Condensed Matter Physics Problems

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Introduction

Condensed Matter Physics Problems (CMPP) is a bank of problems for a condenced matter course. There is nothing much here so far and may never be anything.

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 qfull 00200 1 3 0 easy math: Levi-Civita symbol

1. Let ijk be general integers from the range 1, 2, 3. The Levi-Civita symbol is defined

$$\epsilon_{ijk} = \begin{cases} 1 & \text{if } ijk \text{ are in cyclic order;} \\ -1 & \text{if } ijk \text{ are in anticyclic order;} \\ 0 & \text{if any two of } ijk \text{ are equal.} \end{cases}$$

The Levi-Civita symbol has many uses in mathematics and physics. There are two identities involving the Levi-Civita symbol that are useful to know. The first because it is useful in proving the second and the second because it turns up in many proofs.

The first identity is

$$\epsilon_{ijk}\epsilon_{\ell mn} = \delta_{i\ell}\delta_{jm}\delta_{kn} + \delta_{im}\delta_{jn}\delta_{k\ell} + \delta_{in}\delta_{j\ell}\delta_{km} - \delta_{im}\delta_{j\ell}\delta_{kn} - \delta_{in}\delta_{jm}\delta_{k\ell} - \delta_{i\ell}\delta_{jn}\delta_{km} \ .$$

The second is

$$\epsilon_{ijk}\epsilon_{i\ell m} = \delta_{j\ell}\delta_{km} - \delta_{jm}\delta_{k\ell} \ ,$$

where there is an Einstein summation on the repeated index i.

a) As a first step in proving the first identity, describe the behavior of its left-hand side (LHS). The following parts to part (f) complete the proof of this identity

b) Now show that

$$\text{RHS}(ijk, \ell mn) = \text{RHS}(\ell mn, ijk) \ .$$

This equality shows that the RHS has the same exchange symmetry as the LHS side which is necessary to proving the identity.

What the equality shows is that properties proven for the set of integers in the 2nd argument position (i.e., the 2nd slot) also hold for the set of integers in the 1st argument position (i.e., the 1st slot). For example say that you proved a functional property for ℓmn in RHS$(ijk, \ell mn)$. That functional porperty must also hold for ijk in RHS$(\ell mn, ijk)$ since ijk and ℓmn are general sets of integers. But since RHS$(ijk, \ell mn)$ = RHS$(\ell mn, ijk)$, the property must also hold for ijk in RHS$(ijk, \ell mn)$. Thus, any functional property we prove for the 2nd slot also holds for the 1st slot, and we don't have to repeat the proof nor make a point of not having to repeat the proof.

c) Now show

$$\text{RHS}[ijk, P_\pm(\ell mn)] = \pm\text{RHS}(ijk, \ell mn) \ ,$$

where $P_\pm$ stands for permutation with the upper case being cyclic and the lower case being anticyclic.

d) Now show that the RHS is zero if any two of ℓmn are all equal.

e) Given that all of the ijk have distinct values and all of ℓmn have distinct values, show that the RHS is 1 if the values of ijk and ℓmn have the same cyclicity (i.e., differ in order from each other by an even number of permutations) and -1 if they have different cyclicity (i.e., differ in order from each other by an odd number of permutations).

f) Now complete the proof of the first identity. **HINT:** There is little left to do.

g) Why can't the LHS of the first identity be factored into two identical formulae for the Levi-Civita symbol? **HINT:** The is little left to do.

h) Now prove the second identity from the first identity. into two identical formulae for the Levi-Civita symbol? **HINT:** This is easy.

Chapt. 2 Crystals

Multiple-Choice Problems

Full-Answer Problems

001 qfull 01320 1 3 0 easy math: polygons tiling a plane

2. As a brain exercise in thinking about crystals, lets consider tiling a plane with regular polygons without gaps or overlap.

   a) First derive the general formula for the interior vertex angle θ of a regular n-sided polygon. **HINT:** In constructing a regular polygon by laying down line segments, each segment must deviated from the previous one's direction by the same angle $\theta_{\rm dev}$. To complete the polygon, the sum of the deviation angles must be 2π.

   b) Now assume that we can tile the plane by attaching the regular polygons to each other with exactly overlaping sides between touching polygons. What condition must hold on the sum of the interior angles at each vertex? Derive the general formula for the number of polygons m that meet at a vertex as a function of n. What condition on m is necessary (but not obviously sufficient) in order for our tiling assumption to hold? For what values of n does m satisfy the condition? What the polygons with those n values?

   c) Give an argument that the tiling assumption of part (b) is correct for the regular polygons that meet the condition on m we found in part (b). The regular polygons that don't meet the condition on m are already excluded.

   d) Now consider the case of tiling the whole plane (without gaps or overlap) with regular polygons that do not have exactly overlaping sides between touching polygons. The polygons have touch along sides that do not exactly overlap (i.e., are slide along from exact overlap) or one polygon's vertex just touches anothers side. Derive which cases for which complete tiling is possible.

Chapt. 3 Elasticity

Multiple-Choice Problems

Full-Answer Problems

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003 qfull 00210 1 3 0 easy math:

3. Consider a general solid. Let's consider it in the macroscopic continuum limit: i.e., we assume that the material forms a continuum. Let vector $\vec{r}$ define the (stable) equilibrium positions of the continuum. At each point $\vec{r}$, let define $\vec{u}$ be the displacement of the solid from its equilibrium position: thus $\vec{u}(\vec{r})$, but we won't show the function dependence, unless needed. We assume the solid has translation, point inversion, and rotational symmetries. Let i and j be general direction indices for x_1, x_2, x_3. For compactness, write $\partial u_j/partial x_i$ as $\partial_i x_j$.

   a) Translational symmetry means that none of the thermodynamical or statistical mechanics variables will change change if we displace all parts of a solid sample by a common $\vec{u}_0$. On the other hand, if we distort (e.g., stretch) the sample from equilibrium by applying a varying u field, the thermodynamical or statistical mechanics variables both global and local change. What tensor do at least some of these variables depend on? **HINT:** It is standard practice to designate a tensor by a general element.

   b)

Chapt. 4 Telescopes

Multiple-Choice Problems

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

4. "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

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

5. 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

003 qmult 00120 1 1 3 easy memory: Galilean and Keplerian telescopes

6. Telescopes are also divided into Galilean and ____________ telescopes. The former give an upright image and latter an 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 accommodated. 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

003 qmult 00140 1 1 3 easy memory: diameter of primary

7. 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

003 qmult 00150 1 4 2 easy deducto-memory: focal length defined

8. "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 rays of light (originally parallel to the optical axis converge (i.e., are focussed) after interacting with the lens or mirror. It is among other things a measure of the ray bending power of the lens or mirror. The shorter is, the greater that power."

   What is ____________, Alex?

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

003 qmult 00160 1 4 4 easy deducto-memory: eyepiece defined

9. "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 00164 1 1 4 easy memory: telescope magnification

10. The magnification M of a telescope is given by

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

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

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

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003 qmult 00166 1 1 4 easy memory: field of view and magnification

11. 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

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003 qmult 00180 1 4 5 easy deducto-memory: star diagonal

12. "Let's play *Jeopardy*! For $100, the answer is: It is a mirror or prism device in a telescope that reflects the image beams from the optical axis to an axis perpendicular to the optical axis. The device allows easier viewing. It also causes an line inversion about the diagonal across the field of view that is perpendicular to both the optical axis and axis of reflection. If one is using a Keplerian telescope and the device (which is pretty usual), then there is both a point inversion and a line inversion 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 00182 1 4 2 easy deducto-memory: finderscope

13. "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

Chapt. 5 Planets

Multiple-Choice Problems

006 qmult 00100 1 1 3 easy memory: geocentric solar system

14. Before circa 1500, everyone in the context of ancient-Greek-derived astronomy (i.e., in European and the Mideastearn astronomy) and perhaps nearly everywhere else believed that the solar system was:

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

006 qmult 00110 1 4 2 easy deducto-memory: Copernicus proposed heliocentric model

15. "Let's play *Jeopardy*! For $100, the answer is: This astronomer introduced 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 (1642/3–1727)

006 qmult 00200 1 1 1 easy memory: planetary configuration defined

16. ____________ can be defined as the 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

006 qmult 00210 1 1 5 easy memory: inferior/superior planet defined

17. 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

006 qmult 00220 1 1 4 easy memory: conjunction and opposition defined

18. When two astro-bodies are aligned on the sky, they are ____________ 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

006 qmult 00222 1 1 4 easy memory: inferior/superior conjunction defined

19. 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 far side/near side of c) opposite/across from
    d) on near side/far side of e) colder/hotter than

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006 qmult 00222 1 1 1 easy memory: superior planet never in inferior conjunction

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

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

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006 qmult 00224 1 1 2 easy memory: syzgy defined

21. A syzgy 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.

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006 qmult 00230 1 1 2 easy memory: elongation defined

22. 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 syzgy.

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006 qmult 00232 1 1 2 easy memory: greatest eastern/western elongation

23. 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

Chapt. 6 Jupiter Moons

Multiple-Choice Problems

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

24. "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 (1642/3–1727).

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007 qmult 00110 1 1 5 easy memory: Earth not the center of all motion

25. "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 Phases of Venus

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007 qmult 00120 1 1 1 easy memory: Galilean moons for Galileo

26. 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

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007 qmult 00130 1 4 2 easy deducto-memory: Galilean moons and longitude

27. "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 (1642/3–1727).
    e) Caroline Herschel (1750–1848)

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

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

    What 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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007 qmult 00200 1 1 5 easy memory: names of the Galilean moons

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

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

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007 qmult 00210 1 1 5 easy memory: number of Jupiter moons

30. Jupiter has:

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

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

31. 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.

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007 qmult 003221 1 4 easy memory: tidally locked Io

32. 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.

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

33. The 3 innermost Galilean moons exhibit a 1:2:4 Laplace resonance of the orbital periods. This means that the ratios 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

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

34. 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 The Doppler Effect and the Rotation of Mercury

Multiple-Choice Problems

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008 qmult 00100 1 4 5 easy deducto-memory: Dopper effect defined

35. "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

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

36. 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, $-f$.

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

37. 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 Δf is the frequency shift from source to receiver, f is the frequency of the source, Δv 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

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

38. 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; $f(1-2v/c)$; $f(1+2v/c)$

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008 qmult 00200 1 1 3 easy memory: Mercury

39. 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

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

40. 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

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008 qmult 00220 1 1 3 easy memory: Mercury can transit the Sun

41. 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

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008 qmult 00222 1 1 2 easy memory: Mercury at night never high in sky

42. 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

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008 qmult 00350 1 1 4 easy memory: 3:2 spin-orbit resonance

43. 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

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008 qmult 00360 1 1 2 easy memory: Mercurian year

44. 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 fixed stars 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 fixed stars is $R_2 = 360°/P_2$ where P_2 is the planet rotation period relative to the fixed stars.

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

$$R_1 P_3 + 360° = R_2 P_3 \ .$$

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

Chapt. 8 Sunspots

Multiple-Choice Problems

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

45. 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

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

46. 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.

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

47. "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)

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

48. 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.

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009 qmult 00200 1 1 3 easy memory: Sun rotation

49. 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.

---

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

50. 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.

---

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

51. 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.

---

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

52. 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) 34 days; 24.5 days b) 365.25 days; 34 days c) 100 days; 365.25 days
d) 24.5 days; 34 days e) 365.25 days; 1001 days

---

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

53. "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. Inertial frames are frames of reference to which physical laws are usually and most straightforwardly referenced. The inertial frame often cited is the approximate one defined by the fixed stars, but there are even more exact inertial frames available. The supreme inertial frame 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

---

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

54. "Let's play *Jeopardy*! For $100, the answer is: It is the period of an astronomical rotation or revolution 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

---

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

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

$$Rp_{\rm syn} = R_\oplus p_{\rm syn} + 360^\circ \ ,$$

where R is the (sidereal) rotation/revolution rate of an astro-body (in degrees per unit time), $p_{\rm syn}$ is the synodic period of the body, and $R_\odot$ is the (sidereal) revolution rate of the Earth (in degrees per unit time). This formula embodies the fact that the astro-body has to rotate/revolve around more than 360° to reach the same position it have relative to the Earth at the start of a synodic period. 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. One sees at once that ____________.

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 Brightness and Color of Stars

Multiple-Choice Problems

010 qmult 00100 1 4 5 easy deducto-memory: magnitude system defined

56. "Let's play *Jeopardy*! For \$100, the answer is: It is a system of measuring 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 categories that visual astronomy judged to be of comparable apparent brightnesses. The categories in decreasing order of brightness are 1st, 2nd, 3rd, 4th, 5th, and 6th magnitude. In the 19th century, it was decided to modernize this ancient measurment system, but to regularize it and fix 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 regularization was based on the discovery that the ancient magnitudes were roughly logarithmic in flux and that a change of 5 ancient magnitudes corresponded to roughly a factor of 100 decrease in flux. This rough results were changed into exact prescriptions. Given 2 astro-bodies with fluxes F_1 and F_2, the magnitude difference is

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

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 magntiudes.

Actually, many people think that regularizing the ancient system to make the modern system was a stupid idea. The modern system runs the wrong way—bigger is dimmer. This leads to endless confusion. And the modern system has logarithm based used for nothing else. One could have made the definition

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

and then bigger would be bright 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

010 qmult 00110 1 1 1 easy memory: apparent magnitude

57. 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.

---

010 qmult 00120 1 1 2 easy memory: absolute magnitude

58. 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? Probably because its a round number that is typical for 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

---

010 qmult 00200 1 4 4 easy deducto-memory: color index

59. "Let's play *Jeopardy*! For $100, the answer is: This quantity is the difference between magnitudes in two bands for a star: the redder band magnitude is subtracted from the bluer band magnitude. Because of the subtraction, the distance dependence of the band 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 band usually increases with temperature relative to the blux in the redder band. 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 band magnitude minus the V band magnitude."

    What is ____________, Alex?

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

---

010 qmult 00300 1 1 4 easy memory: luminosity defined

60. 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.

---

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

61. In the 19th century when little was known about star structure, stars were classified by their observed spectra. 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 steadily 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 spectra 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 type. The 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

---

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

62. "Let's play *Jeopardy*! For $100, the answer is: This diagram is logarithmic plot that plots luminosity versus temperature for stars. The luminosity can be replaced by a magnitude that serves as a good proxy and temperature can be replaced by the proxies color index or stellar spectral type. Temperature increases to the left by a quaint convention."

What is the ____________ diagram, Alex?

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

---

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

63. "Let's play *Jeopardy*! For $100, the answer is: This narrow band of stars on an HR diagram starts high on the left-band 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 fuel 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-fuel-burning life is the longest phase and this accounts for the abundance of stars in the band."

What is ____________, Alex?

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

---

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

64. "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

---

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

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

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

Full-Answer Problems

Chapt. 10 Stellar Spectra

Multiple-Choice Problems

---

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

66. "Let's play *Jeopardy*! For $100, the answer is: It is the range of all possible wavelengths of electromagnetic radiation. At least as an ideall 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

---

012 qmult 00110 1 4 1 easy deducto-memory: visible band

67. "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—not to mention 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

---

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

68. 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 separated 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

---

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

69. 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.

---

012 qmult 00170 1 1 2 easy memory: spectroscope

70. 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.

---

012 qmult 00200 1 1 2 easy memory: continuum and line spectrum

71. 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 the part of a ____________ spectrum without large deviations in narrow wavelength bands is considered to be the ____________ part of the spectrum.

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

---

012 qmult 00250 1 4 5 easy deducto-memory: Grotrian diagrams defined

72. "Let's play *Jeopardy*! For $100, the answer is: He is the eponym (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."

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)

---

012 qmult 00320 1 1 3 easy memory: OBAFGKM spectral classification

73. The OBAFGKM spectral 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 letter classes are ordered by decreasing temperature of star and each letter class is divided into subclasses 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 letter class. It is a:

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

---

012 qmult 00322 1 1 2 easy memory: OBAFGKM mnemonic

74. 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.

---

012 qmult 00330 1 1 3 easy memory: Hertzsprung-Russell diagram

75. A ____________ diagram plots logarithmic luminosity of stars versus logarithmic temperature (or alternatively OBAFGKM spectral classification) of stars.

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

---

012 qmult 00342 1 1 1 easy memory: main sequence occupation

76. 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 Entangling Space

Multiple-Choice Problems

Full-Answer Problems

Appendix 12 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
77.	O	O	O	O	O	6.	O	O	O	O	O
78.	O	O	O	O	O	7.	O	O	O	O	O
79.	O	O	O	O	O	8.	O	O	O	O	O
80.	O	O	O	O	O	9.	O	O	O	O	O
81.	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
82.	O	O	O	O	O	11.	O	O	O	O	O
83.	O	O	O	O	O	12.	O	O	O	O	O
84.	O	O	O	O	O	13.	O	O	O	O	O
85.	O	O	O	O	O	14.	O	O	O	O	O
86.	O	O	O	O	O	15.	O	O	O	O	O
87.	O	O	O	O	O	16.	O	O	O	O	O
88.	O	O	O	O	O	17.	O	O	O	O	O
89.	O	O	O	O	O	18.	O	O	O	O	O
90.	O	O	O	O	O	19.	O	O	O	O	O
91.	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
92.	O	O	O	O	O	16.	O	O	O	O	O
93.	O	O	O	O	O	17.	O	O	O	O	O
94.	O	O	O	O	O	18.	O	O	O	O	O
95.	O	O	O	O	O	19.	O	O	O	O	O
96.	O	O	O	O	O	20.	O	O	O	O	O
97.	O	O	O	O	O	21.	O	O	O	O	O
98.	O	O	O	O	O	22.	O	O	O	O	O
99.	O	O	O	O	O	23.	O	O	O	O	O
100.	O	O	O	O	O	24.	O	O	O	O	O
101.	O	O	O	O	O	25.	O	O	O	O	O
102.	O	O	O	O	O	26.	O	O	O	O	O
103.	O	O	O	O	O	27.	O	O	O	O	O
104.	O	O	O	O	O	28.	O	O	O	O	O
105.	O	O	O	O	O	29.	O	O	O	O	O
106.	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
107.	O	O	O	O	O	26.	O	O	O	O	O
108.	O	O	O	O	O	27.	O	O	O	O	O
109.	O	O	O	O	O	28.	O	O	O	O	O
110.	O	O	O	O	O	29.	O	O	O	O	O
111.	O	O	O	O	O	30.	O	O	O	O	O
112.	O	O	O	O	O	31.	O	O	O	O	O
113.	O	O	O	O	O	32.	O	O	O	O	O
114.	O	O	O	O	O	33.	O	O	O	O	O
115.	O	O	O	O	O	34.	O	O	O	O	O
116.	O	O	O	O	O	35.	O	O	O	O	O
117.	O	O	O	O	O	36.	O	O	O	O	O
118.	O	O	O	O	O	37.	O	O	O	O	O
119.	O	O	O	O	O	38.	O	O	O	O	O
120.	O	O	O	O	O	39.	O	O	O	O	O
121.	O	O	O	O	O	40.	O	O	O	O	O
122.	O	O	O	O	O	41.	O	O	O	O	O
123.	O	O	O	O	O	42.	O	O	O	O	O
124.	O	O	O	O	O	43.	O	O	O	O	O
125.	O	O	O	O	O	44.	O	O	O	O	O
126.	O	O	O	O	O	45.	O	O	O	O	O
127.	O	O	O	O	O	46.	O	O	O	O	O
128.	O	O	O	O	O	47.	O	O	O	O	O
129.	O	O	O	O	O	48.	O	O	O	O	O
130.	O	O	O	O	O	49.	O	O	O	O	O
131.	O	O	O	O	O	50.	O	O	O	O	O

Answer Table

	a	b	c	d	e
132.	O	O	O	O	O
133.	O	O	O	O	O
134.	O	O	O	O	O
135.	O	O	O	O	O
136.	O	O	O	O	O
137.	O	O	O	O	O
138.	O	O	O	O	O
139.	O	O	O	O	O
140.	O	O	O	O	O
141.	O	O	O	O	O
142.	O	O	O	O	O
143.	O	O	O	O	O
144.	O	O	O	O	O
145.	O	O	O	O	O
146.	O	O	O	O	O
147.	O	O	O	O	O
148.	O	O	O	O	O
149.	O	O	O	O	O
150.	O	O	O	O	O
151.	O	O	O	O	O
152.	O	O	O	O	O
153.	O	O	O	O	O
154.	O	O	O	O	O
155.	O	O	O	O	O
156.	O	O	O	O	O
157.	O	O	O	O	O
158.	O	O	O	O	O
159.	O	O	O	O	O
160.	O	O	O	O	O
161.	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