TOSS-UP

1) MATHEMATICS *Short Answer* It takes Roger 5 days to read a novel. Each day after the first day, Roger reads half as many pages as the day before. If the novel was 248 pages long, how many pages did Roger read on the first day?

ANSWER: 128

BONUS

1) MATHEMATICS *Short Answer* By name or number, indicate all of the following 4 intervals for which the function given by $f(x) = \frac{x^2 - 2x + 4}{x - 2}$ is concave upward:

1: $-\infty < x < 0$
2: $0 < x < 2$
3: $2 < x < 4$
4: $4 < x < \infty$

ANSWER: 3 AND 4

TOSS-UP

2) EARTH AND SPACE *Multiple Choice* Which of the following best describes the changes in stellar properties that occur once the helium flash has occurred in a sun-like star?

W) luminosity increases and surface temperature increases
X) luminosity increases and surface temperature decreases
Y) luminosity decreases and surface temperature increases
Z) luminosity decreases and surface temperature decreases

ANSWER: Y) LUMINOSITY DECREASES AND SURFACE TEMPERATURE INCREASES

VISUAL BONUS

2) EARTH AND SPACE *Short Answer* Shown in the image is a stream. Answer the following questions about the image shown:

1: What is the name of the line running in the direction of the water flow and indicating the deepest part of the channel, shown here in dark blue?
2: Match the regions labeled A, B, and C, respectively, with the following 3 parts of a meandering stream: zone of erosion, zone of deepest water flow, zone of deposition

ANSWER: 1: THALWEG; 2: A – ZONE OF DEPOSITION, B – ZONE OF DEEPEST WATER FLOW, C – ZONE OF EROSION

TOSS-UP

3) CHEMISTRY *Multiple Choice* Which of the following sets of quantum numbers describes an orbital that is independent of the angular coordinates θ and φ?

W) <2, 1, -1, 1/2>

X) <1, 0, 0, -1/2>
Y) <3, 2, -1, 1/2>
Z) <2, 1, 1, -1/2>

ANSWER: X) <1, 0, 0, -1/2>

BONUS

3) CHEMISTRY *Short Answer* For the synthesis of ammonia at 500 °C, the equilibrium constant is 6.0 x 10^{-2} L^2mol^{-2}. When the initial concentration of ammonia is 1.0 x 10^{-3} *M*, initial concentration of diatomic nitrogen gas is 1.0 x 10^{-5} *M*, and the initial concentration of diatomic hydrogen gas is 2.0 x 10^{-3} *M*, in what direction will the system shift in order to reach equilibrium?

ANSWER: TO THE LEFT

TOSS-UP

4) PHYSICS *Short Answer* Analogous to the Zeeman effect for magnetism and discovered in 1913, what is the term given to the splitting of spectral lines caused by the presence of an electric field, which is responsible for the pressure broadening of spectral lines by charged particles and can be fully explained with quantum mechanical approaches?

ANSWER: STARK EFFECT

VISUAL BONUS

4) PHYSICS *Short Answer* Shown in the image is the position-time graph of a particle whose position is given by $x(t) = 3\ln(t^2) + \cos(2t)$, for all $t \geq 0$. Answer the following three questions about the image.

1: Choosing from points a, b, c, and d, at which point is the particle's velocity greatest?
2: Choosing from points a, b, c, and d, at which point or points is the particle's velocity increasing?
3: Choosing from points a, b, c, and d, at which point or points is the particle's acceleration zero?

ANSWER: 1: a, 2: c, 3: a, d

TOSS-UP

5) BIOLOGY *Short Answer* In what regions of the embryonic human brain do the most profound changes occur after about 5 weeks, eventually giving rise to the cerebrum, including the cerebral cortex, white matter, and basal nuclei?

ANSWER: TELENCEPHALON

BONUS

5) BIOLOGY *Short Answer* A biochip, also known as a gene microarray, is a small square of glass covered with millions of strands of DNA, and can contain hundreds of thousands of gene sequences. Having sequenced over 90% of the human genome, researchers are now comparing their results to look for discrepancies. What is the scientific term given to these DNA sequencing variations that occur when a single nucleotide in the genome differs between members of the same species, which are significant in the development of diseases in humans and use of personalized medicine?

ANSWER: SINGLE NUCLEOTIDE POLYMORPHISMS (ACCEPT: SNIPS)

TOSS-UP

6) ENERGY *Multiple Choice* A reversible adiabatic process can also be said to be which of the following?

W) polytropic
X) isentropic
Y) isothermal
Z) isenthalpic

ANSWER: X) ISENTROPIC

VISUAL BONUS

6) ENERGY *Short Answer* A man walks up to you and tells you that he has a box of tricks. He says that if you hook a compressed-air line at the center pipe, cold air will come out the left end and hot air will come out the right end. Given in the image is a formula for entropy which accounts for changes of an ideal gas with constant heat capacity at constant pressure. Assuming that C_P for air is 29 J mol^{-1} K^{-1}, answer the following three questions about the image.

1: Does this box of tricks violate the first law of thermodynamics?
2: Does this box of tricks violate the second law of thermodynamics?
3: If it doesn't violate the 2nd law, what is the value of Δs_{total}, to the nearest multiple of ten?

ANSWER: 1: NO, 2: NO, 3: 50

TOSS-UP

7) MATHEMATICS *Multiple Choice* How many hours will a car traveling at 40 mph drive before being overtaken by another car leaving from the same place one hour later traveling at 50 mph?

W) 3
X) 4
Y) 5
Z) 6

ANSWER: Y) 5

VISUAL BONUS

7) MATHEMATICS *Short Answer* One arch of a cycloid generated by a circle of radius r can be parameterized by the functions $x = r(t - \sin t)$ and $y = r(1 - \cos t)$, with $0 < t \leq 2\pi$. Given that the image is the graph of a cycloid generated by a circle of radius $r = 2$, what is the area under the arch?

ANSWER: 12π

TOSS-UP

8) EARTH AND SPACE *Short Answer* What phenomenon, which is a consequence of the Coriolis effect, is an idealized description of the way wind-driven ocean currents vary with depth and involves the steadily rotating direction of current flow as depth below the ocean increases?

ANSWER: EKMAN SPIRAL

BONUS

8) EARTH AND SPACE *Short Answer* An unknown star has a parallax in seconds of arc that corresponds exactly with the resolving power of your telescope. If your telescope has a diameter of 55.2 cm, how many parsecs away is the star?

ANSWER: 4

TOSS-UP

9) CHEMISTRY *Short Answer* When analyzing the variation of the equilibrium constant with temperature, a graph is created such that $\ln K$ is plotted on the *y*-axis and $\frac{1}{RT}$ is plotted on the *x*-axis. What quantity can be measured to be the slope of the resulting graph?

ANSWER: ΔG_r° (STANDARD GIBBS FREE ENERGY OF REACTION)

VISUAL BONUS

9) CHEMISTRY *Short Answer* Shown in the image is the experimentally determined pH curve for the titration of H3PO4 with a solution of NaOH. Answer the following 3 questions about the image shown.

1: Which point or points represent the stoichiometric point or points during the titration?
2: At which point does the pH = pKa_2?
3: How many moles of NaOH have been added to the solution up till point F?

ANSWER: 1: B, D, F; 2: C; 3: 3 MOLES

TOSS-UP

10) PHYSICS *Short Answer* A ball is dropped from rest at the top of a building with an unknown height. If the final velocity as the ball hits the ground is 24 ms^{-1} and the acceleration due to gravity is 10 ms^{-2}, in meters to the nearest integer, what is the height of building?

ANSWER: 29

BONUS

10) PHYSICS *Short Answer* A series circuit is set up with *n* number of resistors. The resistance of each resistor, in ohms, is given by $2j + 5$, where $j = 1$ for R_1, 2 for R_2, and so forth until $j = n$ for the *n*th resistor. In a particular circuit with this setup, the voltage drop across the battery is 90 V and there is a total current flow of 2 A. How many resistors are in this circuit?

ANSWER: 7

TOSS-UP

11) BIOLOGY *Multiple Choice* What major group of bacteria is composed mostly of anaerobic bacteria with unusual cell walls, some cells of which produce methane and reduce sulfur, and is not a member of the kingdom Eubacteria?

W) actinomycetes
X) enterobacteria
Y) archaebacteria

Z) pseudomonads

ANSWER: Y) ARCHAEBACTERIA

VISUAL BONUS

11) BIOLOGY *Short Answer* Shown in the image is the water-vascular system of an echinoderm. Answer the following questions about the image shown.

1: What structure is represented by the line labeled d?
2: For the structures labeled c, e, f, and g, which represents the radial canal?

ANSWER: 1: AMPULLA; 2: F

TOSS-UP

12) ENERGY *Short Answer* What set of theoretical nuclear reactors, which is not expected to be available for commercial construction until 2030, includes thermal reactors and fast reactors with significant advances in sustainability, reliability, and economics, and is more advanced than most light-water reactors?

ANSWER: GENERATION IV REACTORS

BONUS

12) ENERGY *Short Answer* What greenhouse gas is usually present in the highest quantities in biogas, including landfill gas, advanced waste treatment technologies, and digested gas, with a percent composition of 55 – 75%?

ANSWER: METHANE

TOSS-UP

13) MATHEMATICS *Short Answer* The mean of six numbers is two. When one of the six numbers is removed, the mean of the remaining numbers is seven. What number was removed?

ANSWER: -23

BONUS

13) MATHEMATICS *Short Answer* Using Wallis's Formulas, find $\int_0^{\frac{\pi}{2}} \cos^4 x dx$, leaving your answer as a fraction in simplest form.

ANSWER: $\frac{3\pi}{16}$

TOSS-UP

14) EARTH AND SPACE *Multiple Choice* The Crab Nebula is a supernova remnant of SN 1054, which was notably recorded by Chinese astronomers as a "guest star". Guest stars recorded by the Chinese correspond to either comets, novae, or supernovae. Which of the following characeristics of SN 1054 allowed it to be characterized as a supernova and not a nova or comet?

W) the guest star was much brighter than a comet or nova would be
X) the guest star was located far from the galactic plane
Y) the guest star had a long period of visibility
Z) the guest star moved substantially along the celestial sphere

ANSWER: Y) THE GUEST STAR HAD A LONG PERIOD OF VISIBILITY

BONUS

14) EARTH AND SPACE *Multiple Choice* Which of the following common rock-forming minerals is in a ferromagnesian silicate?

W) hematite
X) olivine
Y) orthoclase
Z) quartz

ANSWER: X) OLIVINE

TOSS-UP

15) CHEMISTRY *Multiple Choice* For an acetic acid solution in water, the addition of which of the following acids will cause the greatest production of acetic acid by the common-ion effect?

W) hydrocyanic acid
X) hydrosulfuric acid
Y) chloric acid
Z) nitrous acid

ANSWER: Y) CHLORIC ACID

BONUS

15) CHEMISTRY *Short Answer* Assuming that the molar mass of Mg is 24 g mol^{-1}, Faraday's constant is 9.7 x 10^4 C mol^{-1}, and presenting your answer to two significant digits, how many seconds will it take to produce 24 kg of magnesium metal by the electrolysis of molten $MgCl_2$ using a current of 1.00 x 10^2 A?

ANSWER: 2.0 x 10^6

TOSS-UP

16) PHYSICS *Multiple Choice* The cyclotron frequency, or gyrofrequency, of a charged particle is not dependent upon which of the following quantities?

W) mass of the particle
X) radius of the path
Y) charge of the particle
Z) direction of the uniform magnetic field

ANSWER: X) RADIUS OF THE PATH

VISUAL BONUS

16) PHYSICS *Short Answer* In the circuit shown, what are I_1, I_3, and V_6?

ANSWER: $I_1 = 2$ A, $I_3 = 1$ A, $V_6 = 8$ V

TOSS-UP

17) BIOLOGY *Short Answer* Arrange the following three cell layers of the retina from closest to the vitreous humor to farthest from the vitreous humor: rods and cones, ganglion cells, bipolar cells

ANSWER: 2, 3, 1

BONUS

17) BIOLOGY *Short Answer* Indicate all of the following 4 statements that is/are true of vertebrate photoreceptors:

1: the photopigment in rods is photoopsin, which is the protein opsin bound to a molecule of *cis*-retinal
2: there is one absorption maximum in rods and there are three absorption maxima in cones
3: when cGMP is converted into GMP, the Na^+ channels in the rods and cones close
4: in the bleaching reaction, *cis*-retinal isomerizes and dissociates from opsin when the photopigment absorbs light

ANSWER: 2, 3, 4 (ALL BUT 1)

TOSS-UP

18) ENERGY *Short Answer* What location in Nevada was originally looked at by the Department of Energy to be the site of a nationally used nuclear fuel repository in 2002, but was eventually not used because some of the residents near by expressed complaints over possible safety hazards?

ANSWER: YUCCA MOUNTAIN

VISUAL BONUS

18) ENERGY *Multiple Choice* Consider the numbered processes shown in the image. Which of the following calculations will give ΔH for the process $A \rightarrow 2C + E$?

W) $\Delta H_1 + \Delta H_2 - \Delta H_3$
X) $\Delta H_1 + \Delta H_2 + \Delta H_3$
Y) $\Delta H_1 + 2\Delta H_2 + \Delta H_3$
Z) $\Delta H_1 + 2\Delta H_2 - \Delta H_3$

ANSWER: Z) $\Delta H_1 + 2\Delta H_2 - \Delta H_3$

TOSS-UP

19) MATHEMATICS *Short Answer* For the function given by $f(x) = \sin^3 x \cos x + \sin x \cos x$, what is $\int_{-\pi/2}^{\pi/2} f(x)dx$?

ANSWER: 0

VISUAL BONUS

19) MATHEMATICS *Short Answer* Shown in the image are the graphs of three functions. Answer the following questions about the graph.

1: Match the graphs to the following three functions: hyperbolic sine, hyperbolic cosine, hyperbolic tangent.
2: Using the words red, green, and/or blue in your answer, which of the functions has or have a domain given by $(-\infty, \infty)$?

ANSWER: 1: SINH IS RED, COSH IS GREEN, TANH IS BLUE; 2: ALL OF THEM

TOSS-UP

20) EARTH AND SPACE *Multiple Choice* Which of the following terms best describes a stream that flows through an area that has experienced uplift of the land that is slow enough that the stream maintains its previously established course and drainage basin?

W) consequent
X) subsequent
Y) antecedent
Z) superimposed

ANSWER: Y) ANTECEDENT

VISUAL BONUS

20) EARTH AND SPACE *Short Answer* Answer the following 2 questions about the image shown.

1: For the regions labeled A, B, and C, respectively, what aspects dominated the universe's density?
2: In which of the regions A, B, or C, did inflation occur?

ANSWER: 1: A IS RADIATION, B IS MATTER, C IS DARK ENERGY; 2: A

TOSS-UP

21) CHEMISTRY *Short Answer* In the Arrhenius equation, the frequency factor A is the product of what two quantities, denoted z and p, respectively?

ANSWER: COLLISION FREQUENCY AND STERIC FACTOR

VISUAL BONUS

21) CHEMISTRY *Short Answer* Shown in the image is a green laser light in a solution of Rhodamine 6B, where the beam intensity becomes weaker as it passes through the solution. Answer the following two questions about the image.

1: What law or principle is exemplified in the image?
2: If the concentration of the Rhodamine 6B solution is increased while the path length and abosrbance are kept constant, what effect will it have on the molar absorbtivity of the solution?

ANSWER: 1: BEER-LAMBERT LAW, 2: DECREASE

TOSS-UP

22) PHYSICS *Short Answer* In condensed matter physics, what is the term given to pairs of conduction

electrons or other fermions that are bound together at low temperatures, the attraction of which in superconductors is due to the electron-phonon interaction and the presence of which is responsible for superconductivity?

ANSWER: COOPER PAIRS

BONUS

22) PHYSICS *Short Answer* The length of an organ pipe open at one end and closed at the other is 0.3 m. If the speed of sound is 344 ms^{-1}, what is the fundamental frequency of this stopped organ pipe in Hz, to 2 significant figures?

ANSWER: 290 HERTZ

TOSS-UP

23) BIOLOGY *Short Answer* What interior protein network, an example of which is the red blood cell, functions to determine the shape of the cell by forming a supporting scaffold beneath the cell membrane, anchored to both the membrane and the cytoskeleton?

ANSWER: SPECTRIN

BONUS

23) BIOLOGY *Short Answer* A flaccid plant cell with a pressure potential of 0 MPa is placed in a solution of high solute concentration. Indicate all of the following 4 statements that is/are true about this situation:

1: water enters the cell via osmosis
2: the cell's protoplast undergoes plasmolysis
3: the external solute has a greater value of ψ_s than the cell
4: if the cell is then placed in pure water, the cell wall will exert turgor pressure on the protoplast until ψ_p and ψ_s are equal

ANSWER: 2 AND 4

TOSS-UP

24) ENERGY *Short Answer* What is the specific name given to charcoal that is created by the pyrolysis of biomass, which is also under investigation as an approach to carbon sequestration to produce negative carbon dioxide emissions?

ANSWER: BIOCHAR

BONUS

24) ENERGY *Short Answer* Arrange the following 4 nuclear radiation reactions in terms of increasing speed of the radiated particles:

1: $^{53}_{27}Co \rightarrow {}^{52}_{26}Fe + {}^{1}_{1}p$
2: $^{60}_{27}Co^{*} \rightarrow {}^{60}_{27}Co + \gamma$
3: $^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + \beta^{+}$

4: ${}^{137}_{53}\mathrm{I} \rightarrow {}^{136}_{53}\mathrm{I} + {}^{1}_{0}\mathrm{n}$

ANSWER: 4, 1, 3, 2

TOSS-UP

25) MATHEMATICS *Short Answer* A function is given by $f(x) = \frac{1}{x}$. The line $x = m$ is drawn, where m is some integer greater than zero. In terms of m and in simplest form, what is the area under the curve between $x = m$ and $x = 2m$?

ANSWER: ln (2)

BONUS

25) MATHEMATICS *Short Answer* Evaluate the improper integral given by $\int_0^{\infty} \frac{1}{x^2 + 1} dx$.

ANSWER: $\frac{\pi}{2}$