# Introductory Astronomy Laboratory Problems

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# Introduction

*Introductory Astronomy Laboratory Problems* (IALP) is a bank of problems for quizzes given in introductory astronomy laboratories. They were began for labs taught University of Nevada, Las Vegas (UNLV).

I would like to thank the Department of Physics & Astronomy of UNLV for its support for this work. Thanks also to the students who helped flight-test the problems.

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## References

Jeffery, D. J. 2013, Introductory Astronomy Lectures (IAL) (Port Colborne, Canada: Portpentragam Publishing), http://www.nhn.ou.edu/ jeffery/astro/astlec/lecture.html

Wikipedia, http://en.wikipedia.org/wiki/Main_Page

## Chapt. 1 Naked-Eye Astronomy

## Multiple-Choice Problems

001 qmult 00100 1 4 5 easy deducto-memory: naked-eye astronomy defined

1. "Let's play *Jeopardy*! For $100, the answer is: It is observing the sky without instruments."

   What is ____________, Alex?

   a) astronomy b) cosmology c) cosmetology d) free-eye astronomy
   e) naked-eye astronomy

001 qmult 00110 1 1 2 easy memory: naked-eye astronomical objects

2. Naked-eye astronomical objects include the Moon, the 5 non-Earth inner planets, bright stars, constellations, ____________, and, under dark-sky conditions, a few nebulae (meaning cloudy objects in this context).

   a) the moons of Jupiter b) the Milky Way c) the ionosphere
   d) cumulus clouds e) ions

001 qmult 00200 1 4 2 easy deducto-memory: celestial sphere defined

3. "Let's play *Jeopardy*! For $100, the answer is: It is an imaginary sphere centered on the Earth, set at infinity, and used to project all astronomical objects on for mapping."

   What is the ____________, Alex?

   a) celestial globe b) celestial sphere c) celestial cube d) Boundless
   e) sphere of the fixed stars

001 qmult 00210 1 1 2 easy memory: zenith, nadir defined

4. Directly overhead is the ____________ and in the opposite position on the celestial sphere is the ____________.

   a) nadir; zenith b) zenith; nadir c) zenith; the meridian d) the meridian; nadir
   e) the horizon; the meridian

001 qmult 00220 1 4 5 easy deducto-memory: the meridian defined

5. "Let's play *Jeopardy*! For $100, the answer is: It is a great circle on the celestial sphere that intersects due north, the zenith, due south, and the nadir."

   What is the ____________, Alex?

   a) ecliptic b) zenith c) nadir d) meringue e) meridian

001 qmult 00230 1 1 1 easy memory: transit of the meridian

6. When a astronomical object crosses the meridian due to the daily rotation of the celestial sphere on the celestial axis, the event is called in astro jargon a ____________ of the meridian.

   a) transit b) crossing c) saltation d) leaping e) telescoping

001 qmult 00300 1 1 3 easy memory: equatorial coordinates

7. ____________ are the main coordinates for locating astronomical objects on the sky (which in this context is also the celestial sphere). They are analogous to longitude and latitude with ____________ replacing longitude and ____________ replacing latitude.

   a) Equatorial coordinates; right ascension; destination
   b) **EQUILATERAL** coordinates; right ascension; declination
   c) Equatorial coordinates; right ascension; declination
   d) Equatorial coordinates; right dissension; declination
   e) **EQUILATERAL** coordinates; right dissension; destination

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001 qmult 00400 1 4 4 easy deducto-memory: planisphere defined

8. "Let's play *Jeopardy*! For $100, the answer is: It is a primitive sort of analog computer used for calculating the local sky above the horizon for any time for a fixed latitude."

   What is a ____________, Alex?

   a) telescope b) cellphone c) sky map d) planisphere e) celestial globe

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001 qmult 00500 1 1 1 easy memory: bright stars defined

9. When one says ____________ in the context of astronomical observations, one usually means stars of high apparent brightness. "Apparent" in astronomy has the meaning "as observed from the Earth".

   a) bright stars b) dim stars c) dim moons d) artificial satellites
   e) asteroids

---

001 qmult 00510 1 1 1 easy memory: named stars

10. The brightest stars in the sky often have traditional names mostly derived either from Latin or Arabic. These stars are called:

    a) named stars. right b) unnamed stars. c) unnameable stars d) dim stars.
    e) death stars.

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001 qmult 00520 1 1 5 easy memory: star name spelled backwards

11. Which of the following named stars is an astronaut's name spelled backwards?

    a) Aldebaran b) Algol c) Ankaa d) Antares e) Navi

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001 qmult 00530 1 1 3 easy memory: Bayer designation

12. Many bright stars have a Bayer designation. The designation is a Greek letter followed by the genitive form of the star's parent constellation's Latin name. The Greek letters are assigned approximately in order of apparent brightnesses of the stars: the brightest star being alpha (or $\alpha$), the 2nd brightest being beta (or $\beta$), etc. The originator of the Bayer designation system is:

    a) Callisto (fl. 1300? BCE). b) King Arthur (fl. 500 CE).
    c) Johann Bayer (1572–1625). d) Joseph Barbera (1911–2006).
    e) Bear Bryant (1913–1983).

---

001 qmult 00540 1 1 1 easy memory: Bayer designation alpha stars

13. In the Bayer designation scheme for bright stars in constellations, the star of highest apparent brightness in a constellation is **USUALLY** usually labeled:

    a) alpha ($\alpha$). b) beta ($\beta$). c) gamma ($\gamma$). d) delta ($\delta$). e) epsilon ($\epsilon$).

---

001 qmult 00542 1 1 2 easy memory: Bayer designation beta stars

14. In the Bayer designation scheme for bright stars in constellations, the star of second highest apparent brightness in a constellation is usually labeled:

    a) alpha ($\alpha$). b) beta ($\beta$). c) gamma ($\gamma$). d) delta ($\delta$). e) epsilon ($\epsilon$).

---

001 qmult 00550 1 1 4 easy memory: Bayer designation 2nd brightest star in Taurus

15. What is the Bayer designation for the 2nd brightest star (by tradition if not always in fact) in the constellation Taurus?

    a) $\alpha$ Orionis. b) $\beta$ Orionis. c) $\alpha$ Tauri. d) $\beta$ Tauri. e) $\gamma$ Tauri.

---

001 qmult 00552 1 1 4 easy memory: Bayer designation 5th brightest star in Taurus

16. What is the Bayer designation for the 5th brightest star (by tradition if not always in fact) in the constellation Taurus? Recall the Greek alphabet: $\alpha\beta\gamma\delta\epsilon\zeta\eta\theta\iota\kappa\lambda\mu\nu\xi o\pi\rho\sigma\tau\upsilon\phi\chi\psi\omega$.

    a) $\chi$ Orionis. b) $\omega$ Orionis. c) $\delta$ Tauri. d) $\epsilon$ Tauri. e) $\psi$ Tauri.

---

001 qmult 00600 1 4 4 easy deducto-memory: constellation defined

17. "Let's play *Jeopardy*! For $100, the answer is: This astronomical object is traditionally defined as a traditionally recognized group of stars that are relatively close in angle on the sky. In three-dimensional space, the stars can be very far apart and they are usually not physically interacting with each other. In modern astronomy, the object is defined as a patch on the sky. There are only 88 of such modern objects each containing their traditional analogue. The 88 patches tile the whole sky without overlap. Thus, any other astronomical object can be located in a patch."

    What is a ____________, Alex?

    a) galaxy b) planetary system c) nebula d) constellation e) planisphere

---

001 qmult 00610 1 1 4 easy memory: constellation appearance

18. Overwhelmingly most constellations look ____________ like the things they are named for.

    a) exactly b) nearly exactly c) 70 % d) nothing much e) exactly inversely

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001 qmult 00630 1 1 3 easy memory: three northern sky constellations

19. Three contellations relatively near the north celestial pole (the NCP) are:

    a) Mars, Jupiter, Pluto. b) Ursa Major, Ursa Minor, the Southern Cross.
    c) Ursa Major, Ursa Minor, Cassiopeia.
    d) Ursa Major, Ursa Minor, the Northern Cross.
    e) Frankenstein, Dracula, the Mummy.

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001 qmult 00632 1 1 3 easy memory: three northern sky constellations 2

20. Three contellations relatively near the north celestial pole (the NCP) are Ursa Major, Ursa Minor, and:

    a) Pluto. b) the Southern Cross. c) Cassiopeia. d) the Northern Cross.
    e) the Mummy.

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001 qmult 00750 1 1 1 easy memory: your sign is Aries

21. Say the Sun was in the sign of Aries (which is approximately where the constellation Aries was in 500 BCE) when you were born. Your astrological sign is:

    a) Aries. b) Scorpio. c) Canis Major. d) Democritus. e) Taurus.

---

001 qmult 00752 1 1 5 easy memory: your sign is Taurus

22. Say the Sun was in the sign of Taurus (which is approximately where the constellation Taurus was in 500 BCE) when you were born. Your astrological sign is:

    a) Virgo. b) Scorpio. c) Canis Major. d) Democritus. e) Taurus.

## Chapt. 2  The Celestial Sphere

## Multiple-Choice Problems

002 qmult 00070 1 4 5 easy deducto-memory: seven samurai
**Extra keywords:** not a serious question

23. "Let's play *Jeopardy*! For $100, the answer is: In Akira Kurosawa's film *The Seven Samurai* in the misremembering of popular memory, what the samurai leader said when one of the seven asked why they were going to defend this miserable village from a horde of marauding bandits."

    What is "____________," Alex?

    a) For honor.  b) It is the way of the samurai.  c) It is the Tao.  d) For a few dollars more.  e) For the fun of it.

002 qmult 00080 1 4 3 easy deducto-memory: Arabian Nights
**Extra keywords:** mathematical physics

24. "Let's play *Jeopardy*! For $100, the answer is: It is a story very much like a course in physics."

    What is ____________, Alex?

    a) the *Theogony* by Hesiod (circa 700 BCE)
    b) *The Odyssey* by Homer (circa 700 BCE?)
    c) *A Thousand Nights and a Night* by Anonymous (circa 800–900)
    d) *War and Peace* by Lev Tolstoy (1828–1910)
    e) *Ulysses* by James Joyce (1882–1941)

002 qmult 00110 1 1 5 easy memory: not a celestial sphere feature

25. Which of the following is **NOT** a feature of the celestial sphere.

    a) the celestial equator  b) the celestial axis  c) the ecliptic  d) the ecliptic axis  e) the solar constant

002 qmult 00112 1 1 4 easy memory: north pole not on the celestial sphere

26. Which of the following in **NOT** on the celestial sphere?

    a) celestial equator  b) north celestial pole  c) celestial meridian  d) north pole  e) ecliptic

002 qmult 00120 1 1 3 easy memory: rotation on celestial axis

27. From the Earth-at-rest perspective, the celestial sphere rotates ____________ on the ____________ once per ____________.

    a) westward; celestial axis; civil day  b) eastward; celestial axis; sidereal day
    c) westward; celestial axis; sidereal day  d) westward; celestial equator; sidereal day
    e) eastward; celestial equator; civil day

002 qmult 00122 1 1 3 easy memory: rotation on celestial axis 2

28. From the Earth-at-rest perspective, the celestial sphere rotates westward on the ____________ once per sidereal day.

    a) celestial equator  b) ecliptic  c) celestial axis  d) ecliptic axis  e) pole star

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002 qmult 00170 1 1 3 easy memory: celestial globe defined

29. The celestial sphere mapped onto a spherical surface is a:

 a) sky globe b) celestial sphere c) celestial globe d) celestial glove
 e) terrestrial globe

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002 qmult 00200 1 1 1 easy memory: equatorial coordinate system

30. The equatorial coordinate system for the celestial sphere is analogous to the ____________ for the Earth.

 a) geographical coordinate system b) horizontal coordinate system
 c) constellation system d) galactic coordinate system e) GPS system

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002 qmult 00210 1 4 4 easy deducto-memory: right ascension defined

31. "Let's play *Jeopardy*! For $100, the answer is: It is the angular coordinate of the equatorial coordinate system that is measured on the celestial equator eastward from the vernal equinox. It is measured in the somewhat strange angle units hours ($1^{\rm h} = 15^\circ$), minutes ($1^{\rm m} = (1/60)^{\rm h} = 0.25^\circ = 15'$), and seconds ($1^{\rm s} = (1/60)^{\rm m} = 0.25' = 15''$). These angle units are chosen because the celestial sphere rotates 1 hour of angle, etc., in 1 sidereal hour of time etc. Sidereal time units are defined by the Earth's rotational period relative to the observable universe, not relative to the Sun."

 What is ____________, Alex?

 a) altitude b) longitude c) declination d) right ascension
 e) right declination

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002 qmult 00230 1 1 2 easy memory: special case declinations

32. The declinations of the celestial equator, the solstices, and the celestial poles are, respectively:

 a) $\pm 10^\circ$, $\pm 30^\circ$, and $\pm 80^\circ$. b) $0^\circ$, $\pm 23.4^\circ$, and $\pm 90^\circ$. c) $\pm 90^\circ$, $\pm 23.4^\circ$, and $0^\circ$.
 d) $0^\circ$, $\pm 30.0^\circ$, and $\pm 90^\circ$. e) $0^\circ$, $\pm 23.4^\circ$, and $\pm 70^\circ$.

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002 qmult 00270 1 4 5 easy deducto-memory: equatorial coords and precession

33. "Let's play *Jeopardy*! For $100, the answer is: These coordinates depend on time because of the Earth's axial precession."

 What are ____________, Alex?

 a) longitude and latitude b) horizontal coordinates c) local coordinates
 d) Cartesian coordinates e) equatorial coordinates

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002 qmult 00300 1 4 5 easy deducto-memory: horizontal coordinates justified

34. "Let's play *Jeopardy*! For $100, the answer is: These coordinates are most useful for locating objects on the celestial sphere at one instant in time at one place on Earth."

 What are ____________, Alex?

 a) moral coordinates b) longitude and latitude c) Cartesian coordinates
 d) equatorial coordinates e) horizontal coordinates

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002 qmult 00310 1 1 3 easy memory: altitude and azimuth

35. The two angular coordinates of the horizontal coordinate system are:

 a) altitude (Alt) and latitude (Lat). b) algol (Al) and algorithm (Am).
 c) altitude (Alt) and azimuth (Az). d) height (He) and azimuth (Az).
 e) ariel (Ar) and abishag (Ab).

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002 qmult 00320 1 4 2 easy deducto-memory: altitude defined

36. "Let's play *Jeopardy*! For \$100, the answer is: It is the angular coordinate of the horizontal coordinate system that is measured from the horizon along a great circle that passes through zenith."

What is ____________, Alex?

a) polar angle b) altitude c) height d) azimuth e) algol

---

002 qmult 00340 1 1 4 easy memory: highest altitude is on the meridian

37. An astronomical object is at the highest point in the sky above the horizon (i.e., at maximum altitude) when it transits the ____________. If the object is circumpolar and is always above the horizon, it is also at the lowest point in the sky above the horizon (i.e., at lowest altitude) when it transits the ____________.

a) celestial equator; celestial equator b) zenith; nadir c) nadir; zenith
d) meridian; meridian e) right ascension; declination

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002 qmult 00350 1 1 1 easy memory: azimuths of meridian transits

38. In the northern hemisphere north of the tropics, a meridian transit of the Sun occurs at azimuth ____________ (as one would usually record it) and in the southern hemisphere south of the tropics, at azimuth ____________ (as one would usually record it).

a) $180°$; $0°$ b) $0°$; $180°$ c) $90°$; $270°$ d) $0°$; $0°$ e) $180°$; $180°$

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002 qmult 00354 1 1 5 easy memory: azimuth of meridian transit in Las Vegas

39. In Las Vegas, what is the **AZIMUTH** (as one would usually record it) of the Sun when it transits the meridian?

a) $0°$. b) $30°$. c) $90°$. d) $150°$. e) $180°$.

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002 qmult 00364 1 1 3 easy memory: SCP direction for Las Vegas

40. The general formula for altitude along the meridian is

$$A_{\rm N/S} = 90° + (\pm)_{\rm N/S}(L - \delta)$$

where $N/S$ means measured from due north/south, $(\pm)_{\rm N/S}$ means plus/minus for measured from due north/south, $L$ is latitude counted positive/negative for north/south latitude, and $\delta$ is declination.

The declination of the south celestial pole (SCP) is $-90°$ and in Las Vegas the latitude is approximately $36°$ N. For Las Vegas, what is the altitude of the SCP from due south and is it above, on, or below the horizon?

a) $0°$; on the horizon. b) $24°$; above the horizon. c) $-36°$; below the horizon
d) $54°$; above and below the horizon. e) $-90°$; below the horizon.

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002 qmult 00380 1 1 5 easy memory: altitude of summer solstice noon

41. The general formula for altitude along the meridian is

$$A_{\rm N/S} = 90° + (\pm)_{\rm N/S}(L - \delta)$$

where $N/S$ means measured from due north/south, $(\pm)_{\rm N/S}$ means plus/minus for measured from due north/south, $L$ is latitude counted positive/negative for north/south latitude, and $\delta$ is declination.

What is the altitude from due south for the noon meridian transit of the Sun on the day of the summer solstice for north of the equator? What is this altitude for Las Vegas at approximate $36°$ N? **HINT:** You might ask yourself where could the Sun possibly have its noon meridian transit on the summer solstice.

a) $L$; $36°$. b) $90° - L$; $54°$. c) $-L$; $-36°$. d) $66.6° - L$; $30.6°$.
e) $113.4° - L$; $77.4°$.

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002 qmult 00384 1 1 3 easy memory: altitudes from due south for noon meridian solstices and equinoxes

42. The general formula for altitude along the meridian is

$$A_{\rm N/S} = 90^\circ + (\pm)_{\rm N/S}(L - \delta)$$

where $N/S$ means measured from due north/south, $(\pm)_{\rm N/S}$ means plus/minus for measured from due north/south, $L$ is latitude counted positive/negative for north/south latitude, and $\delta$ is declination.

For general latitude $L$, what is the altitude (measured from due south) for the Sun's noon meridian transit on, respectively, the **NORTHERN SOLSTICE** (AKA the summer solstice in the northern hemisphere), the **EQUINOXES**, and the **SOUTHERN SOLSTICE** (AKA the winter solstice in the northern hemisphere)?

a) $113.4^\circ - L$, $L$, and $66.6^\circ - L$. b) $66.6^\circ - L$, $90^\circ - L$, and $113.4^\circ - L$.
c) $113.4^\circ - L$, $90^\circ - L$, and $66.6^\circ - L$. d) $113.4^\circ$, $L$, and $66.6^\circ$.
e) $113.4^\circ$, $90^\circ$, and $66.6^\circ$.

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002 qmult 00386 1 1 5 easy memory: southern solstice date for sun transit

43. Early one morning before dawn, you see Polaris at altitude $45^\circ$ above due north. Later that day you see the Sun transiting the meridian at altitude $21.6^\circ$. What is the date approximately?

**HINT:** You should be able to determine the answer based on ordinary sky knowledge. Ask yourself is altitude $21.6^\circ$ large or small. However, if you want to do a calculation, general formula for altitude along the meridian is

$$A_{\rm N/S} = 90^\circ + (\pm)_{\rm N/S}(L - \delta)$$

where $N/S$ means measured from due north/south, $(\pm)_{\rm N/S}$ means plus/minus for measured from due north/south, $L$ is latitude counted positive/negative for north/south latitude, and $\delta$ is declination.

a) Jan21. b) Mar21. c) Jun21. d) Sep21. e) Dec21.

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## Full-Answer Problems

## Chapt. 3 Telescopes

## Multiple-Choice Problems

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003 qmult 00100 1 4 5 easy deducto-memory: optical telescope defined

44. "Let's play *Jeopardy*! For $100, the answer is: It is an optical device that gathers light from a remote source and focuses it into an image that is photographed or observed directly by a human using an eyepiece."

    What is a ____________, Alex?

    a) kaleidoscope b) spectroscope c) microscope d) radio telescope
    e) telescope

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003 qmult 00110 1 1 1 easy memory: the telescopes: reflectors and refractors

45. Telescopes are divided into two main categories: ____________ and ____________. The distinction is based on the nature of the telescope primary (or objective): for the former it is a lens; for the latter a mirror.

    a) refractors; reflectors b) reflectors; refractors c) diffractors; integrators
    d) integrators; diffractors e) detractors; reenactors

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003 qmult 00120 1 1 3 easy memory: diameter of primary

46. The prime parameter (and first cited one) of any telescope is the ____________ of the primary (AKA the objective) since this determines the light-gathering power of the telescope and the lower limit on its angular resolution (AKA resolving power) with ordinary optics.

    a) shape b) focal length c) diameter d) color e) composition

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003 qmult 00130 1 1 3 easy memory: Galilean and Keplerian telescopes

47. Refractor telescopes are divided into Galilean and ____________ telescopes. The former give an upright image and latter a point inverted image. With point inversion each point of the source is rotated by 180° in the image about the optical axis of the telescope. The ____________ telescope quickly became favored for astronomy since it gives much wider field of view and the inversion is just accepted and adapted to. The inversion can be corrected for if you want to as in most binoculars. The ____________ telescope was invented theoretically by Johannes Kepler (1571–1630), but he never built one to our knowledge.

    a) Scheinerian b) Dutch c) Keplerian d) Newtonian e) Schmidt-Cassegrain

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003 qmult 00140 1 4 4 easy deducto-memory: Cassegrain telescope

48. "Let's play *Jeopardy*! For $100, the answer is: This kind of reflector telescope uses a convex mirror secondary to create an real image on the optical axis (unless the light rays are reflected through 90° by a star diagonal) and effectively increases the focal length of the primary."

    What is a ____________ telescope, Alex?

    a) Galilean b) Keplerian c) Newtonian d) Cassegrain e) Schmidt

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003 qmult 00150 1 4 5 easy deducto-memory: Schmidt telescope

49. "Let's play *Jeopardy*! For $100, the answer is: This kind of reflector telescope typically uses a spherical primary and a corrector plate (a kind of lens) to correct for spherical abberration. The setup gives it a wide field of view."

What is a ____________ telescope, Alex?

a) Galilean b) Keplerian c) Newtonian d) Cassegrain e) Schmidt

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003 qmult 00160 1 4 1 easy deducto-memory: Schmidt-Cassegrain telescope

50. The ____________ telescope combines the defining features of the Schmidt telescope and the Cassegrain telescope.

a) Schmidt-Cassegrain b) Galilean-Keplerian c) Gregorian-Newtonian
d) Galilean-Newtonian e) Gregorian-Cassegrain

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003 qmult 00200 1 1 3 easy memory: parts of the Celestron C8

51. The Celestron C8 Schmidt-Cassegrain telescope has the following prominent parts: clock drive (in base), eyepiece, finderscope, focusing knob, fork arm, LCD keypad, on-off switch, primary mirror, Schmidt corrector plate, secondary mirror, star diagonal, star pointer, telescope tube. There are ____________ parts listed.

a) 10 b) 12 c) 13 d) 15 e) 19

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003 qmult 00220 1 4 4 easy deducto-memory: eyepiece defined

52. "Let's play *Jeopardy*! For $100, the answer is: The optical device closest to the eye in a telescope. It is used to magnify the image created by the primary (AKA objective) of a telescope. The device is rated by its focal length which for small telescopes is usually given in millimeters."

What is a/an ____________, Alex?

a) finderscope b) reticule c) tube d) eyepiece e) star diagonal

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003 qmult 00230 1 4 2 easy deducto-memory: finderscope

53. "Let's play *Jeopardy*! For $100, the answer is: It is a small auxiliary telescope mounted on a main telescope and aligned with the main telescope. It has much smaller light-gathering power and a smaller magnification than the main telescope. However, the auxiliary telescope has much larger field of view than the main telescope and is used to find and center objects that are then viewed with the main telescope. The auxiliary telescope usually has crosshairs (AKA a reticule)."

What is a/an ____________, Alex?

a) star pointer b) finderscope c) eyepiece d) objective e) primary

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003 qmult 00280 1 4 5 easy deducto-memory: star diagonal

54. "Let's play *Jeopardy*! For $100, the answer is: It is a mirror or prism device in a telescope that reflects the image rays from the optical axis to an axis perpendicular to the optical axis where they enter an eyepiece. The device allows easier viewing. It also usually causes an axis reflection about the axis across the field of view that is perpendicular to both the optical axis (of the telescope) and the eyepiece's own optical axis. If one is using a telescope that intrinsically does a point inversion (e.g., a Keplerian telescope or a Schmidt-Cassegrain telescope) and the device in question, then there is both a point inversion and an axis reflection of the image which leads to some mental gymnastics in identifying the cardinal directions of the sky in the image."

What is a star ____________, Alex?

a) reflector b) guide c) pointer d) triangle e) diagonal

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003 qmult 00300 1 1 5 easy memory: focused meaning

55. For most optical devices, "focused" means the light rays from a point source are converged to a/an ____________ image.

a) circle b) oval c) donut d) blurry e) point

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003 qmult 00310 1 4 2 easy deducto-memory: focal length defined

56. "Let's play *Jeopardy*! For \$100, the answer is: It is the distance along the optical axis of a lens or mirror to the point where light rays (originally parallel to the optical axis) converge (i.e., are focused) after interacting with the lens or mirror. It is among other things a measure of the light ray bending power of the lens or mirror. The shorter it is, the greater that power."

    What is ____________, Alex?

    a) angular resolution (AKA resolving power) b) focal length c) image distance d) object distance e) focusing length

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003 qmult 00330 1 1 4 easy memory: telescope magnification

57. The magnification $M$ of common telescopes with an eyepiece is given by

$$M = \frac{f_p}{f_e} ,$$

where $f_p$ is the primary (AKA objective) focal length and $f_e$ is the eyepiece focal length. If $f_p = 2\,\text{m}$ and $f_e = 40\,\text{mm}$, then

a) $M = 1$. b) $M = 20$. c) $M = 40$. d) $M = 50$. e) $M = 0.05$.

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003 qmult 00440 1 1 2 easy memory: Schmidt-Cassegrain star diagonal inversions

58. In a Schmidt-Cassegrain telescope with a star diagonal, the telescope itself gives a ____________ around the optical axis of the telescope and the star diagonal gives a ____________ around the axis perpendicular to the optical axes of the telescope and eyepiece.

    a) axis reflection; point inversion b) point inversion; axis reflection c) translation; axis reflection d) point inversion; translation e) translation; point inversion

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003 qmult 00550 1 1 4 easy memory: field of view and magnification

59. Field of view (FOV) is the angular diameter of the circular region seen through a telescope. As magnification increases, field of view ____________. Another meaning of field of view is just the region seen through the telescope. Context as usual must decide the meaning meant.

    a) fluctuates b) stays the same c) increases d) decreases e) fluctuates wildly

## Chapt. 4 The Moon

## Multiple-Choice Problems

004 qmult 00100 1 1 3 easy memory: Earth-Moon system

60. The Earth and Moon orbit ____________ in ____________ to 1st order.

    a) the Earth's center; circles b) the Earth's center; ellipses
    c) their mutual center of mass; ellipses d) their mutual center of mass; ovals
    e) the Moon's center; ovals

004 qmult 00110 1 4 5 easy deducto-memory: barycenter defined

61. "Let's play *Jeopardy*! For $100, the answer is: It is the center of mass of a gravitationally bound system."

    What is ____________, Alex?

    a) pericenter b) apogee c) perigee d) barometer e) barycenter

004 qmult 00120 1 1 3 easy memory: Earth-Moon system inertial frame, observable universe

62. The Earth and Moon orbit in the inertial frame of the Earth-Moon system center of mass (AKA barycenter). Exact inertial frames are free-fall frames in uniform external gravitational fields as explained by general relativity. The inertial frame of the Earth-Moon system does not relative to the ____________. In fact, all inertial frames do **NOT** rotate with respect to the ____________ or consequently with respect to each other, except perhaps in very strong gravitational fields such as those very near black holes.

    a) asteroids b) Moon's surface c) observable universe d) Earth's surface
    e) Pluto's surface

004 qmult 00130 1 1 2 easy memory: Newtonian physics and inertial frames

63. Newtonian physics was always defined with respect to inertial frames. However, our understanding of inertial frames has evolved since the days of Isaac Newton (1643–1727). Newton thought the fixed stars defined a fundamental inertial frame (which he called absolute space) and reference frames unaccelerated with respect to that inertial frame were also exactly inertial frames. Other references frames could be approximately inertial frames like the Earth's surface (at any point). However, according to general relativity (which has been fully confirmed so far), ____________ in uniform external gravitational fields are exact inertial frames. Among other things, this means that it is still true that the Earth's surface is approximately an inertial frame for most purposes.

    a) rotating frames b) free-fall frames c) non-free-fall frames
    d) spherical frames e) picture frames

004 qmult 00140 1 1 1 easy memory: to zeroth order Earth-Moon system

64. Because the Earth is so much more massive than the Moon, and the Moon's orbital eccentricity is small, to 1st order one can say that relative to the observable universe the Moon orbits:

    a) the Earth in a circle. b) the Earth in a parabola. c) Mars in an ellipse.
    d) the Sun in a parabola. e) Pluto in a parabola.

004 qmult 00150 1 1 2 easy memory: Moon's orbit inclination

65. The Moon's orbit is inclined from the ecliptic plane by about ____________. It crosses the ecliptic plane on the line of ____________.

    a) 0°; nodes  b) 5°; nodes  c) 30°; roads  d) 60°; nodes  e) 180°; toads

---

004 qmult 00152 1 1 5 easy memory: no lunar orbit inclination

66. If counterfactually the Moon's orbit had zero inclination to the ecliptic plane, there would be a total/annular solar eclipse and a total lunar eclipse:

    a) never.  b) one or the other every lunar month.
    c) one or the other every calendar month.  d) two of both every lunar month.
    e) one of each every lunar month.

---

004 qmult 00160 1 1 4 easy memory: lunar month, sidereal month

67. The lunar month is on average about ____________. The sidereal month, which is the physical ________________ is about 27.3 days.

    a) 27.3 days; synodic period  b) 29.5 days; synodic period
    c) 27.3 days; orbital period  d) 29.5 days; orbital period
    e) 27.55 day; anomalistic month

---

004 qmult 00162 1 1 3 easy memory: lunar month, sidereal month calculation

68. The lunar month falls into the general category of synodic period which is the time it takes for a solar-system astronomical object to return to the same angular position relative to the Sun. On the other hand, the sidereal month falls into the general category of orbital period which is the time it takes for an astronomical object to return to the same place relative to the inertial frame of the center of mass (AKA barycenter) of its orbit. If you stand at that center of mass, then the orbital period is the time for the astronomical object to return to the same place relative to the observable universe. The formula for sidereal month is

$$t_{\rm sid} = \frac{t_{\rm syr} t_{\rm syn}}{t_{\rm syr} + t_{\rm syn}} ,$$

    where $t_{\rm sid}$ is the sidereal month, $t_{\rm syn} = 29.530588861$ days (J2000) is the lunar month (i.e., the synodic period month), and $t_{\rm syr} = 365.256363004$ days (J2000) is the sidereal year. Calculate $t_{\rm sid}$ to 4-digit accuracy. **Hint:** If you try to do this in one nonstop calculation on a calculator, the probability of making a mistake (usually due mistakes in order of operations) approaches 100 %. So do the calculations step by step, writing down the intermediate results as you go.

    a) 27.32 days.  b) 29.52 days.  c) 27.35 days.  d) 29.55 days.  e) 28.55 days.

---

004 qmult 00200 1 4 5 easy deducto-memory: tidal locking

69. "Let's play *Jeopardy*! For $100, the answer is: This effect causes the lunar orbital rotation rate and axial rotation rate to be exactly equal on average."

    What is ____________, Alex?

    a) lunar libration  b) lunar phase  c) the ocean tide
    d) the tide in the affairs of men  e) tidal locking

---

000 qmult 00210 1 4 2 easy deducto-memory: tidal locking common

70. "Let's play *Jeopardy*! For $100, the answer is: All major moons in the solar system and, by undoubtable hypothesis, throughout the observable universe have this feature relative to their parent planets."

    What is ____________, Alex?

    a) tidal kicking  b) tidal locking  c) orbital periods under a day
    d) oribtal periods under 10 days  e) highly elliptical orbits

---

004 qmult 00230 1 1 3 easy memory: far side of the Moon

71. Because of tidal locking, the far side of the Moon is:

    a) seen from Earth once per month. b) seen from Earth only at new moon. c) never seen from Earth. d) seen from Earth only during solar eclipses. e) constantly visible from Earth.

---

004 qmult 00300 1 4 5 easy deducto-memory: lunar phase defined

72. "Let's play *Jeopardy*! For $100, the answer is: It is the appearance of the sunlit portion of the Moon as seen by an observer usually located on the Earth."

    What is ____________, Alex?

    a) the terminator b) lunar month c) the leaping rabbit d) a mare e) lunar phase

---

004 qmult 00310 1 1 3 easy memory: the lunar phases in sequence

73. The standard lunar phases in time sequence are: new moon, waxing crescent, ____________, waxing gibbous, full, waning gibbous, 3rd quarter, ________________.

    a) quarter lit; waning crescent b) quarter full; morning crescent
    c) 1st quarter; waning crescent d) half lit; morning crescent
    e) quartic; Mornington Crescent

---

004 qmult 00320 1 4 2 easy deducto-memory: Moon phase sunset

74. At sunset, you see the Moon in the western sky. It is:

    a) a waning crescent. b) a waxing crescent. c) a full moon.
    d) a gibbous moon. e) partially eclipsed.

---

004 qmult 00322 1 4 4 easy deducto-memory: Moon phase sunset

75. At sunrise, you see the Moon in the western sky. It is a:

    a) waning crescent. b) waxing crescent. c) full moon.
    d) waning gibbous moon. e) waxing gibbous moon.

---

004 qmult 00330 2 5 2 moderate thinking question: Moon phase 1999jan20

76. Describe the Moon's phase on 1999 January 20. **HINT:** You could look up the answer (except in a exam situation), but do you really have to?

    a) Waning crescent in the western sky at sunset.
    b) Waxing crescent in the western sky at sunset.
    c) A new moon in opposition.
    d) A full moon in the western sky at sunset.
    e) Waning gibbous moon in the eastern sky at sunrise.

---

004 qmult 00340 1 4 2 easy deducto-memory: Moon phase horned

77. The Moon is a crescent—the horned Moon. Which way, in a rough sense, do the horns point relative to the Sun?

    a) Toward the Sun. b) Away from the Sun. c) They can have any orientation depending on the time of year. d) They can have any orientation depending on the time of day. e) Perpendicular to the line from the Moon to the Sun.

---

004 qmult 00360 1 4 5 easy deducto-memory: werewolf defined

78. "Let's play *Jeopardy*! For $100, the answer is: This creature changes into a wolf on the night of the full moon."

    What is a ____________, Alex?

a) vampire b) zombie c) ghoul d) sasquatch e) werewolf

---

004 qmult 00362 1 1 5 easy memory: werewolf transforms on full moon

79. A werewolf transforms on the night of the:

    a) 1st crescent b) waxing crescent c) 1st quarter moon
    d) waxing gibbous moon e) full moon

---

004 qmult 00370 1 1 2 easy memory: blue moon

80. A rare event is said to happen once in a:

    a) red moon. b) blue moon. c) wolf moon. d) black swan moon.
    e) harvest moon.

---

004 qmult 00372 1 1 2 easy memory: named full moons
**Extra keywords:** Not good for lab quizzes, prep quizzes only

81. Full moons occuring at particular times of the year often have traditional names associated with them that varying with culture. The traditional English name for a full moon in or near January is:

    a) June Moon. b) Wolf Moon. c) Juney Moon. d) Green Cheese Moon.
    e) Waning Moon.

---

004 qmult 00400 1 1 3 easy memory: lunar highlands and maria

82. The surface of the Moon is divided into two main categories: the older, light-colored lunar highlands and the younger, darker:

    a) carla. b) cornelia. c) maria. d) julia. e) henrietta.

---

004 qmult 00410 1 1 2 easy memory: maria less cratered

83. The maria mostly formed 3.5–3 Gyr ago and missed most of the heavy bombardment which bombarded the lunar highlands. As a result the maria are less ____________ than the lunar highlands.

    a) karsted b) cratered c) faulted d) krinkled e) water eroded

---

004 qmult 00430 1 1 3 easy memory: 3 prominent craters on the near side of the Moon

84. Three prominent lunar craters on the near side of the Moon are:

    a) Copernicus, Pluto, Tycho. b) Copernicus, Plato, Groucho.
    c) Copernicus, Plato, Tycho. d) Copper-nickel, Plato, Tycho.
    e) Copper-nickel, Pluto, Groucho.

---

004 qmult 00432 1 4 5 easy deducto-memory: crater Tycho

85. "Let's play *Jeopardy*! For $100, the answer is: It is generally considered to be the most obvious rayed crater on the Moon when looking at the Moon's near side or an image of the Moon's near side. Actually, most people think it is the most obvious crater period."

    What is ____________, Alex?

    a) Meteor Crater b) Phobos c) Andromeda d) Barnes e) Tycho

---

004 qmult 00470 1 4 4 easy deducto-memory: regolith and space weathering 1

86. The surface of the Moon like most airless worlds is covered with regolith consisting of dust and larger fragments of rock. The regolith gives airless worlds a smooth appearance. The surfaces have been pounded to regoligth by:

    a) Moon lightning. b) Mars meteors. c) star light. d) space weathering.
    e) giant impactors.

---

004 qmult 00472 1 4 1 easy deducto-memory: regolith and space weathering 2

87. The surface of the Moon like most airless worlds is covered with ____________ consisting of dust and larger fragments of rock. The regolith gives airless worlds a smooth appearance. The surfaces have been pounded to ____________ by space weathering.

a) regolith. b) frozen lava. c) karst. d) sand. e) boulders.

---

004 qmult 00500 1 1 4 easy memory: lunar geology different from Earth

88. The geology of the Moon is quite different than that of the Earth. There is **NO** evidence that there is or ever was ____________________ and ________________.

a) water and wind erosion; volcanism b) impact erosion; plate tectonics
c) impact erosion; volcanism d) water and wind erosion; plate tectonics
e) glaciation; volcanism

---

004 qmult 00510 1 4 2 easy deducto-memory: lunar highlands

89. "Let's play *Jeopardy*! For $100, the answer is: They constitute the original lunar crust that formed during the chemical differential phase of the Moon's formation. They are made of relatively light colored anorthosite rock. Since formation they have been heavily modified by impact erosion by impactors of all sizes. Most of the erosion happened early on in the first billion years of the Moon's history. The earliest part spanning about 4.6 to 3.8 billion years ago is the heavy bombardment phase of Solar System history."

What are the lunar ____________, Alex?

a) maria b) highlands c) lowlands d) seas e) craters

---

004 qmult 00520 1 1 2 easy memory: the lunar maria

90. Mare is Latin for "sea": the last "e" is not silent, but the pronunciation seems various—mar-ray may be closest—and who knows how the Romans really pronounced it. The plural form maria is more commonly used, often as if it were a singular. A lunar mare is:

a) a region of the light colored lunar highlands.
b) a dark lava plain on the Moon that is **LIGHTLY** cratered compared to the lighter colored lunar highlands.
c) a dark lava plain on the Moon that is **HEAVILY** cratered compared to the lighter colored lunar highlands.
d) a seabed of a dried up lunar sea.
e) the mother of a colt.

---

004 qmult 00522 1 1 2 easy memory: formation of lunar maria

91. The lunar maria from large flows of ____________ to the surface from the Moon's interior which was hotter in the past. Some of the flows may have been initiated by gian impactor breaking the lunar crust, but this theory is still debated. The ____________ solidified on the **SURFACE** to from basalt rock. Most of the maria formed between 3 and 3.5 billion years ago, but some are older and some younger. Because the maria formed after the heavy bombardment, they have suffered far less impact erosion than the rest of the lunar surface. The maria cover only about 16 % of the lunar surface. Most of the mare coverage is on the near side which gives Earth-based observers the impression that the mare coverage is more extensive than it is. **HINT:** There is only 1 best answer as always.

a) water b) lava c) plastic rock d) magma e) mud

---

004 qmult 00650 1 1 1 easy memory: Apollo 11 landed on Mare Tranquillitatis 1

92. Apollo 11 landed on ____________ in 1969.

a) Mare Tranquillitatis b) Mare Serenitatis c) Mare Imbrium
d) Mare Nectaris e) Mare Fecunditatis

---

004 qmult 00652 1 1 2 easy memory: Apollo 11 landed on Mare Tranquillitatis 2

93. Apollo 11 did **NOT** land on ____________ in 1969.

a) Mare Tranquillitatis  b) Mare Serenitatis  c) a mare  d) the Moon
e) solid ground

## Chapt. 5 Planets

## Multiple-Choice Problems

005 qmult 00100 1 1 1 easy memory: planetary configuration defined

94. A ____________ can be defined as an especially significant apparent position of a planet (i.e., its angular position position as see from Earth) relative to the Sun and the relationship of this apparent position to the 3-dimensional position of the planet in the solar system.

    a) planetary configuration  b) galactic coordinate  c) lunar mare
    d) planetary orbit  e) magnitude

005 qmult 00110 1 4 5 easy deducto-memory: importance of planetary configurations

95. "Let's play *Jeopardy*! For $100, the answer is: These special apparent arrangements of the planets on the sky were famous for just being special, but more importantly they were historically important in setting the orbital parameters of the planets."

    What are ____________, Alex?

    a) planetitudes  b) planetary attitudes  c) platitudes  d) planetary nebulae
    e) planetary configurations

005 qmult 00120 1 1 2 easy memory: common planetary configurations listed

96. The most common planetary configurations include conjunction (superior and inferior), opposition, greatest elongation (eastern and western), quadrature (eastern and western), and

    a) syygyy  b) syzygy.  c) mare  d) planetitude  e) magnitude

005 qmult 00130 1 1 5 easy memory: inferior/superior planet defined

97. A/An ____________ planet is one whose orbital radius is lesser/greater than the Earth's orbital radius.

    a) elongated/compacted  b) bad/good  c) raw/cooked  d) hot/cold
    e) inferior/superior

005 qmult 00135 1 1 4 easy memory: conjunction and opposition defined

98. When two astro-bodies are aligned on the sky, they are in ____________ and when they are $180°$ apart on the sky, they are in ____________.

    a) conjunction; antiparallel  b) construction; opposition  c) conduction; opposition
    d) conjunction; opposition  e) parallel; antiparallel

005 qmult 00140 1 1 4 easy memory: inferior/superior conjunction defined

99. An inferior/superior conjunction is when an inferior planet—a low, depraved planet—is in conjunction and is ____________ the Sun.

    a) turned/rotated from  b) on the far/near side of  c) opposite/across from
    d) on the near/far side of  e) colder/hotter than

005 qmult 00145 1 1 1 easy memory: superior planet never in inferior conjunction

100. A superior planet—a lordly, proud planet—is in inferior conjunction:

a) never. b) always when in conjunction. c) when in opposition.
d) when in quadrature. e) when in syzygy.

---

005 qmult 00150 1 1 2 easy memory: elongation defined

101. Elongation is the angle between:

a) a planet and a planet. b) a planet and the Sun. c) the Sun and the Sun.
d) opposition and conjunction. e) conjunction and syzygy.

---

005 qmult 00155 1 1 2 easy memory: greatest eastern/western elongation

102. Greatest or maximum eastern/western elongation occurs when an inferior planet is ____________ the Sun.

a) as far west/east as it can be on a given orbit from b) as far east/west as it can be on a given orbit from c) at 90° east/west from d) at 90° west/east from e) in opposition to/conjunction with

---

005 qmult 00160 1 1 3 easy memory: eastern/western quadrature

103. Eastern/western quadrature occurs when a superior planet is ____________ the Sun.

a) as far west/east as it can be on a given orbit from b) as far east/west as it can be on a given orbit from c) at 90° east/west from d) at 90° west/east from e) in opposition to/conjunction with

---

005 qmult 00165 1 1 2 easy memory: syzygy defined

104. A syzygy is:

a) when black is white and white is black.
b) an alignment of three astronomical bodies in a gravitationally-bound system.
c) when a planet is in conjunction and opposition simultaneously.
d) an alignment of three bodies that also forms a right angle.
e) when a door is both open and closed.

---

005 qmult 00300 1 1 3 easy memory: geocentric solar system belief

105. Before circa 1500, everyone in the context of ancient-Greek-derived astronomy (i.e., in European and the Middle Eastern astronomy) and perhaps nearly everywhere else believed that the Solar System was:

a) heliocentric. b) Venusocentric. c) geocentric. d) Marsocentric.
e) egocentric.

---

005 qmult 00310 1 1 3 easy memory: epicycle models

106. Ancient Greek mathematical astronomers used ____________ models to obtain quantitatively accurate predictions of celestial events.

a) flat Earth b) ethereal sphere c) epicycle d) epic e) pillar Earth

---

005 qmult 00320 1 4 5 easy deducto-memory: epicycle defined

107. "Let's play *Jeopardy*! For $100, the answer is: It is a circular planetary orbit that orbits on a larger circular orbit that is called the deferent. The center of this circular planetary orbit is just an empty point in space."

What is a ____________, Alex?

a) bicycle b) carbon cycle c) ring world d) torus e) epicycle

---

005 qmult 00330 1 4 5 easy deducto-memory: Ptolemy and the Ptolemaic system

108. "Let's play *Jeopardy*! For $100, the answer is: He created a complete geocentric epicycle model for the Solar System which continued to be used for astronomical prediction and was somewhat believed in for about 14 centuries."

Who is ____________, Alex?

a) Aristotle (384–322 BCE) b) Berossos, priest of Bel Marduk (3rd century BCE) c) King Ptolemy I (c.367–c.283 BCE) d) Cleopatra (69–30 BCE) e) Ptolemy (c.100–c.170 CE)

---

005 qmult 00332 1 4 1 easy deducto-memory: The Ptolemaic system

109. "Let's play *Jeopardy*! For $100, the answer is: This complete geocentric epicycle model of the Solar System is called this by modern science."

What is the ____________, Alex?

a) Ptolemaic system b) Berossosian system c) Aristotelian cosmology d) Cleopatran cosmology e) Aristarchan system

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005 qmult 00340 1 1 1 easy memory: wrongness of geocentric epicycle theory

110. The geocentric epicycle theory has two major deficiencies. It is ____________ and it gives ____________ of the solar system.

a) wrong; no uniquely good model b) right; a uniquely good model c) right; no uniquely good model d) wrong; a uniquely good model e) right; two uniquely good models

---

005 qmult 00400 1 4 2 easy deducto-memory: Copernicus proposed heliocentric model

111. "Let's play *Jeopardy*! For $100, the answer is: This astronomer introduced into the permanent historical record the heliocentric model of the solar system as a well-supported hypothesis, and therefore as one that could not be ignored."

Who is ____________, Alex?

a) Aristarchus of Samos (c.310–c.230 BCE) b) Nicolaus Copernicus (1473–1543) c) Galileo Galilei (1564–1642) d) Johannes Kepler (1571–1630) e) Isaac Newton (1643–1727)

---

005 qmult 00410 1 1 4 easy memory: time interval between Ptolemy and Copernicus

112. The time interval from Ptolemy to Copernicus is about ____________ years.

a) negative 400 b) 250 c) 1200 d) 1400 e) 2000

---

005 qmult 00420 1 1 2 easy memory: impossible moving Earth in circa 1550

113. Almost all of Copernicus' contemporaries rejected heliocentrism and mainly it seems because they could **NOT** believe in a/an:

a) unmoving Earth. b) moving Earth. c) moving Moon. d) unmoving Moon. e) moving Mars.

---

005 qmult 00430 1 1 3 easy memory: solar system distances predicted in AU

114. The heliocentric theory allowed Copernicus to predict the locations of all the planets in units of the:

a) meter. b) kilometer. c) astronomical unit. d) mile. e) light-year.

---

005 qmult 00440 1 1 3 easy memory: solar system distances predicted in AU good theory

115. By the standards of modern science, the heliocentric theory was a better theory than the ______________ because it predicted the Solar System structure quantitatively (using astronomical units) and the ______________ did not. This is true even if the heliocentric theory had turned out to be wrong and the ______________ right as far as it went.

a) Philolaic system. b) Cleopatran system. c) geocentric epicycle theory. d) planetitude theory. e) Aristarchan theory.

---

005 qmult 00500 1 4 4 easy deducto-memory: elliptical orbit discoverer

116. "Let's play *Jeopardy*! For $100, the answer is: He/she discovered 3 laws of planetary motion and got rid of epicycles finally in celestial mechanics."

Who is ____________, Alex?

a) Aristarchos of Samos (c.310–c.230 BCE) b) Nicolaus Copernicus (1473–1543)
c) Galileo Galilei (1564–1642) d) Johannes Kepler (1571–1630)
e) Caroline Herschel (1750–1848)

---

005 qmult 00510 1 4 4 easy deducto-memory: Kepler's 1st law

117. Kepler's 1st law states that the planetary orbits are ____________ with the Sun at one focus: the other focus is just an empty point in space.

a) lenses b) epicycles c) equants d) ellipses e) ovals

---

005 qmult 00550 1 1 4 easy memory: Kepler's 3rd law

118. The word formulation of ____________ is period squard is proportional semi-major axis cubed.

a) Newton's 2nd law b) Rayleigh's 3rd law c) Rayleigh's criterion
d) Kepler's 3rd law e) Newton's 3rd law

---

005 qmult 00560 1 1 1 easy memory: Kelper's 3rd law in small mass ratio approximation

119. Kepler's 3rd law (which applies to gravitationally bound two-body systems) in modern equation formulation is

$$P = \sqrt{\frac{4\pi^2}{G(M+m)}} \times a^{3/2} ,$$

where $P$ is orbital period, $G$ is the gravitational constant, $M$ is the mass of the more massive body, $m$ is the mass of the less massive body, and $a$ is the semi-major axis of the relative elliptical orbit. If $m << M$, the formula can be approximated to good accuracy by replacing $(M+m)$ by

a) $M$. b) $m$. c) $M/m$. d) $m/M$. e) $\sqrt{Mm}$.

---

005 qmult 00600 1 1 3 easy memory: exoplanets

120. Planets that orbit stars other than the Sun are called:

a) ex-planets b) epicycles c) exoplanets d) exotic planets
e) unseen planets

---

005 qmult 00610 1 4 4 easy deducto-memory: exoplanet discovery methods

121. "Let's play *Jeopardy*! For $100, the answer is: It is the second of 2 main methods of exoplanet discovery. The first being Doppler spectroscopy."

What is the ____________, Alex?

a) direct imaging method b) light curve method c) traffic method
d) transit method e) gravitational wave method

## Chapt. 6 Galilean Moons of Jupiter

## Multiple-Choice Problems

006 qmult 00100 1 4 3 easy deducto-memory: discoverer of the Galilean moons

122. "Let's play *Jeopardy*! For $100, the answer is: He discovered the first 4 moons of Jupiter."

Who is ____________, Alex?

a) Aristotle (384–322 BCE). b) Nicolaus Copernicus (1473–1543).
c) Galileo Galilei (1564–1642). d) Johannes Kepler (1571–1630).
e) Isaac Newton (1643–1727).

006 qmult 00102 1 1 1 easy memory: Galilean moons named for Galileo

123. Galileo called the 4 Jupiter moons he discovered the Medicean stars to help in obtaining the patronage of the Medici—the rulers of his native Florence—it worked. But posterity, ruling that the Medici have done well enough in fame in other areas, has named these moons the:

a) Galilean moons. b) Dead Sea moons c) Cosmian stars d) Keplerian moons
e) Gan De stars

006 qmult 00110 1 4 2 easy deducto-memory: Galilean moon sinusoidal motion

124. The projected motion on the sky of the Galilean moons is:

a) uniform circular motion. b) sinusoidal motion. c) uniform linear motion.
d) elliptical orbital motion. e) a state of rest.

006 qmult 00112 1 4 2 easy deducto-memory: sinusoidal motion

125. Uniform circular motion seen edge-on is:

a) uniform circular motion. b) sinusoidal motion. c) uniform linear motion.
d) elliptical orbital motion. e) a state of rest.

006 qmult 00120 1 1 5 easy memory: Earth not the center of all motion

126. "Let's play *Jeopardy*! For $100, the answer is: This/these early telescopic discovery/discoveries proved that the Earth was not the center of motion of all astronomical bodies as was posited by Aristolelian cosmology and the Ptolemaic geocentric system."

What is/are ____________, Alex?

a) sunspots b) the partial resolution of the Milky into a quasi-infinity stars
c) the terrestrial-like geological features of the Moon d) Neptune
e) the 4 largest moons of Jupiter and the full phases of Venus

006 qmult 00130 1 4 4 easy deducto-memory: Galilean moons and chronometer

127. Since the orbital periods of the Galilean moons are constant to high accuracy, Galileo suggested that they be used as a

a) barometer. b) speedometer. c) pedometer.
d) marine chronometer (i.e., high accuracy portable clock) for navigation.
e) ornithopter.

006 qmult 00132 1 4 2 easy deducto-memory: Galilean moons and longitude

128. "Let's play *Jeopardy*! For $100, the answer is: He/she was the first to propose and the first person who could have proposed that the orbital motions of the 4 largest moons of Jupiter could be used a worldwide clock that could be used to solve for longitude anywhere on Earth. If you have a worldwide clock, then a comparison to local solar or sidereal time gives longitude. Without knowing longitude navigation was tricky. Consider Columbus—India, America, very different places."

Who is ____________, Alex?

a) Nicolaus Copernicus (1473–1543) b) Galileo Galilei (1564–1642)
c) Johannes Kepler (1571–1630) d) Isaac Newton (1643–1727)
e) Caroline Herschel (1750–1848)

---

006 qmult 00140 1 4 3 easy deducto-memory: Kepler's 3 laws to Galilean moons

129. "Let's play *Jeopardy*! For $100, the answer is: His 3 laws of planetary motion also apply to the Galilean moons of Jupiter."

Who is ____________, Alex?

a) Aristarchus of Samos (c.310–c.230 BCE) b) Nicolaus Copernicus (1473–1543)
c) Johannes Kepler (1571–1630) d) Galileo Galilei (1564–1642)
e) Caroline Herschel (1750–1848)

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006 qmult 00200 1 1 5 easy memory: number of Jupiter moons

130. Jupiter has:

a) no moons. b) 1 moon. c) 2 moons. d) 3 moons. e) more than 60 moons.

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006 qmult 00230 1 1 5 easy memory: innermost moons

131. Jupiter has 4 moons closer than Io. They are:

a) Leto, Europa, Ganymede, Leda. b) Metis, Adrastea, Ganymede, Leda.
c) Metis, Adrastea, Ganymede, Thebe. d) Metis, Adrastea, Callisto, Thebe.
e) Metis, Adrastea, Amalthea, Thebe.

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006 qmult 00232 1 1 5 easy memory: innermost moons 2

132. Jupiter has 5 moons closer than Europa. They are:

a) Leto, Europa, Ganymede, Leda, Io. b) Metis, Adrastea, Ganymede, Leda, Europa.
c) Metis, Adrastea, Amalthea, Thebe, Callisto.
d) Metis, Adrastea, Callisto, Thebe, Io. e) Metis, Adrastea, Amalthea, Thebe, Io.

---

006 qmult 00300 1 1 3 easy memory: Galilean moons

133. The Galilean moons of Jupiter are:

a) Io, Europa, Ganymede, Leda. b) Leto, Europa, Ganymede, Leda.
c) Io, Europa, Ganymede, Callisto. d) Leto, Europa, Demeter, Leda.
e) Leto, Semele, Demeter, Leda.

---

006 qmult 00302 1 1 2 easy memory: Galilean moons

134. The largest Galilean moon and the largest moon in the Solar System is:

a) the Moon. b) Ganymede. c) Europa. d) Amalthea. e) Titan.

---

006 qmult 00310 1 1 5 easy memory: Callisto

135. The Galilean moons in order of increasing orbital radius are Io, Europa, Ganymede, and:

a) Psamanthe. b) Amalthea. c) Leda. d) Arche. e) Callisto.

---

006 qmult 00320 1 1 3 easy memory: Galilean tidally locked

136. The Galilean moons of Jupiter are all tidally locked to Jupiter. This means that each moon has an orbital rotational period and an axial rotational period that are:

a) in 2 to 1 ratio. b) in 1 to 2 ratio. c) the same. d) in 3 to 1 ratio. e) in 1 to 3 ratio.

---

006 qmult 00322 1 1 4 easy memory: tidally locked Io

137. If you stood on Io and saw Jupiter, it would set:

a) in about 1 hour. b) in about 1 day. c) in about 1 week. d) never. e) every 10 minutes or so.

---

006 qmult 00340 1 1 1 easy memory: 1:2:4 resonance of the Galilean moons

138. The 3 innermost Galilean moons exhibit a 1:2:4 Laplace resonance of the orbital periods. This means that the ratio of the orbital periods of the moons going outward is nearly exactly ____________.

a) 1:2:4 b) 1:2:3 c) 1:1:3 d) 1:2:1 e) 1:1:1

---

006 qmult 00420 1 1 2 easy memory: Io most geologically active body

139. Because of its proximity to Jupiter and slightly non-circlar orbit, ____________ has strong tidal flexing which gives it a lot of internal heating which makes it the most geologically active body in the solar system—every time you look at it, it seems, a volcano is erupting somewhere.

a) Amalthea b) Io c) Europa d) Ganymede e) Callisto

## Chapt. 7 Stars

## Multiple-Choice Problems

008 qmult 00100 1 1 2 easy memory: blackbody radiation defined
140. Blackbody radiation is produced by any dense body that is:

a) at zero temperature. b) all at one temperature. c) at two temperatures.
d) at a range of temperatures. e) at infinite temperature.

008 qmult 00110 1 1 3 easy memory: blackbody spectrum shape
141. The shape of the blackbody spectrum depends ____________ of the radiating body.

a) on the temperature and density b) only on the density
c) only on the temperature d) on the color e) on no aspect

008 qmult 00120 1 4 5 easy deducto-memory: Wien's law specified
142. "Let's play *Jeopardy*! For $100, the answer is:

$$\lambda_{max} = \frac{2897.771955\,\mu\mathrm{m\,K}}{T} ,$$

where T is Kelvin temperature. The is law gives the peak wavelength of blackbody radiation."

What is ____________, Alex?

a) the Stefan-Boltzmann law b) Hooke's law c) Rayleigh-Jeans law
d) Gauss's law e) Wien's law

008 qmult 00122 1 4 3 easy deducto-memory: Wien's law calculation 1
143. From Wien's law

$$\lambda_{max} = \frac{2897.771955\,\mu\mathrm{m\,K}}{T}$$

(where T is Kelvin temperature), the approximate peak wavelength for a blackbody radiator at 3000 K is:

a) 3000 $\mu$m. b) 3 $\mu$m. c) 1 $\mu$m. d) 1/3 $\mu$m. e) 1/3000 $\mu$m.

008 qmult 00124 1 4 4 easy deducto-memory: Wien's law calculation 2
144. From Wien's law

$$\lambda_{max} = \frac{2897.771955\,\mu\mathrm{m\,K}}{T}$$

(where T is Kelvin temperature), the approximate peak wavelength for a blackbody radiator at 6000 K is:

a) 6000 $\mu$m. b) 6 $\mu$m. c) 1 $\mu$m. d) 0.5 $\mu$m. e) 1/6000 $\mu$m.

008 qmult 00150 1 1 2 easy memory: photosphere emission approximates blackbody radiation
145. The emission from a stellar photosphere approximates:

a) white light. b) blackbody radiation. c) visible light. d) LED emission.
e) an emission line spectrum.

---

008 qmult 00170 1 1 3 easy memory: photon escape from stellar photosphere

146. The probability of a radially-traveling photon (a particle of light) escaping from a stellar photosphere is approximately:

a) zero. b) 1/10. c) 1/2. d) 1. e) $\infty$.

---

008 qmult 00200 1 4 5 easy deducto-memory: magnitude system defined

147. "Let's play *Jeopardy*! For \$100, the answer is: It is a system of classification the apparent (i.e., as-viewed-from Earth) or absolute brightnesses of stars and other astro-bodies. It originated with the ancient Greek astronomers who classified stars into six classes: the stars in each category judged by naked-eye visual astronomy to be of comparable apparent brightnesses. The classes in order of **DECREASING** brightness are 1st, 2nd, 3rd, 4th, 5th, and 6th magnitude. In the 19th century, it was decided to modernize this ancient classification system fixing its values to objective light flux measurements. (Flux is energy per unit time per unit area either per wavelength or integrated over some wavelength band.) The modernization was based on the discovery that the ancient magnitudes were roughly logarithmic in flux and that an **INCREASE** of 5 ancient magnitudes corresponded to roughly a factor of 100 **DECREASE** in flux. This rough result suggested the implemented prescription that an **INCREASE** of 5 magnitude corresponds to exactly a factor of 100 **DECREASE** in flux. The formula for the presription is

$$\Delta M = -2.5\log(F_2/F_1) \ ,$$

where $\Delta M$ is the difference in magnitude between 2 astro-bodies with fluxes $F_1$ and $F_2$. The negative sign makes magnitude difference increase with decreasing fraction $F_2/F_1$. If $F_2/F_1 = 1/100$, then $\Delta M = 5$. The inverse relationship is

$$\frac{F_2}{F_1} = 10^{-0.4\times\Delta M} \ .$$

We can see now that the logarithms are actually base

$$10^{0.4} = 2.511886\ldots \approx 2.512 \ .$$

This means an increase in magnitude by one corresponds to a decrease in flux by a factor of $\sim 1/2.512$.

In the modern system, fractional magnitudes occur and the magnitudes run over the whole real number line. Very bright objects have negative magnitudes.

Actually, many people (like yours truly) think that making modern system mimic the ancient system was a stupid idea. The modern system runs the wrong way—bigger/smaller is dimmer/brighter. This leads to endless confusion. And the modern system has a logarithm base used for nothing else. One could have made the definition

$$\Delta M = \log(F_2/F_1)$$

and then bigger/lower would be brighter/dimmer and 1 magnitude would correspond to a factor of 10 in flux. That would have been so easy to understand. But no. The dead hand of the past prevails."

What is the ____________, Alex?

a) Greek system b) magification system c) Roman system
d) Ptolemaic system e) magnitude system

---

008 qmult 00210 1 4 5 easy deducto-memory: Ptolemy magnitude system

148. "Let's play *Jeopardy*! For \$100, the answer is: He/She left to posterity and may have invented the ancient Greek system of 6 stellar magnitudes."

Who is ____________, Alex?

a) Aristotle (384–322 BCE) b) Berossos, priest of Bel Marduk (3rd century BCE)
c) King Ptolemy I (c.367–c.283 BCE) d) Cleopatra (69–30 BCE)
e) Ptolemy (circa 100–175 CE)

---

008 qmult 00212 1 1 4 easy memory: Ptolemy specified 6 stellar magnitudes

149. Ptolemy specified ____ stellar magnitudes in what yours truly calls the Ptolemaic magnitude system.

a) zero b) 1 c) 5 d) 6 e) a continuum of

---

008 qmult 00220 1 1 1 easy memory: apparent magnitude defined

150. The magnitude of an astro-body as observed from Earth is:

a) apparent magnitude. b) Earth-based magnitude. c) absolute magnitude.
d) fictional magnitude. e) obvious magnitude.

---

008 qmult 00230 1 1 2 easy memory: absolute magnitude defined

151. In order report the intrinsic brightness of stars, we define ____________ to be the apparent magnitude measured at a distance of 10 parsecs. Why 10 parsecs? Maybe because its a round number that is typical for distances to nearby stars and yields ____________s that are not so different from apparent magnitudes for these nearby stars.

a) luminosity b) absolute magnitude c) flux d) raw magnitude e) watt

---

008 qmult 00300 1 4 4 easy deducto-memory: color index defined

152. "Let's play *Jeopardy*! For $100, the answer is: This quantity is the difference between magnitudes in two passbands for a star: the redder passband magnitude is subtracted from the bluer passband magnitude. Because of the subtraction, the distance dependence of the passband magnitudes cancels out and the quantity is a measure of the instrinsic shape of the star's spectrum. The quantity can be used in many cases to determine the star's surface temperature, and is often used as substitude or proxy for surface temperature in plots and discussions. The flux in the bluer passband usually increases with temperature relative to the blux in the redder passband. But this means that the quantity decreases with increasing temperature—like magnitude, the quantity increases in the wrong way leading often to confusion. The most common version of this quantity is $B-V$: i.e., the $B$ passband magnitude minus the $V$ passband magnitude."

What is ____________, Alex?

a) absolute magnitude b) apparent magnitude c) luminosity
d) color index or color e) blueness

---

008 qmult 00400 1 1 3 easy memory: star spectral type

153. In the 19th century when little was known about star structure, stars were classified by their observed spectra into spectral types. The scheme was that those with the strongest hydrogen lines were A stars, those with the 2nd strongest hydrogen lines were B stars, and so on. Later on it was found out that hydrogen line strength does **NOT** increase/decrease strictly with star surface temperature. It was decided to order the spectral types by temperature from hottest to coldest. Instead of changing the names of the spectral types (i.e., the letters) already existing, the astronomers of that time simply re-ordered the letters in the spectral type sequence and dropped some letters that did not seem to correspond to any useful spectral type. The main spectral type ordering is mnemonicked by the expression "O be a fine girl/guy kiss me" which gives the ordering ____________.

a) ABGKMOF b) BAGKMOF c) OBAFGKM d) MOKFABG
e) BAGMOFK

---

008 qmult 00500 1 1 4 easy memory: luminosity defined

154. The total energy output per unit time could reasonably be called star power or, less reasonably, star wattage, but, in fact, is called:

    a) flux. b) apparent magnitude. c) absolute magntiude. d) luminosity. e) color.

---

008 qmult 00600 1 4 2 easy deducto-memory: HR diagram defined

155. "Let's play *Jeopardy*! For \$100, the answer is: This diagram is a plot that has logarithmic luminosity versus spectral type or color $B-V$ or photospheric temperature for stars. The luminosity can be replaced by absolute V magnitude which is a good proxy for logarithmic luminosity. Since spectral type and color $B-V$ increase to the right, temperature for consistency increases to the left."

    What is the ____________ diagram, Alex?

    a) Bertrand Russell or BR b) Hertzsprung-Russell or HR c) color-color d) star e) true star

---

008 qmult 00610 1 4 5 easy deducto-memory: main sequence defined

156. "Let's play *Jeopardy*! For \$100, the answer is: This narrow band of stars on an HR diagram starts high on the left-hand side, declines rapidly, then declines slowly in middle region of the diagram, and then declines rapidly toward the right-hand side. About 90 % of all stars (i.e., nuclear burning stars) in the Milky Way fall in the band and the same is roughly true of many other galaxies. The stars in the band are burning (in a nuclear sense) hydrogen to helium in their cores. The core-hydrogen-burning phase of a star's nuclear-burning life is the longest phase and this accounts for the abundance of stars in the band."

    What is the ____________, Alex?

    a) color sequence b) giant region c) supergiant region d) white dwarf e) main sequence

---

008 qmult 00620 1 4 3 easy deducto-memory: zero-age main sequence defined

157. "Let's play *Jeopardy*! For \$100, the answer is: Stars on this narrow curve on an HR diagram are just at the beginning of their core-hydrogen-burning phase. The curve is roughly speaking the lower-edge of the main sequence."

    What is ____________ main sequence, Alex?

    a) top b) bottom c) zero-age d) beginning e) infant

---

008 qmult 00630 1 1 1 easy memory: zero-age main sequence = ZAMS

158. The acronym for zero-age main sequence is:

    a) ZAMS. b) AZMS. c) MAZS d) MASZ e) SHAZAM

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## Full-Answer Problems

## Chapt. 8 Sunspots

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## Multiple-Choice Problems

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007 qmult 00100 1 1 1 easy memory: observational sunspot definition

159. Observationally, a ____________ is a small dark region of roughly circular or irregular shape or some other kinds of shape on the surface (i.e., photosphere) of the Sun.

    a) sunspot  b) sun dog  c) sun hole  d) sun pit  e) sun welt

---

007 qmult 00110 1 1 2 easy memory: first record of the sunspots

160. The earliest record of a sunspot was by Chinese astronomer Ge Dan (4th century BCE) in:

    a) 1000 BCE.  b) 364 BCE.  c) 1066.  d) 1610.  e) 1929.

---

007 qmult 00130 1 4 3 easy deducto-memory: Galileo among first telescopic sunspot

161. "Let's play *Jeopardy*! For $100, the answer is: He was not the first, but was among the first, to discover sunspots telescopically circa 1610."

    Who is ____________, Alex?

    a) Nicolaus Copernicus (1473–1543)  b) Miguel de Cervantes (1547–1616)
    c) Galileo Galilei (1564–1642)  d) William Shakespeare (1564–1616)
    e) John Milton (1608-1674)

---

007 qmult 00140 1 1 1 easy memory: early discovery of the rotating sun

162. An early consequence of the telescopic discovery of sunspots was the discovery that the Sun:

    a) rotated.  b) periodically deformed into a cigar shape.  c) was red.
    d) had magnetic fields.  e) had electric fields.

---

007 qmult 00200 1 1 3 easy memory: Sun rotation

163. The Sun rotates:

    a) once around every hour.  b) like solid sphere.  c) differentially.
    d) on an axis lying in the ecliptic plane  e) not at all.

---

007 qmult 00210 1 1 5 easy memory: sun differential rotation because a gas sphere

164. The Sun can rotate differentially since it is:

    a) not in orbit.  b) like the Earth.  c) a liquid sphere.  d) a solid sphere.
    e) a gas sphere.

---

007 qmult 00220 1 1 4 easy memory: solar interior solid-like rotation

165. Helioseismology tells that the Sun interior to about $0.65R_\odot$:

    a) has sunspots.  b) does not rotate.  c) is a solid sphere.
    d) rotates approximately like a solid sphere.  e) rotates very differentially.

---

007 qmult 00230 1 1 4 easy memory: Sun surface period

166. The surface equatorial sidereal period of the Sun is ____________. As one moves toward the poles, the sidereal period increases and reaches a limiting value of about ____________.

a) 38 days; 24.5 days b) 365.25 days; 38 days c) 100 days; 365.25 days
d) 24.5 days; 38 days e) 365.25 days; 1001 days

---

007 qmult 00240 1 4 5 easy deducto-memory: sidereal period

167. "Let's play *Jeopardy*! For $100, the answer is: This kind of rotation or revolution period is regarded as the true physically-motivated period since it is referenced to inertial frames. In our modern general relativity understanding, inertial frames are reference frames in free fall under gravity not rotating with respect to the observable universe (i.e., the bulk matter of the observable universe). All other frames of reference are noninertial frames. However, noninertial frames can changed into effective inertial frames with the use of inertial forces which are not real forces, but techniques for accounting for the noninertial nature of noninertial frames. Inertial forces are not seen as tricks since they have a fundamental connection to gravity. The supreme local inertial frame for Earth in modern understanding is the one defined by cosmologically remote galaxies and the cosmic microwave background radiation."

What is a/an ____________, Alex?

a) synodic period b) sentence period c) periodic table period
d) asynchronous period e) sidereal period

---

007 qmult 00250 1 4 1 easy deducto-memory: synodic period

168. "Let's play *Jeopardy*! For $100, the answer is: It is the period of an astronomical rotation relative to the Sun as viewed from the Earth."

What is a/an ____________, Alex?

a) synodic period b) sentence period c) periodic table period
d) asynchronous period e) sidereal period

---

007 qmult 00260 1 4 5 easy deducto-memory: relating synodic and sidereal periods

169. To relate synodic and sidereal periods for some kinds of astronomical motions consider the following formula:

$$360^\circ = (R - R_\oplus)p_{\rm syn} ,$$

where $R$ is the (sidereal) rotation rate of an astro-body (in degrees per unit time), $p_{\rm syn}$ is the synodic period of the body, and $R_\oplus$ is the (sidereal) revolution rate of the Earth (in degrees per unit time). Both $R$ and $R_\oplus$ are assumed constant as a simplifying approximation. Note $(R - R_\oplus)$ is the rate of rotation of astro-body relative to the Earth. Hereafter, we will think of the astro-body and Earth as aligned at time zero as a mental simplification though this assumption is not necessary to the analysis. If $(R-R_\oplus) > 0$, the astro-body laps the Earth and $p_{\rm syn} > 0$. If $(R-R_\oplus) < 0$, the Earth laps the astro-body and $p_{\rm syn} < 0$ (i.e., one must count $p_{\rm syn}$ as a negative time in this case). If $(R - R_\oplus) = 0$, the astro-body and Earth are at relative rest and $p_{\rm syn} = \infty$. Now $R = 360^\circ/p$ and $R_\oplus = 360^\circ/p_\oplus$, where $p$ and $p_\oplus$ are the sidereal periods of, respectively, the astro-body and the Earth. Note that $p$ must be counted as negative time if the astro-body rotates opposite to the Earth: i.e., it has retrograde rotation. After a little algebra, one finds ____________________.

a) $1/p = p_\oplus + 1/p_{\rm syn}$ b) $1/p = 1/p_\oplus + p_{\rm syn}$ c) $p = 1/p_\oplus + 1/p_{\rm syn}$
d) $1/p + 1/p_\oplus = 1/p_{\rm syn}$ e) $1/p = 1/p_\oplus + 1/p_{\rm syn}$

## Chapt. 9 Double Stars

## Multiple-Choice Problems

009 qmult 00100 1 4 1 easy deducto-memory: double star defined

170. "Let's play *Jeopardy*! For $100, the answer is: Two stars that appear very close on the sky to an observer. Usually the observer is using a telescope."

What is a ____________, Alex?

a) double star b) visual binary c) spectroscopic binary d) close binary
e) doubloon star

009 qmult 00110 1 4 2 easy deducto-memory: two main double star classes

171. The two main classes of double stars are ____________ and ____________.

a) optical doubles; optical twins b) optical doubles; binaries
c) spectroscopic binaries; visual binaries d) optical doubles; optical triples
e) spectroscopic binaries; binary triples

009 qmult 00120 1 4 4 easy deducto-memory: optical double defined

172. Two stars that are very close in angle on the sky, but are not physically related to each other are a/an:

a) optical twin pair. b) binary. c) close binary. d) optical double.
e) wide binary.

009 qmult 00130 1 1 4 easy memory: binary defined

173. A double star that is gravitationally bound is a:

a) single star. b) bound pair. c) gravitational pair. d) binary. e) triple.

009 qmult 00140 1 1 5 easy memory: binaries classified

174. Visual binaries, spectroscopic binaries, wide binaries, close binaries are, respectively:

a) detected by eye only, spectrumless, transferring light, affectionate.
b) detected by spectroscopy, detected by imaging, always transferring mass, gravitiationally interacting only.
c) detected by imaging, detected by spectroscopy, always transferring mass, gravitiationally interacting only.
d) detected by spectroscopy, detected by imaging, gravitationally interacting only, sometimes transferring mass.
e) detected by imaging, detected by spectroscopy, gravitationally interacting only, sometimes transferring mass.

009 qmult 00200 1 4 3 easy deducto-memory: angular resolution

175. "Let's play *Jeopardy*! For $100, the answer is: In a first meaning, it is the ability of an optical system to distinguish small details of an image. In a second meaning, it is the smallest angle that allows two point light sources to be resolved. Context decides which meaning is meant as usual.

What is ____________, Alex?

a) resonance b) angular velocity c) angular resolution d) reassembly
e) angular dissonance

---

009 qmult 00210 1 1 3 easy memory: three characteristic angular resolution limits

176. Angular resolution (in the smallest angle that allows two point light sources to be resolved) does not usually have a hard limit. There are however characteristic limits useful in various contexts. In astronomy, three characteristic limits are the seeing limit, the ____________ criterion, and the human eye angular resolution.

a) Jeans b) Ritz c) Rayleigh d) Janus e) Airy

---

009 qmult 00220 1 1 5 easy memory: seeing defined

177. The ____________ (in its second meaning of term) is the smallest angle on the sky that can be resolved due to the limitations imposed by twinkling and blurring due by the turbulence in the Earth's atmosphere which causes variations of the optical refractive index of the Earth's atmosphere. The qualitative amount of winkling and blurring is ____________ in its first meaning. Excellent ____________ is $0.4''$ and good ____________ is $1''$. In cities the ____________ is often much greater than $1''$.

a) looking b) raining c) blinking d) sighting e) seeing

---

009 qmult 00230 1 1 3 easy memory: angular resolution and Rayleigh criterion

178. In one meaning the term angular resolution is the ability to tell two point sources apart in a optical imaging device. But there is no hard limit to this angular size. However, a precise characteristic or fiducial angular resolution for an optical imaging device with a circular apperature is the angle

$$\theta_{\rm X} = \begin{cases} (1.21966989\ldots) \times \left(\dfrac{\lambda}{D}\right) \quad \text{radians} & \text{standard form;} \\ (1.220\ldots) \times \left(\dfrac{\lambda}{D}\right) \quad \text{radians} & \text{approximate standard form;} \\ (25.16'') \times \left(\dfrac{\lambda_{\mu\rm m}}{D_{\rm cm}}\right) & \text{fiducial value form;} \\ (9.905'') \times \left(\dfrac{\lambda_{\mu\rm m}}{D_{\rm in}}\right) & \text{fiducial value form;} \\ (4.952'') \times \left[\dfrac{\lambda_{\mu\rm m}/(0.5\,\mu\rm m)}{D_{\rm in}}\right] & \text{fiducial value form;} \\ (5'') \times \left[\dfrac{\lambda_{\mu\rm m}/(0.5\,\mu\rm m)}{D_{\rm in}}\right] & \text{approximate fiducial value form,} \end{cases}$$

where $\theta_{\rm X}$ is the fiducial angular resolution itself, $\lambda$ is wavelength, $D$ is circular aperature diameter, subscript "$\mu$" indicates in microns, subscript "cm" indicates in centimeters, subscript "in" indicates in entimeters, and superscript $''$ indicates in arcseconds. If two point sources at optical infinity are farther apart in angle than about $\theta_{\rm X}$, they can usually be resolved. If they are closer than about $\theta_{\rm X}$, then in practice they often cannot be resolved. If you have very high quality observations, you might be able to resolve them if they are somewhat closer than $\theta_{\rm X}$. The angle $\theta_{\rm X}$ is set by the diffraction of light. The angle $\theta_{\rm X}$ is called the ____________ criterion.

a) Kelvin. b) Raleigh c) Rayleigh d) Born e) Newton-John

---

009 qmult 00240 1 1 2 easy memory: human eye angular resolution

179. Human eye angular resolution, of course, varies from person to person. However, a fiducial value is ____________. **Hint:** A finger at arm's length subtends about $1^\circ$.

a) $1''$ b) $1' = 60''$ c) $0.5° = 30'$ d) $2°$ e) $5°$

---

009 qmult 00250 1 1 2 easy memory: telescopic human eye angular resolution

180. A telescope effectively enhances human eye angular resolution. Say the human eye angular resolution limit is $\theta_{\rm H}$ and telescopic magnification is $M = f_{\rm p}/f_{\rm e}$ (with $f_{\rm p}$ / $f_{\rm e}$ being the primary/eyepiece focal length). Then the telescopic human eye angular resolution limit is

$$\theta_{\rm HT} = \theta_{\rm H}/M$$

Now the human eye angular resolution limit is $60''$. What magnification is needed to get a telescopic human eye angular resolution limit of $1''$?

a) $M = 1$ b) $M = 60$ c) $M = 30$ d) $M = 120$ e) $M = 300$

---

009 qmult 00260 1 1 3 easy memory: dominant and overall angular resolution

181. The various angular resolution limits (seeing, Rayleigh criterion, telescopic human eye resolution) combine in a complex in general. However, if one is dominant and if overwhelmingly dominant, then it effectively is the overall angular resolution limit. The dominant one is the:

a) smallest one. b) middle one. c) largest one. d) the one closest to $60''$. e) the one closest to $1'$.

---

009 qmult 00300 1 1 1 easy memory: geometical optics limit

182. Given that $\lambda$ is wavelength and L is a characteristic size for aperatures and obstacles, $\lambda/L \to 0$ implies you:

a) are in the **EXACT** limit of geometrical optics.
b) are in the **INEXACT** limit of geometrical optics.
c) have to consider the **WAVE** nature of light.
d) have to consider the **PARTICLE** nature of light.
e) have consider diffraction.

---

009 qmult 00310 1 1 2 easy memory: Airy diffraction pattern

183. The diffraction pattern for plane waves perpendiculary incident on a circular aperture is the:

a) Airy diffraction pattern which is a diffraction pattern with square symmetry.
b) Airy diffraction pattern which is a diffraction pattern with circular symmetry.
c) powder diffraction pattern which is a diffraction pattern with square symmetry.
d) powder diffraction pattern which is a diffraction pattern with circular symmetry.
e) Newton's ring diffraction pattern.

---

009 qmult 00320 1 1 4 easy memory: geometical optics limit for Rayleigh criterion

184. The Rayleigh criterion is the fiducial angular resolution limit for plane waves of light perpendicularly incident on a circular aperture. The Rayleigh criterion formula is

$$\theta_{\rm R} = \begin{cases} (1.21966989\ldots) \times \left(\dfrac{\lambda}{D}\right) \ \text{radians} & \text{standard form;} \\ (1.220\ldots) \times \left(\dfrac{\lambda}{D}\right) \ \text{radians} & \text{approximate standard form;} \\ (25.16'') \times \left(\dfrac{\lambda_{\mu\rm m}}{D_{\rm cm}}\right) & \text{fiducial value form;} \\ (9.905'') \times \left(\dfrac{\lambda_{\mu\rm m}}{D_{\rm in}}\right) & \text{fiducial value form;} \\ (4.952'') \times \left[\dfrac{\lambda_{\mu\rm m}/(0.5\,\mu\rm m)}{D_{\rm in}}\right] & \text{fiducial value form;} \\ (5'') \times \left[\dfrac{\lambda_{\mu\rm m}/(0.5\,\mu\rm m)}{D_{\rm in}}\right] & \text{approximate fiducial value form,} \end{cases}$$

where $\theta_{\rm R}$ is the Rayleigh criterion itself, $\lambda$ is wavelength, $D$ is circular aperature diameter, subscript "$\mu$" indicates in microns, subscript "cm" indicates in centimeters, subscript "in" indicates in entimeters, and superscript $''$ indicates in arcseconds. Now $\lambda/D \to 0$ implies you:

a) have to consider the **PARTICLE** nature of light.
b) are in the **INEXACT** limit of geometrical optics.
c) have to consider the **WAVE** nature of light.
d) are in the **EXACT** limit of geometrical optics.
e) have consider diffraction.

---

009 qmult 00330 1 1 3 easy memory: Rayleigh criterion calculation

185. The Rayleigh criterion is the fiducial angular resolution limit for plane waves of light perpendicularly incident on a circular aperture. The Rayleigh criterion formula in fiducial value form is

$$\theta_{\rm R} = (4.952'') \times \left[ \frac{\lambda_{\mu{\rm m}}/(0.5\,\mu{\rm m})}{D_{\rm in}} \right] ,$$

where $\theta_{\rm R}$ is the Rayleigh criterion itself, $\lambda_{\mu{\rm m}}$ is wavelength in microns, and $D_{\rm in}$ is circular aperature diameter in inches. What is the Rayleigh criterion for $\lambda = 8\,\mu$m and $D_{\rm in} = 16\,$in?

a) $1.238''$. b) $2.476''$. c) $4.952''$. d) $9.904''$. e) $19.808''$.

---

009 qmult 00400 1 4 2 easy deducto-memory: binary defined

186. "Let's play *Jeopardy*! For $100, the answer is: Two gravitationally bound stars or star-like astronomical objects."

What is a ____________, Alex?

a) single b) binary c) triple d) quadruple e) multiple-star system

---

009 qmult 00410 1 4 2 easy deducto-memory: binaries and Kepler's 1st law

187. Binary stars orbit their mutual ____________ (AKA barycenter) in ____________ in general with the barycenter at a focus. The other focus of each orbit is just an empty point in space.

a) center of mass; circular orbits b) center of mass; ellitptical orbits
c) center of mass; hyperbolic orbits d) center of radiation; circular orbits
e) center of radiation; ellitptical orbits

---

009 qmult 00420 1 4 4 easy deducto-memory: kinds of binaries

188. There are many kinds of binary systems and, in fact, many binaries are classified as of more than one kind. Which of the following is **NOT** a kind of binary?

a) close binary. b) interacting binary. c) spectroscopic binary.
d) planetary system. e) multiple-star system of consisting of two stars.

## Chapt. 10 Stellar Spectra

## Multiple-Choice Problems

010 qmult 00100 1 4 5 easy deducto-memory: electromagnetic specturm defined

189. "Let's play *Jeopardy*! For $100, the answer is: It is the range of all possible wavelengths of electromagnetic radiation. At least as an ideal limit, the wavelengths form a continuum (like real numbers) ranging from arbitrarily close to zero to arbitrarily close to infinity. Real processes may limit the actual range of wavelengths, but we really don't know where those limits are."

    What is ____________, Alex?

    a) white light b) white noise c) colored light d) the energy spectrum
    e) the electromagnetic spectrum

---

010 qmult 00110 1 4 1 easy deducto-memory: atmosphere transparent to visible band

190. "Let's play *Jeopardy*! For $100, the answer is: Because the Earth's atmosphere is very transparent to this electromagnetic radiation band, it has always been very important in the study of star light—and for life in general."

    What is the ____________, Alex?

    a) visible band b) X-ray band c) red band d) gamma-ray band
    e) big band

---

010 qmult 00120 1 1 5 easy memory: visible light spectrum, visible band

191. Visible light is conventionally divided into:

    a) violet, blue, green, yellow, orange, radio.
    b) X-ray, violet, blue green, yellow, orange, tangerine, red.
    c) Gamma-ray, X-ray, ultraviolet, visible, infrared, microwave, radio.
    d) mauve, navy, forest lawn, goldenrod, tamarind, cerise.
    e) violet, blue, green, yellow, orange, red.

---

010 qmult 00150 1 1 3 easy memory: spectrum defined sort of

192. Dispersion separates in space the radiations of different wavelength (i.e., the ____________) that make up a beam or propagating radiation. This allows the ____________ to be analyzed. The dispersed beam is often called a ____________ in a separate, but related, meaning of the word ____________.

    a) range b) electromagnetic spectrum c) spectrum d) domain e) spread

---

010 qmult 00160 1 1 4 easy memory: dispersion of light

193. The dispersion of electromagnetic radiation into a spectrum can be done using a prism or a:

    a) dispenser b) disperser. c) dispersion grating. d) diffraction grating.
    e) diffraction window.

---

010 qmult 00162 1 1 5 easy memory: dispersion of light process: refraction, diffraction

194. A prism disperses electromagnetic radiation into a spectrum by refraction and a diffraction grating by:

a) refraction too. b) dispersion. c) reflection. d) transmission.
e) diffraction.

---

010 qmult 00170 1 1 2 easy memory: spectroscope

195. A device that disperses electromagnetic radiation into a spectrum for analysis (and includes an element like a prism that is the direct agent of dispersion) is called a:

a) stroboscope. b) spectroscope. c) telescope. d) microscope.
e) stethoscope.

---

010 qmult 00200 1 1 2 easy memory: continuous and line spectra

196. A spectrum with no large deviations in narrow wavelength bands is a ____________ spectrum and one with such deviations is a ____________ spectrum. The two classes are **NOT** actually separate since a general spectrum can have both kinds of behavior. The part of a general spectrum **WITHOUT** large deviations in narrow wavelength bands is considered to be the ____________ part of the spectrum.

a) line; continuous; continuous b) continuous; line; continuous
c) continuous; continuous; line d) wavelength; continuous; wavelength
e) line; continuous; line

---

010 qmult 00210 1 1 4 easy memory: incandescent light bulb

197. An incandescent light bulb produces a ____________ spectrum that to good approximation is a ____________ spectrum.

a) line; red hot b) continuous; green hot c) line; white
d) continuous; blackbody e) line; blackbody

---

010 qmult 00220 1 1 3 easy memory: radiating strength 1

198. The radiating strength of an object tends to increase with the surface area per volume all other things being equal, particularly with volume fixed. For example, consider the ratio of surface area per volume for a cylinder (so long that its end areas are negligible) to surface area per volume for a sphere with the volume for both objects the same. The formula for this ratio is

$$R = \left(\frac{1}{2}\right)\left(\frac{4}{3}\right)^{2/3}\left(\frac{L}{a}\right)^{1/3} = (0.6057\ldots) \times \left(\frac{L}{a}\right)^{1/3} ,$$

where $a$ is cylinder radius, $L$ is cylinder length, $r$ is sphere radius, $V$ is the volume of both cylinder and sphere:

$$V_{\text{cylinder}} = \pi a^2 L = V = \left(\frac{4}{3}\right)\pi r^3 = V_{\text{sphere}} ,$$

and $r = [(3/4)a^2 L]^{2/3}$. Given $L = 1\,\text{m}$ and $a = 0.025\,\text{mm}$, what is R? **HINT:** You need to use consistent units in the formula.

a) $0.6057\ldots$ b) 16.44 c) 20.71 d) 4/3 e) 25.31

---

010 qmult 00230 1 1 1 easy memory: radiating strength 2

199. The radiating strength of an object tends to increase with the surface area per volume all other things being equal, particularly with volume fixed. Speaking more loosely extended objects tend have more radiating strength than compacted objects. Say have an object with two characteristic length scales, $a$ which applies in 2 dimensions and $L$ which applies in just 1 dimension. An example of such an object is a cuboid (each face is a rectangle and all corners are right angles) with sides of length $a$, $a$, and $L$. The area to volume ratio for such an object is of order

$$\frac{A}{V} \sim \frac{2a^2 + 4aL}{a^2 L} = \frac{2a + L}{aL} .$$

Now say we have a second object with only one characteristic length scale which applies in all 3 dimensions. An example of such an object is a cube with sides all of length $r$. The area to volume ratio for such the second object is of order

$$\frac{A}{V} \sim \frac{6r}{r^3} = \frac{6}{r} \ .$$

If the objects have the same volume, then

$$r^3 \sim a^2 L \qquad \text{and} \qquad r \sim (a^2 L)^{1/3} \ .$$

The first object is more extended than the second object because the characteristic ratio $R$ of first object surface to volume to the second object surface to volume tends to be greater than 1 in all cases. This characteristic ratio is

$$R = \frac{2a + L}{3a^{1/3} L^{2/3}} \ .$$

If $L >> a$, then $R$ equals approximately ________. If $L = a$, then $R$ equals ________. If $L << a$, then $R$ equals approximately ________.

a) $(1/3)(L/a)^{1/3} >> 1$; 1; $(2/3)(a/L)^{2/3} >> 1$
b) $(1/3)(L/a)^{1/3} << 1$; 1; $(2/3)(a/L)^{2/3} << 1$
c) $(2/3)(a/L)^{2/3} >> 1$; 1; $(1/3)(L/a)^{1/3} >> 1$
d) $(2/3)(a/L)^{2/3} >> 1$; 1/2; $(1/3)(L/a)^{1/3} >> 1$
e) $(2/3)(a/L)^{2/3} << 1$; 1/2; $(1/3)(L/a)^{1/3} << 1$

---

010 qmult 00300 1 1 2 easy memory: emission and absorption line spectrum

200. An emission line spectrum consists of ________ against a dark background and comes from a ________ gas. An absorption line spectrum consists of ________ against a bright background of a continous spectrum and typically comes from a ________ gas overlying a hotter gas.

a) dark lines; cold, dense; bright lines; hotter, dense
b) bright lines; hot, dilute; dark lines; colder, dilute
c) dark lines; hot, dilute; bright lines; colder, dilute
d) dark lines; hot, dilute; dark lines; hotter, dilute
e) bright lines; cold, dilute; bright lines; hotter, dilute

---

010 qmult 00400 1 4 5 easy deducto-memory: Grotrian diagrams defined

201. "Let's play *Jeopardy*! For $100, the answer is: He is the eponym (i.e., person after whom a thing is named) of Grotrian diagrams. A Grotrian diagram shows the energy levels of an atom, ion, or molecule in a standard format and the line transitions between the energy levels that can emit or absorb photons. It is a very abstract diagram of the atom, ion, or molecule"

Who is ________, Alex?

a) John Venn (1834–1923) b) Ejnar Hertzsprung (1873–1967)
c) Henry Norris Russell (1877–1957) d) Edwin Hubble (1889–1953)
e) Walter Grotrian (1890–1954)

---

010 qmult 00410 1 4 1 easy deducto-memory: Grotrian diagram for hydrogen

202. The simplest Grotrian diagram for a neutral atom is for the neutral form of the ________ atom which is also the most abundant atom in the observable universe.

a) hydrogen (H) b) helium (He) c) carbon (C) d) iron (Fe)
e) uranium (U)

---

010 qmult 00500 1 1 2 easy memory: stars best classified by absorption line spectrum

203. The direct observable by which stars are best empirically classified is their:

a) emission line spectrum. b) absorption line spectrum. c) continuous spectrum. d) surface pressure. e) surface gravity.

---

010 qmult 00510 1 1 3 easy memory: OBAFGKM spectral classification

204. The OBAFGKM spectral type classification (AKA the Harvard spectral classification) of stars is based on the line spectra (mainly absorption line spectra) of stars: O stars have a certain spectrum, B stars another, etc. The classification is empirical, but is theoretically understood to be a stellar atmosphere temperature classification. The spectral types (i.e., OBAFGKM) are ordered by decreasing stellar surface (i.e., photosphere) temperature and each **SPECTRAL TYPE** is divided into **SUBTYPES** which are numbered: the numbers in order of decreasing temperature run 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. The Sun is **NOT** in the hottest, 2nd hottest, coldest, or 2nd coldest **SPECTRAL TYPE**. It is a:

a) O5 star. b) B8 star. c) G2 star. d) K6 star. e) M3 star.

---

010 qmult 00520 1 1 2 easy memory: OBAFGKM mnemonic

205. OBAFGKM is mnemonicked—to verb a word—by:

a) Oswald Bastable always failed gnomic, knarled mnemonics.
b) O be a fine girl/guy kiss me.
c) O be fine and grievously kiss me.
d) Opik, Behte, Aristarchus, Tycho, Friedmann, Kepler, Minkowski.
e) Man very early made jars stand up nearly perpendicularly.

---

010 qmult 00530 1 1 3 easy memory: Hertzsprung-Russell diagram

206. A ____________ diagram plots logarithmic stellar luminosity versus stellar logarithmic photosphere temperature (or alternatively versus OBAFGKM spectral type or $B - V$ color).

a) Feynman b) Grotrian c) Hertzsprung-Russell d) Hubble e) Venn

---

010 qmult 00540 1 1 1 easy memory: main sequence most numerous star phase

207. Most stars burning nuclear fuel plotted on a Hertzsprung-Russell diagram lie on the ____________. The main reason for this is that the ____________ phase is by far the longest nuclear burning phase of a star's lifetime, and therefore that's the phase most nuclear-fuel-burning stars will be in.

a) main sequence b) secondary sequence c) red giant branch d) horizontal branch e) white dwarf branch

## Chapt. 11 Galaxies

## Multiple-Choice Problems

011 qmult 00050 1 1 5 easy memory: cycle of the scientific method

208. The history of the discovery of galaxies (other than the Milky Way) can be regarded as very long, slow cycle of ____________ in action.

a) the Scientific Revolution b) a scientific revolution
c) observation without theory d) theory without observation
e) the scientific method

011 qmult 00060 1 4 2 easy deducto-memory: nebulae noted by Ptolemy

209. "Let's play *Jeopardy*! For $100, the answer is: The first person in the historical record to note the existence of nebulae (historical usage)."

Who is ____________, Alex?

a) Berossos, priest of Bel Marduk (3rd century BCE) b) Ptolemy (c.100–c.170 CE)
c) Hypatia (c.360–415 CE) d) Abd al-Rahman al-Sufi (903–986)
e) Christopher Wren (1632–1723)

011 qmult 00074 1 4 3 easy deducto-memory: Immanuel Kant and galaxies

210. "Let's play *Jeopardy*! For $100, the answer is: One of the early and impactful proposers of the theory that the nebulae (historical usage) were other galaxies."

Who is ____________, Alex?

a) physicist Isaac Newton (1643–1727)
b) mathematician and philospher Gottfried Leibniz (1646–1716)
c) philosopher Immanuel Kant (1724–1804)
d) astronomer Caroline Herschel (1750–1848)
e) composer Wolfgang Amadeus Mozart (1756–1791)

011 qmult 00094 1 1 3 easy memory: Hubble discovers galaxies in 1924

211. Edwin Hubble (1889–1953) presented evidence that was soon accepted as decisive that there were other galaxies in:

a) 1915 b) 1920 c) 1924 d) 1929 e) 1936

011 qmult 00100 1 4 5 easy deducto-memory: galaxies defined

212. "Let's play *Jeopardy*! For $100, the answer is: They are large gravitationally bound systems of stars which have undergone multiple cycles of star formation, evolution, and death. In some cases, the cycles have nearly ended and almost all the stars are now just aging. In other cases, the cycles continue to the present epoch of cosmic time and are likely to continue for many billions of years into the future."

What are ____________, Alex?

a) planetary systems b) binaries c) globular clusters d) bulges e) galaxies

011 qmult 00130 1 4 3 easy deducto-memory: Hubble's law discoverer

213. "Let's play *Jeopardy*! For $100, the answer is: This pioneer of extragalactic astronomy is the discoverer of Hubble's law as an observational result. The mathematical statement of the law includes as a factor the relative rate of the expansion of the universe at cosmic present. The said pioneer also devised the empirical galaxy morphological classification scheme that bears his name."

Who is ____________, Alex?

a) William Parsons, 3rd Earl of Rosse (1800–1867) b) Vesto Slipher (1875–1969)
c) Edwin Hubble (1889–1953) d) Carl Seyfert (1911–1960)
e) Allan Sandage (1926–2010)

---

011 qmult 00140 1 4 4 easy deducto-memory: Gerard de Vaucoulers

214. "Let's play *Jeopardy*! For $100, the answer is: This pioneer of extragalactic astronomy devised the empirical galaxy morphological classification scheme that bears his name and that is mostly an **EXTENSION** of the Hubble sequence."

Who is ____________, Alex?

a) William Parsons, 3rd Earl of Rosse (1800–1867) b) Vesto Slipher (1875–1969)
c) Edwin Hubble (1889–1953) d) Gerard de Vaucouleurs (1918–1995)
e) Allan Sandage (1926–2010)

---

011 qmult 00150 1 4 4 easy deducto-memory: Carl Seyfert

215. "Let's play *Jeopardy*! For $100, the answer is: This pioneer of extragalactic astronomy was the founding director of Dyer Observatory—Dyer, not Dire—in Nashville, Tennessee."

Who is ____________, Alex?

a) William Parsons, 3rd Earl of Rosse (1800–1867) b) Vesto Slipher (1875–1969)
c) Edwin Hubble (1889–1953) d) Carl Seyfert (1911–1960)
e) Allan Sandage (1926–2010)

---

011 qmult 00200 1 1 3 easy memory: Hubble sequence

216. The ____________ sequence is an empirical galaxy classification scheme that nowadays has a theoretical understanding. Its eponym (the person after which it is named) concluded it was premature to interpret the ____________ sequence as an evolutionary sequence. We now know that it is not, in fact, an evolutionary sequence in a simple sense.

a) Rosse b) Slipher c) Hubble d) Seyfert e) Sandage

---

011 qmult 00210 1 4 1 easy deducto-memory: hubble tuning fork diagram

217. The two most common galaxy morphological classification schemes are conventionally illustrated with a ____________ diagram.

a) tuning fork b) pitchfork c) Southfork d) South Park e) Gosford Park

---

011 qmult 00220 1 1 1 easy memory: main galaxy types: ellipticals

218. The 6 main galaxy types are ____________, lenticulars, spirals, intermediate spirals, barred spirals, and irregulars.

a) ellipticals b) perpendiculars c) spectaculars d) chroniculars e) consulars

---

011 qmult 00222 1 1 4 easy memory: main galaxy types

219. The 6 main galaxy types are ellipticals, ____________, spirals, intermediate spirals, barred spirals, and irregulars.

a) ellipticals b) perpendiculars c) spectaculars d) lenticulars e) consulars

---

011 qmult 00230 1 4 1 easy deducto-memory: ellipticals described

220. "Let's play *Jeopardy*! For $100, the answer is: These galaxies are spheroidal in shape, largely lack interstellar dust, and consist mainly of very old stars."

What are ____________, Alex?

a) ellipticals b) lenticulars c) spirals d) barred spirals e) irregulars

---

011 qmult 00300 1 1 2 easy memory: galaxy clusters
221. Galaxies are often found in gravitationally bound systems called:

a) bunches. b) clusters. c) flocks. d) gaggles. e) prides.

---

011 qmult 00320 1 4 2 easy deducto-memory: rich and poor clusters
222. "Let's play *Jeopardy*! For $100, the answer is: Rich ones typically have thousands of galaxies, poor ones hundreds of galaxies."

What are ____________, Alex?

a) galaxies b) galaxy clusters c) binaries d) Hubbles e) millionaires

---

011 qmult 00340 1 1 5 easy memory: Virgo cluster location constellation
223. The Virgo cluster is mostly in the constellation:

a) Alien b) Lyra c) Norma d) Scorpius e) Virgo

---

011 qmult 00400 1 4 4 easy deducto-memory: galaxy rotation curve defined
224. "Let's play *Jeopardy*! For $100, the answer is: It is a plot of velocity versus radius for galaxies. The velocity is the velocity of tracer astronomical objects."

What is a galaxy ____________, Alex?

a) orbital curve. b) radius curve c) star curve d) rotation curve
e) Keplerian curve

---

011 qmult 00410 1 1 3 easy memory: galaxy rotation curve plateau velocity
225. The plateau orbital velocity of galaxies is typically of order:

a) 3 km/s. b) 30 km/s. c) 200 km/s. d) 1000 km/s. e) 10,000 km/s.

---

011 qmult 00420 1 1 5 easy memory: dark matter exists
226. The orbital velocities of galaxies strongly suggests the existence of:

a) hydrogen. b) molecular clouds. c) baryonic matter.
d) baryonic dark matter. e) dark matter.

---

011 qmult 00430 1 1 5 easy memory: what is dark matter?
227. The Big Bang theory (which is so well supported that it would be astonishing if it were just plain wrong) tells us that dark matter is:

a) ordinary matter. b) hydrogen. c) quarks. d) baryonic dark matter.
e) exotic matter of some kind.

---

## Full-Answer Problems

## Chapt. 12 Cosmos

## Multiple-Choice Problems

012 qmult 00100 1 4 1 easy deducto-memory: Vesto Slipher

228. "Let's play *Jeopardy*! For \$100, the answer is: This astronomer discovered that most galaxies have redshifts."

Who is ____________, Alex?

a) Vesto Slipher (1875–1969) b) Albert Einstein (1879–1955)
c) Edwin Hubble (1889–1953) d) Georges Lemaitre (1894–1966)
e) E.A. Milne (1896–1950)

012 qmult 00110 1 4 3 easy deducto-memory: Edwin Hubble discovers galaxies

229. "Let's play *Jeopardy*! For \$100, the answer is: This astronomer discovered the extragalactic nature of the spiral nebulae (now called spiral galaxies)."

Who is ____________, Alex?

a) Vesto Slipher (1875–1969) b) Albert Einstein (1879–1955)
c) Edwin Hubble (1889–1953) d) Georges Lemaitre (1894–1966)
e) E.A. Milne (1896–1950)

012 qmult 00120 1 4 2 easy deducto-memory: spiral nebulae

230. Observed galaxies were originally not known to be galaxies though speculation that they were goes back to the 17th century. The spiral nature of some of the observed galaxies was known from mid-19th century on. These galaxies with a spiral nature were usually called ____________________ from the mid-19th century to circa 1924 and even in later years by some including Edwin Hubble (1889–1953) who had proven they were galaxies.

a) island universes b) spiral nebulae c) other Milky Ways d) star clusters
e) star whirlpools

012 qmult 00130 1 4 4 easy deducto-memory: redshift and Doppler shift formulae

231. The cosmological redshift and Doppler shift are both shifts in wavelength of spectrum of electromagnetic radiation between emission and absorption. They are related, but different, effects. The cosmological redshift is caused by the ________________ and the Doppler shift by ordinary velocities relative to inertial frames. but

a) space b) degrowth of space c) quarks d) growth of space
e) general relativity

012 qmult 00140 1 4 1 easy deducto-memory: redshift and Doppler shift calculation 1

232. The 1st order cosmological redshift and 1st order Doppler shift have the same formula in appearance $v = (\Delta\lambda/\lambda)/c$, where $z = \Delta\lambda/\lambda$ is relative wavelength shift, $v$ is the recession velocity for the cosmological redshift and ordinary velocity relative to an inertial frame for the Doppler shift, and $c$ is the vacuum speed of light. Given $v = 1000\,\text{km/s}$ and $2.99792458 \times 10^5\,\text{km/s}$, what is $z = vc$ to 3-digit accuracy.

a) $z = 0.00334$. b) $z = 0.333$. c) $z = 0.533$. d) $z = 0.00534$. e) $z = 1.00$.

---

012 qmult 00142 1 4 3 easy deducto-memory: redshift and Doppler shift calculation 2

233. The 1st order cosmological redshift and 1st order Doppler shift have the same formula in appearance $v = (\Delta\lambda/\lambda)/c$, where $z = \Delta\lambda/\lambda$ is relative wavelength shift, $v$ is the recession velocity for the cosmological redshift and ordinary velocity relative to an inertial frame for the Doppler shift, and $c$ is the vacuum speed of light. Given $v = 2000\,\mathrm{km/s}$ and $2.99792458 \times 10^5\,\mathrm{km/s}$, what is $z = vc$ to 3-digit accuracy?

a) $z = 0.00333$. b) $z = 0.00334$. c) $z = 0.00667$. d) $z = 0.00716$. e) $z = 1.00$.

---

012 qmult 00150 1 4 2 easy deducto-memory: redshift and Doppler shift formulae 1st order

234. The 1st order cosmological redshift and 1st order Doppler shift have the same formula in appearance ________________, but the interpretation is of $v$ is different. For the cosmological redshift, $v$ is recession velocity which is a rate of growth of space literally according to general relativity. For the Doppler shift, $v$ is ordinary velocity measured relative to an inertial frame.

a) $z = vc$ b) $z = v/c$ c) $z = (v/c)^2$ d) $z = (vc)^2$ e) $z = 1/(vc)^2$

---

012 qmult 00200 1 4 1 easy deducto-memory: discovery of expansion of universe

235. The empirical discovery of Hubble's law for the observable universe in 1927 with weak evidence and little notice by George Lemaî̂tre (1894–1966) and independently in 1929 with convincing evidence and much notice by Edwin Hubble (1889–1953) was the empirical discovery of the ________________________. Note Hubble's law is not the same thing as ________________________ since you can have ________________________ without Hubble's law, but not vice versa. Note also that since 1917 some cosmological models by Willem de Sitter (1872–1934), Alexander Friedmann (1888–1925), and George Lemaî̂tre (1894–1966) based on general relativity had predicted the ________________________ and Hubble's law as an unnoticed implication.

a) expansion of the universe b) constraction of the universe c) universe d) static universe e) accelerating universe

---

012 qmult 00210 1 4 2 easy deducto-memory: fiducial value of Hubble constant

236. A fiducial value (i.e., reference value) for the Hubble constant is:

a) 50 (km/s)/Mpc. b) 70 (km/s)/Mpc. c) 85 (km/s)/Mpc. d) 100 (km/s)/Mpc. e) 118 (km/s)/Mpc.

---

012 qmult 00220 1 4 4 easy deducto-memory: Hubble constant has units of 1/t

237. The conventional units the Hubble constant (km/s)/Mpc work out be units of ________________. In physics jargon, we would say that the Hubble constant has the dimension of ________________, where in this context dimension means "nature of."

a) time b) space c) inverse space d) inverse time e) spacetime

---

012 qmult 00240 1 4 1 easy deducto-memory: Hubble time and length

238. Characteristic ages and size scales for most expanding universe models are, respectively, the ____________ and the ____________.

a) Hubble time $1/H_0$; Hubble length $c/H_0$ b) Hubble time $c/H_0$; Hubble length $1/H_0$ c) Hubble length $c/H_0$; Hubble time $1/H_0$ d) Hubble time $H_0$; Hubble length $cH_0$ e) Hubble length $cH_0$; Hubble time $H_0$

---

012 qmult 00300 1 4 3 easy deducto-memory: proper distance and luminosity distance

239. Two distance measures that arise in cosmology are ____________ and ____________.

a) proper distance; improper distance b) improper distance; luminosity distance c) proper distance; proper distance d) improper distance; density distance

e) density distance; luminosity distance

---

012 qmult 00310 1 4 1 easy deducto-memory: proper distance defined

240. Proper distance is a distance:

a) that can be measured at one instant time with a ruler for an object (for which the distance is a length) at rest in the inertial frame of that one instant in time.
b) determined using the formula $r_{\rm L} = [L/(4\pi F)]^{1/2}$ in all cases if extinction is negligible.
c) that is the length of an object undergoing FitzGerald contraction in the inertial frame of measurement.
d) is **NOT** an improper distance.
e) is **NOT** an improper fraction.

---

012 qmult 00320 1 4 2 easy deducto-memory: luminosity distance

241. Luminosity distrance is

a) the same as proper distance in all cases.
b) determined using the formula $r_{\rm L} = [L/(4\pi F)]^{1/2}$ in all cases if extinction is negligible.
c) that is the length of an object undergoing FitzGerald contraction in the inertial frame of measurement.
d) is **NOT** an improper distance.
e) is **NOT** an improper fraction.

---

012 qmult 00400 1 4 2 easy deducto-memory: supernovae defined

242. Supernovae are:

a) the explosions of black holes. b) the giant, bright explosions of stars.
c) the small, faint explosions of stars. d) the giant, bright explosions of planets.
e) the small, faint explosions of planets.

---

012 qmult 00410 1 4 4 easy deducto-memory: supernovae and accelerating universe

243. What kind of supernovae provided the luminosity distances that were the first convincing evidence for the accelerating universe?

a) Type II supernovae (SNe II). b) core collapse supernovae.
c) Type Ib supernova (SNe Ib). d) Type Ia supernovae (SNe Ia).
e) Type IIn supernovae (SNe IIn).

---

012 qmult 00420 1 4 3 easy deducto-memory: supernovae and accelerating universe 2

244. Luminosity distances for Type Ia supernovae (SNe Ia) provided the first convincing evidence for the:

a) expanding universe. b) Einstein universe. c) accelerating universe.
d) de Sitter universe. e) big rip universe.

---

012 qmult 00430 1 4 3 easy deducto-memory: light curve fitting for SNe Ia

245. Luminosity distances for Type Ia supernovae (SNe Ia) are determined by fitting ________________ for known-distance SNe Ia to ________________ for unknown-distance SNe Ia.

a) radio emission. b) spectra. c) light curves. d) color index. e) age.

---

012 qmult 00500 1 4 1 easy deducto-memory: The cosmic scale factor defined

246. The proper distances between all points that participate in the mean expansion vary according to the cosmic scale factor $a(t)$ (where $t$ is cosmic time since the Big Bang) according to the formula:

a) $r = ar_0$. b) $r = a^2 r_0$. c) $r = a^{-2} r_0$. d) $r = a^{-1} r_0$. e) $r = e^a r_0$.

---

012 qmult 00540 1 4 2 easy deducto-memory: scaling of photon energy and wavelength

247. The energy $\varepsilon$ of photons and wavelength $\lambda$ of photons that propagate through the observable universe without interacting obey, rexpectively, the formulae:

a) $\varepsilon = \varepsilon_0(a/a_0)$ and $\lambda = \lambda_0(a_0/a)$. b) $\varepsilon = \varepsilon_0(a_0/a)$ and $\lambda = \lambda_0(a/a_0)$.
c) $\varepsilon = \varepsilon_0(a/a_0)^2$ and $\lambda = \lambda_0(a_0/a)^2$. d) $\varepsilon = \varepsilon_0(a_0/a)^2$ and $\lambda = \lambda_0(a/a_0)^2$.
e) $\varepsilon = \varepsilon_0(a_0/a)^3$ and $\lambda = \lambda_0(a/a_0)^3$.

---

012 qmult 00560 1 4 5 easy deducto-memory: cosmic background radiation energy scaling
248. Given the energy density $E$ of a blackbody radiation field scales as $T^4$ (i.e., temperature to the 4th power) and the cosmic background radiation (CBR) energy density $E$ scales (which is a blackbody radiation field) scales as $a^{-4}$ (where $a$ is the cosmic scale factor), what is the formula for cosmic temperature $T$ in terms of $T_0$, $a_0$ and $a$?

a) $T = T_0(a/a_0)$ b) $T = T_0(a/a_0)^4$ c) $T = T_0(a/a_0)^2$ d) $T = T_0(a_0/a)^4$
e) $T = T_0(a_0/a)$

---

012 qmult 00600 1 4 1 easy deducto-memory: cosmic redshift is primary cosmic distance measure why
249. The cosmological redshift is the primary cosmic distance measure because it is:

a) a direct observable and relatively easy to measure from **SPECTROSCOPY**.
b) a direct observable and relatively easy to measure from **PHOTOMETRY**.
c) an indirect observable and relatively easy to measure from **PHOTOMETRY**.
d) an indirect observable and relatively easy to measure from **SPECTROSCOPY**.
e) in indirect observable and relatively hard to measure from **PHOTOMETRY**.

---

012 qmult 00610 1 4 2 easy deducto-memory: a(t) and z related
250. The relationships between cosmological redshit $z$ and cosmic scale factor $a(t)$ are very simple:

$$\frac{a_0}{a} = z + 1 \ , \qquad z = \frac{a_0}{a} - 1 \ , \qquad \frac{a}{a_0} = \frac{1}{z+1} \ .$$

So getting $a/a_0$ from $z$ is easy. But we do not get $a(t)$ directly: i.e., $a$ as a function of cosmic time $t$. If we did, we would know a lot more about the observable universe. It's a pity galaxies do not have big clock faces on them from which we could read cosmic time.

Now for $z >> 1$ (i.e., cosmological remote astronomical objects), we find:

a) $a/a_0 = z$. b) $a/a_0 = 1/z$. c) $a/a_0 = 1/z^2$. d) $a/a_0 = z^2$. e) $a/a_0 = 1$.

---

012 qmult 00720 1 4 3 easy deducto-memory: CMB temperature
251. The cosmic microwave background (CMB) is the cosmic present form of the cosmic background radiation field (CBR) that evolves with cosmic time. The CBR is always a blackbody radiation field which means it has a temperature. The temperature of the CBR at present (i.e., the temperature of the CMB) is:

a) $T = 3000\,\text{K}$. b) $T = 2726.0(13)\,\text{K}$. c) $T = 2.7260(13)\,\text{K}$. d) $T = 300\,\text{K}$.
e) $T = 272.60(13)\,\text{K}$.

---

012 qmult 00740 1 4 3 easy deducto-memory: $a/a_0$ at recombination
252. Given

$$\frac{a_0}{a} = z + 1 \ ,$$

what is the ratio $a/a_0$ for recombination (i.e., the recombination era of the evolution of the universe) for which $z \approx 1100$?

a) $a/a_0 \approx 1100$. b) $a/a_0 \approx 0.9 \times 10^3$. c) $a/a_0 \approx 0.9 \times 10^{-3}$. d) $a/a_0 \approx 900$.
e) $a/a_0 \approx 110$.

---

012 qmult 00840 1 4 4 easy deducto-memory: dominant component of DEBRA

253. The dominant component of the diffuse extragalactic background radiation (DEBRA) is the:

a) cosmic gamma-ray background (CGB). b) cosmic X-ray background (CXB).
c) cosmic ultraviolet-optical-infrared background (CUVOIRB).
d) cosmic microwave background (CMB). e) cosmic radio background (CRB).

---

012 qmult 00850 1 4 5 easy deducto-memory: weakest component of DEBRA

254. The weakest well-known component of the diffuse extragalactic background radiation (DEBRA) is the:

a) cosmic gamma-ray background (CGB). b) cosmic X-ray background (CXB).
c) cosmic ultraviolet-optical-infrared background (CUVOIRB).
d) cosmic microwave background (CMB). e) cosmic radio background (CRB).

---

012 qmult 00900 1 4 1 easy deducto-memory: accelerating universe defined

255. The term accelerating universe is used to describe a cosmological model in which the rate of expansion of the universe (i.e., the rate of change of the rate of change of the cosmic scale factor $a(t)$) is:

a) increasing. b) decreasing. c) zero. d) undetermined. e) indeterminable.

---

012 qmult 00902 1 4 4 easy deducto-memory: accelerating universe defined 2

256. The term accelerating universe is used to describe a cosmological model in which cosmic scale factor $a(t)$ ____________ as a function of cosmic time.

a) curves downward. b) becomes a straight line. c) plateaus.
d) curves upward. e) goes to infinity at a finite time.

---

012 qmult 00910 1 4 3 easy deducto-memory: age of universe and transition time

257. According to the Λ-CDM model (with parameter values fitted year 2018) the age of the universe is and the transition time from deceleration to acceleration is ____________.

a) 13.8 Gyr; 6.2 Gyr b) 6.2 Gyr; 13.8 Gyr c) 13.8 Gyr; 10.02 Gyr
d) 10.02 Gyr; 13.8 Gyr e) infinite; inapplicable.

## Chapt. 13 Entangling Space

## Multiple-Choice Problems

## Full-Answer Problems

## Chapt. 14 The Doppler Effect and the Rotation of Mercury

### Multiple-Choice Problems

## Chapt. 15 The Doppler Effect and the Rotation of Mercury

## Multiple-Choice Problems

014 qmult 00100 1 4 5 easy deducto-memory: Doppler effect defined

258. "Let's play *Jeopardy*! For $100, the answer is: It is the dependence of the frequency of a wave phenomenon on the motion of an observer."

What is the ____________ effect, Alex?

a) Mössbauer  b) Hall  c) quantum Hall  d) Casimir  e) Doppler

014 qmult 00110 1 1 4 easy memory: sound frequency shifts

259. The general formula for the Doppler effect for sound is

$$f' = f(1 - v/v_{\rm ph}) ,$$

where $f$ is the frequency observed in the rest frame of the air, $v$ is the velocity of an observer counted as positive in the direction of sound propagation, $f'$ is the frequency observed by an observe moving at velocity $v$, and $v_{\rm ph}$ is the phase velocity of sound (i.e., the sound speed relative to the air). What is $f'$ for the cases $v = -2v_{\rm ph}$, $v = -v_{\rm ph}$, $v = -(1/2)v_{\rm ph}$, $v = 0$, $v = (1/2)v_{\rm ph}$, $v = v_{\rm ph}$, and $v = 2v_{\rm ph}$.

a) $3f$, 0, $(3/2)f$, $f$, $(1/2)f$, 0, $f$.  b) $3f$, 0, $(3/2)f$, $f$, $(1/2)f$, 0, $-f$.
c) $3f$, $2f$, $(3/2)f$, $f$, $(1/2)f$, 0, 0.  d) $3f$, $2f$, $(3/2)f$, $f$, $(1/2)f$, 0, $-f$.
e) $2f$, $f$, $(2/3)f$, $(1/2)f$, $(1/3)f$, 0, $-f$.

014 qmult 00150 1 1 3 easy memory: 1st order Doppler effect formula

260. The 1st order Doppler effect formula which holds both for electromagnetic radiation and mechanical waves is:

$$\frac{\Delta f}{f} = \frac{\Delta v}{v_{\rm ph}} ,$$

where $\Delta f$ is the frequency shift from source to receiver, $f$ is the frequency of the source, $\Delta v$ is the relative velocity between observers, and $v_{\rm ph}$ is the phase velocity of the waves (which is $c$ for electromagnetic radiation in a vacuum). The way this formula is written, the relative velocity is counted ____________ for receiver approaching source.

a) either positive or negative  b) negative  c) positive
d) neither positive nor negative  e) zero

014 qmult 00160 1 1 1 easy memory: rotating body Doppler shift

261. Say a light signal comes from all along the equator of rotating planet. The equator rotational velocity is $v$: i.e., the velocity of the planet matter tangent to the equator curve. The velocity $v$ is greater than 0 and is much less that the vacuum light speed $c$. The component of velocity toward the observer is counted as positive for approach and negative for recession. The light signal in the frame of emission has in all cases the frequency $f$. The axis is of rotation is perpendicular to the line of sight to the object. The observer is at rest with respect to the planet center. The observed is signal is a ____________ of frequencies ranging from a low value ____________ to a high value ____________.

a) continuum; $f(1-v/c)$; $f(1+v/c)$ b) continuum; $f(1+v/c)$; $f(1-v/c)$
c) discrete set; $f(1+v/c)$; $f(1-v/c)$ d) discrete set; $f(1-v/c)$; $f(1+v/c)$
e) continuum; $f(1-2v/c)$; $f(1+2v/c)$

---

014 qmult 00200 1 1 3 easy memory: Mercury

262. Mercury is the ____________ planet from the Sun, the ____________ largest Sun-orbiting body in the solar system, and the ____________ largest rocky-icy body in the solar system. Note that Jupiter's moon Ganymede and Saturn's moon Titan are larger than Mercury. These moons count as rocky-icy bodies.

a) 2nd; 10th; 6th b) 1st; 8th; 4th c) 1st; 10th; 6th d) 2nd; 8th; 4th
e) 3rd; 5th; 1st

---

014 qmult 00210 1 1 5 easy memory: Mercury the Roman god

263. Mercury is named for the Roman god ____________ who was identified with the Greek god Hermes.

a) Saturn b) Jupiter c) Mars d) Venus e) Mercury

---

014 qmult 00220 1 1 3 easy memory: Mercury can transit the Sun

264. Because Mercury is an inner planet, it can ____________ the Sun.

a) totally eclipse b) never transit c) transit d) collide with
e) perpetually be transiting

---

014 qmult 00222 1 1 2 easy memory: Mercury at night never high in sky

265. Mercury is an inner planet and the farthest it can get from the Sun in angle is 28°. Consequently, Mercury is **NEVER** ____________ the horizon during the ____________.

a) far below; night b) far above; night c) on; night d) sliding along; night
e) sliding along; day

---

014 qmult 00350 1 1 4 easy memory: 3:2 spin-orbit resonance

266. Mercury has a 3:2 spin-orbit resonance. This means that orbital period $P_1$ over rotation period $P_2$ is effectively exactly $P_1/P_2 = 3/2$ which implies $2P_1 = 3P_3$. (Logically the name should be 3:2 orbit-spin resonance, but the convention is for spin-orbit.) By "effectively exactly" mean that deviations from the exact ratio 3:2 caused by perturbations are damped out by some stabilizing forces. Such perturbations must occur, and so the ratio is constantly being perturbed and being corrected back toward the ratio 3:2. So the ratio is never exactly 3:2, but is always being driven toward it. In fact, the ratio 3:2 holds very accurately all the time and the measured deviation is less than observational error—so the 3:2 holds to within observational error. The orbital period is 87.9691 days and the rotational period is ____________ days.

a) 29.1 b) 55.2 c) 29.323 d) 58.646 e) 175.94

---

014 qmult 00360 1 1 2 easy memory: Mercurian year

267. Let's find the formula giving planet day in terms of orbital and rotation periods. To make the mental picture simple, imagine the planet's axis has no tilt from the ecliptic pole. Now say a rod sticks out from the equator directly toward the Sun: i.e., it is aligned for a moment with the Sun-planet line. Now the Sun-planet line rotates relative to the observable at average angular velocity $R_1 = 360°/P_1$ where $P_1$ is the orbital period (i.e., the planet year). The angular rotation rate of the rod relative to the observable universe is $R_2 = 360°/P_2$ where $P_2$ is the planet rotation period relative to the observable universe.

One day of length $P_3$ has past when that rod rotates around and comes back into alignment with the Sun-planet line. The rod has had to travel 360° plus a bit more to catch up to the rotating Sun-planet line. Given the setup, we must satisfy

$$R_1P_3 + 360° = R_2P_3 \ .$$

Solving for $P_3$ gives

$$P_3 = \frac{360^\circ}{R_2 - R_1} = \frac{P_1 P_2}{P_1 - P_2} = \frac{P_2}{1 - P_2/P_1} = \frac{P_1}{P_1/P_2 - 1} ,$$

and thus finally

$$P_3 = \frac{P_2}{1 - P_2/P_1} = \frac{P_1}{P_1/P_2 - 1} .$$

Let's now consider the case of Mercury where $P_2 = 58.646$ days and $P_2/P_1 = 2/3$ effectively exactly because of the 3:2 spin-orbit resonance (which means $P_1/P_2 = 3/2$ effectively exactly). What is $P_3/P_2$, $P_3/P_1$, and $P_3$ in days?

a) 2; 3; 175.94 days
b) 3; 2; 175.94 days
c) 3; 2; 58.646 days
d) 2; 3; 58.646 days
e) 5; 4; 87.9691 days

## Appendix 16 Multiple-Choice Problem Answer Tables

**Note:** For those who find scantrons frequently inaccurate and prefer to have their own table and marking template, the following are provided. I got the template trick from Neil Huffacker at University of Oklahoma. One just punches out the right answer places on an answer table and overlays it on student answer tables and quickly identifies and marks the wrong answers

## Answer Table for the Multiple-Choice Questions

| | a | b | c | d | e | | a | b | c | d | e |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 268. | O | O | O | O | O | 6. | O | O | O | O | O |
| 269. | O | O | O | O | O | 7. | O | O | O | O | O |
| 270. | O | O | O | O | O | 8. | O | O | O | O | O |
| 271. | O | O | O | O | O | 9. | O | O | O | O | O |
| 272. | O | O | O | O | O | 10. | O | O | O | O | O |

## Answer Table for the Multiple-Choice Questions

| | a | b | c | d | e | | a | b | c | d | e |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 273. | O | O | O | O | O | 11. | O | O | O | O | O |
| 274. | O | O | O | O | O | 12. | O | O | O | O | O |
| 275. | O | O | O | O | O | 13. | O | O | O | O | O |
| 276. | O | O | O | O | O | 14. | O | O | O | O | O |
| 277. | O | O | O | O | O | 15. | O | O | O | O | O |
| 278. | O | O | O | O | O | 16. | O | O | O | O | O |
| 279. | O | O | O | O | O | 17. | O | O | O | O | O |
| 280. | O | O | O | O | O | 18. | O | O | O | O | O |
| 281. | O | O | O | O | O | 19. | O | O | O | O | O |
| 282. | O | O | O | O | O | 20. | O | O | O | O | O |

## Answer Table for the Multiple-Choice Questions

| | a | b | c | d | e | | a | b | c | d | e |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 283. | O | O | O | O | O | 16. | O | O | O | O | O |
| 284. | O | O | O | O | O | 17. | O | O | O | O | O |
| 285. | O | O | O | O | O | 18. | O | O | O | O | O |
| 286. | O | O | O | O | O | 19. | O | O | O | O | O |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 287. | O | O | O | O | O | 20. | O | O | O | O | O |
| 288. | O | O | O | O | O | 21. | O | O | O | O | O |
| 289. | O | O | O | O | O | 22. | O | O | O | O | O |
| 290. | O | O | O | O | O | 23. | O | O | O | O | O |
| 291. | O | O | O | O | O | 24. | O | O | O | O | O |
| 292. | O | O | O | O | O | 25. | O | O | O | O | O |
| 293. | O | O | O | O | O | 26. | O | O | O | O | O |
| 294. | O | O | O | O | O | 27. | O | O | O | O | O |
| 295. | O | O | O | O | O | 28. | O | O | O | O | O |
| 296. | O | O | O | O | O | 29. | O | O | O | O | O |
| 297. | O | O | O | O | O | 30. | O | O | O | O | O |

## NAME:

## Answer Table for the Multiple-Choice Questions

| | a | b | c | d | e | | a | b | c | d | e |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 298. | O | O | O | O | O | 26. | O | O | O | O | O |
| 299. | O | O | O | O | O | 27. | O | O | O | O | O |
| 300. | O | O | O | O | O | 28. | O | O | O | O | O |
| 301. | O | O | O | O | O | 29. | O | O | O | O | O |
| 302. | O | O | O | O | O | 30. | O | O | O | O | O |
| 303. | O | O | O | O | O | 31. | O | O | O | O | O |
| 304. | O | O | O | O | O | 32. | O | O | O | O | O |
| 305. | O | O | O | O | O | 33. | O | O | O | O | O |
| 306. | O | O | O | O | O | 34. | O | O | O | O | O |
| 307. | O | O | O | O | O | 35. | O | O | O | O | O |
| 308. | O | O | O | O | O | 36. | O | O | O | O | O |
| 309. | O | O | O | O | O | 37. | O | O | O | O | O |
| 310. | O | O | O | O | O | 38. | O | O | O | O | O |
| 311. | O | O | O | O | O | 39. | O | O | O | O | O |
| 312. | O | O | O | O | O | 40. | O | O | O | O | O |
| 313. | O | O | O | O | O | 41. | O | O | O | O | O |
| 314. | O | O | O | O | O | 42. | O | O | O | O | O |
| 315. | O | O | O | O | O | 43. | O | O | O | O | O |
| 316. | O | O | O | O | O | 44. | O | O | O | O | O |
| 317. | O | O | O | O | O | 45. | O | O | O | O | O |
| 318. | O | O | O | O | O | 46. | O | O | O | O | O |
| 319. | O | O | O | O | O | 47. | O | O | O | O | O |
| 320. | O | O | O | O | O | 48. | O | O | O | O | O |
| 321. | O | O | O | O | O | 49. | O | O | O | O | O |
| 322. | O | O | O | O | O | 50. | O | O | O | O | O |

## Answer Table

| | a | b | c | d | e |
|---|---|---|---|---|---|
| 323. | O | O | O | O | O |
| 324. | O | O | O | O | O |
| 325. | O | O | O | O | O |
| 326. | O | O | O | O | O |
| 327. | O | O | O | O | O |
| 328. | O | O | O | O | O |
| 329. | O | O | O | O | O |
| 330. | O | O | O | O | O |
| 331. | O | O | O | O | O |
| 332. | O | O | O | O | O |
| 333. | O | O | O | O | O |
| 334. | O | O | O | O | O |
| 335. | O | O | O | O | O |
| 336. | O | O | O | O | O |
| 337. | O | O | O | O | O |
| 338. | O | O | O | O | O |
| 339. | O | O | O | O | O |
| 340. | O | O | O | O | O |
| 341. | O | O | O | O | O |
| 342. | O | O | O | O | O |
| 343. | O | O | O | O | O |
| 344. | O | O | O | O | O |
| 345. | O | O | O | O | O |
| 346. | O | O | O | O | O |
| 347. | O | O | O | O | O |
| 348. | O | O | O | O | O |
| 349. | O | O | O | O | O |
| 350. | O | O | O | O | O |
| 351. | O | O | O | O | O |
| 352. | O | O | O | O | O |

## Name:

| | a | b | c | d | e |
|---|---|---|---|---|---|
| 31. | O | O | O | O | O |
| 32. | O | O | O | O | O |
| 33. | O | O | O | O | O |
| 34. | O | O | O | O | O |
| 35. | O | O | O | O | O |
| 36. | O | O | O | O | O |
| 37. | O | O | O | O | O |
| 38. | O | O | O | O | O |
| 39. | O | O | O | O | O |
| 40. | O | O | O | O | O |
| 41. | O | O | O | O | O |
| 42. | O | O | O | O | O |
| 43. | O | O | O | O | O |
| 44. | O | O | O | O | O |
| 45. | O | O | O | O | O |
| 46. | O | O | O | O | O |
| 47. | O | O | O | O | O |
| 48. | O | O | O | O | O |
| 49. | O | O | O | O | O |
| 50. | O | O | O | O | O |
| 51. | O | O | O | O | O |
| 52. | O | O | O | O | O |
| 53. | O | O | O | O | O |
| 54. | O | O | O | O | O |
| 55. | O | O | O | O | O |
| 56. | O | O | O | O | O |
| 57. | O | O | O | O | O |
| 58. | O | O | O | O | O |
| 59. | O | O | O | O | O |
| 60. | O | O | O | O | O |