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Astro-
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CHAPTER 30 REVIEW

KEY TERMS

amino acids organic compounds that are the molecular building blocks of proteins

astrobiology the multidisciplinary study of life in the universe: its origin, evolution, distribution, and fate; similar terms are *exobiology* and *bioastronomy*

biomarker evidence of the presence of life, especially a global indication of life on a planet that could be detected remotely (such as an unusual atmospheric composition)

DNA (deoxyribonucleic acid) a molecule that stores information about how to replicate a cell and its chemical and structural components

Drake equation a formula for estimating the number of intelligent, technological civilizations in our Galaxy, first suggested by Frank Drake

extremophile an organism (usually a microbe) that tolerates or even thrives under conditions that most of the life around us would consider hostile, such as very high or low temperature or acidity

gene the basic functional unit that carries the genetic (hereditary) material contained in a cell

habitable environment an environment capable of hosting life

habitable zone the region around a star in which liquid water could exist on the surface of terrestrial-sized planets, hence the most probable place to look for life in a star’s planetary system

organic compound a compound containing carbon, especially a complex carbon compound; not necessarily produced by life

organic molecule a combination of carbon and other atoms—primarily hydrogen, oxygen, nitrogen, phosphorus, and sulfur—some of which serve as the basis for our biochemistry

photosynthesis a complex sequence of chemical reactions through which some living things can use sunlight to manufacture products that store energy (such as carbohydrates), releasing oxygen as one by-product

protein a key biological molecule that provides the structure and function of the body’s tissues and organs, and essentially carries out the chemical work of the cell

RNA (ribonucleic acid) a molecule that aids in the flow of genetic information from DNA to proteins

SETI the search for extraterrestrial intelligence; usually applied to searches for radio signals from other civilizations

stromatolites solid, layered rock formations that are thought to be the fossils of oxygen-producing photosynthetic bacteria in rocks that are 3.5 billion years old

thermophile an organism that can tolerate high temperatures

SUMMARY

30.1 The Cosmic Context for Life

Life on Earth is based on the presence of a key unit known as an organic molecule, a molecule that contains carbon, especially complex hydrocarbons. Our solar system formed about 5 billion years ago from a cloud of gas and dust enriched by several generations of heavier element production in stars. Life is made up of chemical combinations of these elements made by stars. The Copernican principle, which suggests that there is nothing special about our place in the universe, implies that if life could develop on Earth, it should be able to develop in other places as well. The Fermi paradox asks why, if life is common, more advanced life-forms have not contacted us.

30.2 Astrobiology

The study of life in the universe, including its origin on Earth, is called astrobiology. Life as we know it requires water, certain elemental raw materials (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur), energy, and an environment in which the complex chemistry of life is stable. Carbon-based (or organic) molecules are abundant in space and may also have been produced by processes on Earth. Life appears to have spread around our planet within 400 million years after the end of heavy bombardment, if not sooner. The actual origin of life—the processes leading from chemistry to biology—is not completely understood. Once life took hold, it evolved to use many energy sources, including first a range of different chemistries and later light, and diversified across a range of environmental conditions that humans consider “extreme.” This proliferation of life into so many environmental niches, so relatively soon after our planet became habitable, has served to make many scientists optimistic about the chances that life could exist elsewhere.

30.3 Searching for Life beyond Earth

The search for life beyond Earth offers several intriguing targets. Mars appears to have been more similar to Earth during its early history than it is now, with evidence for liquid water on its ancient surface and perhaps even now below ground. The accessibility of the martian surface to our spacecraft offers the exciting potential to directly examine ancient and modern samples for evidence of life. In the outer solar system, the moons Europa and Enceladus likely host vast sub-ice oceans that may directly contact the underlying rocks—a good start in providing habitable conditions—while Titan offers a fascinating laboratory for understanding the sorts of organic chemistry that might ultimately provide materials for life. And the last decade of research on exoplanets leads us to believe that there may be billions of habitable planets in the Milky Way Galaxy. Study of these worlds offers the potential to find biomarkers indicating the presence of life.

30.4 The Search for Extraterrestrial Intelligence

Some astronomers are engaged in the search for extraterrestrial intelligent life (SETI). Because other planetary systems are so far away, traveling to the stars is either very slow or extremely expensive (in terms of energy required). Despite many UFO reports and tremendous media publicity, there is no evidence that any of these are related to extraterrestrial visits. Scientists have determined that the best way to communicate with any intelligent civilizations out there is by using electromagnetic waves, and radio waves seem best suited to the task. So far, they have only begun to comb the many different possible stars, frequencies, signal types, and other factors that make up what we call the cosmic haystack problem. Some astronomers are also undertaking searches for brief, bright pulses of visible light and infrared signatures of huge construction projects by advanced civilizations. If we do find a signal someday, deciding whether to answer and what to answer may be two of the greatest challenges humanity will face.

FOR FURTHER EXPLORATION

Articles

Astrobiology

Chyba, C. “The New Search for Life in the Universe.” *Astronomy* (May 2010): 34. An overview of astrobiology and the search for life out there in general, with a brief discussion of the search for intelligence.

Dorminey, B. “A New Way to Search for Life in Space.” *Astronomy* (June 2014): 44. Finding evidence of photosynthesis on other worlds.

McKay, C., & Garcia, V. “How to Search for Life on Mars.” *Scientific American* (June 2014): 44–49. Experiments future probes could perform.

Reed, N. “Why We Haven’t Found Another Earth Yet.” *Astronomy* (February 2016): 25. On the search for smaller earthlike planets in their star’s habitable zones, and where we stand.

Shapiro, R. “A Simpler Origin of Life.” *Scientific American* (June 2007): 46. New ideas about what kind of molecules formed first so life could begin.

Simpson, S. “Questioning the Oldest Signs of Life.” *Scientific American* (April 2003): 70. On the difficulty of interpreting biosignatures in rocks and the implications for the search for life on other worlds.

SETI

Chandler, D. “The New Search for Alien Intelligence.” *Astronomy* (September 2013): 28. Review of various ways of finding other civilizations out there, not just radio wave searches.

Crawford, I. “Where Are They?” *Scientific American* (July 2000): 38. On the Fermi paradox and its resolutions, and on galactic colonization models.

Folger, T. “Contact: The Day After.” *Scientific American* (January 2011): 40–45. Journalist reports on efforts to prepare for ET signals; protocols and plans for interpreting messages; and discussions of active SETI.

Kuhn, J., et al. “How to Find ET with Infrared Light.” *Astronomy* (June 2013): 30. On tracking alien civilizations by the heat they put out.

Lubick, N. “An Ear to the Stars.” *Scientific American* (November 2002): 42. Profile of SETI researcher Jill Tarter.

Nadis, S. “How Many Civilizations Lurk in the Cosmos?” *Astronomy* (April 2010): 24. New estimates for the terms in the Drake equation.

Shostak, S. “Closing in on E.T.” *Sky & Telescope* (November 2010): 22. Nice summary of current and proposed efforts to search for intelligent life out there.

Websites

Astrobiology

Astrobiology Web: **http://astrobiology.com/ (http://astrobiology.com/)** . A news site with good information and lots of material.

Exploring Life’s Origins: **http://exploringorigins.org/index.html (http://exploringorigins.org/index.html)** . A website for the Exploring Origins Project, part of the multimedia exhibit of the Boston Museum of Science. Explore the origin of life on Earth with an interactive timeline, gain a deeper knowledge of the role of RNA, “build” a cell, and explore links to learn more about astrobiology and other related information.

History of Astrobiology: **https://astrobiology.nasa.gov/about/history-of-astrobiology/ (https://astrobiology.nasa.gov/about/history-of-astrobiology/)** . By Marc Kaufman, on the NASA Astrobiology site.

Life, Here and Beyond: **https://astrobiology.nasa.gov/about/ (https://astrobiology.nasa.gov/about/)** . By Marc Kaufman, on the NASA Astrobiology site.

SETI

Berkeley SETI Research Center: **https://seti.berkeley.edu/ (https://seti.berkeley.edu/)** . The University of California group recently received a $100 million grant from a Russian billionaire to begin the Breakthrough: Listen project.

Fermi Paradox: **http://www.seti.org/seti-institute/project/details/fermi-paradox (http://www.seti.org/seti-institute/project/details/fermi-paradox)** . Could we be alone in our part of the Galaxy or, more dramatic still, could we be the only technological society in the universe? A useful discussion.

Planetary Society: **http://www.planetary.org/explore/projects/seti/ (http://www.planetary.org/explore/projects/seti/)** . This advocacy group for exploration has several pages devoted to the search for life.

SETI Institute: **http://www.seti.org (http://www.seti.org)** . A key organization in the search for life in the universe; the institute’s website is full of information and videos about both astrobiology and SETI.

SETI: **http://www.skyandtelescope.com/tag/seti/ (http://www.skyandtelescope.com/tag/seti/)** . *Sky & Telescope* magazine offers good articles on this topic.

Videos

Astrobiology

Copernicus Complex: Are We Special in the Cosmos?: **https://www.youtube.com/watch?v=ERp0AHYRm_Q (https://www.youtube.com/watch?v=ERp0AHYRm_Q)** . A video of a popular-level talk by Caleb Scharf of Columbia University (1:18:54).

Life at the Edge: Life in Extreme Environments on Earth and the Search for Life in the Universe: **https://www.youtube.com/watch?v=91JQmTn0SF0 (https://www.youtube.com/watch?v=91JQmTn0SF0)** . A video of a 2009 nontechnical lecture by Lynn Rothschild of NASA Ames Research Center (1:31:21).

Saturn’s Moon Titan: A World with Rivers, Lakes, and Possibly Even Life: **https://www.youtube.com/watch?v=bbkTJeHoOKY (https://www.youtube.com/watch?v=bbkTJeHoOKY)** . A video of a 2011 talk by Chris McKay of NASA Ames Research Center (1:23:33).

SETI

Allen Telescope Array: The Newest Pitchfork for Exploring the Cosmic Haystack: **https://www.youtube.com/watch?v=aqsI1HZCgUM (https://www.youtube.com/watch?v=aqsI1HZCgUM)** . A 2013 popular-level lecture by Jill Tarter of the SETI Institute (1:45:55).

Confessions of an Alien Hunter: **http://fora.tv/2009/03/31/Seth_Shostak_Confessions_of_an_Alien_Hunter (http://fora.tv/2009/03/31/Seth_Shostak_Confessions_of_an_Alien_Hunter)** . 2009 interview with Seth Shostak on FORA TV (36:27).

Search for Extra-Terrestrial Intelligence: Necessarily a Long-Term Strategy: **http://www.longnow.org/seminars/02004/jul/09/the-search-for-extra-terrestrial-intelligence-necessarily-a-long-term-strategy/ (http://www.longnow.org/seminars/02004/jul/09/the-search-for-extra-terrestrial-intelligence-necessarily-a-long-term-strategy/)** . 2004 talk by Jill Tarter at the Long Now Foundation (1:21:13).

Search for Intelligent Life Among the Stars: New Strategies: **https://www.youtube.com/watch?v=m9WxW2ktcKU (https://www.youtube.com/watch?v=m9WxW2ktcKU)** . A 2010 nontechnical talk by Seth Shostak of the SETI Institute (1:29:58).

COLLABORATIVE GROUP ACTIVITIES

A. If one of the rocks from Mars examined by a future mission to the red planet does turn out to have unambiguous signs of ancient life that formed on Mars, what does your group think would be the implications of such a discovery for science and for our view of life elsewhere? Would such a discovery have any long-term effects on your own thinking?

B. Suppose we receive a message from an intelligent civilization around another star. What does your group think the implications of this discovery would be? How would your own thinking or personal philsophy be affected by such a discovery?

C. A radio message has been received from a civilization around a star 40 light-years away, which contains (in pictures) quite a bit of information about the beings that sent the message. The president of the United States has appointed your group a high-level commission to advise whether humanity should answer the message (which was not particularly directed at us, but comes from a beacon that, like a lighthouse, sweeps out a circle in space). How would you advise the president? Does your group agree on your answer or do you also have a minority view to present?

D. If there is no evidence that UFOs are extraterrestrial visitors, why does your group think that television shows, newspapers, and movies spend so much time and effort publicizing the point of view that UFOs are craft from other worlds? Make a list of reasons. Who stands to gain by exaggerating stories of unknown lights in the sky or simply fabricating stories that alien visitors are already here?

E. Does your group think scientists should simply ignore all the media publicity about UFOs or should they try to respond? If so, how should they respond? Does everyone in the group agree?

F. Suppose your group is the team planning to select the most important sights and sounds of Earth to record and put on board the next interstellar spacecraft. What pictures (or videos) and sounds would you include to represent our planet to another civilization?

G. Let’s suppose Earth civilization has decided to broadcast a message announcing our existence to other possible civilizations among the stars. Your group is part of a large task force of scientists, communications specialists, and people from the humanities charged with deciding the form and content of our message. What would you recommend? Make a list of ideas.

H. Think of examples of contact with aliens you have seen in movies and on TV. Discuss with your group how realistic these have been, given what you have learned in this class. Was the contact in person (through traveling) or using messages? Why do you think Hollywood does so many shows and films that are not based on our scientific understanding of the universe?

I. Go through the Drake equation with your group and decide on values for each factor in the estimate. (If you disagree on what a factor should be within the group, you can have a “minority report.”) Based on the factors, how many intelligent, communicating civilizations do you estimate to be thriving in our Galaxy right now?

EXERCISES

Review Questions

1. What is the Copernican principle? Make a list of scientific discoveries that confirm it.

2. Where in the solar system (and beyond) have scientists found evidence of organic molecules?

3. Give a short history of the atoms that are now in your little finger, going back to the beginning of the universe.

4. What is a biomarker? Give some possible examples of biomarkers we might look for beyond the solar system.

5. Why are Mars and Europa the top targets for the study of astrobiology?

6. Why is traveling between the stars (by creatures like us) difficult?

7. What are the advantages to using radio waves for communication between civilizations that live around different stars? List as many as you can.

8. What is the “cosmic haystack problem”? List as many of its components as you can think of.

9. What is a habitable zone?

10. Why is the simultaneous detection of methane and oxygen in an atmosphere a good indication of the existence of a biosphere on that planet?

11. What are two characteristic properties of life that distinguish it from nonliving things?

12. What are the three requirements that scientists believe an environment needs to supply life with in order to be considered habitable?

13. Can you name five environmental conditions that, in their extremes, microbial life has been challenged by and has learned to survive on Earth?

Thought Questions

14. Would a human have been possible during the first generation of stars that formed right after the Big Bang? Why or why not?

15. If we do find life on Mars, what might be some ways to check whether it formed separately from Earth life, or whether exchanges of material between the two planets meant that the two forms of life have a common origin?

16. What kind of evidence do you think would convince astronomers that an extraterrestrial spacecraft has landed on Earth?

17. What are some reasons that more advanced civilizations might want to send out messages to other star systems?

18. What are some answers to the Fermi paradox? Can you think of some that are not discussed in this chapter?

19. Why is there so little evidence of Earth’s earliest history and therefore the period when life first began on our planet?

20. Why was the development of photosynthesis a major milestone in the evolution of life?

21. Does all life on Earth require sunshine?

22. Why is life unlikely to be found on the surface of Mars today?

23. In this chapter, we identify these characteristic properties of life: life extracts energy from its environment, and has a means of encoding and replicating information in order to make faithful copies of itself. Does this definition fully capture what we think of as “life”? How might our definition be biased by our terrestrial environment?

24. Given that no sunlight can penetrate Europa’s ice shell, what would be the type of energy that could make some form of europan life possible?

25. Why is Saturn’s moon Enceladus such an exciting place to send a mission?

26. In addition to an atmosphere dominated by nitrogen, how else is Saturn’s moon Titan similar to Earth?

27. How can a planet’s atmosphere affect the width of the habitable zone in its planetary system?

28. Why are we limited to finding life on planets orbiting other stars to situations where the biosphere has created planet-scale changes?

Figuring For Yourself

29. Suppose astronomers discover a radio message from a civilization whose planet orbits a star 35 light-years away. Their message encourages us to send a radio answer, which we decide to do. Suppose our governing bodies take 2 years to decide whether and how to answer. When our answer arrives there, their governing bodies also take two of our years to frame an answer to us. How long after we get their first message can we hope to get their reply to ours? (A question for further thinking: Once communication gets going, should we continue to wait for a reply before we send the next message?)

30. The light a planet receives from the Sun (per square meter of planet surface) decreases with the square of the distance from the Sun. So a planet that is twice as far from the Sun as Earth receives $(1/2)^2 = 0.25$ times (25%) as much light and a planet that is three times as far from the Sun receives $(1/3)^2 = 0.11$ times (11%) as much light. How much light is received by the moons of Jupiter and Saturn (compared to Earth), worlds which orbit 5.2 and 9.5 times farther from the Sun than Earth?

31. Think of our Milky Way Galaxy as a flat disk of diameter 100,000 light-years. Suppose we are one of 1000 civilizations, randomly distributed through the disk, interested in communicating via radio waves. How far away would the nearest such civilization be from us (on average)?

A HOW TO STUDY FOR AN INTRODUCTORY ASTRONOMY CLASS

In this brief appendix, we want to give you some hints for the effective study of astronomy. These suggestions are based on ideas from good teachers and good students around the United States. Your professor will probably have other, more specific suggestions for doing well in your class.

Astronomy, the study of the universe beyond the borders of our planet, is one of the most exciting and rapidly changing branches of science. Even scientists from other fields often confess to having had a lifelong interest in astronomy, though they may now be doing something earthbound—like biology, chemistry, engineering, or writing software.

But some of the things that make astronomy so interesting also make it a challenge for the beginning student. The universe is a big place, full of objects and processes that do not have familiar counterparts here on Earth. Like a visitor to a new country, it will take you a while to feel familiar with the territory or the local customs. Astronomy, like other sciences, also has its own special vocabulary, some of which you will have to learn to communicate well with your professor and classmates.

Still, hundreds of thousands of non-science majors take an introductory astronomy course every year, and surveys show that students from a wide range of backgrounds have succeeded in (and even enjoyed) these classes. Astronomy is for everyone, not just those who are “science oriented.”

So, here are some suggestions to help you increase your chances of doing well in your astronomy class.

1. The best advice we can give you is to be sure to leave enough time in your schedule to study the material in this class regularly. It sounds obvious, but it is not very easy to catch up with a subject like astronomy by trying to do everything just before an exam. (As astronomers like to put it, you can’t learn the whole universe in one night!) Try to put aside some part of each day, or every other day, when you can have uninterrupted time for reading and studying astronomy.
2. In class, put your phone away and focus on the class activities. If you have to use a laptop or tablet in class, make a pact with yourself that you will *not* check email, get on social media, or play games during class. A number of careful studies of student behavior and grades have shown that students are not as good at such multi-tasking as they think they are, and that students who do *not* use screens during class get significantly better grades in the end.
3. Try to take careful notes during class. Many students start college without good note-taking habits. If you are not a good note-taker, try to get some help. Many colleges and universities have student learning centers that offer short courses, workbooks, tutors, or videos on developing good study habits. Good note-taking skills will also be useful for many jobs or activities you are likely get involved with after college.
4. Try to read each assignment in the textbook twice, once before it is discussed in class, and once afterward. Take notes as you read or use a highlighter to outline ideas that you may want to review later.
5. Form a small astronomy study group with people in your class. Get together with them regularly and discuss what you have been learning. Also, focus on the topics that may be giving group members trouble. Make up sample exam questions and make sure everyone in the group can answer them confidently. If you have always studied alone, you may at first resist this idea, but don’t be too hasty to say no. Study groups are a very effective way to digest a large amount of new information.
6. Before each exam, create a concise outline of the main ideas discussed in class and presented in your text. Compare your outline with those of other students as a check on your own study habits.
7. If your professor suggests doing web-based sample quizzes, or looking at online apps, animations, or study guides, take advantage of these resources to enhance your studying.

8. At the end of each chapter in this textbook you, will find four kinds of questions. The Collaborative Group Activities are designed to encourage you follow up on the material in the chapter as a group, rather than individually. Review Questions help you see if you have learned the material in the chapter. Thought Questions test deeper understanding by asking you to apply your knowledge to new situations. And Figuring for Yourself exercises test and extend some of the mathematical examples in the chapter. (Not all professors will use the math sections; if they don't, you may not have homework from this section.)
9. If you find a topic in the text or in class especially difficult or interesting, talk to your professor or teaching assistant. Many students are scared to show their ignorance in front of their teacher, but we can assure you that most professors and TA's *like* it when students come to office hours and show that they care enough about the course to ask for help.
10. Don't stay up all night before a test and then expect your mind to respond well. For the same reason, don't eat a big meal just before a test, since we all get a little sleepy and don't think as clearly after a big meal. Take many deep breaths and try to relax during the test itself.
11. Don't be too hard on yourself! If astronomy is new to you, many of the ideas and terms in this book may be unfamiliar. Astronomy is like any new language: it may take a while to become a good conversationalist. Practice as much as you can, but also realize that it is natural to feel overwhelmed by the vastness of the universe and the variety of things that are going on in it.

B ASTRONOMY WEBSITES, IMAGES, AND APPS

Throughout the textbook, we suggest useful resources for students on the specific topics in a given chapter. Here, we offer some websites for exploring astronomy in general, plus good sites for viewing and downloading the best astronomy images, and guides to astronomical apps for smartphones and tablets. This is not an exhaustive listing, but merely a series of suggestions to whet the appetite of those wanting to go beyond the textbook.

Websites For Exploring Astronomy In General

Astronomical Organizations

Amateur Astronomy Clubs. In most large cities and a number of rural areas, there are *amateur astronomy clubs*, where those interested in the hobby of astronomy gather to observe the sky, share telescopes, hear speakers, and help educate the public about the night sky. To find an astronomy club near you, you can try the following sites:

- Night Sky Network club finder: **http://nightsky.jpl.nasa.gov/club-map.cfm (http://nightsky.jpl.nasa.gov/club-map.cfm)** .
- *Sky & Telescope* Magazine astronomy clubs and organizations: **http://www.skyandtelescope.com/community/organizations (http://www.skyandtelescope.com/community/organizations)** .
- *Astronomy* Magazine club finder: **http://www.astronomy.com/groups.aspx (http://www.astronomy.com/groups.aspx)** .
- Astronomical League astronomy clubs and societies: **http://www.astroleague.org/societies/all (http://www.astroleague.org/societies/all)** .
- Go-Astronomy club search: **http://www.go-astronomy.com/astro-club-search.htm (http://www.go-astronomy.com/astro-club-search.htm)** .

American Astronomical Society: **http://www.aas.org (http://www.aas.org)** . Composed mainly of professional astronomers. They have an active education office and various materials for students and the public on the education pages of their website.

Astronomical League: **http://www.astroleague.org (http://www.astroleague.org)** . The league is the umbrella organization of American astronomy clubs. They offer a newsletter, national observing programs, and support for how to form and support a club.

Astronomical Society of the Pacific: **http://www.astrosociety.org (http://www.astrosociety.org)** . Founded in 1889, this international society is devoted to astronomy education and outreach. They have programs, publications, and materials for families, teachers, amateur astronomers, museum guides, and anyone interested in astronomy.

European Space Agency (ESA): **http://www.esa.int/ (http://www.esa.int/)** . Information on European space missions with an excellent gallery of images.

International Astronomical Union (IAU): **http://www.iau.org/ (http://www.iau.org/)** . International organization for professional astronomers; see the menu choice “IAU for the Public” for information on naming astronomical objects and other topics of interest to students.

International Dark-Sky Association: **http://www.darksky.org (http://www.darksky.org)** . Dedicated to combating light pollution, the encroachment of stray light that wastes energy and washes out the glories of the night sky.

NASA: **http://www.nasa.gov (http://www.nasa.gov)** . NASA has a wide range of information on its many websites; the trick is to find what you need. Most space missions and NASA centers have their own sites.

Planetary Society: **http://www.planetary.org (http://www.planetary.org)** . Founded by the late Carl Sagan and others, this group works to encourage planetary exploration and the search for life elsewhere. While much of their work is advocacy, they have some educational outreach too.

Royal Astronomical Society of Canada: **http://www.rasc.ca/ (http://www.rasc.ca/)** . Unites professional and amateur astronomers around Canada; has 28 centers with local activities, plus national magazines and meetings.

Some Astronomical Publications Students Can Read

Astronomy Now: **http://www.astronomynow.com/ (http://www.astronomynow.com/)** . A colorful British monthly, with excellent articles about astronomy, the history of astronomy, and stargazing.

Astronomy: **http://www.astronomy.com (http://www.astronomy.com)** . Has the largest circulation of any magazine devoted to the universe and is designed especially for astronomy hobbyists and armchair astronomers.

Free Astronomy: **http://www.astropublishing.com/ (http://www.astropublishing.com/)** . A new web-based publication, with European roots.

Scientific American: **http://www.sciam.com (http://www.sciam.com)** . Offers one astronomy article about every other issue. These articles, a number of which are reproduced on their website, are at a slightly higher level, but—often being written by the astronomers who have done the work—are authoritative and current.

Sky & Telescope: **http://skyandtelescope.com (http://skyandtelescope.com)** . An older and somewhat higher-level magazine for astronomy hobbyists. Many noted astronomers write for this publication.

Sky News: **http://www.skynews.ca/ (http://www.skynews.ca/)** . A Canadian publication, featuring both astronomy and stargazing information. It also lists Canadian events for hobbyists.

StarDate: **https://stardate.org/ (https://stardate.org/)** . Magazine that accompanies the brief radio program, with a useful website for beginners.

Sites that Cover Astronomy News

Exploring the Universe: **http://fraknoi.blogspot.com (http://fraknoi.blogspot.com)** . An astronomy news blog by one of the original authors of this textbook.

Portal to the Universe: **http://www.portaltotheuniverse.org/ (http://www.portaltotheuniverse.org/)** . A site that gathers online astronomy and space news items, blogs, and pictures.

Science@NASA news stories and newscasts: **http://science.nasa.gov/science-news/ (http://science.nasa.gov/science-news/)** . Well-written stories with, of course, a NASA focus.

Space.com: **http://www.space.com/news/ (http://www.space.com/news/)** . A commercial site, but with wide coverage of space and astronomy news.

Universe Today: **http://www.universetoday.com/ (http://www.universetoday.com/)** . Another commercial site, with good articles by science journalists, but a lot of ads.

Sites for Answering Astronomical Questions

Ask an Astrobiologist: **http://astrobiology.nasa.gov/ask-an-astrobiologist/ (http://astrobiology.nasa.gov/ask-an-astrobiologist/)** . On this site from the National Astrobiology Institute at NASA, astronomer David Morrison answered questions about the search for life on other planets, the origin of life on Earth, and many other topics.

Ask an Astronomer at Lick Observatory: **http://www.ucolick.org/~mountain/AAA/ (http://www.ucolick.org/~mountain/AAA/)** . Graduate students and staff members at this California observatory answered selected astronomy questions, particularly from high school students.

Ask an Astrophysicist: **http://imagine.gsfc.nasa.gov/docs/ask_astro/ask_an_astronomer.html (http://imagine.gsfc.nasa.gov/docs/ask_astro/ask_an_astronomer.html)** . Questions and answers at NASA's Laboratory for High-Energy Astrophysics focus on X-ray and gamma-ray astronomy, and such objects as black holes, quasars, and supernovae.

Ask an Infrared Astronomer: **http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ask_astronomer/faq/index.shtml (http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ask_astronomer/faq/index.shtml)** . A site from the California Institute of Technology, with an archive focusing on infrared (heat-ray) astronomy and the discoveries it makes about cool objects in the universe. No longer taking new questions.

Ask the Astronomer: **http://www.astronomycafe.net/qadir/qanda.html (http://www.astronomycafe.net/qadir/qanda.html)** . This site, run by astronomer Sten Odenwald, is no longer active, but lists 3001 answers to questions asked in the mid-1990s. They are nicely organized by topic.

Ask the Experts at PhysLink: **http://www.physlink.com/Education/AskExperts/index.cfm (http://www.physlink.com/Education/AskExperts/index.cfm)** . Lots of physics questions answered, with some astronomy as well, at this physics education site. Most answers are by physics teachers, not astronomers. Still taking new questions.

Ask the Space Scientist: **http://image.gsfc.nasa.gov/poetry/ask/askmag.html (http://image.gsfc.nasa.gov/poetry/ask/askmag.html)** . An archive of questions about the Sun and its interactions with Earth, answered by astronomer Sten Odenwald. Not accepting new questions.

Curious about Astronomy?: **http://curious.astro.cornell.edu (http://curious.astro.cornell.edu)** . An ask-an-astronomer site run by graduate students and professors of astronomy at Cornell University. Has searchable archives and is still answering new questions.

Miscellaneous Sites of Interest

A Guide to Careers in Astronomy: **http://aas.org/files/resources/Careers-in-Astronomy.pdf (http://aas.org/files/resources/Careers-in-Astronomy.pdf)** . From the American Astronomical Society.

Astronomical Pseudo-Science: A Skeptic's Resource List: **http://www.astrosociety.org/pseudo (http://www.astrosociety.org/pseudo)** . Readings and websites that analyze such claims as astrology, UFOs, moon-landing denial, creationism, human faces on other worlds, astronomical disasters, and more.

Astronomy for Beginners: **http://www.skyandtelescope.com/astronomy-information/ (http://www.skyandtelescope.com/astronomy-information/)** . A page to find resources for getting into amateur astronomy.

Science Fiction Stories with Good Astronomy and Physics: **http://www.astrosociety.org/scifi (http://www.astrosociety.org/scifi)** .

Space Calendar: **http://www2.jpl.nasa.gov/calendar/ (http://www2.jpl.nasa.gov/calendar/)** . Ron Baalke at the Jet Propulsion Laboratory keeps a listing of what space events happened on each day of the year; great if you need a reason to have a space-theme party.

Unheard Voices: The Astronomy of Many Cultures: **http://multiverse.ssl.berkeley.edu/multicultural (http://multiverse.ssl.berkeley.edu/multicultural)** . A guide to resources about the astronomy of native, African, Asian, and other non-Western groups.

Selected Websites For Viewing And Downloading Astronomical Images

The Top Image Sites

Astronomy Picture of the Day: **http://antwrp.gsfc.nasa.gov/apod/lib/aptree.html (http://antwrp.gsfc.nasa.gov/apod/lib/aptree.html)** . Two space scientists scour the internet and feature one interesting astronomy image each day.

European Southern Observatory Photo Gallery: **http://www.eso.org/public/images/ (http://www.eso.org/public/images/)** . Magnificent color images from ESO's largest telescopes. See the topical menu at the top.

Hubble Space Telescope Images: **http://hubblesite.org/images/gallery (http://hubblesite.org/images/gallery)** . Starting at this page, you can select from among many hundreds of Hubble pictures by subject. Other ways to approach these images are through the more public-oriented Hubble Gallery (**http://hubblesite.org/gallery/ (http://hubblesite.org/gallery/)**) or the European ESO site (**http://www.spacetelescope.org/images/ (http://www.spacetelescope.org/images/)**).

National Optical Astronomy Observatories Image Gallery: **http://www.noao.edu/image_gallery/ (http://www.noao.edu/image_gallery/)** . Growing archive of images from the many telescopes that are at the United States' National Observatories.

Planetary Photojournal: **http://photojournal.jpl.nasa.gov/index.html (http://photojournal.jpl.nasa.gov/index.html)** . Features thousands of images from NASA's extensive set of planetary exploration missions with a good search menu. Does not include most of the missions from other countries.

The World at Night: **http://www.twanight.org/newTWAN/index.asp (http://www.twanight.org/newTWAN/index.asp)** . Dramatic night-sky images by professional photographers who are amateur astronomers. Note that while many of the astronomy sites allow free use of their images, these are copyrighted by photographers who make their living selling them.

Other Useful General Galleries

Anglo-Australian Observatory: **http://203.15.109.22/images/ (http://203.15.109.22/images/)** . Soon at **https://www.aao.gov.au/public/images (https://www.aao.gov.au/public/images)** . Great copyrighted color images by leading astro-photographer David Malin and others.

Canada-France-Hawaii Telescope: **http://www.cfht.hawaii.edu/HawaiianStarlight/images.html (http://www.cfht.hawaii.edu/HawaiianStarlight/images.html)** . Remarkable color images from a major telescope on top of the Mauna Kea peak in Hawaii.

European Space Agency Gallery: **http://www.esa.int/spaceinimages/Images (http://www.esa.int/spaceinimages/Images)** . Access images from such missions as Mars Express, Rosetta, and Herschel.

Gemini Observatory Images: **http://www.gemini.edu/index.php?option=com_gallery (http://www.gemini.edu/index.php?option=com_gallery)** . Images from a pair of large telescopes in the northern and the southern hemispheres.

Isaac Newton Group of Telescopes Image Gallery: **http://www.ing.iac.es/PR/images_index.html (http://www.ing.iac.es/PR/images_index.html)** . Beautiful images from the Herschel, Newton, and Kapteyn telescopes on La Palma.

National Radio Astronomy Observatory Image Gallery: **http://images.nrao.edu/ (http://images.nrao.edu/)** . Organized by topic, the images show objects and processes that give off radio waves.

Our Infrared World Gallery: **http://coolcosmos.ipac.caltech.edu/image_galleries/missions_gallery.html (http://coolcosmos.ipac.caltech.edu/image_galleries/missions_gallery.html)** . Images from a variety of infrared astronomy telescopes and missions. See also their "Cool Cosmos" site for the public: **http://coolcosmos.ipac.caltech.edu/ (http://coolcosmos.ipac.caltech.edu/)** .

Some Galleries on Specific Subjects

Astronaut Photography of Earth: **http://eol.jsc.nasa.gov/ (http://eol.jsc.nasa.gov/)** .

Chandra X-Ray Observatory Images: **http://chandra.harvard.edu/photo/category.html (http://chandra.harvard.edu/photo/category.html)** .

NASA Human Spaceflight Gallery: **https://www.flickr.com/photos/nasa2explore (https://www.flickr.com/photos/nasa2explore)** or **http://spaceflight1.nasa.gov/gallery/index.html (http://spaceflight1.nasa.gov/gallery/index.html)** . Astronaut images.

Robert Gendler: **http://www.robgendlerastropics.com/ (http://www.robgendlerastropics.com/)** . One of the amateur astro-photographers who comes closest to being professional.

Sloan Digital Sky Survey Images: **http://www.sdss.org/gallery/ (http://www.sdss.org/gallery/)** .

Solar Dynamics Observatory Gallery: **http://sdo.gsfc.nasa.gov/gallery/main (http://sdo.gsfc.nasa.gov/gallery/main)** . Sun images.

Spitzer Infrared Telescope Images: **http://www.spitzer.caltech.edu/images (http://www.spitzer.caltech.edu/images)** .

Astronomy Apps For Smartphones And Tablets

A pretty comprehensive listing of such apps with brief descriptions and links to their websites can be found at: **http://dx.doi.org/10.3847/AER2011036 (http://dx.doi.org/10.3847/AER2011036)** . The list is now a few years old, but most of the apps are still available.

Listings and Reviews of Apps

11 Best Astronomy Apps for Amateur Star Gazers: **http://www.businessinsider.com/11-best-astronomy-apps-for-amateurs-2013-10 (http://www.businessinsider.com/11-best-astronomy-apps-for-amateurs-2013-10)** . From Kelly Dickerson (2013).

14 Best Astronomy Apps for Stargazers and Space Lovers: **http://nerdsmagazine.com/best-astronomy-apps-for-android/ (http://nerdsmagazine.com/best-astronomy-apps-for-android/)** . Viney Dhiman's recommendations, part of *Nerd's Magazine* (2014).

15 Best Astronomy Applications for iPhone: **http://www.iphoneness.com/iphone-apps/top-astronomy-applications-for-iphone/ (http://www.iphoneness.com/iphone-apps/top-astronomy-applications-for-iphone/)** . From iPhoneness.

Apps for Stargazing: **http://appadvice.com/appguides/show/astronomy-apps (http://appadvice.com/**

appguides/show/astronomy-apps) . App Advice site’s reviews.

NASA Apps for Smartphones and Tablets: **https://www.nasa.gov/connect/apps.html (https://www.nasa.gov/connect/apps.html)** .

Phone/Tablet Apps and the Practical Astronomer: **http://www.cloudynights.com/page/articles/cat/user-reviews/phonetablet-apps-and-the-practical-astronomer-r2925 (http://www.cloudynights.com/page/articles/cat/user-reviews/phonetablet-apps-and-the-practical-astronomer-r2925)** . Active amateur astronomer Tom Fowler reviews 22 apps (2014).

Sky & Telescope Mobile Apps: **http://www.skyandtelescope.com/sky-and-stargazing-apps/ (http://www.skyandtelescope.com/sky-and-stargazing-apps/)** . Apps from *Sky & Telescope* Magazine.

Smartphone Apps Can Make Astronomy as Easy as Point and Gaze: **http://www.heraldnet.com/article/20140511/LIVING/140519988 (http://www.heraldnet.com/article/20140511/LIVING/140519988)** . Mike Lynch for HeraldNet (2014).

C SCIENTIFIC NOTATION

In astronomy (and other sciences), it is often necessary to deal with very large or very small numbers. In fact, when numbers become truly large in everyday life, such as the national debt in the United States, we call them astronomical. Among the ideas astronomers must routinely deal with is that the Earth is 150,000,000,000 meters from the Sun, and the mass of the hydrogen atom is 0.00000000000000000000000000167 kilograms. No one in his or her right mind would want to continue writing so many zeros!

Instead, scientists have agreed on a kind of shorthand notation, which is not only easier to write, but (as we shall see) makes multiplication and division of large and small numbers much less difficult. If you have never used this powers-of-ten notation or scientific notation, it may take a bit of time to get used to it, but you will soon find it much easier than keeping track of all those zeros.

Writing Large Numbers

In scientific notation, we generally agree to have only one number to the left of the decimal point. If a number is not in this format, it must be changed. The number 6 is already in the right format, because for integers, we understand there to be a decimal point to the right of them. So 6 is really 6., and there is indeed only one number to the left of the decimal point. But the number 965 (which is 965.) has three numbers to the left of the decimal point, and is thus ripe for conversion.

To change 965 to proper form, we must make it 9.65 and then keep track of the change we have made. (Think of the number as a weekly salary and suddenly it makes a lot of difference whether we have $965 or $9.65.) We keep track of the number of places we moved the decimal point by expressing it as a power of ten. So 965 becomes 9.65×10^2 or 9.65 multiplied by ten to the second power. The small raised 2 is called an exponent, and it tells us how many times we moved the decimal point to the left.

Note that 10^2 also designates 10 squared, or 10×10, which equals 100. And 9.65×100 is just 965, the number we started with. Another way to look at scientific notation is that we separate out the messy numbers out front, and leave the smooth units of ten for the exponent to denote. So a number like 1,372,568 becomes 1.372568 times a million (10^6) or 1.372568 times 10 multiplied by itself 6 times. We had to move the decimal point six places to the left (from its place after the 8) to get the number into the form where there is only one digit to the left of the decimal point.

The reason we call this powers-of-ten notation is that our counting system is based on increases of ten; each place in our numbering system is ten times greater than the place to the right of it. As you have probably learned, this got started because human beings have ten fingers and we started counting with them. (It is interesting to speculate that if we ever meet intelligent life-forms with only eight fingers, their counting system would probably be a powers-of-eight notation!)

So, in the example we started with, the number of meters from Earth to the Sun is 1.5×10^{11}. Elsewhere in the book, we mention that a string 1 light-year long would fit around Earth’s equator 236 million or 236,000,000 times. In scientific notation, this would become 2.36×10^8. Now if you like expressing things in millions, as the annual reports of successful companies do, you might like to write this number as 236×10^6. However, the usual convention is to have only one number to the left of the decimal point.

Writing Small Numbers

Now take a number like 0.00347, which is also not in the standard (agreed-to) form for scientific notation. To put it into that format, we must make the first part of it 3.47 by moving the decimal point three places *to the right*.

Note that this motion to the right is the opposite of the motion to the left that we discussed above. To keep track, we call this change negative and put a minus sign in the exponent. Thus 0.00347 becomes 3.47×10^{-3}.

In the example we gave at the beginning, the mass of the hydrogen atom would then be written as 1.67×10^{-27} kg. In this system, one is written as 10^0, a tenth as 10^{-1}, a hundredth as 10^{-2}, and so on. Note that any number, no matter how large or how small, can be expressed in scientific notation.

Multiplication And Division

Scientific notation is not only compact and convenient, it also simplifies arithmetic. To multiply two numbers expressed as powers of ten, you need only multiply the numbers out front and then *add* the exponents. If there are no numbers out front, as in 100 × 100,000, then you just add the exponents (in our notation, $10^2 \times 10^5 = 10^7$). When there are numbers out front, you have to multiply them, but they are much easier to deal with than numbers with many zeros in them.

Here’s an example:

$$\left(3 \times 10^5\right) \times \left(2 \times 10^9\right) = 6 \times 10^{14}$$

And here’s another example:

$$\begin{aligned} 0.04 \times 6{,}000{,}000 &= \left(4 \times 10^{-2}\right) \times \left(6 \times 10^6\right) \\ &= 24 \times 10^4 \\ &= 2.4 \times 10^5 \end{aligned}$$

Note in the second example that when we added the exponents, we treated negative exponents as we do in regular arithmetic (−2 plus 6 equals 4). Also, notice that our first result had a 24 in it, which was not in the acceptable form, having two places to the left of the decimal point, and we therefore changed it to 2.4 and changed the exponent accordingly.

To divide, you divide the numbers out front and *subtract* the exponents. Here are several examples:

$$\begin{aligned} \frac{1{,}000{,}000}{1000} &= \frac{10^6}{10^3} = 10^{(6-3)} = 10^3 \\ \frac{9 \times 10^{12}}{2 \times 10^3} &= 4.5 \times 10^9 \\ \frac{2.8 \times 10^2}{6.2 \times 10^5} &= 0.452 \times 10^{-3} = 4.52 \times 10^{-4} \end{aligned}$$

In the last example, our first result was not in the standard form, so we had to change 0.452 into 4.52, and change the exponent accordingly.

If this is the first time that you have met scientific notation, we urge you to practice many examples using it. You might start by solving the exercises below. Like any new language, the notation looks complicated at first but gets easier as you practice it.

Exercises

1. At the end of September, 2015, the New Horizons spacecraft (which encountered Pluto for the first time in July 2015) was 4.898 billion km from Earth. Convert this number to scientific notation. How many astronomical units is this? (An astronomical unit is the distance from Earth to the Sun, or about 150 million km.)
2. During the first six years of its operation, the Hubble Space Telescope circled Earth 37,000 times, for a total

of 1,280,000,000 km. Use scientific notation to find the number of km in one orbit.

3. In a large university cafeteria, a soybean-vegetable burger is offered as an alternative to regular hamburgers. If 889,875 burgers were eaten during the course of a school year, and 997 of them were veggie-burgers, what fraction and what percent of the burgers does this represent?
4. In a 2012 Kelton Research poll, 36 percent of adult Americans thought that alien beings have actually landed on Earth. The number of adults in the United States in 2012 was about 222,000,000. Use scientific notation to determine how many adults believe aliens have visited Earth.
5. In the school year 2009–2010, American colleges and universities awarded 2,354,678 degrees. Among these were 48,069 PhD degrees. What fraction of the degrees were PhDs? Express this number as a percent. (Now go and find a job for all those PhDs!)
6. A star 60 light-years away has been found to have a large planet orbiting it. Your uncle wants to know the distance to this planet in old-fashioned miles. Assume light travels 186,000 miles per second, and there are 60 seconds in a minute, 60 minutes in an hour, 24 hours in a day, and 365 days in a year. How many miles away is that star?

Answers

1. 4.898 billion is 4.898×10^9 km. One astronomical unit (AU) is 150 million km = 1.5×10^8 km. Dividing the first number by the second, we get $3.27 \times 10^{(9-8)} = 3.27 \times 10^1$ AU.
2. $\frac{1.28 \times 10^9 \text{ km}}{3.7 \times 10^4 \text{ orbits}} = 0.346 \times 10^{(9-4)} = 0.346 \times 10^5 = 3.46 \times 10^4$ km per orbit.
3. $\frac{9.97 \times 10^2 \text{ veggie burgers}}{8.90 \times 10^5 \text{ total burgers}} = 1.12 \times 10^{(2-5)} = 1.12 \times 10^{(2-5)} = 1.12 \times 10^{-3}$ (or roughly about one thousandth) of the burgers were vegetarian. Percent means per hundred. So $\frac{1.12 \times 10^{-3}}{10^{-2}} = 1.12 \times 10^{(-3\ -(-2))} = 1.12 \times 10^{-1}$ percent (which is roughly one tenth of one percent).
4. 36% is 36 hundredths or 0.36 or 3.6×10^{-1}. Multiply that by 2.22×10^8 and you get about $7.99 \times 10^{(-1+8)} = 7.99 \times 10^7$ or almost 80 million people who believe that aliens have landed on our planet. We need more astronomy courses to educate all those people.
5. $\frac{4.81 \times 10^4}{2.35 \times 10^6} = 2.05 \times 10^{(4-6)} = 2.05 \times 10^{-2} = \text{about } 2\%$. (Note that in these examples we are rounding off some of the numbers so that we don't have more than 2 places after the decimal point.)
6. One light-year is the distance that light travels in one year. (Usually, we use metric units and not the old British system that the United States is still using, but we are going to humor your uncle and stick with miles.) If light travels 186,000 miles every second, then it will travel 60 times that in a minute, and 60 times that in an hour, and 24 times that in a day, and 365 times that in a year. So we have $1.86 \times 10^5 \times 6.0 \times 10^1 \times 6.0 \times 10^1 \times 2.4 \times 10^1 \times 3.65 \times 10^2$. So we multiply all the numbers out front together and add all the exponents. We get $586.57 \times 10^{10} = 5.86 \times 10^{12}$ miles in a light year (which is roughly 6 trillion miles—a heck of a lot of miles). So if the star is 60 light-years away, its distance in miles is $6 \times 10^1 \times 5.86 \times 10^{12} = 35.16 \times 10^{13} = 3.516 \times 10^{14}$ miles.

D UNITS USED IN SCIENCE

In the American system of measurement (originally developed in England), the fundamental units of length, weight, and time are the foot, pound, and second, respectively. There are also larger and smaller units, which include the ton (2240 lb), the mile (5280 ft), the rod (16 1/2 ft), the yard (3 ft), the inch (1/12 ft), the ounce (1/16 lb), and so on. Such units, whose origins in decisions by British royalty have been forgotten by most people, are quite inconvenient for conversion or doing calculations.

In science, therefore, it is more usual to use the *metric system,* which has been adopted in virtually all countries except the United States. Its great advantage is that every unit increases by a factor of ten, instead of the strange factors in the American system. The fundamental units of the metric system are:

- length: 1 meter (m)
- mass: 1 kilogram (kg)
- time: 1 second (s)

A meter was originally intended to be 1 ten-millionth of the distance from the equator to the North Pole along the surface of Earth. It is about 1.1 yd. A kilogram is the mass that on Earth results in a weight of about 2.2 lb. The second is the same in metric and American units.

Length

The most commonly used quantities of length of the metric system are the following.

Conversions

1 kilometer (km) = 1000 meters = 0.6214 mile
1 meter (m) = 0.001 km = 1.094 yards = 39.37 inches
1 centimeter (cm) = 0.01 meter = 0.3937 inch
1 millimeter (mm) = 0.001 meter = 0.1 cm
1 micrometer (μm) = 0.000001 meter = 0.0001 cm
1 nanometer (nm) = 10^{-9} meter = 10^{-7} cm

Table D1 Length

To convert from the American system, here are a few helpful factors:

- 1 mile = 1.61 km
- 1 inch = 2.54 cm

Mass

Although we don’t make the distinction very carefully in everyday life on Earth, strictly speaking the kilogram is a unit of mass (measuring the quantity of matter in a body, roughly how many atoms it has,) while the pound is a unit of weight (measuring how strongly Earth’s gravity pulls on a body).

The most commonly used quantities of mass of the metric system are the following.

Conversions
1 metric ton = 10^6 grams = 1000 kg (and it produces a weight of 2.205×10^3 lb on Earth)
1 kg = 1000 grams (and it produces a weight of 2.2046 lb on Earth)
1 gram (g) = 0.0353 oz (and the equivalent weight is 0.002205 lb)
1 milligram (mg) = 0.001 g

Table D2 Mass

A weight of 1 lb is equivalent on Earth to a mass of 0.4536 kg, while a weight of 1 oz is produced by a mass of 28.35 g.

Temperature

Three temperature scales are in general use:

- Fahrenheit (F); water freezes at 32 °F and boils at 212 °F.
- Celsius or centigrade[1] (C); water freezes at 0 °C and boils at 100 °C.
- Kelvin or absolute (K); water freezes at 273 K and boils at 373 K.

All molecular motion ceases at about −459 °F = −273 °C = 0 K, a temperature called *absolute zero.* Kelvin temperature is measured from this lowest possible temperature, and it is the temperature scale most often used in astronomy. Kelvins have the same value as centigrade or Celsius degrees, since the difference between the freezing and boiling points of water is 100 degrees in each. (Note that we just say “kelvins,” not kelvin degrees.)

On the Fahrenheit scale, the difference between the freezing and boiling points of water is 180 degrees. Thus, to convert Celsius degrees or kelvins to Fahrenheit degrees, it is necessary to multiply by 180/100 = 9/5. To convert from Fahrenheit degrees to Celsius degrees or kelvins, it is necessary to multiply by 100/180 = 5/9.

The full conversion formulas are:

- K = °C + 273
- °C = 0.555 × (°F – 32)
- °F = (1.8 × °C) + 32

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[1] Celsius is now the name used for centigrade temperature; it has a more modern standardization but differs from the old centigrade scale by less than 0.1°.

E SOME USEFUL CONSTANTS FOR ASTRONOMY

Physical Constants

Name	Value
speed of light (*c*)	2.9979×10^{8} m/s
gravitational constant (*G*)	6.674×10^{-11} $m^3/(kg\ s^2)$
Planck's constant (*h*)	6.626×10^{-34} J-s
mass of a hydrogen atom (M_H)	1.673×10^{-27} kg
mass of an electron (M_e)	9.109×10^{-31} kg
Rydberg constant (R_∞)	1.0974×10^{7} m^{-1}
Stefan-Boltzmann constant (σ)	5.670×10^{-8} $J/(s{\cdot}m^2\ deg^4)$[1]
Wien's law constant ($\lambda_{max}T$)	2.898×10^{-3} m K
electron volt (energy) (eV)	1.602×10^{-19} J
energy equivalent of 1 ton TNT	4.2×10^{9} J

Table E1

Astronomical Constants

Name	Value
astronomical unit (AU)	1.496×10^{11} m
Light-year (ly)	9.461×10^{15} m
parsec (pc)	3.086×10^{16} m = 3.262 light-years
sidereal year (y)	3.156×10^{7} s
mass of Earth (M_{Earth})	5.974×10^{24} kg
equatorial radius of Earth (R_{Earth})	6.378×10^{6} m
obliquity of ecliptic	23.4° 26′

Table E2

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[1] deg stands for degrees Celsius or kelvins

Astronomical Constants

Name	Value
surface gravity of Earth (g)	9.807 m/s^2
escape velocity of Earth (v_{Earth})	1.119×10^4 m/s
mass of Sun (M_{Sun})	1.989×10^{30} kg
equatorial radius of Sun (R_{Sun})	6.960×10^8 m
luminosity of Sun (L_{Sun})	3.85×10^{26} W
solar constant (flux of energy received at Earth) (S)	1.368×10^3 W/m^2
Hubble constant (H_0)	approximately 20 km/s per million light-years, or approximately 70 km/s per megaparsec

Table E2

F PHYSICAL AND ORBITAL DATA FOR THE PLANETS

Physical Data for the Major Planets

Major Planet	Mean Diameter (km)	Mean Diameter (Earth = 1)	Mass (Earth = 1)	Mean Density (g/cm^3)	Rotation Period (d)	Inclination of Equator to Orbit (°)	Surface Gravity (Earth = 1[g])	Velocity of Escape (km/s)
Mercury	4879	0.38	0.055	5.43	58.	0.0	0.38	4.3
Venus	12,104	0.95	0.815	5.24	−243.	177	0.90	10.4
Earth	12,756	1.00	1.00	5.51	1.000	23.4	1.00	11.2
Mars	6779	0.53	0.11	3.93	1.026	25.2	0.38	5.0
Jupiter	140,000	10.9	318	1.33	0.414	3.1	2.53	60.
Saturn	117,000	9.13	95.2	0.69	0.440	26.7	1.07	36.
Uranus	50,700	3.98	14.5	1.27	−0.718	97.9	0.89	21.
Neptune	49,200	3.86	17.2	1.64	0.671	29.6	1.14	23.

Table F1

Physical Data for Well-Studied Dwarf Planets

Well-Studied Dwarf Planet	Diameter (km)	Diameter (Earth = 1)	Mass (Earth = 1)	Mean Density (g/cm^3)	Rotation Period (d)	Inclination of Equator to Orbit (°)	Surface Gravity (Earth = 1[g])	Velocity of Escape (km/s)
Ceres	950	0.07	0.0002	2.2	0.378	3	0.03	0.5
Pluto	2470	0.18	0.0024	1.9	−6.387	122	0.06	1.3
Haumea	1700	0.13	0.0007	3	0.163	—	—	0.8
Makemake	1400	0.11	0.0005	2	0.321	—	—	0.8
Eris	2326	0.18	0.0028	2.5	1.25[1]	—	—	1.4

Table F2

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[1] This measurement is quite uncertain.

Orbital Data for the Major Planets

Major Planet	Semimajor Axis (AU)	Semimajor Axis (10^6 km)	Sidereal Period (y)	Sidereal Period (d)	Mean Orbital Speed (km/s)	Orbital Eccentricity	Inclination of Orbit to Ecliptic (°)
Mercury	0.39	58	0.24	88.0	47.9	0.206	7.0
Venus	0.72	108	0.6	224.7	35.0	0.007	3.4
Earth	1.00	149	1.00	365.2	29.8	0.017	0.0
Mars	1.52	228	1.88	687.0	24.1	0.093	1.9
Jupiter	5.20	778	11.86	—	13.1	0.048	1.3
Saturn	9.54	1427	29.46	—	9.6	0.056	2.5
Uranus	19.19	2871	84.01	—	6.8	0.046	0.8
Neptune	30.06	4497	164.82	—	5.4	0.010	1.8

Table F3

Orbital Data for Well-Studied Dwarf Planets

Well-Studied Dwarf Planet	Semimajor Axis (AU)	Semimajor Axis (10^6 km)	Sidereal Period (y)	Mean Orbital Speed (km/s)	Orbital Eccentricity	Inclination of Orbit to Ecliptic (°)
Ceres	2.77	414.0	4.6	18	0.08	11
Pluto	39.5	5915	248.6	4.7	0.25	17
Haumea	43.1	6452	283.3	4.5	0.19	28
Makemake	45.8	6850	309.9	4.4	0.16	29
Eris	68.0	10,120	560.9	3.4	0.44	44

Table F4

G SELECTED MOONS OF THE PLANETS

Note: As this book goes to press, nearly two hundred moons are now known in the solar system and more are being discovered on a regular basis. Of the major planets, only Mercury and Venus do not have moons. In addition to moons of the planets, there are many moons of asteroids. In this appendix, we list only the largest and most interesting objects that orbit each planet (including dwarf planets). The number given for each planet is discoveries through 2015. For further information see https://solarsystem.nasa.gov/planets/solarsystem/moons (https://solarsystem.nasa.gov/planets/solarsystem/moons) and https://en.wikipedia.org/wiki/List_of_natural_satellites (https://en.wikipedia.org/wiki/List_of_natural_satellites) .

Selected Moons of the Planets

Planet (moons)	Satellite Name	Discovery	Semimajor Axis (km × 1000)	Period (d)	Diameter (km)	Mass (10^{20} kg)	Density (g/cm^3)
Earth (1)	Moon	—	384	27.32	3476	735	3.3
Mars (2)	Phobos	Hall (1877)	9.4	0.32	23	1×10^{-4}	2.0
	Deimos	Hall (1877)	23.5	1.26	13	2×10^{-5}	1.7
Jupiter (67)	Amalthea	Barnard (1892)	181	0.50	200	—	—
	Thebe	Voyager (1979)	222	0.67	90	—	—
	Io	Galileo (1610)	422	1.77	3630	894	3.6
	Europa	Galileo (1610)	671	3.55	3138	480	3.0
	Ganymede	Galileo (1610)	1070	7.16	5262	1482	1.9
	Callisto	Galileo (1610)	1883	16.69	4800	1077	1.9
	Himalia	Perrine (1904)	11,460	251	170	—	—
Saturn (62)	Pan	Voyager (1985)	133.6	0.58	20	3×10^{-5}	—
	Atlas	Voyager (1980)	137.7	0.60	40	—	—

Table G1

Selected Moons of the Planets

Planet (moons)	Satellite Name	Discovery	Semimajor Axis (km × 1000)	Period (d)	Diameter (km)	Mass (10^{20} kg)	Density (g/cm^3)
	Prometheus	Voyager (1980)	139.4	0.61	80	—	—
	Pandora	Voyager (1980)	141.7	0.63	100	—	—
	Janus	Dollfus (1966)	151.4	0.69	190	—	—
	Epimetheus	Fountain, Larson (1980)	151.4	0.69	120	—	—
	Mimas	Herschel (1789)	186	0.94	394	0.4	1.2
	Enceladus	Herschel (1789)	238	1.37	502	0.8	1.2
	Tethys	Cassini (1684)	295	1.89	1048	7.5	1.3
	Dione	Cassini (1684)	377	2.74	1120	11	1.3
	Rhea	Cassini (1672)	527	4.52	1530	25	1.3
	Titan	Huygens (1655)	1222	15.95	5150	1346	1.9
	Hyperion	Bond, Lassell (1848)	1481	21.3	270	—	—
	Iapetus	Cassini (1671)	3561	79.3	1435	19	1.2
	Phoebe	Pickering (1898)	12,950	550 (R)[1]	220	—	—
Uranus (27)	Puck	Voyager (1985)	86.0	0.76	170	—	—

Table G1

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[1] R stands for retrograde rotation (backward from the direction that most objects in the solar system revolve and rotate).

Selected Moons of the Planets

Planet (moons)	Satellite Name	Discovery	Semimajor Axis (km × 1000)	Period (d)	Diameter (km)	Mass (10^{20} kg)	Density (g/cm^3)
	Miranda	Kuiper (1948)	130	1.41	485	0.8	1.3
	Ariel	Lassell (1851)	191	2.52	1160	13	1.6
	Umbriel	Lassell (1851)	266	4.14	1190	13	1.4
	Titania	Herschel (1787)	436	8.71	1610	35	1.6
	Oberon	Herschel (1787)	583	13.5	1550	29	1.5
Neptune (14)	Despina	Voyager (1989)	53	0.33	150	—	—
	Galatea	Voyager (1989)	62	0.40	150	—	—
	Larissa	Voyager (1989)	118	1.12	400	—	—
	Triton	Lassell (1846)	355	5.88 (R)[2]	2720	220	2.1
	Nereid	Kuiper (1949)	5511	360	340	—	—
Pluto (5)	Charon	Christy (1978)	19.7	6.39	1200	—	1.7
	Styx	Showalter et al (2012)	42	20	20	—	—
	Nix	Weaver et al (2005)	48	24	46	—	2.1
	Kerberos	Showalter et al (2011)	58	24	28	—	1.4

Table G1

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[2] R stands for retrograde rotation (backward from the direction that most objects in the solar system revolve and rotate).

Selected Moons of the Planets

Planet (moons)	Satellite Name	Discovery	Semimajor Axis (km × 1000)	Period (d)	Diameter (km)	Mass (10^{20} kg)	Density (g/cm^3)
	Hydra	Weaver et al (2005)	65	38	61	—	0.8
Eris (1)	Dysnomea	Brown et al (2005)	38	16	684	—	—
Makemake (1)	(MK2)	Parker et al (2016)	—	—	160	—	—
Haumea (2)	Hi’iaka	Brown et al (2005)	50	49	400	—	—
	Namaka	Brown et al (2005)	39	35	200	—	—

Table G1

H FUTURE TOTAL ECLIPSES

Future Total Solar Eclipses

We also include eclipses that are *annular*—where the Moon is directly in front of the Sun, but doesn't fully cover it—leaving a ring of light around the dark Moon's edges)

Future Total Solar Eclipses

Date	Type of Eclipse	Location on Earth[1]
September 1, 2016	Annular	S Atlantic Ocean, C Africa, Madagascar, Indian Ocean
February 26, 2017	Annular	SW Africa, S tip of South America
August 21, 2017	Total	U.S. and oceans on either side
July 2, 2019	Total	SW South America, Pacific Ocean
December 26, 2019	Annular	Saudi Arabia, S India, Malaysia
June 21, 2020	Annular	(very short) C Africa, Pakistan, India, China
December 14, 2020	Total	Chile, Argentina, and oceans on either side
June 10, 2021	Annular	N Canada, Greenland
December 4, 2021	Total	Only in Antarctica
April 20, 2023	Total[2]	Mostly in Indian and Pacific oceans, Indonesia
October 14, 2023	Annular	OR, NV, UT, NM, TX, C America, Colombia, Brazil
April 8, 2024	Total	N Mexico, U.S. (TX to ME), SE Canada and oceans on either side
October 2, 2024	Annular	S Chile, S Argentina, and oceans on either side
February 17, 2026	Annular	Only in Antarctica
August 12, 2026	Total	Greenland, Iceland, Spain
February 6, 2027	Annular	S Pacific, Argentina, Chile, Uruguay, S Atlantic
August 2, 2027	Total	Spain, Morocco, Egypt, Saudi Arabia, Yemen, Arabian Sea

Table H1

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[1] Remember that a total or annular eclipse is only visible on a narrow track. The same eclipse will be partial over a much larger area, but partial eclipses are not as spectacular as total ones.

[2] This is a so-called hybrid eclipse, which is total in some places and annular in others.

Future Total Solar Eclipses

Date	Type of Eclipse	Location on Earth
January 26, 2028	Annular	Ecuador, Peru, Brazil, North Atlantic Ocean, Portugal, Spain
July 22, 2028	Total	Indian Ocean, Australia, New Zealand, South Pacific Ocean

Table H1

Future Total Lunar Eclipses

Future Total Lunar Eclipses

Date	Location on Earth
January 31, 2018	Asia, Australia, W North America
July 27, 2018	S America, Asia, Africa, Australia, Indian Ocean
January 21, 2019	N America, S America, W Africa, W Europe
May 26, 2021	E Asia, Australia, Pacific Ocean, W North America, W South America
May 16, 2022	N America, S America, Europe, Africa
November 8, 2022	Asia, Australia, Pacific Ocean, N America, S America
March 14, 2025	Pacific Ocean, N America, S America, Atlantic Ocean, W Europe, W Africa
September 7, 2025	Europe, Africa, Asia, Australia, Indian Ocean
March 3, 2026	E Asia, Australia, Pacific Ocean, N America, C America
June 26, 2029	E North America, S America, Atlantic Ocean, W Europe, W Africa
December 20, 2029	E North America, E South America, Atlantic Ocean, Europe, Africa, Asia

Table H2

Additional Resources

For more information and detailed maps about eclipses, see these resources.

- NASA’s Eclipse Site: **http://eclipse.gsfc.nasa.gov/ (http://eclipse.gsfc.nasa.gov/)**
- Mr. Eclipse site for beginners by Dr. Fred Espenak: **http://www.mreclipse.com/ (http://www.mreclipse.com/)**

- Eclipse Weather and Maps by Meteorologist Jay Anderson: **http://eclipsophile.com/total-solar-eclipses/total-solar-eclipse-2017-august-21/ (http://eclipsophile.com/total-solar-eclipses/total-solar-eclipse-2017-august-21/)**
- Eclipse Maps by Michael Zeiler: **http://www.eclipse-maps.com/Eclipse-Maps/Welcome.html (http://www.eclipse-maps.com/Eclipse-Maps/Welcome.html)**
- Eclipse Information and Maps by Xavier Jubier: **http://xjubier.free.fr/en/site_pages/eclipses.html (http://xjubier.free.fr/en/site_pages/eclipses.html)**

I THE NEAREST STARS, BROWN DWARFS, AND WHITE DWARFS

The Nearest Stars, Brown Dwarfs, and White Dwarfs

Star	System	Discovery Name	Distance (light-year)	Spectral Type	Location: RA[1]	Location: Dec[2]	Luminosity (Sun = 1)
		Sun	—	G2 V	—	—	1
1	1	Proxima Centauri	4.2	M5.5 V	14 29	−62 40	5×10^{-5}
2	2	Alpha Centauri A	4.4	G2 V	14 39	−60 50	1.5
3		Alpha Centauri B	4.4	K2 IV	14 39	−60 50	0.5
4	3	Barnard's Star	6.0	M4 V	17 57	+04 42	4.4×10^{-4}
5	4	Wolf 359	7.8	M6 V	10 56	+07 00	2×10^{-5}
6	5	Lalande 21 185	8.3	M2 V	11 03	+35 58	5.7×10^{-3}
7	6	Sirius A	8.6	A1 V	06 45	−16 42	23.1
8		Sirius B	8.6	DA2[3]	06 45	−16 43	2.5×10^{-3}
9	7	Luyten 726-8 A	8.7	M5.5 V	01 39	−17 57	6×10^{-5}
10		Luyten 726-8 B (UV Ceti)	8.7	M6 V	01 39	−17 57	4×10^{-5}
11	8	Ross 154	9.7	M.05 V	18 49	−23 50	5×10^{-4}
12	9	Ross 248 (HH Andromedae)	10.3	M5.5 V	23 41	+44 10	1.0×10^{-4}
13	10	Epsilon Eridani	10.5	K2 V	03 32	−09 27	0.29
14	11	Lacaille 9352	10.7	M0.5 V	23 05	−35 51	0.011
15	12	Ross 128 (FI Virginis)	10.9	M4 V	11 47	+00 48	3.4×10^{-4}
16	13	Luyten 789-6 A (EZ Aquarii A)	11.3	M5 V	22 38	−15 17	5×10^{-5}

Table I1

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[1] Location (right ascension) given for Epoch 2000.0
[2] Location (declination) given for Epoch 2000.0
[3] White dwarf stellar remnant

The Nearest Stars, Brown Dwarfs, and White Dwarfs

Star	System	Discovery Name	Distance (light-year)	Spectral Type	Location: RA	Location: Dec	Luminosity (Sun = 1)
17		Luyten 789-6 B (EZ Aquarii B)	11.3	M5.5 V	22 38	−15 15	5×10^{-5}
18		Luyten 789-6 C (EZ Aquarii C)	11.3	M6.5 V	22 38	−15 17	2×10^{-5}
19	14	61 Cygni A	11.4	K5 V	21 06	+38 44	0.086
20		61 Cygni B	11.4	K7 V	21 06	+38 44	0.041
21	15	Procyon A	11.4	F51V	07 39	+05 13	7.38
22		Procyon B	11.4	wd[4]	07 39	+05 13	5.5×10^{-4}
23	16	Sigma 2398 A	11.5	M3 V	18 42	+59 37	0.003
24		Sigma 2398 B	11.5	M3.5 V	18 42	+59 37	1.4×10^{-3}
25	17	Groombridge 34 A (GX Andromedae)	11.6	M1.5 V	00 18	+44 01	6.4×10^{-3}
26		Groombridge 34 B (GQ Andromedae)	11.6	M3.5 V	00 18	+44 01	4.1×10^{-4}
27	18	Epsilon Indi A	11.8	K5 V	22 03	−56 46	0.150
28		Epsilon Indi Ba	11.7	T1[5]	22 04	−56 46	—
29		Epsilon Indi Bb	11.7	T6[6]	22 04	−56 46	—
30	19	G 51-15 (DX Cancri)	11.8	M6.5 V	08 29	+26 46	1×10^{-5}
31	20	Tau Ceti	11.9	G8.5 V	01 44	−15 56	0.458
32	21	Luyten 372-58	12.0	M5 V	03 35	−44 30	7×10^{-5}
33	22	Luyten 725-32 (YZ Ceti)	12.1	M4.5 V	01 12	−16 59	1.8×10^{-4}

Table I1

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[4] White dwarf stellar remnant
[5] Brown dwarf
[6] Brown dwarf

The Nearest Stars, Brown Dwarfs, and White Dwarfs

Star	System	Discovery Name	Distance (light-year)	Spectral Type	Location: RA	Location: Dec	Luminosity (Sun = 1)
34	23	Luyten’s Star	12.4	M3.5 V	07 27	+05 13	1.4×10^{-3}
35	24	SCR J184-6357 A	12.6	M8.5 V	18 45	−63 57	1×10^{-6}
36		SCR J184-6357 B	12.7	T6[7]	18 45	−63 57	—
37	25	Teegarden’s Star	12.5	M6 V	02 53	+16 52	1×10^{-5}
38	26	Kapteyn’s Star	12.8	M1 V	05 11	−45 01	3.8×10^{-3}
39	27	Lacaille 8760 (AX Microscopium)	12.9	K7 V	21 17	−38 52	0.029

Table I1

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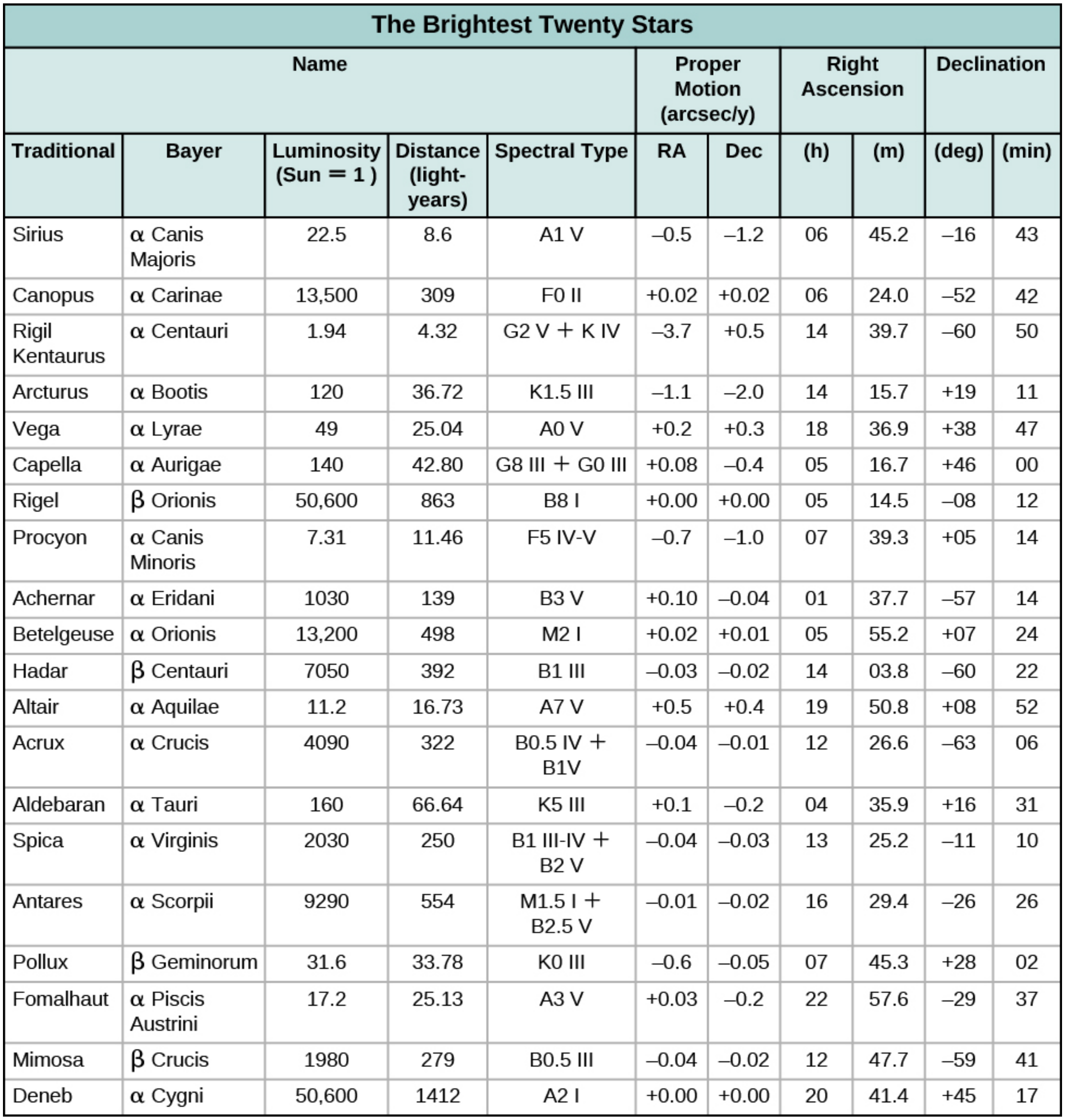
[7] Brown dwarf

J THE BRIGHTEST TWENTY STARS

Note: These are the stars that *appear* the brightest visually, as seen from our vantage point on Earth. They are not necessarily the stars that are intrinsically the most luminous.



The Brightest Twenty Stars

Name					Proper Motion (arcsec/y)		Right Ascension		Declination	
Traditional	**Bayer**	**Luminosity (Sun = 1)**	**Distance (light-years)**	**Spectral Type**	**RA**	**Dec**	**(h)**	**(m)**	**(deg)**	**(min)**
Sirius	α Canis Majoris	22.5	8.6	A1 V	–0.5	–1.2	06	45.2	–16	43
Canopus	α Carinae	13,500	309	F0 II	+0.02	+0.02	06	24.0	–52	42
Rigil Kentaurus	α Centauri	1.94	4.32	G2 V + K IV	–3.7	+0.5	14	39.7	–60	50
Arcturus	α Bootis	120	36.72	K1.5 III	–1.1	–2.0	14	15.7	+19	11
Vega	α Lyrae	49	25.04	A0 V	+0.2	+0.3	18	36.9	+38	47
Capella	α Aurigae	140	42.80	G8 III + G0 III	+0.08	–0.4	05	16.7	+46	00
Rigel	β Orionis	50,600	863	B8 I	+0.00	+0.00	05	14.5	–08	12
Procyon	α Canis Minoris	7.31	11.46	F5 IV-V	–0.7	–1.0	07	39.3	+05	14
Achernar	α Eridani	1030	139	B3 V	+0.10	–0.04	01	37.7	–57	14
Betelgeuse	α Orionis	13,200	498	M2 I	+0.02	+0.01	05	55.2	+07	24
Hadar	β Centauri	7050	392	B1 III	–0.03	–0.02	14	03.8	–60	22
Altair	α Aquilae	11.2	16.73	A7 V	+0.5	+0.4	19	50.8	+08	52
Acrux	α Crucis	4090	322	B0.5 IV + B1V	–0.04	–0.01	12	26.6	–63	06
Aldebaran	α Tauri	160	66.64	K5 III	+0.1	–0.2	04	35.9	+16	31
Spica	α Virginis	2030	250	B1 III-IV + B2 V	–0.04	–0.03	13	25.2	–11	10
Antares	α Scorpii	9290	554	M1.5 I + B2.5 V	–0.01	–0.02	16	29.4	–26	26
Pollux	β Geminorum	31.6	33.78	K0 III	–0.6	–0.05	07	45.3	+28	02
Fomalhaut	α Piscis Austrini	17.2	25.13	A3 V	+0.03	–0.2	22	57.6	–29	37
Mimosa	β Crucis	1980	279	B0.5 III	–0.04	–0.02	12	47.7	–59	41
Deneb	α Cygni	50,600	1412	A2 I	+0.00	+0.00	20	41.4	+45	17

Figure J1 The brightest stars typically have names from antiquity. Next to each star's ancient name, we have added a column with its name in the system originated by Bayer (see the **Naming Stars** feature box.) The distances of the more remote stars are estimated from their spectral types and apparent brightnesses and are only approximate. The luminosities for those stars are approximate to the same degree. Right ascension and declination is given for Epoch 2000.0.

K THE CHEMICAL ELEMENTS

The Chemical Elements

Element	Symbol	Atomic Number	Atomic Weight[1]	Percentage of Naturally Occurring Elements in the Universe
Hydrogen	H	1	1.008	75
Helium	He	2	4.003	23
Lithium	Li	3	6.94	6×10^{-7}
Beryllium	Be	4	9.012	1×10^{-7}
Boron	B	5	10.821	1×10^{-7}
Carbon	C	6	12.011	0.5
Nitrogen	N	7	14.007	0.1
Oxygen	O	8	15.999	1
Fluorine	F	9	18.998	4×10^{-5}
Neon	Ne	10	20.180	0.13
Sodium	Na	11	22.990	0.002
Magnesium	Mg	12	24.305	0.06
Aluminum	Al	13	26.982	0.005
Silicon	Si	14	28.085	0.07
Phosphorus	P	15	30.974	7×10^{-4}
Sulfur	S	16	32.06	0.05
Chlorine	Cl	17	35.45	1×10^{-4}
Argon	Ar	18	39.948	0.02
Potassium	K	19	39.098	3×10^{-4}

Table K1

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[1] Where mean atomic weights have not been well determined, the atomic mass numbers of the most stable isotopes are given in parentheses.

The Chemical Elements

Element	Symbol	Atomic Number	Atomic Weight	Percentage of Naturally Occurring Elements in the Universe
Calcium	Ca	20	40.078	0.007
Scandium	Sc	21	44.956	3×10^{-6}
Titanium	Ti	22	47.867	3×10^{-4}
Vanadium	V	23	50.942	3×10^{-4}
Chromium	Cr	24	51.996	0.0015
Manganese	Mn	25	54.938	8×10^{-4}
Iron	Fe	26	55.845	0.11
Cobalt	Co	27	58.933	3×10^{-4}
Nickel	Ni	28	58.693	0.006
Copper	Cu	29	63.546	6×10^{-6}
Zinc	Zn	30	65.38	3×10^{-5}
Gallium	Ga	31	69.723	1×10^{-6}
Germanium	Ge	32	72.630	2×10^{-5}
Arsenic	As	33	74.922	8×10^{-7}
Selenium	Se	34	78.971	3×10^{-6}
Bromine	Br	35	79.904	7×10^{-7}
Krypton	Kr	36	83.798	4×10^{-6}
Rubidium	Rb	37	85.468	1×10^{-6}
’Strontium	Sr	38	87.62	4×10^{-6}
Yttrium	Y	39	88.906	7×10^{-7}
Zirconium	Zr	40	91.224	5×10^{-6}
Niobium	Nb	41	92.906	2×10^{-7}

Table K1

The Chemical Elements

Element	Symbol	Atomic Number	Atomic Weight	Percentage of Naturally Occurring Elements in the Universe
Molybdenum	Mo	42	95.95	5×10^{-7}
Technetium	Tc	43	(98)	—
Ruthenium	Ru	44	101.07	4×10^{-7}
Rhodium	Rh	45	102.906	6×10^{-8}
Palladium	Pd	46	106.42	2×10^{-7}
Silver	Ag	47	107.868	6×10^{-8}
Cadmium	Cd	48	112.414	2×10^{-7}
Indium	In	49	114.818	3×10^{-8}
Tin	Sn	50	118.710	4×10^{-7}
Antimony	Sb	51	121.760	4×10^{-8}
Tellurium	Te	52	127.60	9×10^{-7}
Iodine	I	53	126.904	1×10^{-7}
Xenon	Xe	54	131.293	1×10^{-6}
Cesium	Cs	55	132.905	8×10^{-8}
Barium	Ba	56	137.327	1×10^{-6}
Lanthanum	La	57	138.905	2×10^{-7}
Cerium	Ce	58	140.116	1×10^{-6}
Praseodymium	Pr	59	140.907	2×10^{-7}
Neodymium	Nd	60	144.242	1×10^{-6}
Promethium	Pm	61	(145)	—
Samarium	Sm	62	150.36	5×10^{-7}
Europium	Eu	63	151.964	5×10^{-8}

Table K1

The Chemical Elements

Element	Symbol	Atomic Number	Atomic Weight	Percentage of Naturally Occurring Elements in the Universe
Gadolinium	Gd	64	157.25	2×10^{-7}
Terbium	Tb	65	158.925	5×10^{-8}
Dysprosium	Dy	66	162.500	2×10^{-7}
Holmium	Ho	67	164.930	5×10^{-8}
Erbium	Er	68	167.259	2×10^{-7}
Thulium	Tm	69	168.934	1×10^{-8}
Ytterbium	Yb	70	173.054	2×10^{-7}
Lutetium	Lu	71	174.967	1×10^{-8}
Hafnium	Hf	72	178.49	7×10^{-8}
Tantalum	Ta	73	180.948	8×10^{-9}
Tungsten	W	74	183.84	5×10^{-8}
Rhenium	Re	75	186.207	2×10^{-8}
Osmium	Os	76	190.23	3×10^{-7}
Iridium	Ir	77	192.217	2×10^{-7}
Platinum	Pt	78	195.084	5×10^{-7}
Gold	Au	79	196.967	6×10^{-8}
Mercury	Hg	80	200.592	1×10^{-7}
Thallium	TI	81	204.38	5×10^{-8}
Lead	Pb	82	207.2	1×10^{-6}
Bismuth	Bi	83	208.980	7×10^{-8}
Polonium	Po	84	(209)	—
Astatine	At	85	(210)	—

Table K1

The Chemical Elements

Element	Symbol	Atomic Number	Atomic Weight	Percentage of Naturally Occurring Elements in the Universe
Radon	Rn	86	(222)	—
Francium	Fr	87	(223)	—
Radium	Ra	88	(226)	—
Actinium	Ac	89	(227)	—
Thorium	Th	90	232.038	4×10^{-8}
Protactinium	Pa	91	231.036	—
Uranium	U	92	238.029	2×10^{-8}
Neptunium	Np	93	(237)	—
Plutonium	Pu	94	(244)	—
Americium	Am	95	(243)	—
Curium	Cm	96	(247)	—
Berkelium	Bk	97	(247)	—
Californium	Cf	98	(251)	—
Einsteinium	Es	99	(252)	—
Fermium	Fm	100	(257)	—
Mendelevium	Md	101	(258)	—
Nobelium	No	102	(259)	—
Lawrencium	Lr	103	(262)	—
Rutherfordium	Rf	104	(267)	—
Dubnium	Db	105	(268)	—
Seaborgium	Sg	106	(271)	—
Bohrium	Bh	107	(272)	—

Table K1

The Chemical Elements

Element	Symbol	Atomic Number	Atomic Weight	Percentage of Naturally Occurring Elements in the Universe
Hassium	Hs	108	(270)	—
Meitnerium	Mt	109	(276)	—
Darmstadtium	Ds	110	(281)	—
Roentgenium	Rg	111	(280)	—
Copernicium	Cn	112	(285)	—
Ununtrium	Uut	113	(284)	—
Flerovium	Fl	114	(289)	—
Ununpentium	Uup	115	(288)	—
Livermorium	Lv	116	(293)	—
Ununseptium	Uus	117	(294)	—
Ununoctium	Uuo	118	(294)	—

Table K1

Note: Some of the newest elements near the bottom of the table have suggested names that are still under review, and those names are not yet listed here. For example, Tennessine is suggested for element 117, after the state where the Oak Ridge National Laboratory is located.

L THE CONSTELLATIONS

The Constellations

Constellation (Latin name)	Genitive Case Ending	English Name or Description	Abbreviation	Approximate Position: α (h)	Approximate Position: δ (°)
Andromeda	Andromedae	Princess of Ethiopia	And	1	+40
Antila	Antilae	Air pump	Ant	10	−35
Apus	Apodis	Bird of Paradise	Aps	16	−75
Aquarius	Aquarii	Water bearer	Aqr	23	−15
Aquila	Aquilae	Eagle	Aql	20	+5
Ara	Arae	Altar	Ara	17	−55
Aries	Arietis	Ram	Ari	3	+20
Auriga	Aurigae	Charioteer	Aur	6	+40
Boötes	Boötis	Herdsman	Boo	15	+30
Caelum	Cael	Graving tool	Cae	5	−40
Camelopardus	Camelopardis	Giraffe	Cam	6	+70
Cancer	Cancri	Crab	Cnc	9	+20
Canes Venatici	Canum Venaticorum	Hunting dogs	CVn	13	+40
Canis Major	Canis Majoris	Big dog	CMa	7	−20
Canis Minor	Canis Minoris	Little dog	CMi	8	+5
Capricornus	Capricorni	Sea goat	Cap	21	−20
Carina[1]	Carinae	Keel of Argonauts’ ship	Car	9	−60
Cassiopeia	Cassiopeiae	Queen of Ethiopia	Cas	1	+60

Table L1

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[1] The four constellations Carina, Puppis, Pyxis, and Vela originally formed the single constellation Argo Navis.

The Constellations

Constellation (Latin name)	Genitive Case Ending	English Name or Description	Abbreviation	Approximate Position: α (h)	Approximate Position: δ (°)
Centaurus	Centauri	Centaur	Cen	13	−50
Cepheus	Cephei	King of Ethiopia	Cep	22	+70
Cetus	Ceti	Sea monster (whale)	Cet	2	−10
Chamaeleon	Chamaeleontis	Chameleon	Cha	11	−80
Circinus	Circini	Compasses	Cir	15	−60
Columba	Columbae	Dove	Col	6	−35
Coma Berenices	Comae Berenices	Berenice’s hair	Com	13	+20
Corona Australis	Coronae Australis	Southern crown	CrA	19	−40
Corona Borealis	Coronae Borealis	Northern crown	CrB	16	+30
Corvus	Corvi	Crow	Crv	12	−20
Crater	Crateris	Cup	Crt	11	−15
Crux	Crucis	Cross (southern)	Cru	12	−60
Cygnus	Cygni	Swan	Cyg	21	+40
Delphinus	Delphini	Porpoise	Del	21	+10
Dorado	Doradus	Swordfish	Dor	5	−65
Draco	Draconis	Dragon	Dra	17	+65
Equuleus	Equulei	Little horse	Equ	21	+10
Eridanus	Eridani	River	Eri	3	−20
Fornax	Fornacis	Furnace	For	3	−30
Gemini	Geminorum	Twins	Gem	7	+20

Table L1

The Constellations

Constellation (Latin name)	Genitive Case Ending	English Name or Description	Abbreviation	Approximate Position: α (h)	Approximate Position: δ (°)
Grus	Gruis	Crane	Gru	22	−45
Hercules	Herculis	Hercules, son of Zeus	Her	17	+30
Horologium	Horologii	Clock	Hor	3	−60
Hydra	Hydrae	Sea serpent	Hya	10	−20
Hydrus	Hydri	Water snake	Hyi	2	−75
Indus	Indi	Indian	Ind	21	−55
Lacerta	Lacertae	Lizard	Lac	22	+45
Leo	Leonis	Lion	Leo	11	+15
Leo Minor	Leonis Minoris	Little lion	LMi	10	+35
Lepus	Leporis	Hare	Lep	6	−20
Libra	Librae	Balance	Lib	15	−15
Lupus	Lupi	Wolf	Lup	15	−45
Lynx	Lyncis	Lynx	Lyn	8	+45
Lyra	Lyrae	Lyre or harp	Lyr	19	+40
Mensa	Mensae	Table Mountain	Men	5	−80
Microscopium	Microscopii	Microscope	Mic	21	−35
Monoceros	Monocerotis	Unicorn	Mon	7	−5
Musca	Muscae	Fly	Mus	12	−70
Norma	Normae	Carpenter’s level	Nor	16	−50
Octans	Octantis	Octant	Oct	22	−85
Ophiuchus	Ophiuchi	Holder of serpent	Oph	17	0

Table L1

The Constellations

Constellation (Latin name)	Genitive Case Ending	English Name or Description	Abbreviation	Approximate Position: α (h)	Approximate Position: δ (°)
Orion	Orionis	Orion, the hunter	Ori	5	+5
Pavo	Pavonis	Peacock	Pav	20	−65
Pegasus	Pegasi	Pegasus, the winged horse	Peg	22	+20
Perseus	Persei	Perseus, hero who saved Andromeda	Per	3	+45
Phoenix	Phoenicis	Phoenix	Phe	1	−50
Pictor	Pictoris	Easel	Pic	6	−55
Pisces	Piscium	Fishes	Psc	1	+15
Piscis Austrinus	Piscis Austrini	Southern fish	PsA	22	−30
Puppis[2]	Puppis	Stern of the Argonauts’ ship	Pup	8	−40
Pyxis[3] (=Malus)	Pyxidus	Compass of the Argonauts’ ship	Pyx	9	−30
Reticulum	Reticuli	Net	Ret	4	−60
Sagitta	Sagittae	Arrow	Sge	20	+10
Sagittarius	Sagittarii	Archer	Sgr	19	−25
Scorpius	Scorpii	Scorpion	Sco	17	−40
Sculptor	Sculptoris	Sculptor’s tools	Scl	0	−30
Scutum	Scuti	Shield	Sct	19	−10
Serpens	Serpentis	Serpent	Ser	17	0

Table L1

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[2] The four constellations Carina, Puppis, Pyxis, and Vela originally formed the single constellation Argo Navis.
[3] The four constellations Carina, Puppis, Pyxis, and Vela originally formed the single constellation Argo Navis.

The Constellations

Constellation (Latin name)	Genitive Case Ending	English Name or Description	Abbreviation	Approximate Position: α (h)	Approximate Position: δ (°)
Sextans	Sextantis	Sextant	Sex	10	0
Taurus	Tauri	Bull	Tau	4	+15
Telescopium	Telescopii	Telescope	Tel	19	−50
Triangulum	Trianguli	Triangle	Tri	2	+30
Triangulum Australe	Trianguli Australis	Southern triangle	TrA	16	−65
Tucana	Tucanae	Toucan	Tuc	0	−65
Ursa Major	Ursae Majoris	Big bear	UMa	11	+50
Ursa Minor	Ursae Minoris	Little bear	UMi	15	+70
Vela[4]	Velorum	Sail of the Argonauts' ship	Vel	9	−50
Virgo	Virginis	Virgin	Vir	13	0
Volans	Volantis	Flying fish	Vol	8	−70
Vulpecula	Vulpeculae	Fox	Vul	20	+25

Table L1

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[4] The four constellations Carina, Puppis, Pyxis, and Vela originally formed the single constellation Argo Navis.

M STAR CHART AND SKY EVENT RESOURCES

Star Charts

To obtain graphic charts of the sky over your head tonight, there are a number of free online resources.

- One of the easiest is at the Skymaps website: **http://www.skymaps.com/downloads.html (http://www.skymaps.com/downloads.html)** . Here you can print out a free PDF version of the northern sky (for roughly latitude 40°, which is reasonable for much of the United States). Maps of the sky from the equator and the southern hemisphere can also be printed.
- Sky charts and other summaries of astronomical information can also be found at **http://www.heavens-above.com/ (http://www.heavens-above.com/)** .
- A free, open-source computer application that shows the sky at any time from any place is called Stellarium. You can find it at **http://www.stellarium.org/ (http://www.stellarium.org/)** .
- **Appendix B** provides a section of information for finding astronomy apps for cell phones and tablets. Many of these also provide star charts. If you have a smartphone, you can find a variety of inexpensive apps that allow you to simply hold your phone upward to see what is in the sky behind your phone.
- A *planisphere* is a sky chart that turns inside a round frame and can show you the night sky at your latitude on any date and time of the year. You can buy them at science supply and telescope stores or online. Or you can construct your own from templates at these two websites:
  - Dennis Schatz’s AstroAdventures Star Finder: **http://dennisschatz.org/activities/Star%20Finder.pdf (http://dennisschatz.org/activities/Star%20Finder.pdf)**
  - Uncle Al’s Star Wheel: **http://www.lawrencehallofscience.org/do_science_now/science_apps_and_activities/starwheels (http://www.lawrencehallofscience.org/do_science_now/science_apps_and_activities/starwheels)**

Calendars Of Night Sky Events

The following resources offer calendars of night sky events.

- Sea and Sky: **http://www.seasky.org/astronomy/astronomy.html (click on the fourth menu button) (http://www.seasky.org/astronomy/astronomy.html)**
- *Sky & Telescope’s* This Week’s Sky at a Glance: **http://www.skyandtelescope.com/observing/sky-at-a-glance/ (http://www.skyandtelescope.com/observing/sky-at-a-glance/)**
- *Astronomy* Magazine’s The Sky This Week: **http://www.astronomy.com/observing/sky-this-week (http://www.astronomy.com/observing/sky-this-week)**
- NASA Sky Cal: **http://eclipse.gsfc.nasa.gov/SKYCAL/SKYCAL.html (http://eclipse.gsfc.nasa.gov/SKYCAL/SKYCAL.html)**
- Night Sky Network Sky Planner: **https://nightsky.jpl.nasa.gov/planner.cfm (https://nightsky.jpl.nasa.gov/planner.cfm)**

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