Introductory Astronomy **NAME:**

Homework 9: The Life of the Sun: Homeworks and solutions are posted on the course web site. Homeworks are **NOT** handed in and **NOT** marked. But many homework problems ($\sim$ 50–70 %) will turn up on tests.

Answer Table

	a	b	c	d	e
1.	O	O	O	O	O
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1. Did you complete reading the Introductory Astronomy Lecture before the **SECOND DAY** on which the lecture was lectured on in class?

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

2. The life history of our own star, the Sun, is known to us by:

   a) direct observations of all of its stages.
   b) direct observations of most of its stages plus observations of other stars in all their stages and modeling.
   c) direct observations of its current stage plus observations of other stars in all their stages and modeling.
   d) modeling alone.
   e) sheer guesswork.

3. The interstellar medium (ISM) consists of:

   a) planets.   b) molecular clouds only.   c) stars.   d) dust only.   e) gas and dust.

4. In modern astronomy, a nebula (plural nebulae) is a:

   a) cloud of a gas in space.   b) large main sequence star.   c) small main sequence star.   d) bright star.   e) young star.

5. The dense, cold component of the interstellar medium from which stars are believed to form is made of:

   a) H II (ionized hydrogen) regions.   b) white dwarfs.   c) protostars.   d) Lyman-Alpha forests.   e) molecular clouds.

6. The composition of molecular clouds in the interstellar medium is dominated by:

   a) carbon dioxide.   b) molecular oxygen only.   c) helium gas only.   d) amino acids.   e) molecular hydrogen gas and helium gas.

7. Molecular clouds are probably about 1 per cent dust by mass.

   a) The dust is **VERY IMPORTANT** to these clouds. It is **HIGHLY OPAQUE** to visible and ultraviolet light, and so keeps most hard electromagnetic radiation out of the inner regions of the clouds. This prevents the destruction of molecules by hard radiation. Moreover, it is probable that many molecules form on dust grains: free atoms stick onto the grains, meet there, bond, and then escape in molecular form: i.e., the grains act as catalysts. Dust tends to promote molecule formation and molecules tend to need dust. Thus, whenever you have a lot of dust, you often have molecules and vice versa.
   b) The dust is **VERY IMPORTANT** to these clouds. It is **COMPLETELY TRANSPARENT** to visible and ultraviolet light, and allows plenty of hard electromagnetic radiation into the inner regions of the clouds. This prevents the destruction of molecules by hard radiation. Moreover, it is probable that many molecules form on dust grains: free atoms stick onto the grains, meet there, bond, and then escape in molecular form: i.e., the grains act as catalysts. Dust tends to promote molecule formation and molecules tend to need dust. Thus, whenever you have a lot of dust, you often have molecules and vice versa.
   c) The dust is **COMPLETELY UNIMPORTANT** to these clouds. True, the dust is **HIGHLY OPAQUE** to visible and ultraviolet light, and so keeps most hard electromagnetic radiation out of the inner regions of the clouds. This prevents the destruction of molecules by hard radiation. Moreover, it is probable that many molecules form on dust grains: free atoms stick onto the grains, meet there, bond, and then escape in molecular form: i.e., the grains act as catalysts. Nevertheless, there are plenty of molecular clouds that are **COMPLETELY DUST-FREE**. In such clouds, the whole process of star formation is laid bare to visible light observers.
   d) The dust is **VERY IMPORTANT** to these clouds. It is **HIGHLY OPAQUE** to visible and ultraviolet light, and so keeps most hard electromagnetic radiation out of the inner regions of the clouds. This prevents the destruction of molecules by hard radiation. Moreover, it is probable that many molecules form on dust grains: free atoms stick onto the grains, meet there, bond, and then escape in molecular form: i.e., the grains act as catalysts. Nevertheless, there are plenty of molecular clouds that are **COMPLETELY DUST-FREE**. In such clouds, the whole process of star formation is laid bare to visible light observers.

e) The presence of this dust is just coincidental. It just happens that where there is dust there are molecular clouds, and where there is no dust there arn't. Things could be entirely otherwise; they just arn't.

8. Interstellar dust probably varies widely in composition, size scale, and structure. But there some ideas about typical dust that are generally accepted.

    a) Although size scale probably varies widely, a typical dust grain may be of order $1\,\mu\text{m} = 10^{-6}\,\text{m}$ in size, but it won't be perfectly spherical. There may be a core of **VOLATILE** material of order $0.05\,\mu\text{m}$ consisting of silicates (silicon and oxygen compounds that make up most terrestrial rock), iron, or graphite. The **GRAIN MANTLE** may be mostly **NONVOLATILE ICES**: e.g., H_2O (water ice), CO_2 (carbon dioxide ice or dry ice), CH_4, and NH_3. The grain surface may have complex molecules forming tarry substances. Dust probably forms in **STELLAR WINDS AND SUPERNOVA EJECTA**. There relatively dense **VOLATILES** condense out forming the cores as the ejected gas cools. As the gas cools more, **NONVOLATILES** condense out on the cores.
    b) Although size scale probably varies widely, a typical dust grain may be of order $1\,\mu\text{m} = 10^{-6}\,\text{m}$ in size, but it won't be perfectly spherical. There may be a core of **NONVOLATILE** material of order $0.05\,\mu\text{m}$ consisting of silicates (silicon and oxygen compounds that make up most terrestrial rock), iron, or graphite. The **GRAIN MANTLE** may be mostly **VOLATILE ICES**: e.g., H_2O (water ice), CO_2 (carbon dioxide ice or dry ice), CH_4, and NH_3. The grain surface may have complex molecules forming tarry substances. Dust probably forms inside the event horizons of **BLACK HOLES**. There relatively dense **NONVOLATILES** condense out forming the cores as the infalling gas cools. As the gas cools more, **VOLATILES** condense out on the cores. The dust then escapes scot-free from the black hole.
    c) Although size scale probably varies widely, a typical dust grain may be of order $1\,\mu\text{m} = 10^{-6}\,\text{m}$ in size, but it won't be perfectly spherical. There may be a core of **NONVOLATILE** material of order $0.05\,\mu\text{m}$ consisting of silicates (silicon and oxygen compounds that make up most terrestrial rock), iron, or graphite. The **GRAIN MANTLE** may be mostly **VOLATILE ICES**: e.g., H_2O (water ice), CO_2 (carbon dioxide ice or dry ice), CH_4, and NH_3. The grain surface may have complex molecules forming tarry substances. Dust probably forms in **STELLAR WINDS AND SUPERNOVA EJECTA**. There relatively dense **NONVOLATILES** condense out forming the cores as the ejected gas cools. As the gas cools more, **VOLATILES** condense out on the cores.
    d) Although size scale probably varies widely, a typical dust grain may be of order $1\,\mu\text{m} = 10^{-6}\,\text{m}$ in size, but it won't be perfectly spherical. There may be a core of **VOLATILE** material of order $0.05\,\mu\text{m}$ consisting of silicates (silicon and oxygen compounds that make up most terrestrial rock), iron, or graphite. The **GRAIN MANTLE** may be mostly **NONVOLATILE ICES**: e.g., H_2O (water ice), CO_2 (carbon dioxide ice or dry ice), CH_4, and NH_3. The grain surface may have complex molecules forming tarry substances. Dust probably forms inside the event horizons of **BLACK HOLES**. There relatively dense **NONVOLATILES** condense out forming the cores as the infalling gas cools. As the gas cools more, **VOLATILES** condense out on the cores. The dust then escapes scot-free from the black hole.
    e) The dust is found under sofas and on other untouched surfaces. It gets there by settling out the air. One often sees dust in air the reflecting bright sunlight.

9. "Let's play *Jeopardy*! For $100, the answer is: It happens whenever a star changes its luminosity and/or its surface temperature."

    What is ____________, Alex?

    a) explodes b) collapses c) turns green d) becomes a white dwarf e) movement on the Hertzsprung-Russell (HR) diagram

10. Star formation in a dusty molecular cloud probably requires some triggering event to initiate the collapse to dense cores that will become stars. Two possible trigger mechanisms are:

    a) **SUPERNOVAE** which compress molecular clouds and **CLOUD-CLOUD COLLISIONS** which also compress the colliding molecular clouds.
    b) **WHITE DWARFS** which ram into and thereby compress molecular clouds and **CLOUD-CLOUD COLLISIONS** which also compress the colliding molecular clouds.
    c) **WHITE DWARFS** which ram into and thereby compress molecular clouds and **PROTOSTAR-PROTOSTAR COLLISIONS** which also compress the molecular clouds.

d) **WHITE DWARFS** which ram into and thereby compress molecular clouds and **BLACK HOLE FORMATION** which also compresses the molecular clouds.
e) **WHITE HOBBITS** which ram into and thereby compress molecular clouds and **BLACK HOLE FORMATION** which also compresses the molecular clouds.

11. In a **FREE-FALL** contraction of part of molecular cloud:

a) the part starts fall to toward a high density point because of gravitational attraction. Pressure forces slow the fall from the beginning.
b) the part starts fall to toward a high density point because of gravitational attraction. Pressure forces are negligible in slowing the fall because it is a free-fall contraction.
c) the entire molecular cloud collapses to form a black hole.
d) the part collapses to form a black hole.
e) planetesimals collide and break apart.

12. The collapsing dense regions that develop into stars and initially have temperatures of order 10 K are called:

a) dense cores. b) dilute cores. c) main sequence stars. d) white dwarfs.
e) rotten cores.

13. A protostar is sometimes conveniently defined to be a:

a) star that can no longer burn hydrogen to produce heat energy.
b) white dwarf.
c) dense core of gas contracting to become a star that is hot enough to radiate in the infrared, but not yet sufficiently hot for nuclear burning.
d) molecular cloud that will become a star.
e) giant molecular cloud that will become a star.

14. The contraction of a protostar is halted eventually by:

a) the thermal energy generated by the contraction which **DECREASES** the gas pressure inside the protostar.
b) the thermal energy generated by the contraction which **INCREASES** the gas pressure inside the protostar.
c) the action of magnetic fields.
d) the action of the dynamo effect.
e) the heat generated by the turning on of nuclear burning which **INCREASES** the gas pressure inside the protostar.

15. Star formation in giant molecular clouds often results in the formation of OB associations: collections of hot, bright OB stars that ionize the surrounding molecular cloud and evaporate dust because of their strong ultraviolet emission. The gas region ionized by an OB associations is called a/an:

a) H II region. b) small molecular cloud. c) black hole. d) dark cloud.
e) He region.

16. "Let's play *Jeopardy*! For $100, the answer is: They are relatively thin, round objects consisting of gas and/or dust and/or particles: the material goes around some large astro-body in nearly circular orbits of varying radii in the same direction."

What are ____________, Alex?

a) CDs b) planets c) disks d) satellites e) projectiles

17. Disk formation is:

a) a unique event that happened only in the case of the formation of the Sun.
b) a common event in star formation as far as astronomers can tell.
c) a process in nuclear burning.
d) never observed in star formation.
e) responsible for the heating up of the protostar.

18. Disk formation is believed to happen fairly generally:

a) in star formation, in the formation of accretion disks about putative black holes, and in the **FORMATION OF SPIRAL GALAXIES**. In the case of black holes, matter is **SPRAYED OUT** of the black hole in random orbits and in a collisional-relaxation-dissipation process, similar to what happens in star formation, relaxes into a disk.
b) in star formation, in the formation of accretion disks about black holes, and in the **FORMATION OF SPIRAL GALAXIES**. In the case of supermassive black holes at the centers of galaxies, it is thought that matter, at least originally, is somehow **GRAVITATIONALLY CAPTURED** by the black hole in random orbits and in a collisional-relaxation-dissipation process, similar to what happens in star formation, relaxes into a disk. This matter gradually loses rotational energy through viscous forces in the disk and spirals into the black hole. While spiraling into the black hole the matter **COOLS DOWN**.
c) in star formation, in the formation of accretion disks about black holes, and in the **FORMATION OF SPIRAL GALAXIES**. In the case of supermassive black holes at the centers of galaxies, it is thought that matter, at least originally, is somehow **GRAVITATIONALLY CAPTURED** by the black hole in random orbits and in a collisional-relaxation-dissipation process, similar to what happens in star formation, relaxes into a disk. This matter gradually loses rotational energy through viscous forces in the disk and spirals into the black hole. While spiraling into the black hole the matter **HEATS UP** due to infall kinetic energy being transformed into heat. Consequently, the infalling material radiates electromagnetic radiation. The object Sgr A^* near or at the dynamical center of the Milky Way, thought to be a black hole of mass of order $3 \times 10^6\,M_\odot$, is a strong radio source.
d) in star formation, in the formation of accretion disks about black holes, and in the **FORMATION OF IMPACT CRATERS**. In the case of supermassive black holes at the centers of galaxies, it is thought that matter, at least originally, is somehow **GRAVITATIONALLY CAPTURED** by the black hole in random orbits and in a collisional-relaxation-dissipation process, similar to what happens in star formation, relaxes into a disk. This matter gradually loses rotational energy through viscous forces in the disk and spirals into the black hole. While spiraling into the black hole the matter **COOLS DOWN**.
e) in star formation, in the formation of accretion disks about black holes, and in the **FORMATION OF IMPACT CRATERS** In the case of supermassive black holes at the centers of galaxies, it is thought that matter, at least originally, is somehow **GRAVITATIONALLY CAPTURED** by the black hole in random orbits and in a collisional-relaxation-dissipation process, similar to what happens in star formation, relaxes into a disk. This matter gradually loses rotational energy through viscous forces in the disk and spirals into the black hole. While spiraling into the black hole the matter **HEATS UP** due to infall kinetic energy being transformed into heat. Consequently, the infalling material radiates electromagnetic radiation. The object Sgr A^* near or at the dynamical center of the Milky Way, thought to be a black hole of mass of order $3 \times 10^6\,M_\odot$, is a strong radio source.

19. "Let's play *Jeopardy*! For \$100, the answer is: It is a star that as observed over relatively short times scales (e.g., all of human history) is burning hydrogen to helium in its core at a constant rate and is in hydrostatic equilibrium."

What is a/an ____________, Alex?

a) dense core b) protostar c) pre-main-sequence star d) H II region
e) main-sequence star

20. For a main sequence star, the energy radiated away as electromagnetic radiation is almost exactly compensated by:

a) gravitational energy converted to heat energy during rapid collapse.
b) neutrinos from space being absorbed by the star. c) energy produced by nuclear burning on the surface. d) energy produced by nuclear burning in the deep interior. e) nothing at all.

21. Atomic nuclei are made up of:

a) protons and neutrons. b) protons and electrons. c) positrons and electrons.
d) positrons and neutrals. e) ponytrons and nuggets.

22. The nucleus is occupies ____________ of the volume of an atom and has ____________ of the atomic

mass.

a) a small part; none b) a small part; almost all c) most; almost all d) most; none e) most; half

23. Nuclei with the same number of protons, but different number of neutrons are ____________ of each other.

    a) isochrones b) isobars c) isotopes d) isodopes e) Isoldes

24. "Let's play *Jeopardy*! For \$100, the answer is: These isotopes of hydrogen have 1 and 2 neutrons, respectively."

    What are ____________, Alex?

    a) uranium-235 ($^{235}_{92}$U) and uranium-238 ($^{238}_{92}$U) b) helium-3 ($^{3}_{2}$He) and helium-4 ($^{4}_{2}$He) c) the deuteronomy (D or $^{2}_{1}$H) and trident (T or $^{3}_{1}$H) d) the deuteron (D or $^{2}_{1}$H) and triton (T or $^{3}_{1}$H) e) carbon ($^{12}_{6}$C) and oxygen ($^{16}_{8}$O)

25. Nuclei are bound together by:

    a) gravity. b) the strong nuclear force. c) the electromagnetic force. d) the centrifugal force. e) the weak nuclear force.

26. Nuclear fusion is the ____________ bonding of nuclei to form ____________ nuclei.

    a) chemical; larger b) nuclear; larger c) nuclear; smaller d) chemical; smaller e) gravitational; smaller

27. In stellar hydrogen fusion to helium, the rest mass energy of the products is ________ less than that of the reactants. The missing rest mass energy went mostly into ____________.

    a) 70 %; heat energy b) 170 %; magnetic field energy c) 0.7 %; heat energy d) 70 %; magnetic field energy e) 0 %; chemical binding energy

28. A mass of 1 kg is equivalent to about how much energy? Recall that the speed of light is 3.00×10^{8} m/s.

    a) 8×10^{16} J. b) 9×10^{16} J. c) 9×10^{8} J. d) 3×10^{8} J. e) 2×10^{8} J.

29. The energy emitted as electromagnetic energy from main sequence stars is supplied by the:

    a) nuclear burning of helium to hydrogen. b) nuclear burning of hydrogen to helium. c) nuclear burning of hydrogen to carbon. d) nuclear burning of helium to carbon. e) chemical burning of hydrogen to carbon.

30. Thermonuclear reactions happen only in a star's core (which for the Sun is the region within about 0.25 solar radii of the Sun's center) because only there is it ____________ enough.

    a) cold and dilute b) hot and dense c) hot and dilute d) bland and fragile e) dirty and smudgy

31. Why don't thermonuclear reactions happen on the surface of main sequence stars?

    a) Not hot and not dense enough. b) Too hot and too dense. c) Too green. d) Too bad. e) Too late.

32. In addition to observations of a star and physics theory, in order to understand the star in detail one needs:

    a) a few calculations on a scrap of paper. b) detailed computer modeling. c) experiments on Sun-size gas balls. d) nothing else at all. e) luck.

33. "Let's play *Jeopardy*! For \$100, the answer is: This is a set of calculated distributions of temperature, density, luminosity, and other physical quantities for a star."

    What is ____________, Alex?

    a) the star mass b) the star itself c) a model of the star d) the star luminosity e) the astronomical unit

34. In a main sequence star (e.g., the Sun) temperature, density, and pressure:

a) vary strongly from center to surface (i.e., photosphere).
b) are constant throughout the star.
c) are never higher than about 6000 K, 2×10^{-7} g/cm^3, and 0.8 Earth atmospheres, respectively.
d) are all equal to 6000 in MKS units.
e) are completely unknown.

35. Hydrostatic equilibrium means that:

a) pressure and other forces in a fluid are **UNBALANCED**, but the fluid is exhibiting a **SMOOTH FLOW** (at least in the reference frame of the fluid center of mass).
b) pressure and other forces in a fluid are **UNBALANCED** and the fluid is exhibiting a **TURBULENT FLOW** (at least in the reference frame of the fluid center of mass).
c) pressure and other forces in a fluid are **BALANCED** and there is **NO FLUID MOTION** (at least in the reference frame of the fluid center of mass).
d) the temperature is a constant throughout a fluid.
e) the temperature is not a constant throughout a fluid.

36. "Let's play *Jeopardy*! For \$100, the answer is: It is an everyday example of hydrostatic equilibrium."

What is ____________, Alex?

a) a boat's wake b) stirring coffee c) a river d) a waterfall e) water at rest in a cup

37. Main sequence stars of low mass are mainly supported against collapse ($\gtrsim 90\,\%$ for $M \lesssim 8M_\odot$) by:

a) the pressure of liquid water. b) the ideal gas pressure of ions and electrons. c) the gravitational force. d) angular momentum. e) the solar wind.

38. An everyday example of heat transfer by radiative transport (or radiative transfer) is

a) boiling water in a pan. b) a spoon in boiling water growing warm. c) sunlight warming. d) a refrigerator cooling. e) a dog barking.

39. In convection between a lower hot layer and an upper cold layer (with downward being the direction of gravity):

a) hot blobs rise and cold blobs rise too. b) hot blobs rise and cold blobs sink. c) hot and cold blobs both sink. d) hot and cold blobs don't form. e) hot and cold blobs madly try to consume the universe.

40. A common reason why some astrophysical systems are described as poorly understood is that these systems involve three-dimensional hydrodynamic effects (e.g., convection).

a) Three-dimensional hydrodynamics cannot be **ACCURATELY COMPUTATIONALLY TREATED** at all.
b) Three-dimensional hydrodynamics cannot be **TREATED EVEN QUALITATIVELY**.
c) Three-dimensional hydrodynamics can **ALWAYS** be understood qualitatively and this allows us to **ALWAYS** predict three-dimensional hydrodynamical phenomena, just not their magnitude. Accurate computations of three-dimensional hydrodynamic effects, however, are only possible in some cases. For example, when **electromagnetic effects** are present, they actually simplify three-dimensional hydrodynamic effects and allow accurate computations in all cases.
d) Three-dimensional hydrodynamics can **OFTEN** be understood qualitatively and this **SOMETIMES** allows us to predict three-dimensional hydrodynamical phenomena. Accurate computations of three-dimensional hydrodynamic effects are also possible in some cases.
e) Three-dimensional hydrodynamics can **OFTEN** be understood qualitatively and this **SOMETIMES** allows us to predict three-dimensional hydrodynamical phenomena. Accurate computations of three-dimensional hydrodynamic effects are also possible in some cases. For example, when **ELECTROMAGNETIC EFFECTS** are present, they actually simplify three-dimensional hydrodynamic effects and allow accurate computations in all cases. Maybe someday all three-dimensional hydrodynamic effects will be accurately calculable.

41. During a star's **MAIN SEQUENCE LIFE**, the star is relatively unchanging. But, of course, it is actually changing slowly on the road to its demise. The key change is that:

a) carbon dioxide (CO_2) is being expelled by the star's wind.
b) molecular nitrogen (N_2) is being expelled by the star's wind.

c) hydrogen fuel is being exhausted in its core.
d) hydrogen fuel is being exhausted on its surface.
e) helium fuel is being exhausted in its core.

42. Most nuclear-burning stars are main sequence stars. The reason for this is that the main sequence phase of the nuclear-burning life of star of any mass is the:

    a) shortest phase. b) most popular phase. c) wettest phase. d) longest phase. e) darndest phase.

43. As a **MAIN SEQUENCE STAR** ages, its luminosity (i.e., total energy output):

    a) decreases. b) increases. c) oscillates wildly. d) becomes tangential. e) incinerates.

44. At the time the Sun first became a main sequence star, its luminosity was probably ____________ than at present.

    a) 30 % greater b) 100 % greater c) 50 times greater d) 30 % lower e) 100 % lower

45. The end of a star's **MAIN SEQUENCE LIFE** (not its nuclear burning life) comes when it has:

    a) exhausted the hydrogen fuel in its corona. b) exhausted the hydrogen fuel in its core region. c) become a white dwarf. d) become a green dwarf. e) exhausted the hydrogen fuel in its sunspots.

46. When a star exhausts its core hydrogen fuel its:

    a) main sequence phase is ended. b) main sequence phase is at midpoint. c) main sequence phase is beginning. d) red giant phase is ended. e) AGB phase is ended.

47. After the end of its main sequence lifetime, the Sun will probably go through the following phases in order:

    a) red giant, helium flash (a very short stage), horizontal branch star, green giant, cometary nebula/pre-white dwarf, white dwarf, black dwarf (very far in the future).
    b) red giant, helium flash (a very short stage), horizontal branch star, jolly green giant, planetary nebula/pre-white dwarf, white dwarf, black dwarf (very far in the future).
    c) red giant, helium flash (a very short stage), vertical branch star, second red giant (i.e., asymptotic [red] giant branch star or ABG star), cometary nebula/pre-white dwarf, white dwarf, black dwarf (very far in the future).
    d) red giant, helium flash (a very short stage), horizontal branch star, second red giant (i.e., asymptotic [red] giant branch star or ABG star), planetary nebula/pre-white dwarf, white dwarf, black dwarf (very far in the future).
    e) red giant, Larry, Curly, Moe, black dwarf (very far in the future).

48. "Let's play *Jeopardy*! For $100, the answer is: These stars typically have radiii 10 to 100 times that of the Sun and surface temperatures of 2000–4500 K."

    What are ____________, Alex?

    a) white dwarfs b) green dwarfs c) red dwarfs d) blue giants e) red giants

49. After its hydrogen-burning life main sequence, a star usually will:

    a) expand into a blue supergiant. b) expand into a red giant. c) shrink into a red dwarf. d) just fade out. e) implode to form a protostar.

50. Lower mass stars (i.e., those which had main sequence mass $\lesssim 8M_\odot$) when burning helium to carbon and oxygen in their **CORES** are called ____________ stars.

    a) red giant b) supergiant c) horizontal branch d) vertical branch e) oblique branch

51. Lower mass stars (i.e., those which had main sequence mass $\lesssim 4M_\odot$) when burning helium to carbon and oxygen in a shell around an inert carbon-oxygen core, but before they have lost a lot of mass in helium shell flashes, are called ____________ stars.

a) red dwarf b) asymptotic giant branch (AGB) c) horizontal branch d) vertical branch
e) oblique branch

52. If in its AGB (asymptotic red giant) phase (or 2nd red giant phase), the Sun has expanded and enveloped the Earth, the Earth will:

    a) very quickly collapse to a black hole.
    b) become a red giant star.
    c) spiral into the deeper layers of the Sun because of the drag forces of the Sun's outer layers. There the Earth will be totally vaporized. "So the glory of this world passes away": *Sic transit gloria mundi.*
    d) gain escape velocity and be ejected from the solar system because of the drag forces of the Sun's outer layers.
    e) implode to form a protostar.

53. "Let's play *Jeopardy*! For $100, the answer is: These short-time scale episodes of explosive helium shell burning in late stellar evolution eject material that become planetary nebulae."

    What are ____________, Alex?

    a) hydrogen shell flashes b) helium shell flashes c) supernovae d) hypernovae
    e) novae

54. A planetary nebula is:

    a) a **cloudy planet**.
    b) a cloud that will coalesce into a **planet**.
    c) a shell of gas thrown off by a dying star before it becomes a **protostar**.
    d) a shell of gas thrown off by a dying star before it becomes a **white dwarf**.
    e) a shell of gas thrown off by a dying star before it becomes a **galaxy**.

55. White dwarfs are:

    a) the compact remnants of stars. They are **NOT** burning nuclear fuel. They are **COOLING DOWN** forever.
    b) giant red stars.
    c) the compact remnants of stars. They are **STILL** burning nuclear fuel.
    d) the compact remnants of stars. They are **NOT** burning nuclear fuel. But they are **HEATING UP** forever.
    e) the compact remnants of stars. They are **NOT** burning nuclear fuel. They have **NEVER** been observed: they are merely predicted theoretically.

56. A black dwarf is:

    a) a black hole.
    b) a protostar hidden in a molecular cloud.
    c) a protostar after emerging from its cocoon of gas and dust.
    d) what a white dwarf becomes when it has cooled off to near absolute zero temperature.
    e) a shell of gas thrown off by a dying star before it becomes a galaxy.