The 64th Annual
Merck State Science Day Competition
May 19, 2014

ADVANCED INTEGRATED SCIENCE

DIRECTIONS

The "answer panel" at the bottom of the window is pre-set to show 10 answer boxes per page.

1.The current question has a black border.
2. Enter your answer choice using the keyboard.
3. Click Confirm to record your answer.
4. Questions that have been answered will be tinted Green
5. Any answer can be edited. Confirm the correction.
6.> moves to the next set of questions (<moves back)
7.Click on any number to answer that question.
8. Confirm all entries. Each answer is recorded only when Confirm is used.
9. When finished, use FINISHED TEST in lower left.

Hint: The size of the lettering in the bottom answer panel can be adjusted using CTRL + to magnify the browser view.

There is subject-specific information on the reference sheet that you may find useful in answering certain questions. Be sure to view it before you begin the test. A periodic table is also available for use.

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

1995 IUPAC masses and Approved Names from http://www.chem.qmw.ac.uk/iupac/AtWt/
masses for 107-111 from C&EN, March 13, 1995, p. 35
112 from http://www.gsi.de/z112e.html

General Information: Physics and Advanced Integrated Tests

Proton mass, $m_P = 1.67x10^{-27} kg$	Electron charge, $e = 1.60x10^{-19} C$
Electron mass, $m_e = 9.11x10^{-31} kg$	1 electron volt, $1eV = 1.60x10^{-19} J$
Avogadro's Number, $N_o = 6.02x10^{23} mole^{-1}$	Speed of light, $c = 3x10^8 \, m/s$
Universal gas constant, $R = 8.31 \, J/(mol \cdot K) = 0.0821 \, atm \cdot liter/(mole \cdot K)$	Universal gravitation constant, $G = 6.67x10^{-11} \, m^2/(kg \cdot s^2)$
Boltzmann's constant, $k_B = 1.38x10^{-23} \, J/K$	Acceleration due to gravity at Earth surface: $g = 10 \, m/s^2$
$1cal = 4.184J$	

Unified atomic mass unit, $u = 1.66x10^{-27} kg = 931 \, MeV/c^2$
Planck's constant, $h = 6.60x10^{-34} J \cdot s = 4.14x10^{-15} eV \cdot s$
Coulomb's Law constant, $k = 9x10^9 \, N \cdot m^2/C^2$
1 earth atmosphere pressure, $1atm = 1.0x10^5 \, N/m^2$

Equations:

$v_f = v_i + at$	$2ad = v_f^2 - v_i^2$
$d = v_i t + \frac{1}{2} at^2$	$\Sigma F = ma$
$a_c = \frac{v^2}{r}$	$K = \frac{1}{2} mv^2$
$P_g = mgh$	$W = Fd$
$P = \frac{W}{t} = \frac{\Delta E}{t}$	$F_g = G \frac{M_1 M_2}{R^2}$
$F_B = DVg$	$A_1 v_1 = A_2 v_2$
$P + Dgy + \frac{1}{2} Dv^2 = Constant$	$v = \lambda f$
$n_i \sin i = n_r \sin r$	$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$
$f = \frac{R}{2}$	$E = hf = pc$
$\Delta E = \Delta mc^2$	$Q = mc\Delta T$
$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$	$PV = nRT$
$V = IR$	$P = VI$

CHEMISTRY Test

Universal gas constant:	R = 0.0821 atm-liter/(mole-K)	$1dm^3 = 1$ L
	R = 8.31 kPa-liter/(mole-K)	PV=nRT
		Specific heat $_{H2O}$ = 4.184 J/g°C
1 Faraday ($\mathfrak{F}$) = 96,500 coulombs/mole		1 calorie = 4.184 joules
= 96,500 joules/volt		$Q = mc\Delta T$
1 electron volt/atom = 96.5 kilojoules/mole		$KE_{ave} = ½mv^2$
Speed of light in vacuum = 3.00×10^8 m/sec		K_f water = -1.86 °C/*m*
Planck's constant, h = 6.63×10^{-34} joule-sec		K_b water = 0.51°C/*m*
Boltzmann's constant, k = 1.38×10^{-23} joule/K		
Avogadro's number = 6.02×10^{23} molecules/mole		

1st Year Integrated Test

INFORMATION THAT MAY BE USEFUL IN SOLVING SOME PROBLEMS

1 calorie = 4.184 joules
$1/f = 1/d_o + 1/d_I$
$C = 2f$
$h_i/h_o = d_i/d_o$
$E = hf$
speed of light in vacuum = 3.0×10^8 m/sec
Planck's constant, h = 6.63×10^{-34} joule-sec
$v = c\sqrt{1 - v^2/c^2}$
Avogadro's Number = 6.02×10^{23}
$Q = mc\Delta T$
$KE_{ave} = 1/2mv^2$
$PE_{grav} = mgh$
$W = F \times S$

$W = Vq$
$v_{avg} = s/t$
$s = v_o t + 1/2at^2$
$v_f^2 = v_i^2 + 2as$
$v_f = v_i + at$
$c = f\lambda$
$P_1V_1/T_1 = P_2V_2/T_2$
$I = V/R$
$1\ C = 6.25 \times 10^{18}\ e^-$
$D = M/V$
$\nu = f\lambda$
$P = W/t$
K_f water = 1.86 °C/*m*
K_b water = 0.51°C/*m*

Universal gas constant: R = 8.31 kPa-liter/(mole-K) = 0.0821 atm-liter/(mole-K)

Merck State Science Day 2014 **Advanced Integrated Science in the Environment**

Multiple Choice

Identify the choice that best completes the statement or answers the question and place your selection IN THE ANSWER PANEL then ***"Confirm".***

I. Cell Signaling

In Sutherland and colleagues' groundbreaking work, they discovered that cell signaling involves a variety of molecules as well as a three stage process of reception, transduction, and response.

1. Which of the following statement (s) are **TRUE** about membrane receptors?
- **A)** G-protein linked receptors are dependent on the dephosphorylation of ATP.
- **B)** Receptor tyrosine kinases produce only one cellular response at a time.
- **C)** Ligand-gated ion channels are very important in the digestive system.
- **D)** Receptor tyrosine kinases are dependent on the dephosphorylation of ATP.
- **E)** Both A and D are correct

2. Sutherland later discovered that the binding of epinephrine to the plasma membrane of a liver cell elevates the concentration of a compound called cyclic AMP. How is cyclic AMP produced?
- **A)** GTP is converted to cyclic AMP during transduction.
- **B)** An enzyme embedded in the plasma membrane converts ATP to cyclic AMP.
- **C)** An increase in the sodium level in the cells converts AMP to cyclic AMP.
- **D)** A decrease in the phosphorous level in the cells converts AMP to cyclic AMP.
- **E)** Testosterone receptor, which as a transcription factor, converts AMP to cyclic AMP

3. Which of the following enzymes is **NOT** involved in the signaling pathway that breaks down glycogen?
- **A)** Adenyly Cyclase
- **B)** Protein Kinase A
- **C)** Phosphorylase Kinase
- **D)** Glycogen Phosphorylase
- **E)** Phospholipase C

4. Epinephrine has different effects on different types of cells. For example, it stimulates liver cells to break down glycogen and it causes heart cells to contract. How do we account for these differences?
- **A)** Responses are dependent upon the level of phosphorous.
- **B)** Responses are dependent upon the amount of mitochrondria found within the various cell types.
- **C)** Responses are dependent on the different collection of proteins found within the various cell types.
- **D)** Responses are dependent upon the level of nitrogen within the cells.
- **E)** None of the above are correct

5. The amplication of cell signaling is dependent upon which of the following molecules:
- **A)** DNA
- **B)** Cascade of Protein Kinases
- **C)** Signal Molecules
- **D)** Sulfur Hydroxide
- **E)** Both B and C are correct

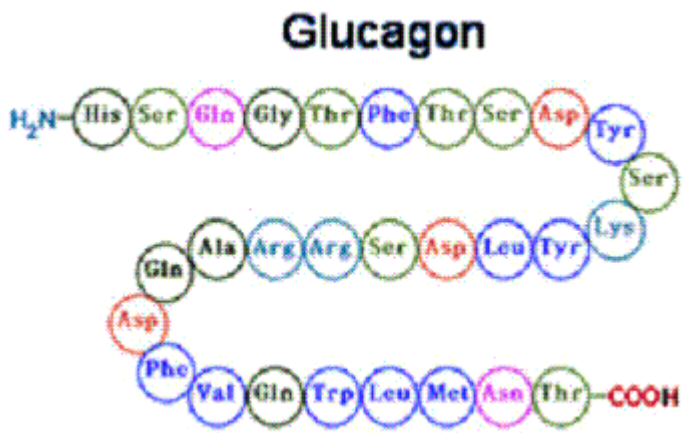
6. Modern London does not have these same epidemics due to modern
- **A)** food inspection.
- **B)** sewage treatment.
- **C)** vaccinations.
- **D)** refrigeration.
- **E)** pollution controls.

7. The birth of epidemiology, the study of epidemics, is credited to Dr. John Snow. He stopped an epidemic of _____ in 1854 by convincing authorities to remove the handle from a water pump in London. This disease affects the _____ cell signaling process.
- **A)** cholera.... G-protein
- **B)** smallpox.... tyrosine kinase
- **C)** plague.... G-protein
- **D)** cholera .... tyrosine kinase
- **E)** plague ... tyrosin kinase

8. Which of the following techniques would Dr. Snow have been likely to use in his study of this epidemic?

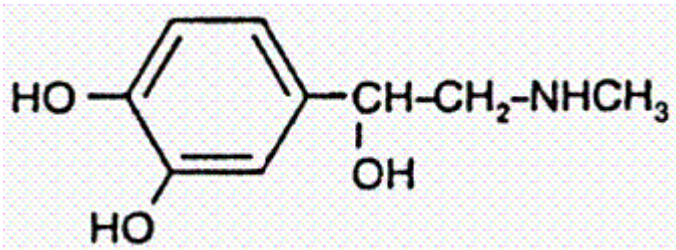
I. case studies
II. DNA analysis
III. vaccination

- **A)** only one of the above
- **B)** I and II only
- **C)** II and III only
- **D)** I and III only
- **E)** all of the above.



9. The diagram above is the sequence of amino acids in glucagon. Why doesn't this have any disulfide bridges?

A) It lacks any cysteine.
B) Doesn't have enough hydrogen bonds.
C) The protein structure creates a tight alpha-helix.
D) The thiol groups are broken when the peptide linkages are made.
E) Hydrophobic areas are located on the outside edges of the structure.

10. 

Above is the structure of epinephrine that was studied by Sutherland and colleagues in the 1950. What functional groups are present?

A) methyl and oxy
B) ketone and nitro
C) methyl and benzyl
D) methyl and primary amine
E) hydroxyl and secondary amine

11. When an ATP molecule is converted into an ADP molecule

A) bonds are broken and energy is released.
B) bonds are broken and energy is absorbed.
C) bonds are formed and energy is released.
D) bonds are formed and energy is absorbed.
E) no energy is involved in the reaction.

II. Martian Soil

A scientific paper published in October 2013 details the investigation of a chemical in the Martian soil that interferes with the techniques used by the Curiosity rover to test for traces of life. The chemical causes the evidence to burn away during the tests.

In search of clues to life's presence on Mars, Curiosity rover checks Martian soil and rocks for molecules known as organic carbon compounds that are the hallmark of living organisms on Earth. The rover found evidence of perchlorate in some aeolian deposit samples in the Gale crater. When Curiosity heats a scoop of Martian soil to test it for organic carbon, perchlorates can cause a chemical reaction that destroys organic carbon. Glavin said he now believes the troublesome perchlorates are likely prevalent throughout the Martian surface.

"The presence of perchlorates isn't good news for some of the techniques we're currently using with Curiosity," said Glavin. "This may change the way we search for organics in the future on Mars."

The Curiosity rover's Sample Analysis on Mars (SAM) system tests soil samples by heating them in an instrument, called a pyrolysis gas chromatograph mass spectrometer, GCMS. Any perchlorate salts in the heated sample decompose as the temperature goes above 200°C and release pure oxygen. Organic molecules in the sample are destroyed and the molecular evidence of their presence is lost. Several chlorinated hydrocarbons including chloromethane, dichloromethane, trichloromethane, a chloromethylpropene, and chlorobenzene were identified by SAM above background levels.

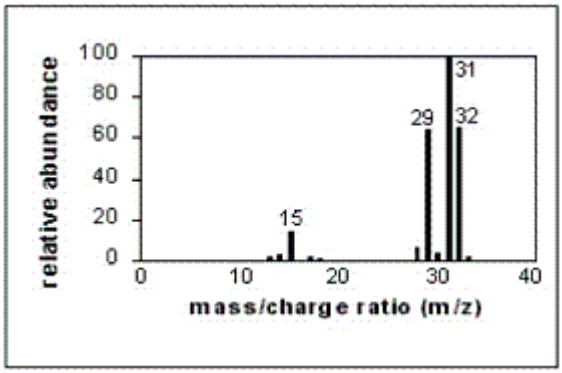
Glavin noted that scientists can account for the destroyed organic carbon by assuming a certain baseline of perchlorate in the Martian soil. Curiosity has the potential to avoid the perchlorate problem in the future by using techniques that do not involve heating the soil to the point where perchlorates break down.

Galvin, David, *et.al.*, *Journal of Geophysical Research: Planets*
Volume 118, Issue 10, pages 1955–1973

12. 1.What is the formula for the perchlorate ion?

A) $PClO_3^{1-}$
B) ClO^{1-}
C) ClO_2^{1-}
D) ClO_3^{1-}
E) ClO_4^{1-}

13. Below is a sample output from the MS section of GCMS. Which is the likely compound?



A) CH_4
B) NH_3
C) CH_3OH
D) CO_2
E) CCl_4

14. Some organic carbon would likely survive the analysis. What would account for this occurrence?
I. incased in more heat-resistant materials
II. detected before the breakdown of perchlorates
III. surface molecules exposed to cosmic radiation creates stronger C-C bonds

A) III only
B) I and II only
C) I and III only
D) II & III only
E) I, II, and III

15. How are aeolian deposits created?

A) cosmic dust
B) wind driven
C) volcanic lava flows
D) evaporated from water
E) ancient seashore waves

16. Soil is an important abiotic factor in an ecosystem. Which of the following statements is true about soil?

A) The pH of soil is 6-7.
B) The distinct soil layers are called loams.
C) Soil has its origin in the weathering of solid rock.
D) The first layer of soil is called subsoil.
E) Soil does not play an important role in chemical cycles.

17. Chlorine is a component of the following insecticide:

A) DDT
B) Sevin
C) Neonicotinoid
D) Roundup
E) none of the above

"Perchlorate can be widespread in ground water, soils and plants, and makes its way up the food chain accordingly...in 16 percent of conventionally produced lettuces and other leafy greens and in 32 percent of otherwise similar but organically produced samples...[perchlorate] can disrupt the thyroid's ability to produce hormones.... the EPA is currently working on setting national standards for how much perchlorate can be allowed in drinking water"

from Scientific American ,"Perchlorate in Drinking Water Raises Health Concerns", 12/21/2012.

18. California has already set perchlorate maximum levels at 6 ppb for drinking water. This measure is the same as

A) 6 g/mL.
B) 6 g/kg.
C) 6 mg/L.
D) 6 ug/L.
E) 6 ug/mL.

19. The EPA has the authority to enact national standards due to the

A) Clean Water Act.
B) Safe Drinking Water Act.
C) Toxic Substances Act.
D) Endangered Species Act.
E) Federal Food, Drug and Cosmetic Act.

20. Perchlorate is an endocrine disruptor, as is

A) lead.
B) mercury.
C) DDT.
D) CO.
E) radon.

21. Perchlorate is an environmental hazard because it can

i. biomagnify.
ii. bioaccumulate.
iii. be carcinogenic.
iv. biodegrade.

A) only one of the above
B) i, ii, iii only
C) ii, iii, iv only
D) i, ii, iv only
E) all of the above.

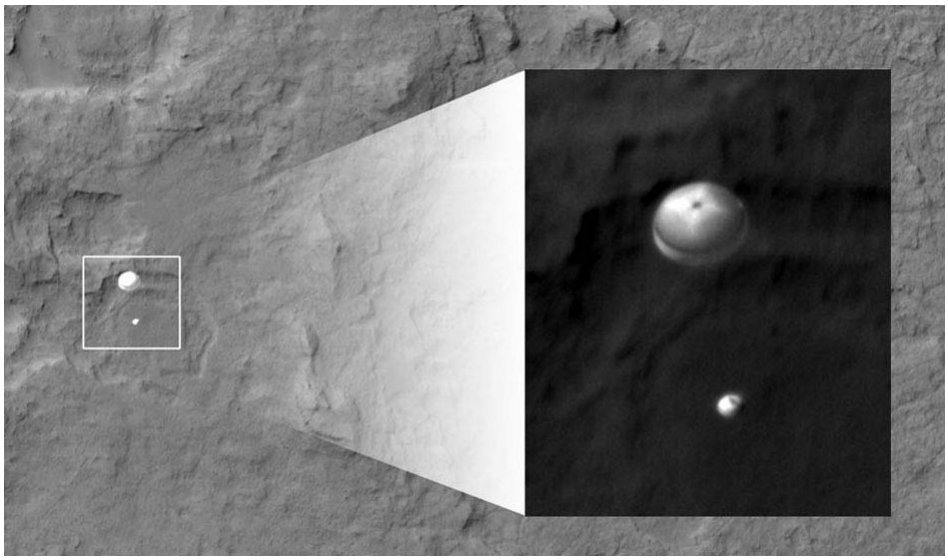
Here is a list of physical characteristics of the rover Curiosity (formally named Mars Science Laboratory: MSL) and of the planet Mars.

Curiosity Rover Data
Curiosity Mass = 900 kg
Curiosity Maximum Land Speed = 600 m/day
Speed of descent module entering Mars atmosphere = 13,000 MPH = 21,000 Km/hr
Vertical Speed of Curiosity at "Touchdown" = 1.0 MPH = 1.6 Km/hr
Time of Descent Through Martian Atmosphere = 7 minutes
Curiosity Wheel Diameter = 50 cm
Electrical Energy Source: Plutonium-238

Mars Data
Mass = 0.1 Earth Mass
Radius = 0.5 Earth Radius

22. Calculate Curiosity's weight as measured on the surface of Mars.
A) 900 kg
B) 900 N
C) 3600 kg
D) 3600 N
E) 9000 N

23.



The above true optical image was taken by the *Mars Reconnaissance Orbiter* and depicts the Curiosity parachuting to the surface of Mars. During the parachute deployment, the Curiosity underwent a deceleration from a vertical speed of 405 m/s at an altitude of 11 km to a vertical speed of only 80 m/s at an altitude of only 1.5 km. Calculate the magnitude of the average force provided by the parachute during this time.

NOTE: During this entire descent phase, the rover was ***inside*** a deployment capsule. The total mass of the deployment capsule and the rover inside was 3500 kg, including over 600 kg of rocket propellant for later additional deceleration.

[Image Source: APOD.com, http://apod.nasa.gov/apod/ap120808.html]

A) 14,000 N B) 29,000 N C) 35,000 N D) 43,000 N E) 78,000 N

24. Curiosity uses the heat generated by the decay of Plutonium-238, ${}^{238}_{94}Pu$, to create electricity. If one ${}^{238}_{94}Pu$ nucleus undergoes one alpha emission and one beta emission, what is the resulting daughter nucleus?

A) ${}^{236}_{94}Pu$ **B)** ${}^{236}_{92}U$ **C)** ${}^{234}_{93}Np$ **D)** ${}^{233}_{92}U$ **E)** ${}^{233}_{93}Np$

III. CSP

Two new concentrated-solar-power (CSP) plants are being in stalled in Arizona and California. These plants concentrate solar power using either curved mirrors or flat concentrating mirrors. These mirrors direct the sun's rays to heat a conducting liquid medium. This heated medium then runs a conventional style electric generating plant. One advantage of this technology over the more common photovoltaic cells is that the medium can retain thermal energy for longer periods of time, thus generating electricity even without sunlight. One disadvantage is the need for intense, predictable sunlight.

Adapted from Chemical & Engineering News 12/16/2013

25. Other disadvantages of solar power include

I. *need for large areas of land*
II. *death of birds*
III. *limited potential installation sites*
IV. *increase in CO_2 emissions*
V. *lack of tax incentives for installation*

A) only one of the above
B) only two of the above
C) only three of the above
D) only four of the above
E) all of the above

26. What type of plant species would you expect to find most abundant in areas where CSP factories were established?

A) C3
B) C4
C) CAM
D) Both B and C are correct
E) Both A and B are correct

27. Photosynthesis is comprised of a noncyclic and cyclic electron flow. Which of the following statements below is *true* about the cyclic electron flow?

A) The cyclic electron flow involves photosystem II but not photosystem I
B) The cyclic electron flow produces NADPH and ATP
C) The final electron carrier in the cyclic electron flow is water.
D) The cyclic electron flow produces no NADPH
E) Both A and B are correct

28. In the light dependent reaction, what is the final electron acceptor of the electron transport chain?
- **A)** Water
- **B)** $NADP^+$
- **C)** SO_2
- **D)** ATP
- **E)** ADP

29. Installation of similar solar plants was delayed when _____ were discovered in the location.
- **A)** Deposits of uranium
- **B)** Rattlesnakes
- **C)** Mountain lions
- **D)** Desert tortoises
- **E)** PCBs

30. Which of the following components would most likely NOT be found in the CSP electric generating plant?
- **A)** Steam circuit
- **B)** Turbine
- **C)** Transmission lines
- **D)** Large cooling towers
- **E)** All of the above would be found there

31. The ecosystem or biome best suited for these solar plants is the
- **A)** Tundra.
- **B)** Desert.
- **C)** Coast.
- **D)** Plains.
- **E)** Mountains.

32. Another likely site for a CSP plant would be
- **A)** Utah.
- **B)** Oregon.
- **C)** Washington.
- **D)** Kentucky.
- **E)** New Jersey.

33. If a large single mirror used in a CSP is a concave spherical mirror of radius R, what distance from the geometric center of the mirror should the conducting liquid collector be placed to optimize energy transfer?

A) 2R **B)** 3R/2 **C)** R **D)** R/2 **E)** $2\pi R$

34. Solar cell operation is a real world application of the photoelectric effect. This effect was first discovered by Heinrich Hertz back in 1887 when he noticed that certain metals used as electrodes would spark when illuminated by UV light. Which of the following famous and/or semi-famous scientists was the first to fully explain the photoelectric effect.

A) Albert Einstein
B) Nicola Tesla
C) James Clerk Maxwell
D) Max Planck
E) Neils Bohr

35. Silicon crystal is the most common bulk material used in solar cells. The work function of a typical silicon crystal surface is 1 eV. If sunlight of wavelength 550 nm is incident up this silicon surface, with what maximum kinetic energy do electrons escape the surface?

A) Zero, no electrons escape.
B) 0.5 eV
C) 1.0 eV
D) 1.25 eV
E) 1.5 eV

36. In the photoelectric effect, the maximum speed of the electrons emitted by a metal surface when it is illuminated by light depends on which of the following?

I. Intensity of the light
II. Frequency of the light
III. Nature of the photoelectric surface

A) *I* only
B) *III* only
C) *I* & *II* only
D) *II* & *III* only
E) All three; *I*, *II*, & *III*.

37. During a particular CSP data run, light of a particular wavelength is incident on a metal surface and electrons are emitted from the surface as usual. However, the engineers need to produce more electrons per unit time that have less kinetic energy per electron. The engineers should do which of the following to achieve this result?

A) Increase the intensity and decrease the wavelength of the light.
B) Increase the intensity and the wavelength of the light.
C) Decrease the intensity and the wavelength of the light.
D) Decrease the intensity and increase the wavelength of the light.
E) None of the above would produce the desired result.

38. Why has Abu Dhabi built the largest CSP plant in the world?
A) Fossil fuels are non-renewable.
B) There are very limited sources of fossil fuels in the area.
C) They want to be the first country that uses 100% renewable energy.
D) CSP plants are less expensive to build and produce more power than a gas or oil power plant.
E) It was built as a showcase project by the UN to help encourage solar development in poor countries.

39. In the United States, what is the primary use of solar hot water?
A) heating, ventilation and air conditioning (HVAC) in commercial buildings
B) HVAC in residential buildings.
C) commercial electric power generation
D) distillation of water to create potable water
E) heating swimming pools

40. At the equinox, if the concentration of sunlight (insolation) on the earth's surface at the equator is designated as 100, approximately what would it be in New Jersey?
A) 120
B) 85
C) 65
D) 50
E) 30

IV. Higgs-Boson

A strange thing called the Higgs-Boson made all the news last year. The Higgs boson, or Higgs particle, is an elementary particle initially theorized in 1964 by Peter Higgs and five others. The Higgs particle discovery was announced at CERN (European Organization for Nuclear Research) on 4 July 2012, and confirmed on 14 March 2013 (Einstein's birthday and Pi Day, coincidentally).

Two of the original researchers, Peter Higgs and François Englert, were awarded the 2013 Nobel Prize in Physics for their work and prediction. (Englert's co-researcher Robert Brout had died in 2011).

41. Why is the Higgs boson needed?

A) It explains how particles differ from waves.
B) It explains why some particles have mass and some don't.
C) It explains why particles cannot exceed the speed of light.
D) It explains why photons travel at the speed of light.
E) It explains how protons and neutrons bond together to form nuclei.

42. The Higgs particle belongs to a group of particles called "bosons." The bosons are responsible for

A) carrying forces associated with fields.
B) transferring electrical charge between other particles.
C) carrying particles through force fields.
D) causing electromagnetic disturbances.
E) dark matter.

43. The Standard Model falls short of being the "Theory of Everything" and is sometimes called the "Theory of Almost Everything." The main reason for this is

A) the lack of incorporating the full theory of gravitation as described by Einstein's General Theory of Relativity.
B) none of the exotic subatomic particles it predicts, like muons and Pi mesons, have ever actually been detected.
C) it does not explain nuclear beta positive (positron) decay properly.
D) the lack of correct predictions of the existence of many subatomic particles.
E) the lack of a proper explanation of the strong nuclear force.

44. Quarks are the subatomic particles that combine to make many of the members of what is commonly referred to as the "Particle Zoo." The most common of these are the baryons; the proton and the neutron are the most familiar baryons. There are six types of quarks. The least massive, the "up" and the "down" quarks, were found first in 1968 at Stanford Linear Accelerator Lab, CA. It wasn't until 1995 that a team at Fermilabs near Chicago found the most massive of the quarks, the Top quark. The Top quark has a very high mass, almost as massive as a gold nucleus. Why was the most massive quark the last to be found?

A) For years, the top quark was mistaken for a more massive particle that was already named.
B) The top quark was hiding deep inside the nucleus of larger atoms.
C) The top quark is actually a combination of other smaller and less massive quarks.
D) It required more and more energetic proton-antiproton collisions to force the "production" of more massive particles.
E) Until recently, there existed no technology to actually measure a mass that large.

45. The existence of a "Higgs field" was necessary if the Standard Model was to be considered correct. Just what is the "Standard Model?"

A) A simple set of rules that govern atomic interactions.
B) A simple set of rules that explains electromagnetic radiation.
C) A simple set of rules that explains why the Universe is even here.
D) A simple set of rules that explains the fundamental particles that make up all regular matter and the interactions between them.
E) A complex and esoteric set of rules that explains everything.

46. Particles such as electrons are important in biology because they join together to form bonds. Depending upon the type of bond formed, there are certain properties of these bonds that allow living things to fulfill the characteristics of life. An example of this is the van der Waals interactions which allows gecko lizards to walk up walls. What else is correct about van der Waals interactions?

A) They are weak and occur when atoms and molecules are far apart.
B) They are strong and occur when atoms and molecules are far apart.
C) They are weak and occur when atoms and molecules are close together.
D) They are strong and occur when atoms and molecules are close together.
E) They are strong regardless of the distance of the molecules and atoms.

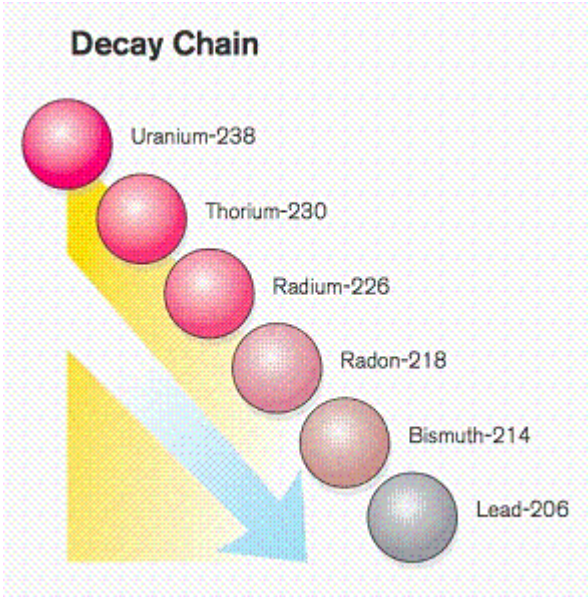
47. Given the 4 major types of nuclear decays: alpha particle, beta particle, gamma ray and electron capture, which has the most penetrating power?

A) alpha particle
B) beta particle
C) gamma ray
D) electron capture
E) all are the same

48. Which decay would have the most Higgs-Bosons?

A) alpha particle
B) beta particle
C) gamma ray
D) electron capture
E) all are the same

49.



What kind of decays must occur in the series above to change a U-238 into a Th-230?

A) 1 alpha and 1 beta
B) 2 alphas and 1 beta
C) 1 alpha and 2 betas
D) 2 alphas and 2 betas
E) 1 alpha and 3 betas

50. Iodine-131 is used for medical diagnosis, it has a half-life, $T_{1/2}$, of 8.1 days. If you were injected with 40 micrograms of this isotope how much would remain un-decayed after 97 hours?

A) 38 µg
B) 30 µg
C) 28 µg
D) 20 µg
E) 14 µg

V. DNA

James Watson and Francis Crick published their findings of the structure of DNA in 1953. Shortly thereafter, many scientists began to investigate causes of errors in DNA replication. Many of the scientists believed that replication errors were caused by something known as tautomeric shifts. These shifts occur when a proton changes its position resulting in a rare tautomeric form.

**Information taken from: Pray, L. (2008) DNA replication and causes of mutation. Nature Education 1(1):214*

51. The Watson - Crick Model of DNA required that nucleotide bases be in their 'keto' form. Which of the following nitrogenous bases is appropriately matched with a tautomeric form?

A) Thymine-Enol
B) Cytosine-Enol

C) Guanine-Imino
D) Adenine- Imino
E) Both A and D are correct

52. The enzyme, DNA polymerase, is pretty accurate when adding nucleotides during DNA replication; however, these enzymes do make mistakes at a rate of about 1 per 100,000 nucleotides. Approximately, how many mistakes would this translate into in a human diploid cell?

A) 5,000
B) 10,000
C) 120,000
D) 1,000,000
E) 200,000,000

53. Replication errors can involve insertions or deletions of nucleotide bases that occur during a process called *strand slippage*. Which type of DNA would be more likely to have an error due to *strand slippage?*

A) Short Non Repeating DNA Sequences
B) Long Repeating DNA Sequences
C) Short Repeating DNA Sequences
D) Long Non Repeating DNA Sequences
E) None of the above are correct

54. Most mutations are believed to be caused by replication errors, but they can also be caused by environmental factors as well as spontaneous changes to DNA that occur prior to replication. Which of the following would be an example of a spontaneous change?

A) Transformation
B) Hydrolysis
C) Deamination
D) Inversion
E) Both B and C are correct

55. Exposure to radiation is one cause of DNA mutation. Which of the following nuclear plants is known to have released the most radiation?
A) Three Mile Island
B) Oyster Creek
C) Chernobyl
D) Fukushima
E) Exxon Valdez

56. Which of the following environmental hazards is most responsible for carcinogenic mutations?
A) formaldehyde
B) X-rays
C) ozone hole depletion
D) cigarette smoke
E) radioactivity

57. Which of the following energy sources is responsible for the most human deaths, per year (from extraction through processing through production)?
A) hydroelectric
B) coal
C) natural gas
D) fracking
E) nuclear

58. What is the most common form of DNA mutation?

A) purine into a pyrimidine
B) a exon into a intron
C) a thymine into a uracil
D) an *m*-RNA into a Okazaki fragment
E) none of the above

59. Intercalating agents such as ethidium bromide and proflavine can cause mutations during replication. How does it cause this?

A) misreading of the codon
B) crosslinking of the double helix
C) acting as a competitive inhibitor
D) dephosphorization of the DNA backbone
E) disruption of the hydrogen bonding of the base pairs

VI. Money Laundering

Recently, two researchers determined that there was an effective and efficient method of "laundering" paper money. A dollar bill gets around, passing from hand to hand, falling on streets and sidewalks, eventually getting so grimy that a bank machine flags it and sends it to the shredder. Rather than destroying it, scientists have developed a new way to clean paper money to prolong its life. The research could save billions and minimize the environmental impact of banknote disposal.

Lawandy and Smuk point out that replacing old currency is a growing problem. When bills become too dirty, central banks take them out of circulation and replace them with crisp new bills. As a result, the world's treasuries print nearly 150 billion new banknotes every year at a cost approaching $10 billion. And about 150,000 tons of old bills become destined for shredding and disposal. The main culprit for this costly turnover is human sebum. Over a bill's lifetime of about 3 to 15 years depending on the denomination, sebum accumulates on its surface, reacts with oxygen in the air and turns a yellowish hue. To delay a banknote's retirement, Lawandy's team decided to see if they could just clean it, removing the accumulated sebum.

They turned to "supercritical" CO_2, which acts like both a gas and a liquid and is commonly used in other cleaning applications. When they tested it on banknotes from around the world, they found that it effectively removed oxidized sebum and motor oil while leaving intact security features such as holograms and phosphorescent inks.

*(**Supercritical Fluid Cleaning of Banknotes, Nabil Lawandy and Andrei Smuk,** Ind. Eng. Chem. Res., **2014**, 53 (2), pp 530–540, December 6, 2013).*

60. Carbon dioxide behaves as a supercritical fluid above its critical temperature (31.1°C or 304.25 K) and critical pressure (72.9 atm or 7.39 MPa), expanding to fill its container like a gas but with the _?_ like that of a liquid.

A) color
B) boiling point
C) density
D) intermolecular forces
E) viscosity

61. Supercritical CO_2 is becoming an important commercial and industrial solvent for use in chemical extraction. Which properties contribute to its expanded use?

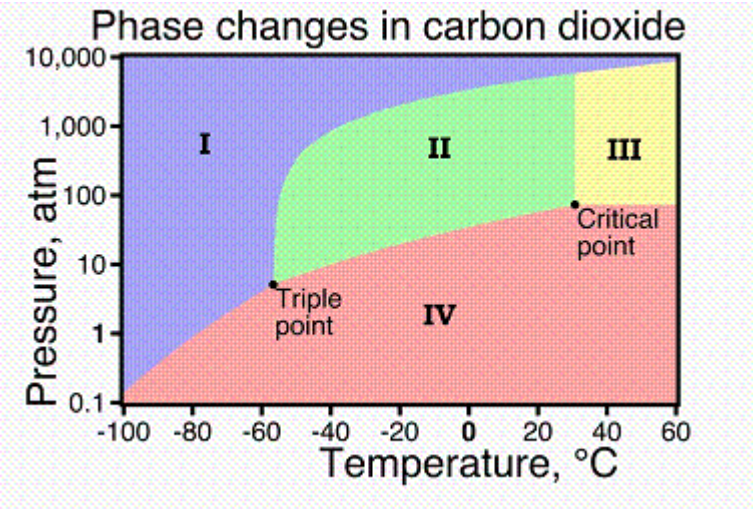
I. low cost
II. low toxicity
III. non-polar solvent
IV. minimal environmental impact
V. relatively low temperatures compared to other supercritical fluids

A) I & II only
B) I & III only
C) I, III, IV, & V
D) I, II, III, V
E) all of them, I-V

62. If it acts like an ideal gas, what will the volume of one liter of CO_2 at STP occupy at its critical temperature (31.1^{o}C) and critical pressure (72.9 atm) ?

A) 4.51×10^{-5}L
B) 0.0153L
C) 0.240 L
D) 65.4L
E) 6.05×10^{6}L

63. In the phase diagram below, regions I. II, III and IV represent, in order



A) gas, liquid, solid, supercritical fluid
B) liquid, solid, supercritical fluid, gas
C) solid, liquid, supercritical fluid, gas
D) supercritical fluid, gas, liquid, solid
E) solid, liquid, gas, supercritical gas

64. All the paper used to make US banknotes do not contain starch. Cashiers frequently try to mark a banknote with a special pen to check for counterfeit money. If it is counterfeit, the mark turns black. The pen contains which substance?

A) sugar
B) iodine
C) carbon
D) oxygen
E) a UV sensitive compound

65. Organic molecules, such as glucose, can be joined with other organic molecules to form polymers. What molecule needs to be removed in order to form these polymers?

A) Carbon dioxide
B) Water
C) Carboxyl
D) Carbonyl
E) Sulfhydrl

66. Assuming the newly printed replacement 150 billion banks notes are the same size as the US $1 bill with a thickness of 0.1 mm. How tall would a vertical stack of these 150 billion $1 bills reach?

A) $1.5x10^6 m$
B) $1.5x10^7 m$
C) $1.5x10^8 m$
D) $1.5x10^9 m$
E) $1.5x10^{10} m$

67. Increased levels of CO_2 are implicated in which of the following environmental problems:

i. climate change
ii. acid deposition
iii. the ozone hole

A) only one of the above.
B) i and ii only
C) ii and iii only
D) i and iii only
E) all of the above.

68. One method of disposal of solid wastes is burying them in a landfill. Which of the following is (are) environmental concern(s) associated with landfills?

i. contamination of groundwater
ii. odors and vermin
iii. climate change
iv. production of dioxins

A) only one of the above
B) only two of the above
C) only three of the above
D) all of the above
E) none of the above

69. One method of disposal of solid wastes is incineration. Which of the following is (are) environmental concern(s) associated with incinerators?

i. contamination of groundwater
ii. odors and vermin
iii. climate change
iv. production of dioxins

A) only one of the above.
B) only two of the above
C) only three of the above
D) all of the above
E) none of the above

VII. Sea Stars

Hundreds of sea stars on both coasts of the United States are being killed by a disease known as sea star wasting syndrome. This illness progresses from a small lesion to loss of the sea star's rays to disintegration of the animal into a gooey mess. The cause of the syndrome is not yet known. Although epidemics have been known to occur in the past on the West Coast, the recent outbreak is unique in both location and severity. Up to 95% of some afflicted populations have died.

Adapted from www.foxnews.com/science/2013/11/11/mysterious-disease-turning-sea-stars-to-goo

70. The loss of the sea star population is a serious concern to ecologists because sea stars are considered a(n)_____ species.

A) Invasive
B) Producer
C) Keystone
D) Predator
E) Endangered

71. Sea stars are a type of echinoderm. Which of the following characteristic (s) is displayed by echinoderms?

I. Vertebrate
II. Invertebrate
III. Deuterostome
IV. Protostome

A) I, III
B) I,IV
C) II,III
D) I, III, IV
E) II, III, and IV

72. What term below best exemplifies the symmetry of echinoderms and cnidarians?

A) Convergent evolution
B) Divergent evolution
C) Directional selection
D) Sympatric Speciation
E) Allopatric Speciation

73. Climate change could be a factor in this recent outbreak because

I. increased ocean temperatures would favor pathogens.
II. Increased ocean temperatures would stress multicellular organisms.
III. decreased ocean acidity would harm cell membranes.

A) only one of the above
B) I and II only
C) II and III only
D) I and III only
E) All of the above

74. Although the cause of the syndrome is unknown, a viral pathogen is considered unlikely because

A) The salinity of ocean water hinders viral replication.
B) Sea stars have an effective antiviral immune system.
C) Viruses only affect land organisms, not marine organisms.
D) There is no obvious way for the virus to travel to New Jersey.
E) Other marine organisms are not affected by the syndrome.

75. One of the earliest consequences of the loss of the sea star population would probably be
- **A)** An increase in the mussel population.
- **B)** A decrease in the density of corals.
- **C)** A stabilization of the sea star's prey populations.
- **D)** An increase in the dissolved oxygen content of the water.
- **E)** An increase in the marine biodiversity.

76. Which of the following adaptation (s) of sea stars allow them to capture their prey?
- **A)** Ability to regenerate body parts
- **B)** Spines
- **C)** Madreporite
- **D)** Water vascular system
- **E)** All of the above

77. The efficiency of a steam (or any gas) powered turbine is dependent upon
- **A)** the temperature of the input steam.
- **B)** the temperature of the steam at the outlet.
- **C)** the temperature difference between the input and the outlet.
- **D)** the polarity of the steam (or gas) molecules.
- **E)** the source of heat that creates the steam.

78. What is one cause of ocean acidification?
- **A)** increase in the burning of fossil fuels
- **B)** oil pollution from drilling rigs and oil tanker leaks
- **C)** thinning of the arctic ice sheet
- **D)** nitrogenous waste (mainly ammonia) from animals like sea stars
- **E)** radioactive water escaping from the damaged Fukushima nuclear plant

79. Coral bleaching is another ocean ecological problem. What is a cause of the coral change color?
- **A)** virus spread by dying starfish
- **B)** overfishing by commercial fishing fleets
- **C)** death or expulsion of the symbiotic algae
- **D)** increase in UV light due to holes in the ozone layer of the atmosphere
- **E)** laundry chemicals entering the ocean from inefficient coastal sewage plants

80. Why are starfish are not found in freshwater habitats?
- **A)** they need deepwater pressure to live
- **B)** freshwater algae are different than ocean algae
- **C)** freshwater ecosystems are generally shallower and too warm
- **D)** there is not enough calcium in freshwater ecosystems to create skeletal systems
- **E)** they need to maintain an internal electrolyte balance in equilibrium with sea water

81. Which type of radiation is most dangerous?

A) alpha.
B) beta.
C) gamma.
D) ultra-violet.
E) infra-red.

82. A radioactive substance is generally considered "safe" after _____ half-lives.

A) 5
B) 10
C) 20
D) 50
E) 100

83. Gamma radiation could be useful for

i. cancer treatment. *ii. pest control.* *iii. water purification.*

A) only one of the above.
B) i and ii only.
C) i and iii only.
D) ii and iii only.
E) all of the above.

84. Many New Jersey residents have an increased risk of radiation exposure due to

A) lead.
B) radon.
C) nuclear power plants.
D) industrial smog.
E) ground level ozone.

VIII. Dark Matter

*It was recently reported that a NASA space probe has found what could be the first direct evidence of the existence of the strange **Dark Matter** (DM). On 07 April 2014, data from NASA's Fermi mission, formally named GLAST for Gamma Ray Large Area Space Telescope, was released that indicated a massive amount of gamma rays emanating from the area surrounding the center of our own Milky Way galaxy. These gamma rays were in the predicted range of dark matter particle annihilations. WIMPs, Weakly Interacting Massive Particles, are a leading candidate for the exotic nature of dark matter, so these are thought to be WIMP-WIMP annihilation events.*

*Before this, the Universe had provided plenty of evidence for the existence of DM; all in the form of dark matter gravitationally interacting with regular matter. Even the **CMBR**, **Cosmic Microwave Background Radiation**, reveals details of the existence of DM.*

When the densities of dark matter are high enough, two of its particles could collide with each other, producing energetic debris. By looking at the places where we expect the highest concentrations of dark matter, like the core of galaxies, and seeing if there's an excess of certain types of radiation, we might be able to detect signs of these dark matter collisions. Fermi results point to gamma radiation in the 30-40 GeV range, exactly where the predicted WIMP-WIMP annihilation states the energy should be.

85. Dark matter was first envisioned in 1933 by CalTech's Swiss astronomer, Fritz Zwicki, (even though Dutch astronomer Jan Oort performed similar calculations one year earlier) who noticed

A) the abundance of "dark" areas in the night sky.
B) that there were more dark (reflective) nebulae than light (emitting) nebulae.
C) there was an abundance of strange matter that absorbed light, but did not release it.
D) that there was a large dark spot at the core of our Milky Way galaxy.
E) the speeds of galaxies within a large galaxy cluster were too fast for the gravitational effects from the visible matter.

86. The WIMP is the particle physicists' solution to the dark matter problem. What are the properties of the WIMP that cause it to not interact with regular particle matter?

A) They interact via the nuclear weak and gravitational forces, but nor the nuclear strong or electromagnetic forces.
B) They interact via the nuclear strong or electromagnetic forces, but nor the nuclear weak and gravitational forces.
C) They interact via the gravitational and nuclear strong force, but not via the nuclear weak and electromagnetic force.
D) They interact only via the electromagnetic force.
E) They interact only via the strong nuclear force.

87. Dark matter was corroborated by Vera Rubins in 1967 after she noticed

A) orbital velocities of the four outer planets disobeyed Newton's Law of Universal Gravity.
B) orbital velocities of the four outer planets disobeyed Kepler's 3rd Law.
C) tangential velocities of stars in individual galaxies disobeyed Kepler's 3rd Law.
D) tangential accelerations of stars in individual galaxies disobeyed Kepler's 3rd Law.
E) the cores of large galaxies contained supermassive black holes.

88. According to modern cosmology, the Universe is made up of the following ratios of regular matter (atoms) to dark matter to dark energy.

A) 33/33/33
B) 20/20/60
C) 5/27/68
D) 5/68/27
E) 27/5/68

89. Dark matter is related to dark energy in what way?

A) Dark energy is caused by concentrated areas of dark matter.
B) Dark matter annihilates and turns into dark energy.
C) Dark energy is the dark matter equivalency just like regular energy is the mass equivalency of matter in $E = mc^2$.
D) Neither exists here in our region of the Universe, but only in far away reaches of the edge of the Universe.
E) They are not related at all.

90. The WIMP, strangely enough, is its own anti-particle. Most are familiar with electron-positron or proton-antiproton annihilation. When a piece of matter meets its anti-matter counterpart, they annihilate into energy. This is done all the time in large accelerators like FermiLabs and CERN; they both use energetic proton-antiproton collisions and examine what "pops out." When a WIMP meets another WIMP, they annihilate because they are each others anti-particle. If two WIMPS are in the same vicinity in space each with very low velocities and bump into each other and annihilate, at what angle do the two gamma photons created depart the collision point?

A) 0°
B) 30°
C) 90°
D) 120°
E) 180°

91. The expected average energy of the gamma photons emitted from the dark matter annihilation is 35 GeV. This would represent a gamma photon with a frequency equal to

A) $3.5x10^{10} Hz$
B) $8.5x10^{24} Hz$
C) $5.3x10^{43} Hz$
D) $1.9x10^{-44} Hz$
E) $1.2x10^{-25} Hz$

92. Radiation can be problematic to different forms of life. For example, in the 1920's Hermann Muller discovered that x-rays caused genetic changes in fruit flies and later it was discovered the hazardous effect of radiation to the genetic material of people. Which of the following type(s) of mutations are usually the most serious since they always involve the formation of a nonfunctional protein?

I. Silent Mutations
II. Missense Mutations
III. Nonsense Mutations

A) I only
B) II only
C) III only
D) I and II
E) II and III

93. According to cosmologists, what is the primary composition of dark matter?
A) Higgs bosons
B) neutrinos
C) positrons
D) quantum strings
E) a not yet characterized subatomic particle

94. Dark matter has been postulated to exist in high-redshift galaxies. What does a *redshift* mean?
A) It is moving toward us.
B) It is moving away from us.
C) It has a large number of red giant stars.
D) It can only be detected by the use of a red filter in a telescope.
E) Gravitational waves in the galaxy block all but the red light from its stars.

===== End of Test =====