world to self-motivated students who should be intrinsically eager to experience their lecture. They disappointingly view disinterested students as unfortunately individuals who are choosing to miss a rare opportunity to learn. Most importantly, most positivist teachers believe that a lecturers' enthusiasm is probably the most important aspect to gaining and keeping students' attention so they can learn.

Among college and university professors, this is clearly the most widely adopted philosophy of teaching. At secondary levels, this is somewhat less prevalent, but still dominant. In this instance, the theoretical position, which is really a philosophical one, is that students learn astronomy by attentively listening to precisely delivered astronomy lectures and the practice consistent with this view is to provide accurate, professor-centered instruction where the teacher, or by proxy the teacher's assigned readings, is the sole source of information and learning in the course. Students' are assigned homework or in class activities designed to practice reciting or applying the teacher-delivered procedures—tests are more of the same.

In contrast, let's consider a philosophical viewpoint called constructivism. Perhaps the most influential teaching philosophy driving innovation and reformation in astronomy teaching is that of constructivism. Constructivism is grounded in the notion that students enter your classroom already holding pre-existing ideas about the way the world works. In this context, students enter your classroom already knowing why it is hotter in the summer than in the winter, why the leaves change color in autumn, and why rain falls from clouds. Many of the ideas and explanations students hold were constructed with considerable mental effort and students deeply own and are committed to holding on to their ideas. The problem for the astronomy teacher is that some of the student-created explanations about how the Universe works are scientifically accurate, whereas many others are completely wrong.

In the late 1960's, noted educator David Ausubel (1968) was well known for saying that "the task of the teacher is to determine what the student already knows and teach them accordingly." In response, much of the astronomy education research since that time has focused on devising strategies to measure the range and domain of students' misconceptions in astronomy. The number of tests for measuring the knowledge and conceptual knowledge in astronomy is a lot and these surveys and tests have evolved considerably over the years. Currently, the best landscape survey we know of is probably the TOAST _Test Of Astronomy STandards_ (Slater, 2014). The driving force behind the effortful construction of such surveys is to carefully determine what students initially think they know about astronomy as they come into the classroom so that the constructivist teacher can teach the students accordingly. Constructivist astronomy teachers pay careful attention to the results of these surveys and tests.

A constructivist teacher recognizes that their students already hold ideas about astronomy, some correct, some incorrect, and many partially correct. As a result they spend considerable energy questioning students to find out what they think. In real-time response to their questions, constructivist teachers continuously query their students about examples and counter examples and provide students with metacognitive feedback about

their own evolving ideas. Most constructivist teachers realize that students don't simply move from the wrong idea to the correct idea, but that there is long, convoluted journey with multiple pathways in leading students to more complete and scientifically accurate ideas. Teachers who hold a constructivist teaching philosophy tend to be more open to trying different teaching innovations as compared to their positivist philosophy holding colleagues. In this context, the theory is that the teacher's job is to move students from naïve understanding and misconceptions to scientifically accurate understanding of astronomy. The practice aligned with this philosophical position is that teachers are not only dispensers of knowledge, but rather serve as coaches and guides for students who are responsible for the learning. Homework or in-class activities then take the form of aligning student thinking with scientific thinking, often making use of collaborative groups (Adams & Slater, 2002).

These are not the only two teaching philosophies, but rather represent two opposite ends of a philosophical continuum. Perhaps, when thinking about how these perspectives are manifested in the classroom, this continuum is better described as a teacher-centered to learner-centered classroom continuum. In the teacher-centered classroom, the teacher is the primary source of information and ideas and is characterized by the teacher doing most of the talking. In contrast, in the learner-centered classroom, the students are doing most of the talking, debating, and articulating of ideas— often talking to each other rather than to the teacher.

The teaching-centered classroom can have its problems. The instructor may not explain the material as well as she thinks she is. She may understand it so well that she cannot break it down in ways that are understandable to her (not-as-well-prepared) students. Indeed, this problem of the "genius" not being a good teacher has reached public discussion recently. As Adam Grant wrote about his undergraduate experience in an 2018 op-ed piece in The New York Times, "It was that (brilliant professors) knew too much about their subject, and had mastered it too long ago, to relate to my ignorance about it." One suggestion he offers is that students should seek out those instructors who have the least natural ability in the field — they are the ones who struggled to master it.

This advice seems fine on paper, but students are not always the best judges of an instructor's academic background. However, in the classroom, a student is with peers, and most of them are on the same playing field. Therefore, if a student does not understand a given topic, he may feel more comfortable speaking (and listening) only to one or two other colleagues.

This break from the lecture method towards a discussion-based model occurred much earlier in the humanities and social sciences. It made students more vulnerable, but it also made them more accountable for their education. By interacting with a peer, the student may end up in a better

position to understand the material. Discussion and debate is imperative. The late Amy Winans, a professor of English at Susquehanna University talking about her practice of encouraging discussion in the classroom, wrote "We need to approach what is often simply termed 'class participation' as an occasion for ongoing practice, not only of speech but also of silence and listening."   And sometimes speaking and listening to each other is a valuable way to learn.

So, what? This book is about how to successfully implement teaching strategy where the teacher presents an idea in a traditional lecture format and then asks students to stop taking notes and answer a question about the ideas they were just presented. Questions posed by the teacher to the students can either be simple recall (e.g., which planet has the highest surface temperature?) or can be questions of application (e.g., at which phase of the moon will a solar eclipse occur?). Less often, but still quite effective at improving students' achievement, teachers can pose questions encouraging students to encounter a widely known misconception (e.g., how often does the Moon's appearance change?). Besides "think-pair-share", these questions have also been referred to as "clicker" (for the devices that can be used to record students' answers) and sometimes as *Peer Instruction* "ConcepTests." To use these questions, an instructor may incorporate beforehand the questions in a presentation for class such as in Apple *Keynote* or Microsoft *PowerPoint* (they may be handwritten, but that may take too much time during class).

There are many different ways the instructor can decide for students to respond. The students may use clicker response units that will record their answers. Typical clicker response software allows students to change their answer up to a certain number before time ends. Because the software records the students' answers, an instructor can use that data for assessment purposes later. In addition, the instructor can see at a glance what percentage of the class answered correctly and how many gave other answers.

Another way to have students present their answer is to use flashcards (see http://www.caperteam.com/s/ABCD-Cards-nk38.pdf), fingers (one finger for "A", two fingers for "B", etc.), or a smartphone app (see https://itunes.apple.com/us/app/capercard/id843445157).

The benefit of using the first two is that they do not require any special technology, but the instructor at a glance can see how the class as a whole is understanding the material. The smartphone app nay be desirable because many students have a smartphone, and even if they forget their clicker or flashcard they will have their phone.

The clickers are definitely quite popular among students as a way to interact with the instructor and, in the process, with one another, but it has been suggested that there is not much enhanced learning being done over simply using hand-held voting flashcards (Lasry 2008; Prather & Brissenden 2009). In any case, the benefits of the think-pair-share question have been demonstrated many times (*viz*., Mazur 1997; LoPresto, 2019; Slater 2008, 2019, and the references contained therein).

If the instructor wishes, the aggregate response of the class may be presented to the students. If the instructor desires, the class may be instructed to talk to their neighbor (especially if the instructor thinks that a not-sufficient portion of the class did not answer correctly). One of us (Morgan) usually suggests that the students try to convince their classmate of their answer ("pair"). One might be concerned that students will "teach one another" incorrect ideas without the teacher present to monitor and correct scientific inaccuracies.

Perhaps surprisingly, this intervention on the part of the teacher is rarely needed. Students generally teach each other correctly because the scientifically accurate ideas are generally easier to explain and defend than the inaccurate ideas. More importantly, students who have just recently come to understand the new ideas are better able to know which aspects of a concept are most confusing and are much better positioned to help other new learners come to know an idea than a teacher who struggled with learning the idea for the first time themselves years or even decades before. Students who are talking to other students of similar age and similar cultural backgrounds are able to use a more natural student language with analogies and metaphors that the teacher might be unable to devise to help students learn. In other words, students are well positioned to explain ideas to other students in ways that are most rapidly comprehensible. Typically, by the end of the sharing—perhaps no more than 30-seconds has elapsed—the discussion has become quite lively.

This is where the learning event happens. To follow up, the instructor may ask the students to answer the question again. Typically, most students have come around to the correct answer. If not, the instructor has learned that the students may need more instruction and/or discussion about the topic.

Most importantly, how do you know if all of this is working? First, and foremost, are students doing better on your exams? Sage advice from long standing astronomy teachers is that you and your students will benefit greatly

if after the exam, you can show them how their practice voting questions are reflected in the actual exam questions – whether they be identical or just slightly altered.

Second, you can systematically measure what is working in your classroom. This isn't unusual, many traditionally science trained faculty want to monitor the effect of new approaches to teaching by collecting data. Although a number of assessment instruments for ASTRO101 exist the most commonly used pre- and post-test astronomy knowledge survey to date is the TOAST _Test Of Astronomy STandards_, created by Stephanie Slater and colleagues (Slater, 2014; Slater, Schleigh, & Stork, 2015). The TOAST is a 27-item multiple choice style survey that covers the breadth of the typical ASTRO101 survey, utilizes well-crafted and deeply researched items from previous astronomy surveys, and de-emphasizes rote vocabulary memorization. Used in a pre- and post-class style, the TOAST is frequently used by ASTRO101 faculty in exploring and formally accountably documenting the impact of their active learning-oriented teaching efforts. In contrast, successful, reliable, and widely adopted surveys of how ASTRO101 students' attitudes change during ASTRO101 courses are yet to have reached any degree of consensus acceptance, considerably expended effort notwithstanding,

At the same time, Carl Weiman (2015) and colleagues have developed an exceptionally easy to use tool to systematically observe and document the behavior of both faculty and students in classrooms. Known as the COPUS _Classroom Observation Protocol for Undergraduate STEM_ (Smith, Jones, Gilbert, & Wieman, 2013). This tool allows classroom observers to create a minute-to-minute level script of what faculty are doing during instruction, and what students are doing. Behaviors such as lecturing, question posing, listening, individual on-topic conversations, and the like, are systematically cataloged for holistic analysis, providing a glimpse into the student learning experience. This tool, nor any of its similar siblings, has not yet found its way entrenched in the discipline-based science education research literature, but we believe it could become widely adopted quickly because of its ease-of-use and how straightforward the resulting data analysis is to conduct. We enthusiastically recommend both of these tools to you.

In the end, countless astronomy students are using astronomy clicker questions with varying degrees of success. By and large, our experience is that most people who have used active learning clicker-voting style, think-pair-share questions continue to use them course after course. At the same time, talented teachers are creating their own astronomy clicker questions based on these notions

What we can offer you is a set of ready-to-use questions tied to the _Investigating Astronomy_ textbook written by Timothy F Slater, Inge Heyer, and Stephanie J. Slater. These questions are designed to probe students' understanding of the topic at hand. The question bank included here is not

meant to be exhaustive nor proprietary; the questions are intended as a jumping-off point for future development and enhancement. We enthusiastically encourage instructors to adopt adapt, and eventually create their own questions that are tightly aligned with exams. In addition, there are question banks of varying quality available from other sources and we believe that resourceful professors should use everything that can be found that helps their students learn best, regardless of who authored them.

How to Implement *Peer Instruction* and T*hink-Pair-Share*

The approach advocated here is based on the notion of a Socratic dialogue. Socratic dialogue is a learning theory based on the idea that if students are simply asked the correct questions in the correct sequence that the student themselves will come to know an idea. Although lecture is a teaching strategy on could adopt and use no others, a more common strategy for intellectually engaging students with questions to think about and debate is *Think-Pair-Share*, also known as *Clicker Questions* and described in detail elsewhere (see, for example, Slater, 2008).

THINK-PAIR-SHARE is an approach where the teacher presents an idea in a traditional lecture format and then asks students to stop taking notes and answer a question about the ideas they were just presented. Questions posed by the teacher to the students can either be simple recall (*e.g., which planet has the highest surface temperature?*) or can be questions of application (*e.g., at which phase of the moon will a solar eclipse occur?*). Less often, but still quite effective at improving students' achievement, teachers can pose questions encouraging students to encounter a widely known misconception (*e.g., how often does the Moon's appearance change?*).

What makes this approach different than simply interjecting questions to the entire group of students in a lecture is that the teacher directs this process in three distinct steps: (i) As an opening step, the teacher poses the question to students who must personally and privately commit to an answer without speaking to anyone. Traditionally, this is done after some lecturing has occurred. (ii) Next, the teacher asks students to vote on the question's answer. There are two important reasons for this second step. The first reason is that students need to be held accountable for devising an answer to the question; if the students do not give a meaningful attempt to answer the question to the teacher, then the students haven't actually engaged intellectually with the idea being taught.

The second reason is that the teacher too needs to understand the extent to which students understand the topic so that they can decide if more lecture needs to occur. If most of the students have the correct answer, then the teacher can move on with the lecture. On the other hand, if most of the

students have an incorrect answer, then the teacher needs to re-teach the idea, perhaps in a different way with different illustrations, examples or analogies.

As a brief aside, this think-pair-share approach of asking students to answer and then provide their answer to the teacher requires the teacher to have an infrastructure or system by which to get students' answers. Experienced teachers know that if they ask students to share their answers in front of the rest of the class, rarely will more than one or two students volunteer an answer freely. It is possible to randomly call out student names and ask them to provide an answer—one such strategy is to write student names on pieces of paper or popsicle craft sticks and then randomly draw a students' name—but this astronomy teaching practice can be risky because some students are simply unable to speak confidently in front of the rest of their classmates. Instead, a common practice is to give students a sheet of paper or a small chalk or re-useable white board on which they can write their answers in big letters and then simultaneously all hold up their answers for the teacher to see and evaluate. This approach to having students hold up their solutions on a piece of paper or erasable board is generally known as WHITE BOARDING (Slater, 2016).

More recently, teachers have started using cell phone voting systems where students can text-message their answers to the teacher or a computer system where the frequency of various answers can be rapidly tabulated for the teacher. Instead of clicking their cell phone key pads, some teachers ask students to purchase electronic personal response systems that allow them to send their answers as "votes" to the teacher's computer. These often look like handheld television remote controls and are called "clickers." Because of the rapidly growing abundance of these clickers, sometimes this think-pair-share teaching strategy is more widely known specifically as using ASTRONOMY CLICKER QUESTIONS (Ducan, 2006; Waller & Slater, 2011).

Going back to the steps in this think-pair-share approach, there is a third step that can often be used in this teaching strategy. It is this third step that is often the most valuable part of this teaching strategy. In the event that 40-70% of the students have the correct answer, then the teacher asks students to collaborate with another student, in a pair of two students, to discuss their answers and their rationale for why they answered the way they did. After students have had a few moments to share their answers and rationale and contemplate their partner's answers, students are asked to vote again. What generally occurs is that a much larger number of students, if not all, have come to the correct answer without further teacher intervention.

One might be concerned that students will "teach one another" incorrect ideas without the teacher present to monitor and correct scientific inaccuracies. Perhaps surprisingly, this intervention on the part of the teacher is rarely needed. Students generally teach each other correctly because the

scientifically accurate ideas are generally easier to explain and defend than the inaccurate ideas. More importantly, students who have just recently come to understand the new ideas are better able to know which aspects of a concept are most confusing and are much better positioned to help other new learners come to know an idea than a teacher who struggled with learning the idea for the first time themselves years or even decades before. Students who are talking to other students of similar age and similar cultural backgrounds are able to use a more natural student language with analogies and metaphors that the teacher might be unable to devise to help students learn. In other words, students are well positioned to explain ideas to other students in ways that are most rapidly comprehensible.

This CLICKER QUESTION strategy exploits and leverages this situation and has been shown to dramatically improve student learning. The reason this three-step approach is known as THINK-PAIR-SHARE is because students THINK first by themselves about a question, the PAIR collaboratively with another student to share their thinking, and finally they SHARE their answers and rationale with each other and the teacher.

Countless astronomy students are using astronomy clicker questions with varying degrees of success. By and large, our experience is that most people who have used them, continue to use them course after course. At the same time, talented teachers are creating their own astronomy clicker questions based on Peer Instruction. Fantastic resources exist on the Internet, including a great YouTube video on this is available by Derek Bruff at http://youtu.be/IyzEXBKWx44 describing his book (Bruff, 2009) as being a perfect place to start.

Investigating Astronomy
Chapter Sequence

Chp 1. Predicting the Motions of the Stars, Sun, and Moon

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Predicting the Motions of the Stars, Sun, and Moon

1. Ancient astronomers knew that the Earth was spherical because
a) $the shadow of the Earth during a lunar eclipse was always curved.
b)   the shadow of the Earth during a solar eclipse was always curved.
c)   new and different stars appeared when one traveled north or south.
d)   Well, actually, the ancient astronomers never knew the Earth was spherical.

2. It is noon. You see the Sun is directly overhead. Where are you?
a)   In the northern hemisphere
b)   At the equator
c)   In the southern hemisphere
d) $Cannot answer with information given.

3. If today were December 2, the Sun would be directly overhead at noon for someone
a)   in the northern hemisphere.
b)   at the equator.
c) $in the southern hemisphere.
d)   Not enough information to answer the question.

4. You have been stranded on a dessert isle. While eating your ice cream and cake, you decide to determine your latitude. You locate the North Star. It is 32° above the northern horizon. What is your latitude?
a)   32º south latitude.
b) $32º north latitude.
c)   58º south latitude.
d)   58º north latitude.

5. The constellation Libra appears to be highest in the sky at midnight in mid-May. The Sun will next be in the constellation
a)   during the day in mid-May.
b)   in mid-September.
c) $in mid-November.
d)   in mid-March.

6. The zenith is
a)   where the North Star is.
b) $the highest point in the sky.
c)   the axis about which the sky appears to rotate.
d)   the brightest point in the sky after the Sun and Moon.

7. If a star rises at 10:00 a.m. then about a month from now it will rise at
a) $8:00 a.m.
b)   10:00 a.m.
c)   12:00 noon.
d)   None of the above; no star (besides the Sun) cannot rise during the day.

8. The circumpolar stars are those that
a) $never rise and never set.
b)   only can be seen from one pole or the other.
c)   cannot be seen from the equator.
d)   All of the above.

9. Which two fundamental misconceptions made Ptolemy's geocentric model very complicated and prevented it from adequately describing the movements of bodies in the Solar System?
            I.   The Sun is at the center of the universe.
            II.   All heavenly bodies move in combinations of perfect circles.
            III.   The Earth is at the center of the universe.
            IV.   The stars never move.
a)   I and IV.
b)   II only.
c)   III only.
d) $II and III.

10. Retrograde motion is
a) $the apparent "backwards" motion of a superior (outer) planet.
b)   a backwards rotation of a planet.
c)   the motion of the celestial sphere.
d)   the movement of the Sun from West to East over the course of a year.

11. Precession is explained in part by the
a)   gravitational pull of stars like Vega and the North Star.
b) $gravitational pull of the Sun and the Moon.
c)   the movement of the Sun around the center of the Galaxy.
d)   the weight of people and other forms of life on the Earth.

12. The most important contribution of Copernicus to modern astronomy is
a) $removing the Earth from the center of the universe.
b)   recognizing that the Moon was not a planet.
c)   showing that the Sun was more important than the Earth.
d)   demonstrating that astrology was not a true science.

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13. Which of the following were *not* one of Galileo's discoveries with his telescope?
a)   There was no such thing as full Venus as viewed from Earth.
b) $Retrograde motion could be explained a different way than Ptolemy's way.
c)   Jupiter had its own satellites.
d)   The Sun and the Moon were not perfect spheres.

14. Why can a solar eclipse *not* be seen at night?
a)   a solar eclipse needs a new moon, and a new moon is only up during the day
b)   a solar eclipse needs the Sun, and the Sun is up only during the day
c) $both of the above
d)   none of the above

15. Excluding eclipses, how much of the surface of the Moon is illuminated by the Sun at any one time?
a)   one quarter
b) $one half
c)   the entire Moon
d)   it depends

16. A waning crescent Moon can be highest in the sky
a)   at 7:00 a.m.
b)   at 11:00 a.m.
c) $at both 7:00 a.m. and 11:00 a.m.
d)   at neither 7:00 a.m. and 11:00 a.m.

17. If you see a first quarter Moon today, what will people on the other side of the Earth see later today?
a)   A new Moon.
b) $A first quarter Moon.
c)   A full Moon.
d)   It depends on the time of night.

18. It is 2:00 a.m. and you see a moon right on the eastern horizon (altitude 0°). Its phase is
a) $waning crescent.
b)   third quarter.
c)   waning gibbous.
d)   waxing gibbous.

19. Where would one look to see a third quarter Moon at 5:00 a.m.?
a) $Near the highest point in the sky.
b)   Near the western horizon.
c)   Near the eastern horizon.
d)   One cannot see a third quarter Moon at 5:00 a.m.

20. Where would one look to see a full Moon at 12 noon?
a)   At the highest point in the sky.
b)   At the western horizon.
c)   At the eastern horizon.
d) $One cannot see a full Moon at 12 noon.

21. For people in the southern hemisphere, the Moon rises in the _____ and sets in the _____.
a)   west, east
b) $east, west
c)   north, south
d)   None of the above; it depends on the season.

22. For somebody in the Northern Hemisphere, the noontime altitude of the Sun gets lower between
a)   January and March.
b)   April and June.
c) $August and October.
d)   None of the above.

23. The Earth is tilted at an angle of 23.5º from perpendicular to the plane of the ecliptic. *Compared to what we experience now*, how would the seasons be different if Earth were tilted at an angle of 40º from perpendicular to the plane of the ecliptic?
a)   There would be no difference.
b) $The difference between winters and summers would be more extreme.
c)   The difference between winters and summers would be less extreme.
d)   One cannot tell without more information.

24. What causes winter to be cooler than summer? Following are three possible reasons:
I. The Sun is higher in the sky in the summer.
II. Earth is closer to the Sun in the summer.
III. The hours of daylight in the summer is longer than in the winter.
a)   I & II.
b)   II & III.
c) $I & III.
d)   I, II, & III.

25. Northerners have cold days in January because
a)   the Earth is farthest from the Sun in January.
b)   the orbital velocity of the Earth is largest in January.
c) $the Sun is lower in the sky in January.
d)   Both b) and c).

26. A certain star is highest in the sky at about 1:00 a.m. in early October. It will be highest in the sky for someone on the other side of the Earth (at the same latitude) at about
a) $1:00 a.m. in early October.
b)   1:00 p.m. in early October.
c)   1:00 a.m. in early April.
d)   1:00 a.m. in early April.

27. As seen from the Moon, how often does the Earth rise?
a)   Never.
b)   About every 24 hours.
c) $About once per month.
d)   About once per year.

28. From the day of the summer solstice to the day of the autumnal equinox, the azimuth of sunrise shifts
a) $toward the east.
b)   toward the south.
c)   toward the west.
d)   toward the north.

29. During a single night, the Moon
a)   moves from west to east in the sky.
b)   moves from east to west in the sky.
c)   appears fixed in the sky above a given location on Earth.
d) $appears fixed in the sky relative to the constellations.

30. During a solar eclipse, the Moon crosses the face of the Sun from
a)   west to east.
b) $east to west.
c)   north to south.
d)   south to north.

31. A certain star rises at 10:00 p.m. tonight. A month from now, it will rise at approximately
a) $8:00 p.m.
b)   9:00 p.m.
c)   11:00 pm.
d)   12 midnight.

Decoding the Hidden Messages in Starlight

1. Which moves faster in a vacuum, an X ray photon or a radio photon?
a)   The X ray photon
b)   The radio photon
c) $They both travel at the same speed
d)   Impossible to know without more information.

2. If you were going to design a pair of glasses for seeing animals at night, you would want them to convert
a) $infrared photons to optical photons.
b)   X-ray photons to optical photons.
c)   infrared photons to X-ray photons.
d)   optical photons to ultraviolet photons.

3. The Doppler effect occurs only when
a) $the distance between the observer and the emitting object is changing.
b)   there is gas and dust between the observer and the emitting object.
c)   the emitting object is hotter than the observer.
d)   the emitting object is moving around the observer.

4. Atoms have particular associated spectral lines because
a)   the speed of light is constant.
b) $electrons have only certain allowed orbits.
c)   light consists of waves.
d)   light waves can show the Doppler effect.

5. Consider an atom with energy levels 1, 2, 5, 11, and 13. A photon of energy level 11 is absorbed by one of the atom's electrons. At what level is the electron after absorption?
a)   Energy level 11
b)   Energy level 13
c)   Either 11 or 13
d) $Not enough information

6. Which has more energy, an X-ray photon or a radio photon?
a) $The X ray photon
b)   The radio photon
c)   They both have the same energy
d)   Impossible to know without more information

7. Spectra can be used to directly measure what properties of a star?
a)   Mass
b) $Chemical composition
c)   Both of the above
d)   None of the above

8. A cool gas in front of a hotter source produces
a)   an emission-line spectrum.
b) $an absorption-line spectrum.
c)   a continuous spectrum.
d)   a Kirchoff spectrum.

9. The Bohr model of the hydrogen atom consists of an electron and a proton. In this model, how does it look?
a) $The proton is the nucleus and the electron orbits around it.
b)   The electron is the nucleus and the proton orbits around it.
c)   Both the electron and proton are the nucleus and a photon orbits around it.
d)   None of the above.

10. A star has a flux of f and is a distance d from you. If you move to a distance three times as far (3d), the flux is now
a) $f/3$
b) $f/6$
c) $$f/9$
d) $3f$

11. A star has a luminosity of L and is a distance d from you. If you move to a distance three times closer (d/3), the luminosity is now
a)   L/9
b) $L
c)   3L
d)   9L

12. For any kind of wave, the frequency of the wave and the wavelength
a) $are inversely proportional.
b)   are directly proportional.
c)   have nothing to do with each other.
d)   are related, but the right answer is not shown.

13. A "blackbody" is called that because
a)   it emits light over all wavelengths.
b) $it absorbs all light that falls upon it.
c)   Both of the above.
d)   None of the above.

8

14. If a star has a surface temperature of 6000 K and its spectrum peaks at about 500 nm, then a star with a surface temperature of 3000 K will have its spectrum peak at about _____.
a)   250 nm
b)   500 nm
c)   750 nm
d) $1000 nm

15. A star's spectrum is similar to a person's fingerprints because
a)   both tell where the star or person have been.
b) $both are unique.
c)   both tell the chemical composition of the star or person.
d)   both have not changed since the birth of the star or person.

16. Elements can have different isotopes. This means that an atom of the element can have different
a)   numbers of electrons.
b)   numbers of protons.
c) $numbers of neutrons.
d)   masses

17. You observe a star through a 10-inch telescope on Earth. Your identical twin observes the same star from 3 times farther away. How big a telescope does your twin need to make the star appear as bright as it does to you?
a)   5 inches.
b)   10 inches.
c)   30 inches.
d) $90 inches.

18. A hydrogen ion can be
a)   just an electron.
b)   just a neutron.
c) $just a proton.
d)   just a photon.

19. The greenhouse effect occurs in a car or greenhouse because
a)   visible-light photons cannot easily travel through glass.
b)   ultraviolet photons cannot easily travel through glass.
c) $infrared photons cannot easily travel through glass.
d)   the glass itself absorbs all the sunlight.

20. We notice that a galaxy's spectral lines are redshifted. This means that the galaxy
a)   is getting closer to us.
b) $is moving away from us.
c)   has stars that are getting older.
d)   is behind a giant dust cloud.

21. Consider two telescopes. One has a diameter of 6 m, and the other has diameter of 18 m. They are otherwise identical. The larger telescope collects _____ times as much light as the smaller one.
a) 3
b) 6
c) $9
d) 12

22. Light is refracted (bent) when passing through a lens because
a) light is absorbed by the surface of the lens and then re-radiated in a different direction.
b) $light moves at different speeds in the glass than it does in air.
c) the wavelength changes when the light strikes the glass which causes a bending of the wave.
d) internal reflections caused by atoms in the lens deflect the light rays.

23. The resolution of a telescope is determined by
a)   the wavelength of the light.
b)   the diameter of the telescope.
c) $both of the above.
d)   neither of the above.

24. Many optical telescopes are placed on the ground. Why are some optical telescopes, like the Hubble Space Telescope, placed in space?
a) $Because the light received by the ground-based telescopes experiences absorption and distortion by Earth's atmosphere.
b) Because the space-based telescopes are closer to astronomical objects.
c) Because the space-based telescopes can be made as big as we want because they are weightless.
d) Because the ground-based telescopes are affected by the weather on Earth.

25. A telescope has focal length of 720 mm. Which eyepiece focal length will give a magnification of 60 times?
a)   10 mm
b) $12 mm
c)   36 mm
d)   144 mm

26. What is the best way to study low-surface-brightness features?
a)   Use a telescope with the biggest collecting area.
b)   Switch from a visible telescope to a radio telescope.
c)   Collect the light for a long period of time.
d) $All of the above will help.

27. Astronomers who observe in non-visible wavelengths sometimes use false-color images of the detected objects. This is because
a)   the objects are too far away to know what color the objects are.
b) $human eyes can only see visible light.
c)   most objects cannot be seen in visible light.
d)   the objects are too faint.

28. Which of the following telescopes *have* to be in space to work effectively?
a)   Optical
b)   Ultraviolet
c) $X-ray
d)   Radio

29. The largest refracting telescope has a 1-meter diameter lens. The mirrors of the largest reflecting telescopes have diameters larger than 10 meters, and there are several that are much bigger than 1 meter. Why are reflecting telescopes so much bigger?
a) $Glass is heavy, and a lens can only be supported by its circumference, while a mirror can be supported by its back.
b)   The bigger the piece of glass, the less chromatic aberration.
c)   Reflecting telescopes are currently in fashion at the moment.
d)   It is easier to polish a mirror than a lens.

30. Suppose you are looking at Jupiter through a 100-mm aperture telescope with an f/10 ratio and a 20-mm eyepiece. If you wanted to make Jupiter look twice as big, you would
a) $change to a 10-mm eyepiece.
b)   change to a 40-mm eyepiece.
c)   cover the outer part of the telescope to make a 50-mm aperture.
d)   move the lens or mirror until the focal ratio was f/5.

31. Consider a telescope with a 1000-mm aperture, a 5-meter focal length, and an eyepiece with a 50-mm focal length. Which of the following is true?
a) $The system has a f-ratio of f/5.
b)   The system has a magnification of 10 times.
c)   The system can collect twice as much light as a telescope with a 500-mm aperture.
d)   Only a) and c).

Analyzing Scales and Motions of the Universe

1.   Johannes Kepler used the observations of _____ to develop his laws of planetary motion.
a)   Nicolaus Copernicus
b)   Galileo Galilei
c) $Tycho Brahe
d)   Ptolemy

2.   Kepler's 3d law (that the period squared is proportional to the average distance cubed) does NOT apply to the motion of
a)   an artificial satellite around the Earth.
b)   one star about the other in a binary star system.
c)   a comet around the Sun.
d) $None of the above.

3.   If one could magically turn off gravity from the Sun, the Earth would
a)   leave the Solar System along a line connecting the Earth and Sun.
b)   spiral outward from the Solar System.
c)   collide with the Moon.
d) $travel in a nearly straight line in a direction perpendicular to a line connecting Earth and Sun.

4.   Which of the following did the models of Copernicus and Kepler have in common?
a)   The Sun is located at the exact center of the Earth's orbit.
b)   The planets move on epicycles.
c) $The inner planets move faster than the outer planets.
d)   The planets move in elliptical orbits.

5.   Which of Kepler's laws explains why it the southern hemisphere is warmer in January?
a)   First law.
b)   Second law.
c)   Third law.
d) $None of the above; this phenomenon is unrelated to Kepler's laws.

6.   Which of Kepler's laws explains why the Sun has a slightly larger apparent size in January than in July?
a) $First law.
b)   Second law.
c)   Third law.
d)   None of the above; this phenomenon is unrelated to Kepler's laws.

7. Which of Kepler's laws explains why February is shorter than August?
a) First law.
b) Second law.
c) Third law.
d) $None of the above; this phenomenon is unrelated to Kepler's laws.
8-9. Consider the drawing below. The planet obeys Kepler's laws.
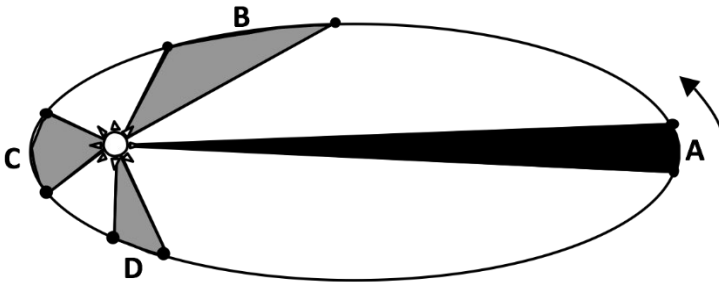
8. During how many portions of the planet's orbit (points A, B, C and D) would the planet be speeding up the entire time?
a) $Only during one of the portions shown.
b) During two of the portions shown.
c) During three of the portions shown.
d) During four of the portions shown.

9. During how many segments of the planet's orbit (points A, B, C and D) would the planet be slowing down the entire time?
a) $Only during one of the portions shown.
b) During two of the portions shown.
c) During three of the portions shown.
d) During four of the portions shown.

10. Kepler's second law says, "a line joining a planet and the Sun sweeps out equal areas in equal amounts of time." Which of the following statements means nearly the same thing?
a) $Planets move farther in each unit of time when they are closer to the Sun.
b) Planets move equal distances throughout their orbit of the Sun.
c) Planets move slowest when they are moving away from the Sun.
d) Planets move fastest when they are moving toward the Sun.

11. Imagine you have discovered an asteroid which you decide to name Nosnikcid. It appears to get as close to the Sun as 2 astronomical units, and as far from the Sun as 6 astronomical units. What is its period, approximately?
a) 2.8 years
b) $8.0 years
c) 15. years
d) 23. years.

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12.   An object has a density of 50 g/cm³. Assuming the object is homogeneous (the same throughout), which of the following is true?
a)   A 25-gram chunk of the object would have a volume of 2 cm³.
b) $A 25-gram chunk of the object would have a volume of 0.5 cm³.
c)   The object cannot have a mass greater than 50 grams.
        d)   A 0.7-cm³ chunk of the object has a mass of 30 grams.

13.   A figure skater spinning faster when he brings his arms closer to his torso is an example of
a) $conservation of angular momentum.
b)   acceleration.
c)   conservation of momentum.
d)   inertia.

14.   If an object moves along a curved path at a constant speed, that means that
a) $a force is acting upon it.
b)   its velocity is not changing.
c)   no forces are acting upon it.
d)   both a) and b) are true.

15.   Imagine a cup of water sitting on a table in your classroom. Consider the following forces:
                I.   Force of the cup on the table.
                II.   Force of the table on the cup.
                III.   Force of the table on the Earth.
                IV.   Force of the Earth on the cup.

Which of the following are Newton Third Law pairs (action-reaction)?
a) $I & II
b)   II & III
c)   I & IV
d)   II & IV

16.   What is a density of 4 g/cm³ in kg/m³?
a)   0.004
b)   4.
c)   400.
d) $4,000.

17.   At the distance of Saturn, about 10 astronomical units from the Sun, how strong is the Sun's gravitational force on a space probe compared to when the probe was at Earth's distance from the Sun?
a)   100 times stronger
b) $100 times weaker
c)   10 times stronger
d)   10 times weaker

18. What is stronger right now, the gravitational force of your shoe on Neptune (about 30 astronomical units away) or the gravitational force of Neptune on your shoe?
a) the force on your shoe on Neptune
b) the force of Neptune on your shoe
c) $the forces are the same
d) We cannot tell, based on what is given.

19. Why didn't Kepler include mass in his version of Kepler's Third Law?
a) He did not know of the existence of mass.
b) He did not know the mass of the Sun.
c) The mass of the Sun was negligible.
d) $The mass of the planets were negligible compared to the Sun.

20. When an athlete throws a ball to a teammate, why does the ball not go into Earth orbit?
a) The ball is not thrown at an angle that would allow the ball to go into orbit.
b) The ball is not massive enough.
c) $The ball is not thrown at sufficient speed.
d) The ball goes back toward the ground because of air pressure.

21. The discovery of Neptune was
a) $a triumph of Newtonian physics.
b) completely by accident.
c) surprising to astronomers.
d) awarded to the astronomer who first saw it in the telescope.

Exploring Our Evolving Solar System

1.   The densest planet in the solar system is
a)   Mercury
b) $Earth
c)   Mars
d)   Saturn

2.   The gas giants are characterized by
a)   their relatively large number of moons.
b)   their rings.
c)   strong magnetic fields.
d) $all of the above.

3.   The least dense planet in the solar system is
a)   Earth.
b)   Mars.
c) $Saturn.
d)   Neptune.

4.   The terrestrial planets are those planets that have
a)   lots of water.
b)   moons.
c)   little or no atmosphere.
d) $none of the above.

5.   The planets' orbits
a)   are roughly the same size.
b) $are roughly in the same plane.
c)   are in different directions.
d)   have none of the above characteristics.

6.   We have clues as to how the solar system formed because
a)   we can look back in time at the early solar system.
b)   the Earth's moon can tell us about the early solar system.
c)   the differentiation of the planets' interiors tell us about the early solar system.
d) $we can see planetary systems forming around other stars.

7.   An object that has existed since the beginning of the solar system and has fallen to the Earth is a
a)   meteor.
b) $meteorite.
c)   meteoroid.
d)   comet.

8. A planet is more likely to hold on to its atmosphere if it has
a) $high mass and low temperature.
b) high mass and high temperature.
c) low mass and low temperature.
d) low mass and high temperature.

9. The planets Venus and Uranus have rotations that are vastly different from those of the other planets. What could be a cause of these different rotations?
a) The planets simply formed that way.
b) The planets' internal composition caused the different rotations.
c) $The planets experienced a cataclysmic event such as a collision.
d) None of the above.

10. Most of the knowledge we have about the planets is from
a) $telescopic observations.
b) sending spacecraft to the planets.
c) theoretical conjecture.
d) comparing them to each other.

11. The interior of the Earth is differentiated, while the interiors of asteroids generally are not. This is because
a) the asteroids are too far from the Sun.
b) Earth has an atmosphere, while asteroids do not.
c) the rotation rate of the Earth is faster than most asteroids.
d) $the asteroids are much smaller than the Earth.

12. Jupiter's moon Io is similar in size, density, and age to the Earth's Moon. However, unlike the Moon, Io is geologically active. This is because
a) like the Earth, Io's interior is heated by the decay of radioactive materials.
b) energy radiated from Jupiter heats Io.
c) $tidal forces on Io heat the interior.
d) Io is unstable and will eventually explode.

13. Jupiter's moon Europa seems to be the only object in the solar system besides the Earth that has
a) $a large ocean.
b) active volcanoes.
c) life.
d) tidal waves.

14. Jupiter's moon Ganymede has a magnetic field; this is evidence that Ganymede likely has
a) $a liquid core.
b) a differentiated interior.
c) a high density.
d) an atmosphere.

18

15. To the surprise of many astronomer's Jupiter's moon Callisto was found to
a) be covered in ice.
b) $not have a differentiated interior.
c) have liquid water.
d) not be cratered.

16. Saturn's moon Titan is the
a) $only moon in the solar system with a thick atmosphere.
b) largest moon in the solar system.
c) only moon with water falling as rain.
d) All of the above.

17. Saturn's moon Titan is slightly smaller than Jupiter's moon Ganymede.
However, Titan has a thick atmosphere, while Ganymede does not. This is
likely because
a) the much higher gravitational pull of Jupiter does not allow an atmosphere to
exist.
b) Titan's escape velocity is much higher than Ganymede's.
c) $Ganymede's atmosphere froze solid and is in the surface.
d) Titan is very cold due to its distance from the Sun.

18. Neptune's moon Triton is unusual in that it has
a) $an orbit that is opposite the rotation of Neptune.
b) an extremely high density.
c) an orbit within the Roche limit of Neptune.
d) a thick atmosphere.

19. The sizes of particles comprising Saturn's rings are studied by analyzing
a) shadows cast by the rings.
b) $how light is scattered by the ring particles.
c) excess radiation emitted by the rings.
d) excess radiation emitted by the planet that is blocked by the rings.

20. Pluto was discovered by astronomers looking for an object affecting the
planet Neptune. Fairly soon after its discovery, Pluto was known to not be
the planet astronomers had been looking for because
a) it was in the wrong place to affect Neptune.
b) $it was not dense enough to affect Neptune.
c) Pluto's atmosphere is nonexistent.
d) Actually, astronomers did not know for years that it wasn't the right object.

21. The mass of Pluto was determined by
a) measuring its gravitational effect on Neptune.
b) $measuring its gravitational effect on its moon Charon.
c) measuring its gravitational effect on many of the other Trans-Neptunian
objects.
d) measuring the amount of light blocked by a background star.

22. The Pluto/Charon system is similar to the Earth/Moon system in that
a) $the size of Charon compared to Pluto is not insignificant.
b) Charon and Pluto are tidally locked to each other.
c) Both of the above.
d) None of the above.

23. Most asteroids are found
a) beyond the orbit of Neptune.
b) in approximately the same orbit as Jupiter.
c) crossing the orbit of the Earth.
d) $between the orbits of Mars and Jupiter.

24. The density of most asteroids is closest to
a) $that of the terrestrial planets.
b) that of the Jovian planets.
c) that of the Sun.
d) that of the Moon.

25. The sizes of asteroids are determined by
a) seeing how long it takes for them to block light from a background star.
b) seeing how much sunlight they reflect.
c) $seeing how much sunlight they reflect as well as how much infrared light is emitted.
d) observing their apparent diameter directly with telescopes.

26. Only a few asteroids have shapes that are close to spherical. They are that way because
a) $they are massive enough that gravity makes them spherical.
b) they are old enough that repeated impacts have made them spherical.
c) they are young enough that they have not had time for impacts to make them spherical.
d) None of the above.

27. Most asteroids are found between the orbits of Mars and Jupiter. There are "gaps" where few asteroids are found, caused by Jupiter. Jupiter takes twelve years to orbit the Sun and is on average 5.2 astronomical units from the Sun. Some of the possible distances from the Sun in astronomical units for the gaps include
a) 1.3, 2.6, and 3.9
b) 2.0, 3.0, and 4.0
c) $2.1, 2.5, and 3.3
d) 2.5, 5.2, and 12.0

28. Asteroids are unlikely to be fragmented planets because
a) $the total mass of asteroids is small.
b) asteroid orbits are in the ecliptic.
c) asteroids are typically only a few kilometers across.
d) asteroids can have different colors.

29. Astronomers are especially interested in studying Earth-approaching asteroids because
a) we might be able to mine the asteroids for minerals.
b) we might need to defend the Earth against the asteroids.
c) $Both of the above.
d) None of the above.

30. Comets that are believed to originate in the Kuiper Belt have orbits that are _____ and have relatively _____ periods.
a) mostly in the ecliptic, long
b) $mostly in the ecliptic, short
c) randomly oriented, long
d) randomly oriented, short

31. Comets that are believed to originate in the Oort Cloud have orbits that are _____ and have relatively _____ periods.
a) mostly in the ecliptic, long
b) mostly in the ecliptic, short
c) $randomly oriented, long
d) randomly oriented, short

32. Bright comets are seen at night with the naked eye,
a) moving rapidly across the sky.
b) moving slowly against the background stars.
c) with its tail "waving" slowly.
d) $not perceptibly moving during the night.

33. The composition of comets is typically
a) primarily rock and some water ice.
b) $primarily water ice and some rock.
c) approximately half rock and half water ice.
d) all water ice.

34. A comet's ion tail is
a) $always pointed directly from the Sun.
b) always in a curved path away from the Sun.
c) always coincident with the dust tail.
d) a stream of ionized particles from the Sun blowing off ice particles.

35. Edmund Halley
a) discovered Halley's Comet.
b) $determined the orbit of Halley's Comet.
c) determined the composition of Halley's Comet.
d) None of the above.

36. A comet's nucleus is approximately the size of
a) ten meters.
b) $one kilometer.
c) one hundred kilometers.
d) the Earth.

37. A short-period comet will likely disappear after several approaches to the inner solar system, because
a) the continual approaches will affect the orbit of the comet and eventually it will leave the solar system.
b) $the continual approaches will diminish the amount of ice and eventually it will be too small to sublimate.
c) the comet will eventually crash into the Sun.
d) the comet will melt.

38. Data from the Philae lander on Comet Churyumov-Gerasimenko (67P) indicates that the nucleus is
a) solid ice.
b) solid rock.
c) $fluffy ice.
d) gravelly rock.

39. Asteroids can be made of
a) stone (silicates).
b) metal.
c) stone (silicates) and carbon.
d) $All of the above kinds are seen.

40. A meteor is
a) $a small piece of solid matter that enters Earth's atmosphere and burns up, popularly called a shooting star because it is seen as a small flash of light
b) a small piece of solid matter that survives passage through the atmosphere and strikes the ground
c) a small piece of matter from the early solar system that is in orbit around the Sun.
d) studied by meteorologists.

41.   Meteorites have hit very few buildings or people, because
a) $the surface of the Earth is mostly uninhabited.
b)   meteorites are attracted to water.
c)   scientists can predict when and where meteorites will strike the Earth, and warn the authorities.
d)   meteorites typically fall at night, when most people are asleep.

42.   The primary reason for the denser terrestrial planets being closer to the Sun than the less dense gas giant planets is that
a) $the denser materials could solidify in warmer temperatures.
b)   the denser materials were pulled by gravity to be nearer the Sun.
c)   the gas giants were able to float further from the Sun.
d)   the gas giants were able to gather much more of the gases available in the solar system.

43.   The process in which denser materials fall to the center of a planet is called
a)   convection
b) $differentiation
c)   nucleation
d)   accretion

44.   Evidence for the age of the solar system includes
a)   studies of Earth rocks.
b)   studies of Moon rocks.
c) $studies of meteorites.
d)   studies of the Sun.

45.   In the early solar nebula, the object that became the Sun first began to heat due to
a)   radioactive decay.
b)   thermonuclear fusion.
c) $release of gravitational energy.
d)   chemical reactions.

46.   The reason that the Sun rotates, and almost all the planets and moons rotate and revolve in the same direction is due to
a) $the early solar nebula rotating in the same direction.
b)   every object in the Universe moving in the same direction.
c)   a coincidence — not *everything* moves in the same direction.
d)   Astronomers do not think they know for sure.

47.   Venus rotating in the opposite direction than every other planet in the solar system is likely due to
a) $a cataclysmic event forcing the opposite rotation.
b)   its magnetic field reversing.
c)   interactions with the Sun.
d)   It is likely that it has always been that way.

48. _____ is the name of the process whereby small objects collide and stick together to form bigger objects.
a)   Differentiation
b)   Nucleation
c)   Convection
d) $Accretion

49.   Sort the following in order of when it happens in the geological history of a terrestrial planet:
        I.   Formation of solid crust
        II.   Accretion, heating, differentiation.
        III.   Plate tectonics
        IV.   Widespread volcanism
a)   II, III, I, IV
b)   I, II, III, IV
c) $II, I, IV, III
d)   I, III, II, IV

50.   Of the following, the hardest method of detecting planets orbiting other stars at the moment is
a)   observing the tiny "wiggle" of stars by the gravitational pull of the planets.
b) $observing the planet in the optical part of the spectrum.
c)   observing the transit of the planet across the face of the star.
d)   All of these are relatively easy ways to detect planets orbiting other stars.

51.   The Kepler telescope found the most exoplanets by which of the following methods?
a) $Observing the transit of the planet across the face of the star.
b)   Observing the tiny "wiggle" of stars by the gravitational pull of the planets.
c)   Directly observing the planet in the optical part of the spectrum.
d)   Listening for radio signals from the planet.

52.   One of the astonishing revelations of the results from the Kepler probe is that
a) $the most common types of planets in the Galaxy are not in our solar system.
b)   most planets are in the Galaxy are Earth-like.
c)   there are actually not too many planets in the Galaxy.
d)   stars like the Sun do not have as many planets as the Sun does.

53.   The Kepler probe was limited to planets
a)   that had masses greater than Neptune's.
b)   had diameters that were at least the 5% of the diameters of their star.
c)   that orbited more than 1.5 astronomical units from their star.
d) $with orbital periods of 400 days or less.

54. The discovery of thousands of exoplanets have forced astronomers to
a) $revise theories of how planetary systems, including our own, have been formed.
b) think that our solar system had a unique way of forming.
c) wonder why our solar system only has eight planets.
d) think that an exoplanet capable of supporting life is highly unlikely.

Uncovering Earth's Systems

1. Volcanoes are usually found in places where
a) the low pressure of the atmosphere pulls the lava/magma to the surface.
b) $earthquakes occur from oceanic plates colliding with continental plates.
c) deep-rooted mountains have cracked Earth's crust.
d) Earth's rotation has caused weak spots in its crust.

2. The Earth's core is hot due in part to
a) solar heating.
b) large scale meteoroid bombardment.
c) $radioactivity.
d) the greenhouse effect.

3. How do we know what the interior of the Earth is like?
a) Geologists use X rays.
b) Drilling allows us to see almost all of the interior layers of the Earth.
c) $Earthquakes.
d) Our knowledge of the interior of the Earth is solely theoretical.

4. From surface to outer space, the layers of the Earth's atmosphere are in what order?
    I.   Ionosphere
    II.   Stratosphere
    III.   Troposphere
    IV.   Mesosphere
a) II, III, IV, I
b) III, II, I, IV
c) $III, II, IV, I
d) IV, III, II, I

5. We know that the core of the Earth is denser than the crust because
a) the average density of the Earth is denser than the crust's density.
b) Each succeeding layer from the core to the crust is less dense and floating upon the underlying layer.
c) We can measure density of the underlying layers by understanding the actions of earthquakes.
d) $all of the above.

6. The fact that the Earth has undergone differentiation tells us that the Earth's interior
a) $was once liquid.
b) has always been a solid.
c) causes the continents to move.
d) must not have a core.

7. Which of the following is evidence that the Earth's interior is not rigid?
I.   Plate tectonics
II. The liquid oceans
III. The greenhouse effect
IV. The magnetic field
a)   I & II
b) $I & IV
c)   II & III
d)   II & IV

8. What happens to crust of a continental plate that is forced underneath the other?
a)   the crust is crushed by the high weight of the one that stays on top.
b) $the crust is melted by the high temperatures of the interior of the Earth.
c)   the crust begins a mountain range.
d)   the crust is forced down into the core.

9. Which of the following is *not* a major component of the Earth's atmosphere?
a) $Carbon Dioxide ($CO_2$)
b)   Oxygen (O_2)
c)   Nitrogen (N_2)
d)   Argon (Ar)

10. Most of the carbon dioxide on Earth is
a)   in the atmosphere
b)   mixed in the Earth's water
c) $in Earth's rocks
d)   in the core of the Earth

11. A friend says that it will be hot in August. That is an example of
a) $climate
b)   weather
c)   weather forecasting
d)   global warming

12. The greenhouse effect came about from
a)   human activity putting greenhouse gases into the atmosphere.
b) $the natural presence of greenhouse gases in the atmosphere.
c)   increased infrared radiation from the Sun.
d)   increased optical light from the Sun.

13. Which of the following is a primary characteristic of greenhouse gases?
a)   They absorb more molecules in the atmosphere than they give off.
b)   They concentrate sunlight as it travels through the atmosphere.
c)   They can completely trap forms of light in the atmosphere.
d) $They absorb some forms of light but allow other forms of light to pass through.

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14.   Which of the following is an effective greenhouse gas?
a) $water
b)   oxygen
c)   ozone
d)   nitrogen

15.   Heating of the Earth's surface by the Sun is an example of transfer of energy by
a)   conduction.
b)   convection.
c) $radiation.
d)   the greenhouse effect.

16.   Evolution of life on this planet is determined by
a)   natural selection.
b)   luck in surviving random impacts.
c)   being able to adapt to slowly changing environments.
d) $all of the above.

Exploring Terrestrial Surface Processes and Atmospheres

1. Which of the following heavenly bodies have humans visited?
   - I. Moon
   - II. Mars
   - III. Venus
   - IV. Jupiter
   a) $I only
   b) I & II
   c) I, II, & IV
   d) I, II, III, & IV

2. There is very little atmosphere on the Moon because
   a) dry rocks on the Moon absorbed its own atmosphere.
   b) it was blown away by meteor bombardment
   c) $its low mass and high temperature allowed most gases to escape.
   d) the gravitational tidal forces from the Earth stripped it away.

3. What has been found on the surface of the Moon recently?
   a) liquid water
   b) $water ice
   c) life
   d) a thick atmosphere in places

4. You purchase a 6-kilogram bag of sugar at a store on the Earth. You decide to return it to a store on the Moon. You haven't used any of the sugar, but the clerk says you have used 5 kilograms of the sugar when he weighs the bag. What do you tell him?
   - I. mass is the same anywhere in the universe.
   - II. things weigh only 1/6 on the Moon of what they do on Earth.
   - III. his scale is broken.
   - IV. he needs to take into account the volume of the sugar.
   a) $I & II
   b) II & III
   c) I, II, & III
   d) I, II, II, & IV

5.   Place the statements concerning lunar formation below in chronological order from the time of formation:
                    I.   Coalesced from orbiting debris
                    II.   Cooling of interior
                    III.   Mare formed
                    IV.   Surface melting by heavy bombardment
a) $I, IV, III, II
b)   III, II, IV, I
c)   I, II, III, IV
d)   II, III, IV, I

6.   The temperature of the Moon is much more extreme (can be much hotter to much colder) than the Earth because
a)   there are no bodies of water on the Moon.
b) $there is no atmosphere on the Moon.
c)   there is no wind on the Moon.
d)   the Moon can get closer to the Sun and farther away from the Sun than the Earth can.

7.   The Moon's highlands appears to be older than the maria, because of data coming from
a) $crater counting.
b)   analysis of color of the surface.
c)   the sharpness of the craters on the maria.
d)   the smoothness of the highlands.

8.   The Moon is believed to have come from a giant impact on the Earth. Evidence for this is
a)   the density of the Moon is similar to the density of the mantle of the Earth.
b)   there is very little metal in the Moon
c)   there are very little volatile material on the Moon.
d) $All of the above.

9.   The Moon
a)   always points the same face toward the Sun.
b)   does not rotate.
c)   rotates at the same rate as the Earth - once per day.
d) $rotates on its axis with the same period as its revolution about the Earth.

10. Mercury's atmosphere is almost non-existent because of
    I.   Small mass
    II.   Slow rotation
    III.   High surface temperature
    IV.   High density
a) I & II
b) I, II, & III
c) $I & III
d) III & IV

11. From Earth, Mercury is difficult to see mostly because it
a) has a low albedo.
b) is very dense.
c) is very small.
d) $always appears near the Sun.

12. The density of Mercury was determined by
a) measuring its gravitational effect on the Moon and its radius.
b) $measuring its gravitational effect on space probes and its radius.
c) measuring its gravitational effect on the Sun and its radius.
d) all of the above.

13. The density of Mercury tells us that
a) it is the densest planet in the solar system.
b) it could not support an atmosphere.
c) it has a strong effect on the Sun.
d) $it has a large metal core.

14. The compression or shriveling of Mercury gives rise to its
a) $scarps
b) lack of atmosphere.
c) dense metal core.
d) several impact craters.

15. The surface of Venus is mostly low-density rock, while the average density of Venus is similar to that of Earth. The interior of Venus must therefore be
a) rapidly rotating.
b) also composed of low-density material.
c) $denser than the average density of Earth.
d) spongy.

16. Venus's magnetic field is weak because of its
a) high temperature.
b) eccentric orbit.
c) numerous craters.
d) $slow rotation.

17. One possible cause for Mars's atmosphere to be particularly thin compared to most of the other planets is because of
a) Mars's volcanoes.
b) Mars's distance from the Sun.
c) $the solar wind.
d) no liquid water on the planet.

18. The Martian moon Phobos will likely be destroyed because of
a) Phobos's distance from Mars.
b) $Phobos's interaction with the Martian atmosphere.
c) Mars's retrograde motion.
d) Phobos's retrograde motion.

19. Venus and Mars both have an extremely large relative abundance of carbon dioxide in their atmospheres, but the respective greenhouse effects are quite different. This is primarily due to the planets' relative
a) distance from the Sun.
b) $atmospheric pressures.
c) number of moons.
d) densities.

20. The age of the surface of Venus is between 300 and 600 million years. This tells us that Venus is a planet with _____ geological activity.
a) little
b) rapid
c) $persistent
d) slow

21. The transit of Venus allowed astronomers to determine the
a) $distance to the Sun.
b) age of the solar system
c) age of the Sun.
d) size of Venus.

22. _____ makes the possibility of life on the surface of Mars extremely unlikely.
a) Ultraviolet radiation from the Sun
b) $Low atmospheric pressure
c) A small abundance of oxygen
d) Impact cratering

23. The evidence of past water on Mars include
a) erosion features.
b) sedimentary rock.

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c)   remnants of salt.
d) $all of the above.

24.   The surface temperature of Venus is high primarily because of
  a)   the slow rotation of the planet.
  b)   its proximity to the Sun.
  c)   the abundance of lava domes on the surfacc.
  d) $the abundance of carbon dioxide in the atmosphere.

25.   Much of the carbon dioxide on Earth is not in the atmosphere, but locked in
          _____. Therefore Earth will not have a naturally-caused runaway
          greenhouse effect.
  a)   ocean water
  b) $rocks
  c)   plants
  d)   just a) and b)

26.   For centuries, astronomers were unable to look at the surface of Venus with
          telescopes because
  a)   it was too far away.
  b)   it was too close to the Sun.
  c) $it was covered in clouds.
  d)   it was too small.

27.   Because of _____, the probes that landed on Venus did not
          survive longer than about two hours.
  a)   high atmospheric pressure
  b)   high temperature
  c) $Both of the above
  d)   Neither of the above

Observing the Dynamic Giant Planets

1.   If we had a big enough bathtub of water, _____ would float in it.
a)   Jupiter
b) $Saturn
c)   Uranus
d)   Neptune

2.   The Jovian planets have retained most of their atmospheres because
a)   they are further from the Sun's gravitational pull than the terrestrial planets.
b)   they are very warm and massive.
c) $they are very cold and massive.
d)   the planet's rings keep the planetary atmosphere from leaving.

3.   The strong magnetic fields of the Jovian planets are caused by the planets'
a) $rapidly spinning cores.
b)   high masses.
c)   distances from the Sun.
d)   low temperatures.

4.   The Great Red Spot is a storm in the southern hemisphere of Jupiter which
      rotates counter-clockwise. This information tells us that the Spot is a
a)   low-pressure system.
b) $high-pressure system.
c)   short-lived disturbance.
d)   Not enough information to answer the question.

5.   The Jovian planets are slightly flattened at the poles (the shape is called an
      oblate spheroid). They are flattened because of
a) $the planets' rapid rotations.
b)   the planets' high masses.
c)   the planets' high hydrogen content.
d)   the planets' cores not producing enough energy.

6.   Uranus's axis is tilted at 98º from perpendicular to the ecliptic. This causes
      dramatic shifts in its
a)   orbit.
b) $seasons.
c)   atmospheric temperature.
d)   magnetic field.

7.   The sizes of particles comprising Saturn's rings are studied by analyzing
a)   shadows cast by the rings.
b) $how light is scattered by the ring particles.
c)   excess radiation emitted by the rings.
d)   excess radiation emitted by the planet that is blocked by the rings.

8.   How much light does Neptune receive from the Sun compared to what Earth receives from the Sun, considering that Neptune is 30 times as far from the Sun as the Earth?
a) $1/30^2=1/900$ times as much.
b)   1/30 times as much.
c)   30 times as much.
d) $30^2 = 900$ times as much.

9.   We see different sides of Saturn's rings over the course of Saturn's orbit around the Sun. This is because of Saturn's
a)   fast rotation rate.
b) $almost constant tilt in one direction.
c)   changing tilt.
d)   rings' constant motion.

10.   Both Uranus and Neptune appear blue because of the _____ in their atmospheres. This gas absorbs red light and the remaining light is returned to space.
a)   hydrogen (H_2)
b)   helium (He)
c)   water vapor (H_2O)
d) $methane ($CH_4$)

11.   Neptune was discovered by
a)   accident.
b) $mathematical calculation.
c)   ancient civilizations.
d)   a comet hunter.

12.   A layer of the gas giants is believed to be made of liquid metallic hydrogen. "Metallic" in this context means that the layer
a) $allows electrons to move easily as in a metal.
b)   is known to be shiny.
c)   is under low pressure.
d)   None of the above.

13.   The low densities of the Jovian planets tell us that the planets are primarily made of
a)   hydrogen.
b)   helium.
c) $Both of the above.
d)   None of the above.

16. The light-colored zones of the gas giants are caused by ammonia clouds that are rising, and the dark-colored belts of the giants are falling. This motion is called
a) conduction.
b) $convection.
c) radiation.
d) equilibrium temperature.

17. The rings of the Jovian planets are known to be solid particles because
a) we can occasionally see stars through the rings.
b) if the rings were made of gases, the gases would disperse in a short time.
c) if the rings were made of liquid, the liquid would freeze.
d) $All of the above.

18. The rings of the Jovian planets are believed to be primarily _____. We know this because of the _____ off the rings.
a) rock, low reflectivity
b) ice, low reflectivity
c) rock, high reflectivity
d) $ice, high reflectivity

19. The gaps in planetary rings are believed to caused by
a) $resonance interactions with a moon of the planet.
b) waves caused by gravitational interactions with a moon of the planet.
c) Both of the above.
d) None of the above.

20. The origin of the planetary rings is believed to be caused by interactions with the Roche limit, which is the
a) maximum mass of a moon or a comet near a planet.
b) $minimum distance within which a moon or comet will be tidally destroyed.
c) highest rotation speed of a planet.
d) weakest possible magnetic field for a planet.

21. Occasionally the rings of the planets will disappear from our view on Earth. This occurs because
a) planetary rings do not last forever and they have to be created periodically.
b) the reflected light from the planetary rings is too dim for us to see it.
c) $planetary rings are extremely thin and we are looking at their edge.
d) we happen to be looking at ring particles that are too small to see.

Looking for Life Beyond Earth

1.   Life as we know it on Earth could only form in a "habitable zone", which is the range of
a)   planet orientations that create seasons.
b) $distances from a star where most water will be liquid.
c)   latitudes that stay warm during an ice age.
d)   time when there is no longer bombardment by comets and asteroids.

2.   You are conducting a search for life outside the Solar System. To maximize your chances of finding planets, you should focus on studying
a)   main sequence stars like our Sun.
b)   stable rather than pulsating stars.
c)   stars at least a few billion years old.
d) $All of the preceding.

3.   The Arecibo telescope in Puerto Rico used _____ to send a message to possible civilizations in the universe.
a)   infrared light
b)   X rays
c) $radio waves
d)   neutrinos

4.   Around what type of star is there the greatest chance of finding planets inhabited by intelligent beings?
a)   a main-sequence O star
b) $a main-sequence K star
c)   a K-type supergiant
d)   a neutron star

5.   If astronomers or cosmologists found that there was something special about where we were, they would be suspicious, because that would be a violation of
a)   the Copernican principle
b)   the cosmological principle
c)   that there is nothing special about Earth.
d) $all of the above.

6.   The Fermi paradox asks the question
a)   "Why are we alone?"
b)   "Why is the Earth *not* special?"
c) $"Where are the other intelligent civilizations?"
d)   "How likely is it that there are other intelligent civilizations?"

7.   generations of stars are needed before life can form because
a)   the first generation stars were too luminous to allow life to form.
b)   the first generation stars did not live long enough for life to form.
c) $life needs heavy elements, and they need to be made in stars.
d)   the universe needed to cool to a survivable temperature.

8.   "Life as we know it" means life that requires
a)   sunlight.
b) $water.
c)   oxygen.
d)   all of the above

9.   What makes us optimistic that life is abundant outside the Earth?
a)   that we have found life on Earth in many different and extreme locations.
b)   Carbon-based molecules have been discovered in abundance in space.
c)   That life on Earth seems to have come into existence very soon after the
planet formed.
d) $all of the above.

10.   Why are astronomers and biologists interested in Mars, in regards to life?
I.   Because there might still be life on the surface of the Red Planet.
II.   Because while there might may not be life on the surface, there could be
some underground.
III.   Because there might be evidence that life existed in the past on Mars.
IV.   Because there is evidence that liquid water existed in the past.
a)   I & IV
b)   II & IV
c)   I, III, & IV
d) $II, III, & IV

11.   How can liquid water exist on some moons of the outer solar system?
a)   Some of the moons can generate enough energy to keep water liquid.
b)   The planets they orbit radiate enough energy to keep water liquid.
c)   Sunlight is just barely enough to keep water liquid.
d) $The tidal forces between exerted on the moons create enough friction to
keep water liquid.

12.   The Drake equation
a)   tells us where to look for extraterrestrial civilizations.
b) $tells us an estimate of the number of extraterrestrial civilizations.
c)   tells us an average of how long an extraterrestrial civilization could exist.
d)   is an equation that should be understandable by any extraterrestrial
civilization that can detect it.

13.   You are a radio astronomer. You detect a message that has appears to be
221 characters. What would be a way to decode the message?
a)   look for any reference to water or hydrogen in the message.
b) $put it into a two-dimensional array of 17 x 13.
c)   compress the characters into 30 to make it easier to read.
d)   look for any reference to the building blocks of life.

16.   Living organisms like those on Earth may exist on planets going around stars
other than the Sun because
a)   we have detected comets in other star systems.
b)   life here may have come here from other star systems.
c)   we have detected radio signals from other star systems.
d) $the laws of physics and chemistry are universal.

Probing the Dynamic Sun

1. The most common element in the Sun is
a) $hydrogen.
b) helium.
c) deuterium.
d) magnesium.

2. How would sunspots appear if you could magically remove them from the surface of the Sun?
a) Because sunspots are dark spots, they would be invisible against the blackness of space.
b) They would shine only with reflected sunlight.
c) $They would shine brightly.
d) They would not appear any differently than on the surface of the Sun.

3. Space weather is
a) the effect of space on the weather of the Earth.
b) $the effect of solar activity on the Earth.
c) impossible to occur because weather cannot exist without an atmosphere.
d) activity surrounding stars.

4. The density of the Sun is
a) $significantly less than the Earth's.
b) roughly equal to the Earth's.
c) significantly more than the Earth's.
d) unknown.

5. The Sun and other stars are primarily made of
a) hydrogen.
b) helium.
c) $both of the above.
d) none of the above.

6. The Maunder Minimum was a period when
a) $the number of sunspots was relatively low.
b) there were few stars in the Universe.
c) the solar system was extremely small.
d) the number of detected neutrinos was very low.

7. Solar flares are
a) $powerful eruptions on the surface of the Sun.
b) never found in the vicinity of sunspots.
c) are seen only in the optical and infrared parts of the electromagnetic spectrum.
d) are what allows solar panels to generate energy.

8. The surface temperature of the Sun is about 6000 K, and the typical temperature of the umbra of a sunspot is about 4500 K. The sunspot umbra is _____ times less bright than the Sun's surface.
a) 1.33
b) 1.78
c) $3.16
d) 9.99

9. How can we forecast that a solar coronal mass ejection will hit the Earth?
a) Coronal mass ejections are periodic and we can predict when they will occur.
b) $Coronal mass ejections travel much slower than light, so we can see the event before gas hits the Earth.
c) Coronal mass ejections are unpredictable, so we cannot forecast.
d) Coronal mass ejections cause the Sun to dim appreciably, so we know it has happened.

10. We can tell that the Sun rotates at different rates at different latitudes because of the
a) $sunspots.
b) prominences.
c) granules.
d) corona.

11. _____ is/are caused by the differential rotation of the Sun.
a) $Sunspots.
b) Prominences.
c) Granules.
d) Corona.

12. The time between peaks of activity on the Sun is called the solar cycle and lasts about
a) 30 days
b) 365 days
c) $11 years
d) 22 years

13. The Kelvin-Helmholtz theory of gravitational contraction to explain why the Sun shines does not work because
a) $the length of contraction is too short for the age of the Sun.
b) not enough meteors are falling onto the Sun.
c) the Sun is not massive enough to shine so brightly.
d) the carbon-nitrogen-oxygen cycle is the true explanation.

14. The mass of helium-4 is _____ the mass of four protons.
a) $less than
b) the same as
c) greater than

15. The four fundamental forces in the universe are the electromagnetism, gravity, the strong force, and the weak force. In order of declining dominance, they are
a) strong, weak, electromagnetism, gravity.
b) gravity, strong, weak, electromagnetism.
c) strong, gravity, electromagnetism, weak.
d) $strong, electromagnetism, weak, gravity.

16. The only two atomic bombs that have been used in war (by the United States) used the process of _____.
a) $nuclear fission
b) nuclear fusion
c) neutrinos
d) smashing atoms

17. The method for creating energy inside the Sun, the proton-proton chain, starts off with two protons, which are both positively charged and have equal mass. After they combine, what must be conserved?
a) $charge
b) mass
c) the two protons
d) energy

18. What is produced after the first reaction in the proton-proton chain?
a) helium-3 and a neutrino
b) $deuterium, a positron, and a neutrino
c) helium-4, a positron, and a neutrino
d) deuterium, a neutrino, and a gamma ray

19. Fundamentally, the proton-proton chain takes _____ protons to make _____ helium-4 nucleus/nuclei and energy.
a) six, one
b) six, two
c) four, one
d) $four, two

20. The carbon-nitrogen-oxygen cycle is fundamentally a method of creating _____ in high-mass main-sequence stars.
a) carbon
b) nitrogen and oxygen
c) all of the above
d) $none of the above

21. The Sun keeps its size and shape through the interaction of
a) pressure and sunlight.
b) $pressure and gravity.
c) gravity and convection.
d) convection and radiation.

22. The solar neutrino problem was caused by
a) astronomers' fundamental misunderstanding of how energy is created in the Sun.
b) astronomers' instruments not being sensitive enough to detect neutrinos.
c) the flux of neutrinos at the distance of Earth being too low for astronomers to see.
d) $astronomers not realizing that neutrinos could transform from one kind to another.

23. After the Sun's core hydrogen is depleted by nuclear fusion the core will consist primarily of
a) carbon.
b) deuterium.
c) $helium.
d) oxygen.

24. Why does a photon take hundreds of thousands of years to travel to the surface of the Sun from the core, while a neutrino takes just a couple of seconds to get to the surface from the core?
a) $Because a neutrino interacts with almost nothing, but a photon travels very small distances at a time.
b) Because a photon takes a very long time to be created in the Sun.
c) Because a neutrino travels faster than the speed of light.
d) Because a photon starts out as a gamma ray, and gamma rays are very slow.

25. The three ways of transferring heat are conduction, convection, and radiation. _____ is *not* significant in the Sun.
a) $Conduction
b) Convection
c) Radiation

26. _____ is the method of heat transfer in a fluid (gas or liquid).
a) Conduction
b) $Convection
c) Radiation

27. Ways we can directly see what is going on inside the Sun include studying
a) solar neutrinos, photons, and helioseismology.
b) $solar neutrinos and helioseismology.
c) photons and helioseismology.
d) photons and solar neutrinos.

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28. Solar photons take _____ time than solar neutrinos to travel from the surface of the Sun to the Earth.

a) a shorter
b) the same
c) $a longer

Observing Properties of Distant Stars

1. Star A is twice as far away as Star B, but they have the same luminosity. This means Star B has _____ times the flux of Star A.
a) 1/4
b) 1/2
c) 2
d) $4

2. How would the brightness of an 8th magnitude star compare to a 7th magnitude star?
a) 10 times brighter than the 7th magnitude star.
b) 10 times dimmer than the 7th magnitude star.
c) 2.5 times brighter than the 7th magnitude star.
d) $2.5 times dimmer than the 7th magnitude star.

3. You see a star with luminosity L. You move four times farther away. What is its luminosity now?
a) L/16
b) L/4
c) $L
d) 16L

You have four stars, A, B, C, and D. Their apparent magnitudes are as follows:

Star	Apparent magnitude
A	+3
B	-2
C	+1
D	-3

4. Which star appears to be exactly 100 times brighter than star D?
a) A
b) B
c) C
d) $None of them.

You have four stars, A, B, C, and D. Their apparent magnitudes are as follows:

Star	Apparent magnitude
A	+3
B	-2
C	+1
D	-3

5.   Which two stars appear to be 2.5 times brighter (or dimmer) than each other?
a)   A & B
b)   A & C
c)   B & C
d) $B & D

You see four stars: E, F, G, and H. Their colors appear as follows:

Star	Color
E	Red
F	White
G	Orange
H	Blue

6.   Which is the coolest star?
a) $E
b)   F
c)   G
d)   H

7.   Why are hydrogen lines alone not a good method for classifying stellar spectra?
a) $Hydrogen lines are not visible in very hot or very cool stars.
b)   Hydrogen is not abundant in very cool stars.
c)   Helium lines are much more visible in all stars.
d)   Even though they are not as abundant, lines from ionized metals are visible in all stars.

8. Which property of a star would not change if we observed it from twice as far away?
a) apparent magnitude
b) apparent size
c) $color
d) radial velocity

9. For which of the following is Harvard astronomer Annie Jump Cannon known?
a) She was the first woman to be awarded an honorary degree from Oxford.
b) She was the first woman to be an officer of the American Astronomical Society.
c) She realized that spectral classes are best ordered by temperature.
d) $All of the above.

10. Imagine you are looking out a window at raindrops falling from the sky. Assume that the raindrops are all falling straight down at the same speed. Raindrops closer to you appear to fall _____ raindrops far away from you. (**Hint**: think of motion across the line of sight).
a) $faster than
b) slower than
c) the same speed as
d) None of the above.

11. Astronomers determine the 'color' of a star by calculating the
a) $ratio of the fluxes as measured with two different filters.
b) difference between the fluxes as measured with two different filters.
c) ratio of the absolute and the apparent brightnesses.
d) difference between the absolute and the apparent brightnesses.

12. The Doppler effect allows us to determine the
a) speed of a star across the sky.
b) $rotation rate of a star.
c) Both of the above.
d) None of the above.

13. You are looking at the spectrum of a star and see that its spectral lines are particularly broad. What could be the cause?
a) The star is rotating rapidly.
b) The star is not a giant, but a dwarf.
c) $Both of the above.
d) None of the above.

14. A star most likely to show evidence of molecules in its spectrum would have a spectral type of
a) B
b) O
c) $M
d) F

15. Student Morgan says that stars on a list of the 50 brightest visible from Earth are typical stars. Student Jean says that they are not typical, because they are picked by their apparent brightness. Who is correct?
a) Morgan
b) $Jean
c) Neither of them.
d) Cannot tell without more information.

16. What is needed to determine the masses of two stars in a binary system, if we know the period and how far away from each other they are on average?
a) Nothing else.
b) $The speeds of the two stars and their orientation.
c) The speeds of the two stars and their color.
d) Just the speeds of the two stars.

17. Star A has a radius R and a temperature T. Star B has a radius 4R and a temperature T/2. Which has the higher surface Flux?
a) $Star A
b) Star B
c) They are the same.
d) Cannot tell.

18. Star A has a radius R and a temperature T. Star B has a radius 4R and a temperature T/2. Which has the higher Luminosity?
a) Star A
b) Star B
c) $They are the same.
d) Cannot tell.

19. Main-sequence stars are more common than giant stars because
a) $stars spend an overwhelming time of their life in the main-sequence.
b) main-sequence stars are more easily seen than giant stars.
c) giant stars are created much more rarely than main-sequence stars.
d) Astronomers are still trying to figure out the answer!

20. A main-sequence star is a star that
a) appears on a band that runs from the upper left to the lower right of the standard Hertzsprung-Russell diagram.
b) converts hydrogen to helium in its core.
c) are the most common stars in the universe.
d) $All of the above.

21. The best determinant of a star's life and evolution is
a) color
b) temperature.
c) luminosity.
d) $mass.

22. Why are so hard to detect white dwarfs?
a) They are too small.
b) $They are too dim.
c) They are too hot.
d) There are very few white dwarfs.

23. A star is seen to have a parallax of 0.05 arcseconds. It is at a distance of
a) 2 parsecs.
b) 5 parsecs.
c) $20 parsecs.
d) 200 parsecs.

24. It is best to find the parallax of a star when
a) $it is front of several faraway stars.
b) we observe it from one night to the next.
c) it has a high proper motion.
d) the star is very large compared to the other stars in the field.

25. Neptune is approximately 30 astronomical units on average from the Sun. If there were Neptunian astronomers with the same technology we currently have, how much further could they calculate a distance through astronomical parallax?
a) 15 times.
b) $30 times.
c) 60 times.
d) 900 times.

26. If the parallax of a star is 0.020 arcseconds as viewed from Earth, what would it be if observed from Venus (distance from the Sun = 0.7 astronomical units)?
a) 0.011 arcseconds
b) $0.014 arcseconds
c) 0.020 arcseconds
d) 0.029 arcseconds

27.   A period-luminosity relationship of certain stars is beneficial because it allows
        astronomers to
a)   determine periods of those stars if we know their luminosities.
b) $determine the distances to those stars.
c)   check that their understanding of stellar evolution is correct.
d)   determine the mass of those stars.

28.   A star is at a distance of 50 parsecs. It has a parallax of
a) $0.02 arcseconds
b)   0.04 arcseconds
c)   0.05 arcseconds
d)   0.08 arcseconds

29.   You are looking at two K7 stars. You see that one K7 star has narrow
        spectral lines, while the other has broader spectral lines. They have the
        same apparent magnitude. Which one is further away?
a) $The star with narrow lines.
b)   The star with broader lines.
c)   They are the same distance, because they are the same spectral type and
        have the same apparent magnitude.
d)   One cannot tell with the information given.

Inferring Patterns in Star Life Cycles

1. "Stellar evolution" is
a)   the method by which stars have adapted and changed since the beginning of the Universe.
b)   how stars have survived over their lifetimes.
c) $how individual stars have aged and changed over their lifetimes.
d)   a controversial method for describing how the stars we see today came into being.

2. As a star leaves the main sequence, its radius increases dramatically and its temperature decreases moderately. This results in the star's
a)   mass and volume increasing.
b)   mass decreasing and the volume increasing.
c)   luminosity decreasing.
d) $luminosity increasing.

3. As a star leaves the main sequence, its radius increases dramatically and its temperature decreases moderately. This results in the star's
a) $density decreasing and color reddening.
b)   surface gravity increasing and color becoming more red.
c)   escape velocity increasing.
d)   escape velocity decreasing and color becoming more blue.

4. When a star has reached the zero-age main sequence, that means that it has
a)   reached a certain point in space where it will turn hydrogen into helium.
b)   begun to shine for the first time.
c) $started making its own energy, but has not changed its composition by nuclear reactions.
d)   reached the endpoint of its life as a star.

5. How do astronomers determine how stars evolve?
a)   They watch a particular star and see how it ages over its lifetime.
b) $They look at a cluster of stars and see how stars of different masses are different.
c)   They look at a cluster of stars and see how stars of different masses change over time.
d)   There is no way to know for sure how stars evolve.

6. A globular cluster has characterized by
a) $primarily thousands of red stars.
b)   being in the spiral arms.
c)   Both of the above.
d)   None of the above.

7.   An open cluster is characterized by
a)   being held together by its own gravity.
b) $containing mostly young stars.
a)   Both of the above.
b)   None of the above.

8.   The reason we do not see too many open clusters is because
a)   open clusters are rarely formed.
b)   open clusters do not stay together for very long.
c)   they are so small they are very hard to see.
d) $open clusters are in the disk, where there is also a lot of obscuring dust.

9.   Consider the H-R diagram of the following cluster of stars.
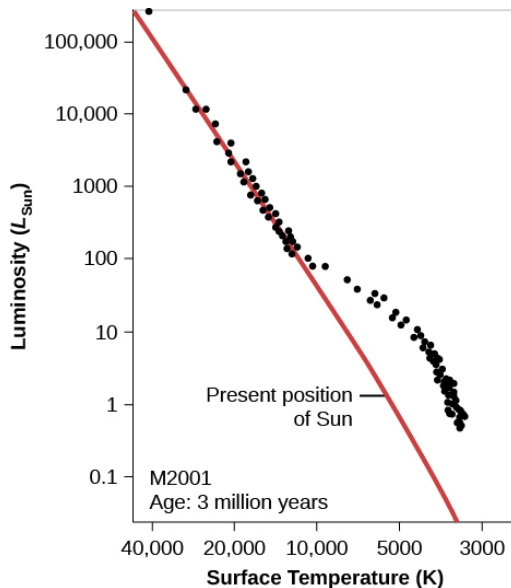
This cluster is _____.
a)   a young cluster, because we see that the cooler stars are not yet on the main sequence.
b) $a young cluster, because we see that the more luminous stars are on the main sequence.
c)   an old cluster, because we see that the cooler stars are already leaving the main sequence.
d)   an old cluster, because we see that the more luminous stars are on the main sequence.

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10.   Consider the H-R diagram of the following cluster of stars.
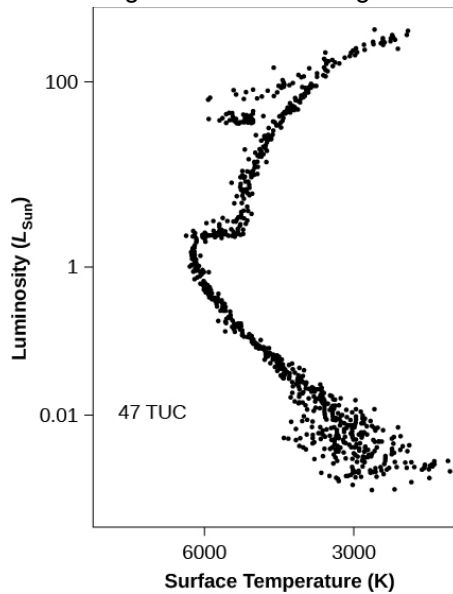
This cluster is _____.
a)   a young cluster, because we see that the cooler stars are on the main sequence.
b)   a young cluster, because we see that the more luminous stars have not yet reached the main sequence.
c)   an old cluster, because we see that the cooler stars are already on the main sequence.
d) $an old cluster, because we see that the more luminous stars have left the main sequence.

11.   When the hydrogen in the core of a main sequence star is all but exhausted,
a) $the core begins to fuse helium into carbon.
b)   the star stops fusing atoms.
c)   the star starts splitting atoms.
d)   the star starts the carbon-nitrogen-oxygen (CNO) cycle.

12.   When the hydrogen-shell burning ends in a star, what happens next is
a) $three helium atoms are fused into an carbon atom.
b)   helium atoms are split back into hydrogen.
c)   iron is formed.
d)   None of the above.

13.   When the triple-alpha process begins, the core's temperature has reached 100 million K. What characterizes this stage of the star's evolution?
a)   It lasts about half as long as the main sequence lifetime.
b) $The star is many times its original main-sequence size.
c)   The star is hotter and more luminous than it was when on the main sequence.
d)   None of the above.

14. A planetary nebula is
a) a nebula that is believed to be where planets are formed.
b) a nebula that orbits planetary bodies.
c) $the endpoint of a low-mass star.
d) the endpoint of a high-mass star.

15. High-mass stars, once they leave the main-sequence, have which of the following characteristics?
a) They lose mass easily.
b) They expand to enormous sizes.
c) $They can fuse elements heavier than oxygen and carbon.
d) All of the above.

16. Which cluster would you expect to have more "metals", and why?
a) $Open clusters, because they have younger stars that formed with more "processed materials."
b) Open clusters, because they have older stars that have been able to make heavier elements.
c) Globular clusters, because they have younger stars that formed with more "processed materials."
d) Globular clusters, because they have older stars that have been able to make heavier elements.

17. Most of the material in the interstellar medium is
a) solid.
b) $gas.
c) liquid.
d) There is no material in the space between the stars.

18. The density of air is approximately _____ that of the average density of the interstellar medium.
a) ten thousand times (10^4)
b) ten million times (10^7)
c) ten trillion times(10^{13})
d) $ten million trillion times (10^{19})

19. A typical interstellar dust grain is made of
a) rock.
b) ice.
c) $rock surrounded by ice.
d) ice surrounded by rock.

20. A clue that interstellar gas and dust is the raw material for stars is
a) the huge volume of interstellar space.
b) $the huge amount of mass of interstellar material.
c) the temperature of interstellar material.
d) the density of interstellar material.

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21.   The most abundant gases in the interstellar medium is
a) $helium and hydrogen.
b)   methane and water.
c)   hydrogen and methane.
d)   hydrogen and water.

22.   Imagine the absorption-line spectrum of a star. If there is an interstellar dust cloud
        between us and the star, the absorption lines are narrow. This is because
a)   the pressure in the dust cloud is too high.
b) $the pressure in the dust cloud is too low.
c)   the dust cloud is not spinning rapidly.
d)   the dust cloud is not moving relative to us.

23.   The 21-centimeter line is a good way to search for
a)   interstellar dust clouds.
b)   water clouds.
c) $atomic hydrogen (HI) clouds.
d)   ionized hydrogen (HII) regions.

24.   Ultraviolet radiation from stars is capable of
a)   melting most forms of interstellar ice.
b) $breaking apart molecules.
c)   causing molecules to form.
d)   burning interstellar dust.

25.   A star is observed behind an interstellar dust cloud. It appears reddened because
a)   the star is moving away from us.
b)   the star is intrinsically red.
c)   shorter wavelengths of the starlight is scattered by the cloud.
d) $All of the above are possible.

26.   Imagine a dust cloud between us and a star. It is dense enough that the cloud blocks
        the light from the star and is itself dark. A way to detect the cloud is to
a)   use a more powerful optical telescope.
b)   observe the cloud in X rays, so the light can penetrate the cloud.
c)   observe the cloud in ultraviolet, because so much of the radiation is in ultraviolet.
d) $observe the cloud in infrared, because the cloud is absorbing starlight.

27.   The Sun and the solar system are inside a "bubble" of interstellar material. This
        bubble is believed to have been formed by
a)   material released by the Sun in its early life.
b) $the life cycle of massive stars.
c)   intergalactic winds.
d)   the constant blowing of the solar wind.

28.   Since angular momentum is conserved, the rotational speed of a collapsing gas cloud
a)   depends on its mass
b)   decreases.
c) $increases.
d)   does not depend on its initial rotation.

29.   What kind of protostars arrive on the main sequence the quickest?
a)   Low-mass stars
b) $High-mass stars
c)   They take about the same time.
d)   It does not depend on mass at all.

30.   Stars are directly formed from the contents of
a)   larger stars.
b)   many small stars coming together.
c) $giant molecular clouds.
d)   supernova explosions.

31.   As a protostellar cloud collapses, it becomes a disk. This is due to
a) $the increasing rotation rate.
b)   the influence of magnetic fields.
c)   the increasing temperature of the cloud.
d)   All of the above.

32.   As a protostar begins to approach the main sequence, its radius decreases and its temperature increases. This results in
a)   the luminosity decreasing.
b) $the luminosity increasing.
c)   The luminosity changes, but not because of the radius or the temperature.
d)   the mass decreasing.

33.   The theory of how stars form tells us that the formation of planets around the star
a) $is very likely.
b)   depends on the mass of the star.
c)   depends on how long it takes stars to form.
d)   depends on how luminous the star is.

Predicting the Violent End of the Largest Stars

1. The event that marks the end of a star's evolutionary life before becoming a white dwarf is
a) a nova.
b) the exhaustion of hydrogen in the core.
c) the helium flash.
d) $a planetary nebula.

2. The Chandrasekhar limit for white dwarves says that
a) white dwarves cannot be above a certain density.
b) white dwarves have a minimum temperature.
c) minimum distance white dwarves can be from a star.
d) $white dwarves have a maximum mass.

3. Imagine a cluster of stars that originally had stars ranging from 1 solar mass to 10 solar masses. In 20 billion years, what would the cluster look like?
a) It would still have stars that were shining and producing their own energy, as well as supernova remnants.
b) $It would have several cooling white dwarfs, supernova remnants, and no stars.
c) It would have white dwarfs, red giants, and supernova remnants.
d) It would have supernova remnants and red giants.

4. The most common non-primordial elements in the universe have atomic masses that are multiples of four. This tells us that the most common method of creating elements is
a) $by fusing elements with helium, or those made by helium.
b) by the proton-proton chain.
c) by quadruple reaction.
d) by the carbon-nitrogen-oxygen cycle.

5. What is the most likely element in the outer shell of a high-mass star?
a) Iron
b) Silicon
c) Helium
d) $Hydrogen

6. In a very high-mass star, each thermonuclear reaction generates energy until _____ is formed.
a) $Iron
b) Silicon
c) Carbon
d) Oxygen

7. When iron is created in a star, the thermonuclear fusion stops because
   _____.
   a) the core is now a brown dwarf.
   b) $it costs energy to fuse anything beyond iron.
   c) the iron in the dense core cannot move fast enough to fuse with anything else.
   d) the temperature of the core is too high.

8. What is the *first* thing that happens when iron is formed in the core of a high-mass star?
   a) the core shrinks and heats up, just as it did when earlier elements were exhausted from making heavier elements.
   b) the star immediately explodes.
   c) the core shrinks and heats up to make heavier elements.
   d) $the iron begins to break down into lighter elements.

9. In a high-mass star, when electrons and protons fuse to create neutrons and neutrinos, what happens?
   a) Energy is created, causing the core to explode in a runaway effect.
   b) Energy is created, causing the star to continue to shine, but only for a few days or weeks.
   c) $Energy is used, causing the core to collapse.
   d) Energy is used, causing the star to cool and appear much redder than it normally does.

10. In a supernova explosion, _____ can be observed.
    a) protons and neutrinos
    b) $photons and neutrinos
    c) neutrons and photons
    d) neutrons and protons

11. What tangible object can be left after the death of a high-mass star?
    a) A black hole
    b) A neutron star
    c) $Both of the above.
    d) A white dwarf.

12. What tangible object is left after the death of a low-mass star?
    a) A black hole
    b) A neutron star
    c) Both of the above.
    d) $A white dwarf.

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13. A supernova from a high-mass star is caused by
a) $the core suddenly exploding and pushing the outer layers out.
b) the core suddenly getting smaller and causing the star's outer layers to collapse.
c) the core's neutrinos pushing the outer layers out when they escape.
d) None of the above.

14. The last supernova explosion seen in our own Galaxy was first observed in
a) 1054.
b) $1604.
c) 1743.
d) 1987.

15. The first neutrinos detected from outside the solar system were from
a) SN 1054.
b) $SN 1987A.
c) the center of the Galaxy.
d) Betelgeuse.

16. What is wrong with the name "neutron star"?
a) $A neutron star is not a star.
b) A neutron is not made of neutrons.
c) Both of the above.
d) There is nothing wrong with the name "neutron star".

17. A pulsar is called a pulsar because
a) the neutron star periodically gets bigger and smaller.
b) the neutron star emits electromagnetic radiation periodically in pulses.
c) $the neutron star appears to emit electromagnetic radiation periodically.
d) the neutron star emits electromagnetic radiation in random pulses.

18. Imagine a white dwarf that is alone in space. Which of the following is the most likely?
a) The white dwarf becomes a nova.
b) The white dwarf becomes a supernova.
c) $The white dwarf cools off and becomes a black dwarf.
d) None of the above is likely to happen.

19. What is necessary for a nova to occur?
a) $A white dwarf and a companion star in a binary system.
b) Two white dwarfs in a binary system.
c) A white dwarf in a planetary nebula.
d) A white dwarf and a black hole.

20. Imagine a binary system with a 2-solar-mass and 9-solar-mass star. Which of the following would happen first?
a) A nova explosion.

b)   An X-ray binary.
c) $One of the stars would evolve off the main sequence.
d)   A neutron star would form.

21.   Some gamma-ray bursts are believed to come from
a) $the collisions of the remnants of high-mass stars.
b)   the collisions of the remnants of low-mass stars.
c)   the creation of neutron stars.
d)   a neutron-star— regular star binary system.

22.   A black hole is best defined as
a)   the final result of all stellar evolution.
b) $any object that is smaller than its event horizon.
c)   a star that sucks all matter into itself.
d)   a window to another universe.

23.   The reason an astronaut is weightless in a spacecraft orbiting the Earth is
a)   there is no pull of gravity on the astronaut from the Earth.
b)   there is no pull of gravity on the astronaut from the spacecraft.
c)   the spacecraft is pulling the astronaut with the same force as the Earth.
d) $the spacecraft is falling at the same rate as the astronaut.

24.   Einstein became a celebrity known around the world because of
a)   his prediction of the precession of Mercury's orbit.
b) $his observation of the deflection of starlight by the Sun.
c)   the confirmation of his prediction of starlight by the Sun.
d)   the observation of starlight during the day.

25.   Light being emitted from the vicinity of a massive object will appear to have
a)   a longer wavelength.
b)   a lower energy.
c) $Both of the above.
d)   None of the above.

26.   What would happen if the Sun suddenly turned into a one-solar-mass black
        hole?
a)   the Earth would suddenly spiral into the center of the solar system.
b)   the Earth would travel in a straight line in a direction perpendicular to the
        Earth-Sun line.
c)   the Earth would move closer to the Sun, but would not fall into it.
d) $nothing would happen to the Earth's orbit.

27. Imagine we were observing a robot astronaut traveling toward a black hole. What of the following would we notice?
   I.   we would see the robot cross the event horizon.
   II. we would see the robot be stretched as it approached the black hole.
   III. We would never see the robot disappear into the event horizon.
a) I & II
b) $II & III
c) I & III
d) I, II, & III

28. You observe a 30-solar mass star, HDE 226868, that is revolving about an unseen companion object. The period of the star is 5.6 days, and the unseen companion's mass is calculated to be about 10 solar masses. The unseen companion is likely to be
a) a white dwarf.
b) a neutron star.
c) $a black hole.
d) a very small star.

29. The only way to tell if a black hole is present is to
a) $see how the environment is affected in the vicinity.
b) use telescopes in other wavelengths to see the black hole directly.
c) look for the event horizon.
d) see how time is affected by the object.

30. Gravitational waves can be caused by
a) the merger of a two neutron stars or black holes.
b) the death of a extremely massive star to make a black hole.
c) the beginning of the universe.
d) $all of the above.

Exploring Our Galaxy

1.   Compared to the present-day Milky Way Galaxy, the Milky Way of 3 billion years ago would have had
a) $more gas in the disk.
b)   more stars in the halo.
c)   more metal-rich stars.
d)   no solar system.

2.   The position of the Sun in the Milky Way Galaxy is best described as
a)   in a globular cluster in the halo.
b)   in the disk, very close to the center.
c)   in an open cluster in the disk.
d) $in the disk, slightly more than halfway out from the center.

3.   Why was William Herschel unable to accurately map the Milky Way?
a)   he did not have very good optical telescopes.
b) $he assumed that the stars were the same brightness.
c)   he could not see past the interstellar dust.
d)   he could not look in all directions of the sky.

4.   In the Milky Way, the amount of "metals" (heavy elements) is highest in the
a) $the disk.
b)   the halo.
c)   the bulge.
d)   They all have about the same abundance.

5.   The oldest stars in the Milky Way are in the
a)   the disk.
b) $the halo.
c)   the bulge.
d)   They are all about the same age.

6.   Why can we not easily observe the bulge of the Milky Way?
a)   The stars in the bulge are too dim.
b) $The Galactic dust is too thick.
c)   The light from the disk stars is too bright.
d)   The bulge is too small to see well.

7.   The spiral arms of the Milky Way probably formed
a) $through differential rotation of interstellar material.
b)   by material being stretched out by passing galaxies.
c)   by material being stretched out by satellite galaxies of the Milky Way.
d)   through the merger of two earlier galaxies.

8.	If the spiral arms formed through differential rotation, what else must be happening?
a)	$Some other mechanism must be at work; otherwise the arms would disappear after a few hundred million years.
b)	The spiral arms must not be undergoing differential rotation any more.
c)	The spiral arms are moving too slowly now to cause the arms to disappear.
d)	The spiral arms are not subject to Kepler's Laws any more.

9.	The mass of the Milky Way is best found by
a)	counting the number of stars in the sky.
b)	counting the star clusters in the sky.
c)	$measuring the rotation of the Galaxy.
d)	radio measurements of the amount of interstellar hydrogen.

10.	The rotation curve of the Galaxy shows that
a)	$there is matter that we cannot see that is inside the disk of the Milky Way.
b)	the Galaxy is rotating more slowly than theory suggests.
c)	the solar system is not in the center of the Galaxy.
d)	the Galaxy is contracting.

11.	Careful radio measurements of the orbits of stars in the center of the Milky Way show
a)	an enormous amount of hydrogen gas.
b)	exactly how much dust there is in the center.
c)	$there is a supermassive black hole.
d)	the stars have many planets.

12.	Population I stars generally have which of the following characteristics?
I.	Higher metallicity
II.	Circular orbits
III.	Generally blue
IV.	In the disk
a)	I & III
b)	I & IV
c)	I, II, & III
d)	$I, II, III, & IV

13.	The primary reason that massive O-type stars are not found in the galactic halo is because they are
a)	too massive to be kicked into the halo from the disk.
b)	so massive they settle into the thin disk.
c)	$too short-lived to have persisted from halo formation until today.
d)	closer to us in the disk than in the extended halo.

14. We think that the cloud from which the Milky Way formed was originally
a) spherical because galactic clouds are almost always spherical.
b) $spherical because the bulge and the halo are spherical.
c) flat because the disk is flat.
d) flat because the cloud would have collapsed under its own gravity.

15. Computer modeling suggests that the Milky Way
a) $evolved from collisions with smaller galaxies.
b) will slowly lose the gas in the spiral arms.
c) will become an elliptical galaxy on its own.
d) formed from a flat cloud of gas and dust.

16. The objects we know to be galaxies were originally found to be very far away by
a) looking at their redshift and using Hubble's Law.
b) $looking at light curves from Cepheid variables.
c) determining their parallax.
d) studying their proper motion.

17. The Hubble "tuning-fork" diagram gives us information on
a) $the comparative shapes of the galaxies.
b) the evolution of galaxies.
c) the evolution of stars.
d) the movement of sound waves through space.

18. Because elliptical galaxies have very little gas or dust, we know that
a) $little star formation is going on.
b) the stars in the galaxies do not orbit in an organized fashion.
c) there is very little interstellar reddening and the stars must appear blue.
d) we can see through the galaxies to the other side.

19. Calculations of the masses of the Andromeda galaxy and the Milky Way show that
a) the two galaxies will collide.
b) $the Andromeda galaxy is more massive than the Milky Way.
c) the Andromeda galaxy is younger than the Milky Way.
d) the Andromeda galaxy is a spiral, just like the Milky Way.

20. Looking at line broadening tells us
a) the numbers of old and young stars in the galaxy.
b) $the mass of a galaxy.
c) the speed of the galaxy away from us.
d) the abundance of certain elements in the galaxy.

21.   The typical color(s) of a spiral galaxy are
a) $red and blue
b)   all red
c)   all blue
d)   none of the above.

22.   Why are the disks of spiral galaxies generally blue, even though there are
        many more less massive (and red) stars in the disk?
a)   the dust obscures the dimmer red stars.
b) $the blue stars that are there are far more luminous than the smaller red
        stars.
c)   the red stars are being Doppler-shifted away from us.
d)   the red stars are exploding.

23.   If the mass-to-light ratio for a galaxy is 100, that means that
a)   we are actually seeing not as much light as we think we are.
b) $there is a lot of matter that we cannot see.
c)   the galaxy is dimming over a short time.
d)   the galaxy is pretty young.

24.   Which of the following is impossible to use in estimating distances to other
        galaxies?
a) $white dwarfs, because they are too dim.
b)   supernovae, because they do not last long enough.
c)   pulsating variable stars, because they are too variable.
d)   globular clusters, because they are too large and fuzzy.

25.   What type of galaxy would not be a good place to observe type II
        supernovae?
a)   irregular
b)   spirals
c) $ellipticals
d)   all of these are good places to observe a type II supernova.

26.   The best way to measure distances to a galaxy is by looking at
a)   the stellar populations.
b)   the color of the galaxy.
c) $the luminosity of some of the stars.
d)   the spectral type of the galaxy.

27.   The Tully-Fisher relation is a way of determining the luminosity of an elliptical
        galaxy by looking at its
a)   mass.
b)   distance.
c) $rotation rate.
d)   none of the above.

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28. You see a galaxy that is 550 million light-years away. Using the value of Hubble's constant in the text, what is the speed and direction of the galaxy?
a) 12,100 km/sec toward us.
b) $12,100 km/sec away from us.
c) 25 km/sec toward us.
d) 25 km/sec away from us.

29. Hubble's constant is not really a constant. We can say this because
a) the value changes for a given galaxy.
b) the value changes depending on the direction we observe.
c) $the value changes over time.
d) the value is different in different parts of the universe.

30. If we observe three different galaxies, which one appears to be moving the fastest?
a) Galaxy A 1 billion light years away.
b) Galaxy B 2 billion light years away.
c) $Galaxy C 3 billion light years away.
d) All of them appear to move at the same speed.

31. Maarten Schmidt determined that the spectra of quasars were simply
a) that of normal absorption line spectra.
b) that of previously unknown elements, but highly redshifted.
c) $highly-redshifted emission-line spectra.
d) that of highly-ionized elements.

32. We know that the source of the quasars' energy must be relatively small because
a) we cannot see the emitting object directly.
b) the quasar does not obscure its surrounding galaxy.
c) $the variability of the emitted light occurs over no more than a matter of weeks.
d) None of the above.

33. We know that quasars must be intrinsically luminous because
a) they are in galaxies.
b) $they have extremely high redshifts.
c) they are extremely massive.
d) they have powerful jets.

34. What is the same for Seyfert galaxies, quasars, and radio galaxies?
a) how they appear.
b) how long they last.
c) $how they are powered.
d) where they occur.

35.   Observations of distant galaxies tell us that
a)   galaxies look very much like the ones we see near us.
b)   only spiral galaxies existed in the past.
c) $galaxies looked substantially different than nearby ones.
d)   galaxies were usually larger than nearby galaxies.

36.   Which of the following have we learned from galaxies from several billion
        years ago?
I.   They were smaller than today's galaxies
II.   Galaxies had a lot of gas
III.   They were blue
a)   I only
b)   I & II
c)   I & III
d) $I, II, & III

37.   When galaxies collide, their stars rarely collide because
a)   the mutual force of gravity between the stars repels the stars.
b)   all of the stars enter into binary star orbits.
c) $the distance between the stars is vast compared to their sizes.
d)   the interstellar gas and dust "cushions" any collisions.

38.   When two galaxies collide, if one (or both) of them has a lot of gas and dust,
        which of the following will happen?
a)   the gas and dust will evaporate.
b) $the gas and dust will be squeezed, and star formation will be triggered.
c)   the gas and dust will obscure both galaxies.
d)   the gas and dust will become extremely colorful.

39.   Active galactic nuclei
I.   can trigger star formation.
II.   can be aided by continual mergers providing fresh fuel
III.   can slow or stop star formation
IV.   were more common in the early universe.
a)   I & II
b)   II & III
c)   I & IV
d) $II, III, & IV

40.   In the cosmological principle, it is said the universe is both isotropic and
        homogeneous. This means
a)   the universe is smooth and the same everywhere.
b) $the universe both looks the same and is the same in large amounts.
c)   the universe looks the same in all directions.
d)   that, for example, there are many versions of the Earth in all directions.

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41. What would cosmology be like if we did not have the cosmological principle?
   I.   We would not be able to observe faraway galaxies.
   II. We would only be able to describe and study the nearby universe.
   III. We would not be able to draw conclusions about any part of the unseen universe.
a) I & II
b) I & III
c) $II & III
d) I, II, & III

42. The group of galaxies to which the Milky Way belongs is called the
a) the Milky Way Group
b) the Andromeda-Milky Way Cluster
c) the Virgo Cluster
d) $the Local Group

43. In large clusters of galaxies, why are we more likely to see spiral galaxies at the edges?
a) $Because if spirals were in the middle, they would be ripped apart.
b) There is more gas and dust at the edges.
c) Gravitational interactions with elliptical galaxies at the center forced the spirals to the edges.
d) All of the above.

44. Gravitational lenses have been seen to
I.   Brighten a background object
II. Allow astronomers to measure the mass of a cluster.
III. Create multiple images of the same object.
IV. Create distorted images of the same object.
a) I & II
b) I & III
c) I, II, & III
d) $I, II, III, & IV

45. If we observe to a distance four times as far away as an earlier survey, we are covering a volume _____ times as large.
a) 4
b) 16
c) $64
d) 256

46. How do we know there is very little dark matter in the solar system?
a) The solar wind pushes any dark matter out of the solar system.
b) Any dark matter is attracted to the planets and the Sun and is therefore not in space.
c) $There is no gravitational deviation of the planets' motions we can detect.
d) Actually, we *don't* know that there is very little dark matter in the solar system.

47. How do we know that there is dark matter inside clusters?
a) The motion of galaxies in the clusters is too fast for the visible matter to hold the galaxies gravitationally.
b) We can see X-ray emission from the dark matter.
c) We can see gravitational lensing by the dark matter.
d) $all of the above.

48. How do we think the universe we see today formed in what order?
    I. The universe was almost entirely smooth
    II. Stars formed
    III. Voids and filaments came into being
    IV. Galaxies formed by mergers
a) I, II, III, IV
b) I, IV, III, II
c) III, IV, II, I
d) $I, III, IV, II

Observing the Evolution of the Universe

1. If a galaxy has a redshift of z = 3, the universe is currently how many times bigger than it was when the light left the galaxy?
a)   twice as big
b)   three times as big
c) $four times as big
d)   nine times as big

2. How have astronomers figured out the universe is expanding?
a)   The edge of the universe is moving away from us.
b)   The disks of galaxies are getting smaller over time.
c) $The redshifts of more distant galaxies are higher.
d)   All of the above.

3. The current value for the Hubble constant is H_0=22 km/sec/(10^6 ly). This corresponds to an age for the universe of
a)   7 billion years
b)   11 billion years
c) $14 billion years
d)   22 billion years

4. The revolutionary discovery that the universe was speeding up (accelerating) its expansion means
a)   the universe is older than we had thought.
b)   there is some mechanism that is causing this acceleration.
c)   galaxies are farther away than we had thought.
d) $all of the above are true.

5. If the Hubble constant were found to be twice as big as we now think it is, that would mean the age of the universe would be
a) $halved.
b)   doubled.
c)   the same.
d)   squared.

6. The determined density of the universe and the discovery of the existence of dark energy tell us that the universe will
a) $expand steadily forever.
b)   expand for a while and then stop.
c)   expand for a while and then fall back into itself.
d)   expand steadily for a while and then slow down.

7. Which of the following materials are believed to have been present after the Big Bang?

        I.   Hydrogen
        II.   Helium
        III.   Deuterium
        IV.   Lithium

a) I & II
b) I & III
c) I, II, & III
d) $I, II, III, & IV

8. The cosmic microwave background radiation is directly from
a) the recombination of electrons and nuclei at a temperature of about 3 K.
b) $the recombination of electrons and nuclei at a temperature of about 3000 K.
c) when stars first formed at a temperature of about 30,000 K.
d) the immediate aftermath of the Big Bang at a temperature of about 10^{31}K.

9. If we were to take an object and put it in intergalactic space, far away from any objects, what would the eventual temperature be after waiting?
a) the original temperature of the object.
b) $3 K
c) 300 K
d) 30,000 K

10. The cosmic microwave background has a spectrum of a blackbody. That tells us that
a) $the radiation originated from an opaque, uniform emitter of energy.
b) the radiation originated from a dark object.
c) the universe is cooling.
d) the universe is bigger than it was billions of years ago.

11. Careful observation of the cosmic microwave background radiation show tiny fluctuations in the CMB. These fluctuations are believed to be the origin of
a) $galaxies and galaxy clusters.
b) supernova explosions.
c) the critical density of the universe.
d) dark energy.

12. The universe is made of what of the following amounts of material?

        I.   Ordinary matter that we can see easily.
        II.   Ordinary matter in intergalactic space.
        III.   Dark matter
        IV.   Dark energy

a) I (5%), II (63%) III (5%), IV (27%)
b) I (1%), II (26%) III (68%), IV (5%)
c) I (5%), II (22%), III (5%), IV (68%)
d) $I (1%), II (4%), III (27%), IV (68%)

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13. The inflationary model solves what concern of cosmologists?
a) Why the Big Bang occurred.
b) How the Big Bang occurred.
c) $Why the universe seems to be the same in all directions.
d) Why there is dark energy.

14. The anthropic principle says, in essence,
a) "Humans are the most important entities in the universe."
b) "Only humans can understand the universe."
c) "Humans are here because the Universe allows us to be here."
d) $"The Universe is here because humans are here to understand it."

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