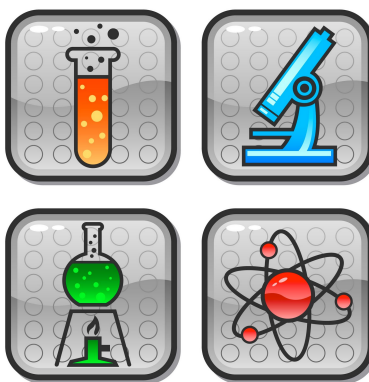




UNIVERSITY INTERSCHOLASTIC LEAGUE

# Science

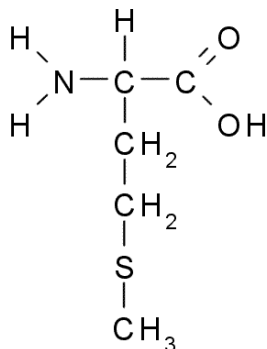
State • 2021



## GENERAL DIRECTIONS:

- **DO NOT OPEN EXAM UNTIL TOLD TO DO SO.**
- Contestants may take up to two hours to complete the contest. If you are in the process of actually writing an answer when the signal to stop is given, you may finish writing that answer.
- Papers may not be turned in until 30 minutes have elapsed. If you finish the test in less than 30 minutes, remain at your seat and retain your paper until told to do otherwise. You may use this time to check your answers.
- All answers must be written on the answer sheet provided. Indicate your answers in the appropriate blanks provided on the answer sheet. Write clearly and legibly!
- You may place as many notations as you desire anywhere on the test paper but not on the answer sheet, which is reserved for answers only.
- You may use additional scratch paper provided by the contest director.
- All questions have ONE and only ONE correct (BEST) answer. There is a penalty for all incorrect answers.
- If a question is omitted, no points are given or subtracted.
- The back two pages of this test include a copy of the periodic table of the elements, as well as listings of other scientific relationships. You may use this information during the contest and may detach the back page from the test if you wish.
- A simple scientific calculator is sufficient for the high school Science contest. **The UIL provides a list of approved calculators that meet the criteria for use in the Science contest. No other calculators are permitted during the contest.** The Science Contest Approved Calculator List is available in the current Science Contest Handbook and on the UIL website. Contest directors will perform a brief visual inspection to confirm that all contestants are using only approved calculators. Each contestant may use up to two approved calculators during the contest.

B01. The molecule in this image would be found in



- A) polypeptides.
- B) nucleic acids.
- C) membranes.
- D) sugars.
- E)  $\text{NAD}^+$ .

B02. A plasma cell (activated B cell) would contain large amounts of \_\_\_\_\_ relative to a muscle cell.

- A) the Golgi complex
- B) mitochondria
- C) nucleoli
- D) lysosomes
- E) myosin

B03. During Anaphase I, which protein protects cohesin between the sister chromatids to prevent premature separation of the chromatids?

- A) adhesin
- B) shugoshin
- C) separase
- D) kinetochore proteins
- E) telomerase

B04. A temperate bacteriophage

- A) only replicates via the lysogenic cycle.
- B) only replicates via the lytic cycle.
- C) is only replicated as a prophage.
- D) can replicate via either the lysogenic or lytic cycles.
- E) can infect human cells.

B05. What group of organisms undergoes anoxygenic photosynthesis?

- A) fungi
- B) terrestrial plants
- C) cyanobacteria
- D) methanogens
- E) green sulfur bacteria

B06. The ability to fly can be found in insects, birds, and mammals, yet the anatomical structures for flight are very diverse. Which of the following accounts for this phenomenon?

- A) divergent evolution
- B) adaptation
- C) dissimilar selective pressures
- D) convergent evolution
- E) common ancestor

B07. Which of the following would decrease genetic diversity in a population?

- A) gene flow
- B) mutation
- C) bottleneck effect
- D) recombination
- E) random mating

B08. Ants release pheromones that assist others in locating a specific pathway to and from a food source. An ant trail is an example of

- A) kinesis.
- B) hydrotaxis.
- C) chemotaxis.
- D) phototaxis.
- E) aerotaxis.

B09. The main enzyme in transcription is a/an

- A) RNA-dependent DNA polymerase.
- B) RNA-dependent RNA polymerase.
- C) DNA-dependent DNA polymerase.
- D) DNA-dependent RNA polymerase.

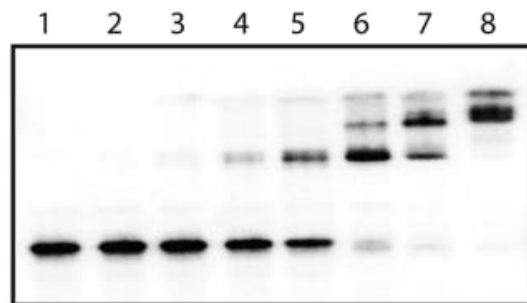
- B10. In the nitrogen cycle, lightning
- is responsible for a majority of nitrogen fixation.
  - converts dinitrogen gas into nitrogen oxides in the air.
  - reduces nitrates into nitrogen gas.
  - generates ammonia.
  - oxidizes ammonia into nitrates.

- B11. Genetic engineering of the 16S rRNA of a ribosome could
- prevent peptidyltransferase activity.
  - prevent GTP hydrolysis.
  - result in the inability of a charged tRNA to bind to the A-site.
  - result in the failure of the large subunit to recognize the start codon.
  - impact the ability of the small subunit to recognize the ribosome binding site.

- B12. Deamination of adenosine in RNA yields the modified base, inosine (dI pairs with dG), which is essential for wobble base pairing in tRNAs. However, the same event occurring in DNA requires the action of DNA repair mechanisms or else a mutation occurs. In an unrepaired situation, a \_\_\_\_\_ mutation occurs.
- frameshift
  - transversion
  - transition
  - nonsense
  - deletion

- B13. Genes *A* and *B* are linked in a coupling arrangement and are positioned 30 map units apart. An organism that is heterozygous for both *A* and *B* (*AB/ab*) is crossed with an organism that is homozygous recessive for both gene *a* and *b* (*ab/ab*). What proportion of the offspring is expected to be dominant for both traits?
- 0%
  - 15%
  - 30%
  - 35%
  - 70%

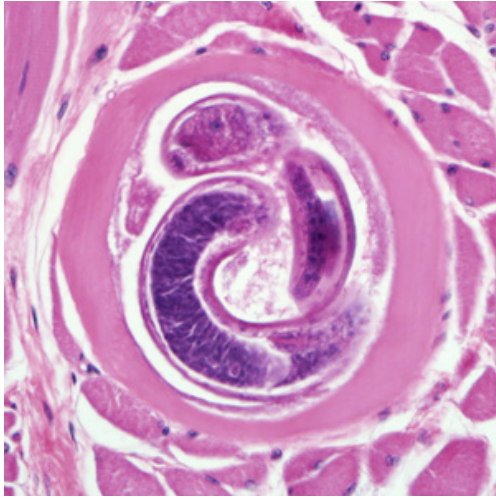
- B14. A researcher labeled a small, double-stranded DNA molecule with radioactivity. The labeled DNA was incubated without purified protein (Lane 1) and with increasing concentration of purified protein (Lanes 2 thru 8). The protein was previously identified as having a helix-turn-helix motif. The samples were subjected to gel electrophoresis and a film was exposed to determine the locations of the bands. The image below is the outcome of this experiment. What do you think is the original hypothesis for this experiment?



- The protein is a DNA-binding protein that recognizes a sequence on the sample DNA.
- The DNA moves more quickly through the gel when protein is bound.
- The DNA and protein only form a complex in the presence of the gel.
- Cofactors are required for the protein to bind to DNA.
- Not enough information is presented to formulate a hypothesis.

- B15. An aquatic snake species and a closely-related terrestrial snake species live in the same geographic area. Both mate at the same time of year and in the evening, and can produce hybrids, but the two remain separate species. Which reproductive barrier is most likely preventing gene flow between these two species?
- temporal isolation
  - mechanical isolation
  - behavioral isolation
  - habitat isolation
  - post-gametic isolation

- B16. This image identifies encysted *Trichinella* species within muscle tissue.



This organism is classified

- A) as a protist.  
 B) in Phylum Nematoda.  
 C) as a vector-borne infection.  
 D) as a unicellular parasite.  
 E) as a tapeworm.
- B17. In March 2021, several brands of Hispanic-style soft and fresh cheeses were recalled from grocery stores because they were linked to an outbreak of
- A) *Salmonella enterica*.  
 B) SARS-CoV-2.  
 C) *Listeria monocytogenes*.  
 D) *Escherichia coli* O103.  
 E) *Escherichia coli* O157.
- B18. Foundation species specifically play roles in structuring
- A) species.  
 B) communities.  
 C) populations.  
 D) predator-prey relationships.  
 E) primary producer activity.
- B19. What is the function of a basophil?
- A) generates antibodies  
 B) directly attacks parasites  
 C) kills bacteria and viruses via phagocytosis  
 D) clots blood  
 E) promotes inflammation, including seasonal allergies
- B20. During skeletal muscle contraction, which of the following events occurs third relative to the other events listed?
- A) Cross-bridge formation between myosin heads and actin filaments.  
 B) The Z-lines move closer together.  
 C) Depolarization of the sarcolemma causes the sarcoplasmic reticulum to release calcium ions.  
 D) ATP binding to the myosin head.  
 E) The actin filament slides along myosin.  
 F) Calcium ions bind to troponin, which repositions tropomyosin and causes a shape change that exposes myosin heads.

- C01. Which of these compounds is not likely to exist?
- A) Copper(I) oxide
  - B) Iron(II) oxide
  - C) Iron(III) oxide
  - D) Lead(IV) oxide
  - E) Zinc(I) oxide
- C02. When cyanate ions react with hypochlorite ions in basic solution, the products include carbonate ions, nitrogen gas, and chloride ions. What is the lowest whole-number coefficient on  $\text{H}_2\text{O}$  in the balanced equation for this reaction?
- A) 1
  - B) 2
  - C) 3
  - D) 4
  - E) 6
- C03. How many values of  $m_l$  are allowed for an electron in a  $5f$  subshell?
- A) 5
  - B) 7
  - C) 9
  - D) 11
  - E) 14
- C04. What is the bond order and magnetism predicted by molecular orbital theory for the  $\text{Li}_2^+$  ion?
- A) 0, diamagnetic
  - B) 0, paramagnetic
  - C)  $\frac{1}{2}$ , diamagnetic
  - D)  $\frac{1}{2}$ , paramagnetic
  - E) 1, diamagnetic
  - F) 1, paramagnetic
- C05. A 12.0 L equimolar mixture of helium and sulfur dioxide gas is at  $38.0^\circ\text{C}$  and 1140 torr pressure. What is the total mass of the gas mixture?
- A) 12.72 g
  - B) 18.36 g
  - C) 24.00 g
  - D) 25.44 g
  - E) 48.00 g
- C06. At  $65.0^\circ\text{C}$ , which of these compounds has a vapor pressure of 369 torr?
- A) Ethanol
  - B) Acetone
  - C) Methanol
  - D) Water
  - E) Isopropanol
- C07. An average adult human diet is 2000 Calories per day. If humans were powered by gasoline, how much gasoline would we have to drink each day to keep us going? (Assume gasoline can be represented by octane. The heat of combustion of octane is  $5470\text{ kJ/mol}$  and the density of octane  $0.703\text{ g/mL}$ . *Don't drink gasoline, kids!*)
- A) 249 mL (about one cup)
  - B) 964 mL (about a quart)
  - C) 59 mL (about 2 oz.)
  - D) 476 mL (about a pint)
  - E) 123 mL (about half a cup)
- C08. What is the change in entropy when water goes from liquid to gas at its normal boiling temperature?
- A)  $1.26\text{ J/mol}\cdot\text{K}$
  - B)  $149\text{ J/mol}\cdot\text{K}$
  - C)  $407\text{ J/mol}\cdot\text{K}$
  - D)  $136.5\text{ J/mol}\cdot\text{K}$
  - E)  $109\text{ J/mol}\cdot\text{K}$
- C09. At 750 K the equilibrium constant  $K_C$  for the reaction  $2\text{AB}(\text{s}) \rightarrow 2\text{A}(\text{s}) + \text{B}_2(\text{g})$  is 244. Calculate the equilibrium constant for the reaction  $\text{A}(\text{s}) + \frac{1}{2}\text{B}_2(\text{g}) \rightarrow \text{AB}(\text{s})$  at the same temperature.
- A)  $6.94 \times 10^{-3}$
  - B)  $8.20 \times 10^{-3}$
  - C)  $6.40 \times 10^{-2}$
  - D)  $1.22 \times 10^{-2}$
  - E)  $4.10 \times 10^{-3}$

C10. 15.0 mL of a dibasic weak base is titrated using 0.183 M HCl. If it takes 50.0 mL to reach the second equivalence point in the titration, what is the concentration of the weak base in the original solution?

- A) 0.183 M
- B) 0.305 M
- C) 0.366 M
- D) 0.061 M
- E) 0.610 M

C11. A scientist mixes 200 mL of 0.20 M potassium chromate with 0.175 mL of 0.25 M calcium nitrate and allows the system to reach equilibrium. What is the final calcium ion concentration in the solution? The  $K_{sp}$  of calcium chromate is  $7.1 \times 10^{-4}$ .

- A) 0.010 M
- B) 0.022 M
- C) 0.032 M
- D) 0.071 M
- E) 0.081 M

C12. A scientist needs to construct a battery capable of generating 7.5 mV. He has all the glassware and other equipment necessary, but the only reagents he has available are 48 grams of  $\text{AgNO}_3$  and two strips of silver metal to use as electrodes. If each half-cell of the battery contains the same volume of solution and the scientist uses all 48 grams of  $\text{AgNO}_3$ , how much  $\text{AgNO}_3$  should he put into each half-cell to generate exactly 7.5 mV of voltage?

	Grams of $\text{AgNO}_3$ in the anodic half-cell	Grams of $\text{AgNO}_3$ in the cathodic half-cell
A)	20.5	27.5
B)	30.8	17.2
C)	24.0	24.0
D)	17.2	30.8
E)	27.5	20.5

C13. What is the rate constant for the reaction  $2 \text{AB}(g) + 2 \text{C}_2(g) \rightarrow \text{A}_2(g) + 2 \text{C}_2\text{B}(g)$ , given the reaction data below?

Trial	$[\text{AB}] M$	$[\text{C}_2] M$	Initial Rate
1	0.250	0.250	$1.22 \times 10^{-3}$
2	0.400	0.250	$1.95 \times 10^{-3}$
3	0.400	0.400	$3.12 \times 10^{-3}$

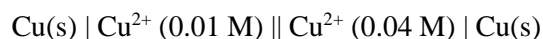
- A)  $7.81 \times 10^{-2} M/s$
- B)  $5.15 \times 10^{-3} M/s$
- C)  $1.03 \times 10^{-2} M^{-2} s^{-1}$
- D)  $1.95 \times 10^{-2} M^{-1} s^{-1}$
- E)  $1.03 \times 10^{-2} M^{-1} s^{-1}$

C14.  $2 \text{AB}(s) + \text{X}_2\text{Y}(g) \rightarrow \text{A}_2\text{Y}(s) + 2 \text{XB}(g)$   
 $\Delta H^\circ = -18.8 \text{ kJ/mol}$ .

Complete the sentence based on the information above: This reaction is spontaneous...

- A) at any temperature.
- B) at no temperature.
- C) only at high temperatures.
- D) only at low temperatures.
- E) only at high pressures.
- F) only at low pressures.

C15. What is the change in free energy for the chemical reaction represented by this electrochemical shorthand notation?



- A) -982 J
- B) -3439 J
- C) -2213 J
- D) -4562 J
- E) -1188 J

- C16. 100.0 mL of a  $\text{Pb}(\text{NO}_3)_2$  solution is mixed with 100.0 mL of a KI solution, and a precipitate forms. Analysis of the solution above the precipitate reveals that it still contains  $3.50 \times 10^{-2}$  M iodide ion. How many grams of solid  $\text{Pb}(\text{NO}_3)_2$  must be added to this solution to lower the  $\text{I}^-$  concentration to  $1.00 \times 10^{-4}$  M?  $K_{\text{sp}} = 4.41 \times 10^{-9}$
- A) 0.033 g  
B) 16.9 g  
C) 29.2 g  
D) 14.6 g  
E) 7.00 g
- C17. In the Schrödinger model of the atom, electrons are treated as matter waves instead of as particles. When an ultraviolet photon with a frequency of  $9.5 \times 10^{14}$  Hz wavelength strikes a lanthanum metal surface in a vacuum, an electron is ejected. What is the wavelength of the ejected electron? The work function  $\phi$  for lanthanum is  $5.61 \times 10^{-19}$  J.
- A) 316 nm  
B) 1.68 angstroms  
C) 105 nm  
D) 533  $\mu\text{m}$   
E) 1.88 nm correct
- C18. A 3.7 amp current is passed through an electrolytic cell, and  $\text{Al}^{3+}$  is reduced to Al at the cathode. What mass of solid aluminum is produced after six hours?
- A) 7.45 g  
B) 0.828 g  
C) 1.24 g  
D) 22.3 g  
E) 0.276 g
- C19. In the van der Waals equation of state, the pressure correction term is proportional to the molar volume of the gas *squared* because:
- A) pressure is force per unit *area* and area is a squared term.  
B) at any given temperature pressure is proportional to molar volume ( $V/n$ ), but the ideal gas law already contains one  $V$  and one  $n$ , which turns the ( $V/n$ ) correction term into  $(V/n)^2$ .  
C) although molar volume is a cubic dimension, the ideal gas law already contains one  $V$  and one  $n$ , which mathematically cancel one  $V/n$  from the original  $(V/n)^3$  correction term, leaving  $(V/n)^2$ .  
D) the overall strength of the intermolecular attractions and the pressure exerted on the walls of the container by the gas are both proportional to molar volume, resulting in a correction term that is proportional to  $(V/n)^2$ .  
E) the result of the calculation matches experimental measurements, but there is no actual physical reason behind it. It is a purely empirical correction term.
- C20. Which of these redox reactions involves the greatest number of electrons transferred in the overall balanced equation?
- A)  $\text{Cu}^{2+} + \text{Zn} \rightarrow \text{Cu} + \text{Zn}^{2+}$   
B)  $\text{Cu}^{2+} + \text{Al} \rightarrow \text{Cu} + \text{Al}^{3+}$   
C)  $\text{MnO}_4^- + \text{Br}^- \rightarrow \text{MnO}_2 + \text{BrO}_3^-$   
D)  $\text{AlH}_4^- + \text{H}_2\text{CO} \rightarrow \text{Al}^{3+} + \text{CH}_3\text{OH}$   
E)  $\text{Mg} + \text{Cr}(\text{OH})_3 \rightarrow \text{Cr} + \text{MgO}$

- P01. According to Rovelli, the final stage in the life of a star as predicted by loop quantum gravity, where the quantum fluctuations of space-time balance the weight of matter, is called a...
- Degenerate star
  - Planck star
  - Neutron star
  - Quantum star
  - Quasar

- P02. According to Rovelli, there is a detectable difference between the past and the future only when...
- excitations of fields produce more particles than anti-particles
  - energy is not conserved in particle collisions.
  - there are no frictional forces.
  - the flow of time is directly measured.
  - there is flow of heat.

- P03. According to Rovelli, what did the Dutch philosopher Baruch Spinoza understand?
- that “I” am the same as “the neurons in my brain”.
  - that the human experience is described by integrated information theory.
  - that there is a clear difference between “sensing” and “knowing”.
  - that our communication with the world distinguishes us from the rest of nature.
  - that it is in our nature to be curious.

- P04. A star you are observing has an apparent magnitude of +14.5. The star is part of a cluster that is known to be 1600 light-years away. What is the approximate absolute magnitude of this star? Note: 1.0 parsec = 3.26 light-years.
- +12.3
  - +6.0
  - +3.5
  - 5.0
  - 10.9

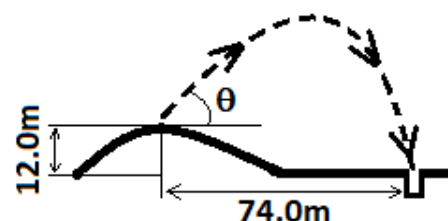
- P05. What are the units of  $Z$  in the following equation?  $C$  is capacitance in [Farads],  $B$  is magnetic field strength in [Teslas],  $v$  is velocity in [meters/second], and  $t$  is time in [seconds].

$$Z = C(Bvt)^2$$

- [Amperes]
- [meters]
- [kilograms/Coulomb]
- [Volts]
- [kilograms]

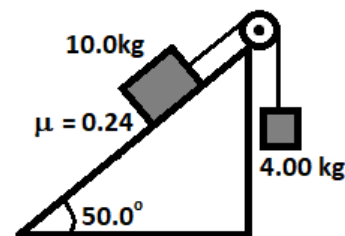
- P06. A golf ball is hit from the top of a hill, 12.0m above the green. The initial speed of the ball is 25.1m/s. The ball flies along the trajectory shown, and without bouncing, plops directly into the hole. The hole is 74.0m (horizontally) from where the ball was hit. At which of these angles (relative to the horizontal) could the ball have been initially struck?

- 26.2°
- 34.1°
- 55.9°
- 63.8°
- 76.6°

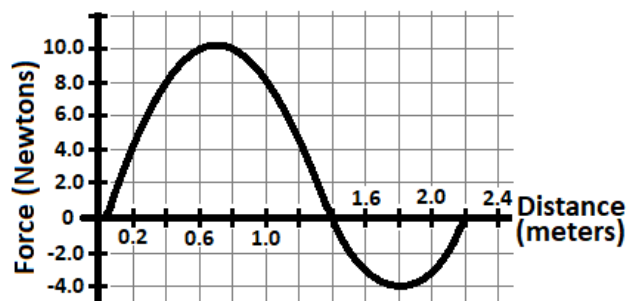


- P07. A 10.0kg box of tea is placed on a ramp that is inclined at an angle of 50.0° relative to the horizontal. A rope that is attached to the box of tea passes over a frictionless pulley to a 4.00kg hanging mass. The coefficient of friction between the box of tea and the ramp is 0.24. Once released, what is the acceleration of the box of tea?

- 1.48 m/s<sup>2</sup>
- 2.08 m/s<sup>2</sup>
- 2.56 m/s<sup>2</sup>
- 3.64 m/s<sup>2</sup>
- 4.28 m/s<sup>2</sup>



- P08. A 200g toy, starting from rest, is subjected to the varying force graphed below. The toy’s motion is entirely along a horizontal line. After experiencing this force, what is the approximate speed of the toy?



- 4.7 m/s
- 5.7 m/s
- 8.1 m/s
- 9.4 m/s
- 11 m/s

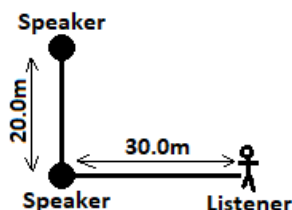


P09. A cylindrical tub is freely spinning on frictionless bearings at an angular speed of 30.0 rad/s. The tub can be treated as a cylindrical ring with a mass of 5.00kg. The tub is slowly filled with sand, at a constant rate of 1.50kg/s, until it contains 15.0kg of sand. In the tub, the sand has the shape of a solid disk with the same radius as the tub. While sand was being added to the tub, what was the effective angular acceleration of the tub? Note: the moment of inertia of a cylindrical ring is  $I = MR^2$  and the moment of inertia of a solid disk is  $I = \frac{1}{2}MR^2$ .

- A)  $-1.00 \text{ rad/s}^2$
- B)  $-1.20 \text{ rad/s}^2$
- C)  $-1.80 \text{ rad/s}^2$
- D)  $-2.00 \text{ rad/s}^2$
- E)  $-2.25 \text{ rad/s}^2$

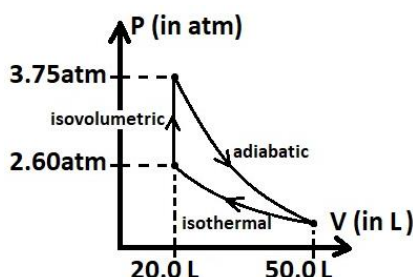
P10. Two 100.0W speakers are playing loud music at a dance competition. The speakers and the listener are located as shown. Assuming that the sound waves expand spherically from the speakers, and that the sound waves from the two speakers are not coherent, then what is the sound intensity (in dB) at the listener's location?

- A) 123 dB
- B) 117 dB
- C) 108 dB
- D) 102 dB
- E) 94.3 dB

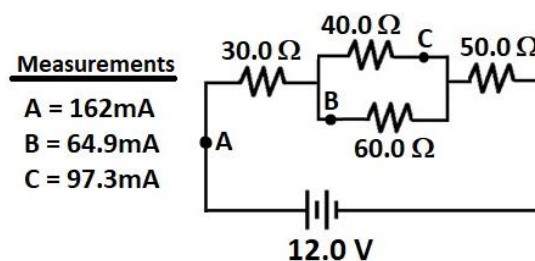


P11. 1.60mols of a diatomic ideal gas are taken through an engine cycle represented by the PV-diagram shown below. How much heat energy must be added to the gas ( $Q_{in}$ ) to go through one complete cycle? Note, the specific heat capacities for a diatomic ideal gas are:  $C_V = \frac{5}{2}R$  and  $C_P = \frac{7}{2}R$ .

- A) 990 J
- B) 4830 J
- C) 5820 J
- D) 8150 J
- E) 10650 J



P12. In this circuit, the current is measured at the three points indicated (A, B, and C). However, the measurements do not match the expected values. What could explain the problem with this circuit?

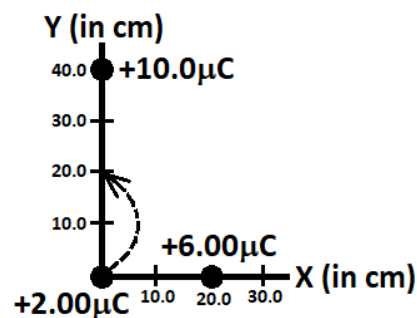


**Measurements**  
 A = 162mA  
 B = 64.9mA  
 C = 97.3mA

- A) The battery has dropped below 12.0V.
- B) The 50.0Ω resistor is shorted (zero ohms).
- C) The 30.0Ω resistor is shorted (zero ohms).
- D) The 40.0Ω resistor is open (infinite ohms).
- E) The 60.0Ω resistor is open (infinite ohms).

P13. Three charges are arranged as shown – a  $+10.0\mu\text{C}$  at (0.0, 40.0cm), a  $+6.00\mu\text{C}$  at (20.0cm, 0.0), and a  $+2.00\mu\text{C}$  at (0.0, 0.0). How much energy is needed to move the  $+2.00\mu\text{C}$  charge from (0.0, 0.0) to (0.0, 20.0cm)?

- A) 0.292 J
- B) 0.450 J
- C) 0.989 J
- D) 1.28 J
- E) 2.02 J

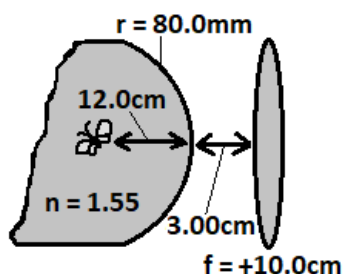


P14. A current of 49.66A flows in a wire that has a radius of 2.50mm. The current density in the wire is given by the function:  $J(r) = 5.0e^{-0.25r^2}$  where  $r$  is in mm. What is the magnetic field at a point inside the wire, 1.50mm from the center of the wire?

- A) 0.573 mT
- B) 1.76 mT
- C) 2.39 mT
- D) 3.60 mT
- E) 4.77 mT

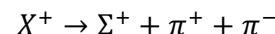
- P15. A parallel plate capacitor is constructed from identical circular plates, each with a diameter of 24.0mm and separated by 0.050mm. The capacitor is initially charged to a voltage of 25.0V. Suddenly, in a time of 100.0 $\mu$ s, the voltage on the capacitor is raised to 35.0V. What average magnetic field is produced along the edge of the capacitor's plates as a result of the voltage increase?
- A)  $8.01 \times 10^{-10}$  T
  - B)  $5.34 \times 10^{-10}$  T
  - C)  $3.34 \times 10^{-10}$  T
  - D)  $2.67 \times 10^{-10}$  T
  - E)  $1.34 \times 10^{-10}$  T

- P16. A fly trapped in amber is located 12.0cm from the polished spherical surface of the amber. The polished surface has a radius of curvature of 80.0mm. A lens with a focal length of +10.0cm is held 3.00cm above the polished amber surface. What is the location of the final image of the fly, relative to the lens? The index of refraction of amber is 1.55.



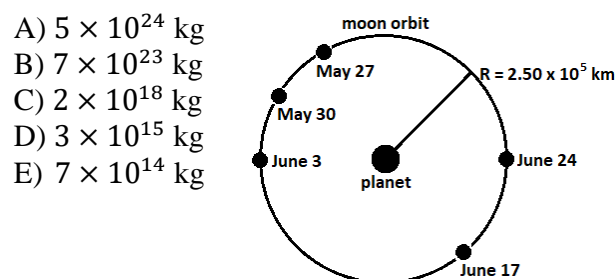
- A) 6.23 cm left of the lens
  - B) 41.4 cm left of the lens
  - C) 11.0 cm right of the lens
  - D) 20.5 cm right of the lens
  - E) 25.3 cm right of the lens
- P17. The energy eigenvalues of a three-state quantum system are  $(\psi_1)E_1 = 1.10\text{eV}$ ,  $(\psi_2)E_2 = 2.60\text{eV}$ , and  $(\psi_3)E_3 = 8.40\text{eV}$ . One of these systems exists in a mixed state described by the wavefunction:  $\Psi = 0.6|\psi_1\rangle + 0.8|\psi_2\rangle$ . The calculated expectation value of energy for this mixed state is 2.06eV. When you perform a single energy measurement on this mixed state, what value of energy are you most likely to measure?
- A) 8.40eV
  - B) 3.70eV
  - C) 2.60eV
  - D) 2.06eV
  - E) 1.10eV

- P18. A massive, unknown particle,  $X^+$ , undergoes the following decay:

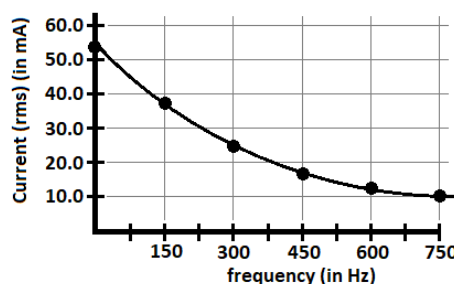


The mean lifetime of this unknown particle is about  $10^{-12}$  seconds. What is the most likely quark structure of the unknown particle, according to the standard model?

- A)  $uuc$
  - B)  $udc$
  - C)  $uus$
  - D)  $u\bar{s}$
  - E)  $u\bar{c}$
  - F)  $\bar{d}c$
- P19. Over several weeks, you plot the location of a moon that is orbiting an unknown planet. Your observations are plotted below. The orbit of the moon is perfectly circular, with a radius of  $2.50 \times 10^5$  km. What is the approximate mass of the unknown planet?



- A)  $5 \times 10^{24}$  kg
  - B)  $7 \times 10^{23}$  kg
  - C)  $2 \times 10^{18}$  kg
  - D)  $3 \times 10^{15}$  kg
  - E)  $7 \times 10^{14}$  kg
- P20. An AC circuit consists of a single 9.0V<sub>rms</sub> power supply, a resistor, and an inductor – all in series. You measure the magnitude of the current (rms) as the frequency of the power supply is varied. From this data, determine the sizes of the resistor and inductor.



- A)  $R = 240 \Omega$  and  $L = 260$  mH
- B)  $R = 240 \Omega$  and  $L = 40$  mH
- C)  $R = 170 \Omega$  and  $L = 180$  mH
- D)  $R = 170 \Omega$  and  $L = 28$  mH
- E)  $R = 27 \Omega$  and  $L = 40$  mH
- F)  $R = 27 \Omega$  and  $L = 28$  mH

Science • State • 2021

Chemistry

1A 1																									8A 18
H 1.01																									He 4.00
3 Li 6.94	2A 4 Be 9.01																								
11 Na 22.99	12 Mg 24.31																								
		3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	9B 9	10B 10	11B 11	12B 12	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17A 17 Cl 35.45	18 Ar 39.95								
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80								
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29								
55 Cs 132.91	56 Ba 137.33	57 La 138.9	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)								
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (293)	118 Og (294)								

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Water Data

$T_{mp} = 0^{\circ}\text{C}$   
 $T_{bp} = 100^{\circ}\text{C}$   
 $c_{ice} = 2.09 \text{ J/g}\cdot\text{K}$   
 $c_{water} = 4.184 \text{ J/g}\cdot\text{K}$   
 $c_{steam} = 2.03 \text{ J/g}\cdot\text{K}$   
 $\Delta H_{fus} = 334 \text{ J/g}$   
 $\Delta H_{vap} = 2260 \text{ J/g}$   
 $K_f = 1.86 \text{ }^{\circ}\text{C}/m$   
 $K_b = 0.512 \text{ }^{\circ}\text{C}/m$

Constants

$R = 0.08206 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$   
 $R = 8.314 \text{ J}/\text{mol}\cdot\text{K}$   
 $R = 62.36 \text{ L}\cdot\text{torr}/\text{mol}\cdot\text{K}$   
 $e = 1.602 \times 10^{-19} \text{ C}$   
 $N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$   
 $k = 1.38 \times 10^{-23} \text{ J/K}$   
 $h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$   
 $c = 3.00 \times 10^8 \text{ m/s}$   
 $R_H = 2.178 \times 10^{-18} \text{ J}$   
 $m_e = 9.11 \times 10^{-31} \text{ kg}$

Electrical charge quantities

1 mol of electrons = 96,485 C  
 $1 \mathcal{F} = 96,485 \text{ C/mol}$

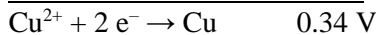
Compound Boiling Point ( $^{\circ}\text{C}$ )  $\Delta H_{vap}$  (kJ/mol)

Ethanol	78.4	38.6
Acetone	56	31.3
Methanol	64.7	35.2
Water	100	40.7
Isopropanol	82.6	41.0

Energy Unit Conversions

1 Calorie = 1000 calories  
 1 calorie = 4.184 J

Standard Reduction Potentials



## Physics

### Useful Constants

quantity	symbol	value
Free-fall acceleration	$g$	$9.80 \text{ m/s}^2$
Permittivity of Free Space	$\epsilon_0$	$8.854 \times 10^{-12} \text{ C}^2/\text{Nm}^2$
Permeability of Free Space	$\mu_0$	$4\pi \times 10^{-7} \text{ Tm/A}$
Coulomb constant	$k$	$8.99 \times 10^9 \text{ Nm}^2/\text{C}^2$
Speed of light in a vacuum	$c$	$3.00 \times 10^8 \text{ m/s}$
Fundamental charge	$e$	$1.602 \times 10^{-19} \text{ C}$
Planck's constant	$h$	$6.626 \times 10^{-34} \text{ Js}$
Electron mass	$m_e$	$9.11 \times 10^{-31} \text{ kg}$
Proton mass	$m_p$	$1.67265 \times 10^{-27} \text{ kg}$ $1.007276 \text{ amu}$
Neutron mass	$m_n$	$1.67495 \times 10^{-27} \text{ kg}$ $1.008665 \text{ amu}$
Atomic Mass Unit	$\text{amu}$	$1.66 \times 10^{-27} \text{ kg}$ $931.5 \text{ MeV}/c^2$
Gravitational constant	$G$	$6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$
Stefan-Boltzmann constant	$\sigma$	$5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$
Universal gas constant	$R$	$8.314 \text{ J/mol} \cdot \text{K}$ $0.082057 \text{ L} \cdot \text{atm/mol} \cdot \text{K}$
Boltzmann's constant	$k_B$	$1.38 \times 10^{-23} \text{ J/K}$
Speed of Sound (at 20°C)	$v$	$343 \text{ m/s}$
Avogadro's number	$N_A$	$6.022 \times 10^{23} \text{ atoms/mol}$
Electron Volts	$\text{eV}$	$1.602 \times 10^{-19} \text{ J/eV}$
Distance Conversion	miles $\rightarrow$ meters	1.00 mile = 1609 meters
Rydberg Constant	$R_\infty$	$1.097 \times 10^7 \text{ m}^{-1}$
Standard Atmospheric Pressure	1 atm	$1.013 \times 10^5 \text{ Pa}$
Density of Pure Water	$\rho_{\text{water}}$	$1000.0 \text{ kg/m}^3$

**UIL HIGH SCHOOL SCIENCE CONTEST  
ANSWER KEY  
2021 STATE**

**Biology**

B01. A  
B02. A  
B03. B  
B04. D  
B05. E  
B06. D  
B07. C  
B08. C  
B09. D  
B10. B  
B11. E  
B12. C  
B13. D  
B14. A  
B15. E  
B16. B  
B17. C  
B18. B  
B19. E  
B20. A

**Chemistry**

C01. E  
C02. A  
C03. B  
C04. D  
C05. C  
C06. E  
C07. A  
C08. E  
C09. C  
C10. B  
C11. C  
C12. A  
C13. D  
C14. A  
C15. B  
C16. C  
C17. E  
C18. A  
C19. D  
C20. D

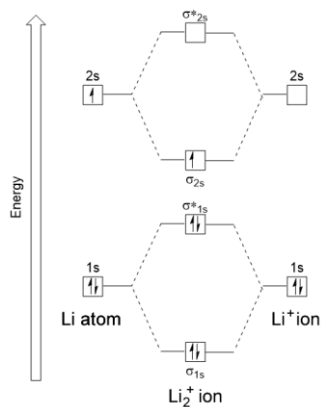
**Physics**

P01. B  
P02. E  
P03. A  
P04. B  
P05. E  
P06. B  
P07. A  
P08. C  
P09. C  
P10. D  
P11. C  
P12. C  
P13. A  
P14. D  
P15. E  
P16. D  
P17. C  
P18. B  
P19. B  
P20. D

## CHEMISTRY SOLUTIONS – UIL STATE 2021

- C01. (E) Zinc always forms a +2 ion so the neutral compound would be zinc(II) oxide, ZnO.
- C02. (A) The balanced equation is  $2\text{OCN}^- + 3\text{ClO}^- + 2\text{OH}^- \rightarrow 2\text{CO}_3^{2-} + \text{N}_2 + 3\text{Cl}^- + \text{H}_2\text{O}$
- C03. (B) Allowed  $m_\ell$  values range from  $-\ell, \dots, 0, \dots, +\ell$ , so there are  $2\ell+1$  possible values for  $m_\ell$ . The  $f$  subshell corresponds to  $\ell = 3$ , so  $2 \times 3 + 1 = 7$ . The 7  $m_\ell$  values reflect the 7  $f$  orbitals.

- C04. (D) There are a total of  $6 - 1 = 5$  electrons in the ion. Filling the molecular orbitals from the lowest energy upward results in a diagram like the one shown on the right (modified from <https://opentextbc.ca/chemistry/chapter/8-4-molecular-orbital-theory>).



In determining the bond order, there are 3 electrons in bonding orbitals and 2 electrons in an anti-bonding orbital, leaving a net difference of 1 electron in a bonding orbital. This divided by 2 results in a bond order of  $\frac{1}{2}$ . Since the ion has one unpaired electron, it is paramagnetic.

- C05. (C)  $P = 1140 \text{ torr} = 1.50 \text{ atm}$     $T = 38^\circ\text{C} = 311 \text{ K}$     $V = 12.0 \text{ L}$   
 total moles of gas =  $(PV/RT) = (1.50 \times 12.0)/(0.08206 \times 311) = 0.7053 \text{ mol}$   
 moles of He =  $(0.7053/2) = 0.3527 \text{ mol He}$   
 moles of  $\text{SO}_2$  = moles of He =  $0.3527 \text{ mol SO}_2$   
 grams of He =  $0.3527 \text{ mol} \times 4.00 \text{ g/mol} = 1.410 \text{ g}$   
 grams of  $\text{SO}_2$  =  $0.3527 \text{ mol} \times 64.07 \text{ g/mol} = 22.59 \text{ g}$   
 total mass =  $1.410 \text{ g} + 22.59 \text{ g} = 24.00 \text{ g}$

Alternatively, since the mixture is equimolar, you could a) calculate the total moles of gas and multiply that by the average molar mass.  $0.7053 \text{ mol} \times 32.035 \text{ g/mol} = 24.00 \text{ g}$ ; or b) calculate the mass of 6.0 L of He under these conditions and the mass of 6.0 L of  $\text{SO}_2$ , and add them; or c) calculate the mass of 12.0 L of He at half the pressure and 12.0 L of  $\text{SO}_2$  at half the pressure and add those.

- C06. (E) There are a couple different ways to solve this, but they both involve some trial and error. The simplest way is for each possible answer, enter the temperature and pressure data (including normal boiling point and 1 atm as one of the temperature/pressure pairs) into the Clausius-Clapeyron equation and calculate  $\Delta H_{\text{vap}}$ . If the result matches the value given on the data page, that's the correct compound.

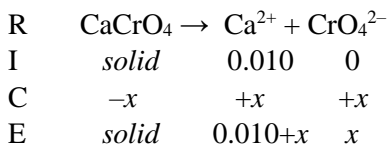
$$\ln \frac{P_2}{P_1} = \frac{\Delta H_{\text{vap}}}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$

That's a lot of trial and error, but there are some clues to narrow the field. The vapor pressure at  $65^\circ\text{C}$  is lower than atmospheric pressure, so that eliminates anything with a boiling point at or below  $65^\circ\text{C}$  (answer choices B and C). At most, then, you would need to try only two compounds from A, D, and E, and if it's not one of those two, it must be the third one.

- C07. (A) 2000 Calories = 2,000,000 calories  
 2,000,000 calories  $\times$  4.184 J/cal = 8,368,000 J = 8368 kJ  
 8368 kJ/5470 kJ/mol = 1.530 mol  
 1.530 mol  $\times$  114.26 g/mol = 174.8 g  
 174.8 g / 0.703 g/mL = 249 mL. One cup is 236.6 mL
- C08. (E)  $\Delta G = \Delta H - T\Delta S$  Since the phase change occurs at the normal boiling point, it's occurring at the equilibrium temperature and  $\Delta G = 0$ . Therefore  $\Delta H = T\Delta S$  and  $\Delta S = \Delta H/T$ . The normal boiling point of water is 100 °C (373 K) and  $\Delta H_{\text{vap}}$  is given on the data sheet as 2260 J/g. This has to be converted to J/mol to match the units in the answers, so  
 $\Delta H_{\text{vap}} = 2260 \text{ J/g} \times 18 \text{ g/mol} = 40,680 \text{ J/mol}$ .  $\Delta S = 40680 \text{ J/mol} / 373 \text{ K} = 109 \text{ J/mol}\cdot\text{K}$ .
- C09. (C)  $K_{\text{forward}} = [\text{B}_2] = 244$   $K_{\text{reverse}} = 1/[\text{B}_2]^{1/2}$   $K_{\text{reverse}} = 1/[244]^{1/2} = 1/15.62 = 0.0640$
- C10. (B) If it takes 50.0 mL of 0.183 M HCl to reach the second equivalence point, then it would have taken 25.0 mL of the acid to reach the first equivalence point.  
 Moles of base = (0.025 L)(0.183 M) = 0.004575 moles. The original volume of the base is 15 mL, so the original concentration is 0.004575 mol/0.015 L = 0.305 M.
- C11. (C) Assume the reaction goes to completion, then allow some of the solid to dissociate.

0.200 L  $\times$  0.20 M = 0.040 moles of chromate    0.175 L  $\times$  0.25 M = 0.04375 moles of  $\text{Ca}^{2+}$   
 This is enough to form 0.040 moles of  $\text{CaCrO}_4$ , leaving 0.00375 moles of  $\text{Ca}^{2+}$  left over in solution. The concentration of  $\text{Ca}^{2+}$  in solution is 0.00375 mol/0.375 L = 0.010 M

Now allow the precipitate to dissolve:



If you neglect  $x$  as small relative to 0.010 you get  $K_{\text{sp}} = 7.1 \times 10^{-4} = [0.010][x]$   $[x] = 7.1 \times 10^{-2}$ , so  $[\text{Ca}^{2+}] = 0.01 + 0.071$ . Clearly  $x$  is *not* negligible compared to 0.01 so we need to use the quadratic formula to solve for  $x$ .

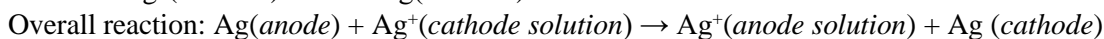
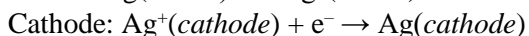
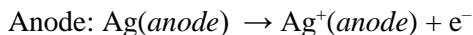
$$K_{\text{sp}} = (0.010 + x)(x) \quad x^2 + 0.010x - K_{\text{sp}} = 0 \quad a = 1; \quad b = 0.010; \quad c = -7.1 \times 10^{-4}$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} = \frac{-(0.010) \pm \sqrt{(0.010)^2 - 4(1)(-7.1 \times 10^{-4})}}{2}$$

$$x = 0.0221$$

$$[\text{CrO}_4^{2-}] = 0.022 \text{ M} \quad [\text{Ca}^{2+}] = 0.010 + 0.022 = 0.032 \text{ M}$$

C12. (A) This is a concentration cell, so you have to be careful about labeling the two solution concentrations so that you have the correct ratio for Q. If you realize up front that the cathodic half-cell must have a higher  $\text{Ag}^+$  concentration than the anodic half-cell, then you can already reduce the possible answer choices to just A and D. But here's the full solution:



$$Q \text{ for this reaction} = \frac{[\text{Ag}^+]_{\text{anode}}}{[\text{Ag}^+]_{\text{cathode}}}$$

$$E = E^\circ - \frac{0.0591}{n} \log Q$$

$E = 0.0075 \text{ v}$ ,  $E^\circ = 0$ ,  $n = 1$ , solve for Q

$$0.0075 = 0 - \frac{0.0591}{1} \log \left( \frac{[\text{Ag}^+]_{\text{anode}}}{[\text{Ag}^+]_{\text{cathode}}} \right)$$

$$-0.1269 = \log \left( \frac{[\text{Ag}^+]_{\text{anode}}}{[\text{Ag}^+]_{\text{cathode}}} \right)$$

$$10^{-0.1269} = \frac{[\text{Ag}^+]_{\text{anode}}}{[\text{Ag}^+]_{\text{cathode}}} = 0.7466 = Q$$

$$[\text{Ag}^+]_{\text{anode}} = 0.7466 \times [\text{Ag}^+]_{\text{cathode}}$$

Since the volumes are the same in each half-cell, this concentration ratio is also the mass ratio of  $\text{AgNO}_3$  in each cell.

$$\text{grams of AgNO}_3(\text{anode}) = 0.7466 \times \text{grams of AgNO}_3(\text{cathode})$$

$$\text{AgNO}_3_{\text{anode}} + \text{AgNO}_3_{\text{cathode}} = 48.0 \text{ g}$$

$$0.7466 \text{ AgNO}_3_{\text{cathode}} + \text{AgNO}_3_{\text{cathode}} = 48.0 \text{ g}$$

$$1.7466 \text{ AgNO}_3_{\text{cathode}} = 48.0 \text{ g}$$

$$\text{AgNO}_3_{\text{cathode}} = \frac{48.0 \text{ g}}{1.7466} = 27.5 \text{ grams}$$

$$\text{AgNO}_3_{\text{anode}} = 48.0 - 27.5 = 20.5 \text{ grams}$$



C13. (D) rate =  $k[AB]^a[C_2]^b$  Looking at trials 1 and 2,

$$\left(\frac{[AB]_2}{[AB]_1}\right)^a = \frac{\text{rate}_2}{\text{rate}_1}$$

$$\left(\frac{[0.400]}{[0.250]}\right)^a = \frac{1.95}{1.22}$$

$$1.60^a = 1.60, \text{ so } a = 1$$

Doing the same for trials 2 and 3,

$$\left(\frac{[0.400]}{[0.250]}\right)^b = \frac{3.12}{1.95}$$

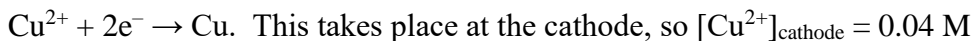
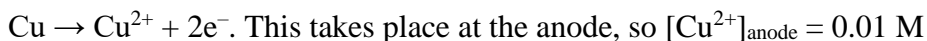
$$b = 1.$$

Knowing it's a second order reaction eliminates answers A – C because the units on  $k$  are not correct for a second order reaction. Pick any trial to determine  $k$ . Let's use trial 1:

$$\text{rate} = k[AB][C_2]. \quad 1.22 \times 10^{-3} \text{ M/s} = k [0.250]^2, \text{ so } k = 0.0195 \text{ M}^{-1} \text{ s}^{-1}$$

C14. (A)  $\Delta G = \Delta H - T\Delta S$  There are two factors that lead to a process being spontaneous: a negative  $\Delta H$  and a positive  $\Delta S$ . If a reaction has both of these going for it, it will always be spontaneous. If it has neither going for it, it will never be spontaneous. If it has one but not the other, then it will be spontaneous only when the temperature is raised ( $+\Delta H/+ \Delta S$ ) or lowered ( $-\Delta H/- \Delta S$ ) enough to allow the favorable term to dominate. In this case  $\Delta H$  is negative ( $\Delta H^\circ = -18.8 \text{ kJ/mol}$ ) and  $\Delta S$  is positive. We know  $\Delta S$  is positive because producing a gas increases entropy and this reaction has more moles of gaseous product than it does moles of gaseous reactant:  $\Delta n = 2 - 1 = +1$ . That's an increase in entropy, so  $\Delta S = (+)$ . Since the reaction has both a  $-\Delta H$  and a  $+\Delta S$ , it is spontaneous at any temperature.

C15. (B) First determine the voltage of the concentration cell, then use  $\Delta G = -nFE_{\text{cell}}$  to calculate the change in free energy. The two half-reactions are



The overall reaction is  $\text{Cu(s)} + \text{Cu}^{2+}_{\text{cathode}} \rightleftharpoons \text{Cu}^{2+}_{\text{anode}} + \text{Cu(s)}$ , so the equilibrium expression is

$$K = \frac{[\text{Cu}^{2+}]_{\text{anode}}}{[\text{Cu}^{2+}]_{\text{cathode}}}$$

Using the Nernst equation,

$$E_{\text{cell}} = E_{\text{cell}}^\circ - \frac{0.0592 \text{ V}}{n} \log Q$$

$$E_{\text{cell}} = 0 \text{ V} - \frac{0.0592 \text{ V}}{2} \log \frac{[\text{Cu}^{2+}]_{\text{anode}}}{[\text{Cu}^{2+}]_{\text{cathode}}}$$

$$E_{\text{cell}} = 0 \text{ V} - \frac{0.0592 \text{ V}}{2} \log \frac{[0.01]}{[0.04]}$$

$$E_{\text{cell}} = 0 \text{ V} - (-0.01782 \text{ V}) = 0.0178 \text{ V}$$

Now calculate  $\Delta G$  from  $E_{\text{cell}}$ .

$$\Delta G = -nFE_{\text{cell}} = (2)(96485)(0.0178) = -3439 \text{ J}$$

You do not need the standard reduction potential for  $\text{Cu}^{2+}$  that is provided on the data page. The  $E^{\circ}_{\text{cell}}$  for any concentration cell is 0 V.

C16. (C)  $K_{\text{sp}} = 4.41 \times 10^{-9} = [\text{Pb}^{2+}][\text{I}^{-}]^2$ .  $[\text{I}^{-}] = 1 \times 10^{-4}$ , so  $[\text{Pb}^{2+}] = K_{\text{sp}}/[\text{I}^{-}]^2 = 4.41 \times 10^{-9}/[1 \times 10^{-4}]^2 = 0.441 \text{ M}$ .  $0.441 \text{ M} \times 0.200 \text{ L} = 0.0882$  moles  $\text{Pb}(\text{NO}_3)_2$ . The molar mass of lead nitrate is 331.22 g/mol, so  $= 0.0882$  moles  $\times 331.22 \text{ g/mol} = 29.2$  grams needed.

C17. (E) Note the subtle difference in the symbols here:  $v$  = velocity, and  $\nu$  = frequency. The DeBroglie equation says  $\lambda = h/mv$  ( $v$  = velocity), so to determine the wavelength of the electron we need to know its mass and velocity. The kinetic energy of the ejected electron is determined from the photoelectric effect equation:  $KE = h\nu_{(\text{frequency})} - \phi$ .

$$KE = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})(9.5 \times 10^{14} \text{ s}^{-1}) - 5.61 \times 10^{-19} = 6.847 \times 10^{-20} \text{ J} \quad KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2 \times 6.847 \times 10^{-20}}{9.11 \times 10^{-31}}} = 387,700 \text{ m/s}$$

$$\lambda = h/mv = 6.626 \times 10^{-34}/(9.11 \times 10^{-31} \times 387,700) = 1.876 \times 10^{-9} \text{ m} = 1.88 \text{ nm}$$

C18. (A) 1 amp = 1 coulomb/second

96,485 coulomb = 1 mol of electrons, sometimes stated as 1 Faraday = 1  $\mathcal{F}$  = 96,485 C/mol  
Multiply current  $\times$  time ( $I \times t$ ) to get total charge in coulombs, and divide coulombs by 96,485 C/mol to get the number of moles of electrons flowing into the reaction. Then use the balanced equation (or half-reaction) to calculate the number of moles of metal reduced from the number of moles of electrons.

$$\text{Moles of electrons} = (3.7 \times 6 \times 60 \times 60)/96,485 = 0.8283 \text{ moles } e^{-}$$

From the balanced half-reaction  $\text{Al}^{3+} + 3e^{-} \rightarrow \text{Al}$ , it takes 3 electrons to reduce one  $\text{Al}^{3+}$  ion to a metal atom, so moles of Al =  $0.8283/3 = 0.276$  mol.  $0.276 \text{ mol} \times 26.98 \text{ g/mol} = 7.45 \text{ g}$  of Al.

- C19. (D) In a non-ideal gas each molecule feels an attractive force from the other molecules. For a molecule in the center of the container, the other molecules are distributed randomly around it, so the attractive forces are equal in all directions and cancel out. But for a molecule that is about to hit the wall, most of the other molecules are on the side of the molecule opposite the wall, and there is a net force pulling the molecule back toward the center. This slows down the molecule before it hits the wall and lessens the pressure. The strength of this attractive force depends on the molar density of the gas, so the decrease in pressure depends on the molar density,  $n/V$ .

But that's for just one molecule hitting the wall. The total pressure difference is that pressure difference multiplied by the number of collisions with the wall, which is also proportional to  $n/V$ . When you multiply these terms together you get the  $n^2/V^2$  term in the van der Waal's equation.

- C20. (D) You don't have to balance all these equations, you just have to recognize how many electrons are required for each reduction and oxidation process. The overall number of electrons required will be the least common multiple of the two.
- A) 2 in each half-reaction, so 2 overall;
  - B) 2 and 3 in the two half-reactions, so 6 overall;
  - C) 3 in the  $\text{MnO}_4^-$  reduction and 6 in the  $\text{Br}^-$  oxidation, so 6 overall;
  - D) 8 in the hydride oxidation to  $\text{H}^+$  and 2 in the formaldehyde reduction to methanol so 8 overall;
  - E) 3 in the  $\text{Cr}^{3+}$  reduction and 2 in the Mg oxidation so 6 overall.

## PHYSICS SOLUTIONS – UIL STATE 2021

- P01. (B) Page 44: “If the theory of loop quantum gravity is correct, matter cannot really have collapsed to an infinitesimal point.... This hypothetical final stage in the life of a star, where the quantum fluctuations of space-time balance the weight of matter, is what is known as a ‘Planck star’.”
- P02. (E) Page 60: “There is a detectable difference between the past and the future only when there is flow of heat.”
- P03. (A) Page 71: “Does this mean that when I make a decision it’s ‘I’ who decides? Yes, of course, because it would be absurd to ask whether ‘I’ can do something different from what the whole complex of my neurons has decided: the two things, as the Dutch philosopher Baruch Spinoza understood with marvelous lucidity in the seventeenth century, are the same. There is not an ‘I’ and ‘the neurons in my brain’. They are the same thing.”
- P04. (B) The equation relating apparent magnitude, absolute magnitude, and distance for a star is written as:  $d = (10pc) * 10^{\left(\frac{m-M}{5}\right)}$ . Here  $m$  is the apparent magnitude,  $M$  is the absolute magnitude, and  $d$  is the distance to the star in parsecs. The distance that we are given is 1600 light-years, which when converted to parsecs is  $d = \frac{1600}{3.26} = 491pc$ . So, putting this, along with the given apparent magnitude, into the equation:  $d = 491 = 10 * 10^{\left(\frac{14.5-M}{5}\right)} \rightarrow 49.1 = 10^{\left(\frac{14.5-M}{5}\right)}$ . Taking the log (base-10) of both sides:  $Log(49.1) = 1.7 = \frac{14.5-M}{5} \rightarrow 8.5 = 14.5 - M \rightarrow M = 6.0$ .
- P05. (E) First, let’s break down the composite units, such as the Tesla, which is  $1 \text{ Tesla} = 1 \frac{\text{Newton*second}}{\text{Coulomb*meter}}$ , and the Farad, which is  $1 \text{ Farad} = 1 \frac{\text{Coulomb}}{\text{Volt}} = 1 \frac{(\text{Coulomb})^2}{\text{Joule}}$ . Putting these units into the equation gives:  $[Z] = \frac{(\text{Coulomb})^2}{\text{Joule}} * \left( \frac{\text{Newton*second}}{\text{Coulomb*meter}} * \frac{\text{meter}}{\text{second}} * \text{second} \right)^2 = \frac{(\text{Coulomb})^2}{\text{Joule}} \left( \frac{\text{Newton*second}}{\text{Coulomb}} \right)^2$ . Squaring out the second term:  $[Z] = \frac{(\text{Coulomb})^2}{\text{Joule}} * \frac{(\text{Newton})^2}{(\text{Coulomb})^2} * (\text{second})^2 = \frac{(\text{Newton})^2}{\text{Joule}} * (\text{second})^2$ . Recall that  $1 \text{ Joule} = 1 \text{ Newton} * \text{meter}$  and that  $1 \text{ Newton} = 1 \frac{\text{kilogram*meter}}{(\text{second})^2}$ . This gives us:  $[Z] = \frac{(\text{Newton})^2}{\text{Newton*meter}} * (\text{second})^2 = \frac{\text{Newton}*(\text{second})^2}{\text{meter}} = \frac{\text{kilogram*meter}*(\text{second})^2}{\text{second}^2*\text{meter}} = \text{kilogram}$ .
- P06. (B) Trajectory problems in which you do not know the angle can be challenging. That said, we can still rely on our standard uniformly accelerated motion equations: Since we know both horizontal and vertical distances, we should start with the equation  $x = x_0 + v_0t + \frac{1}{2}at^2$ . Let’s begin with the horizontal:  $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 = 74.0 = 0 + (25.1)\cos\theta t + 0$ . This gives us the useful relation  $t\cos\theta = 2.948$ . For the vertical we have  $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = 0 = 12 + (25.1)\sin\theta t + (0.5)(-9.8)t^2$ , which leads to another relation:  $t\sin\theta = 0.1952t^2 - 0.4781$ . Now things get tricky. These are transcendental equations since they involve both polynomial terms and trigonometric functions. One way to tackle these is to square both equations and add them together. So,  $(t\cos\theta)^2 = 8.691 = t^2\cos^2\theta$ . And from the other equation:  $(t\sin\theta)^2 = t^2\sin^2\theta = (0.1952t^2 - 0.4781)^2 = 0.0381t^4 - 0.18665t^2 + 0.22858$ . Adding these together gives something very helpful:  $t^2\cos^2\theta + t^2\sin^2\theta = t^2(\cos^2\theta + \sin^2\theta) = t^2$ . For what this equals, we get:  $t^2 = 8.691 + 0.0381t^4 - 0.18665t^2 + 0.22858$ . Simplifying and collecting terms:  $t^4 - 31.15t^2 + 234.1 = 0$ . We then solve for  $t^2$  using the quadratic formula:  $t^2 = \frac{1}{2}(31.15 \pm \sqrt{33.9}) = 18.5, \text{ or } 12.7$ . This gives time solutions of  $t = 4.30s, \text{ or } 3.56s$ . (Here we ignore the negative solutions since negative time is meaningless). Now, we go back to our original equations: Using the first equation:  $t\cos\theta = 2.948 \rightarrow (4.30)\cos\theta = 2.948 \rightarrow \theta = 46.7^\circ$  and  $(3.56)\cos\theta = 2.948 \rightarrow \theta = 34.1^\circ$ . Note: you get the same angles if you use the second equation. For most trajectory problems, there are two different angles that will get you to the same destination, so both of these angles are solutions to the problem. However, only one of these angles is listed as an answer choice:  $\theta = 34.1^\circ$ .

- P07. (A) To begin, we should decide which way the box of tea will slide. Given that the hanging mass is small, it is reasonable to assume that the box of tea will slide down the incline. If that turns out not to be the case, then the mathematics will give us a nonsense answer. As long as we get a reasonable answer, then we know we have chosen correctly.

In looking at the forces on the box of tea, we tilt our coordinate system to match the angle of the incline. The positive x-direction points down the incline, and the positive y-direction points up and left, perpendicular to the incline. The forces on the box are the tension ( $T$ ) in the negative x-direction; the friction ( $F_f$ ), also in the negative x-direction; the normal force ( $F_N$ ) in the positive y-direction; and gravity ( $Mg$ ), which points straight down. We must break the gravitational force into components. The component  $Mg\sin\theta$  points in the positive x-direction, and the component  $Mg\cos\theta$  points in the negative y-direction. The acceleration in the y-direction is zero, and the acceleration in the x-direction is what we are solving for. Applying Newton's second law, we get two equations.

For the y-direction:  $\sum F_y = F_N - Mg\cos\theta = 0 \rightarrow F_N = Mg\cos\theta$ , and for the x-direction:

$\sum F_x = Mg\sin\theta - T - F_f = Ma$ . We also know  $F_f = \mu F_N$ , which gives  $F_f = \mu Mg\cos\theta$ . To find the tension, we need to take a look at the hanging mass:

The hanging mass has only two forces acting on it, both in the vertical: Tension ( $T$ ) upward, and gravity ( $mg$ ) downward. The hanging mass is also accelerating upward, so we get the equation:

$$\sum F_V = T - mg = ma.$$

Plugging numbers into these various equations gives the following:

$$T - (4)(9.8) = 4a \rightarrow T = 4a + 39.2; F_f = (0.24)(10)(9.8) \cos(50) \rightarrow F_f = 15.12 \text{ N}; \text{ and}$$

$$(10)(9.8) \sin(50) - T - 15.12 = 10a, \text{ which reduces to } T = 59.95 - 10a. \text{ Equating our two expressions for tension yields: } 4a + 39.2 = 59.95 - 10a \rightarrow 20.75 = 14a \rightarrow a = 1.48 \text{ m/s}^2.$$

- P08. (C) We can find the speed of the toy from its final kinetic energy, and since it starts from rest and slides horizontally, we can equate the final kinetic energy to the work done on the toy by the varying force. The work done by the varying force equals the area under the curve on the Force-Distance graph. Using the grid, we can estimate the area under the curve: for the positive part, it would appear that the area under the curve is about 22 grid-blocks. Each grid-block is 2.0N by 0.2m, or 0.4J. So, for the positive part of the force curve, the area under the curve is  $A_1 = (22)(0.4) = 8.8\text{J}$ .

For the negative part of the force curve, we have an area of about 5.5 grid-blocks. The grid-blocks are the same size, so we get a negative area of  $A_2 = -(5.5)(0.4) = -2.2\text{J}$ . Thus, the total work done on the toy is  $W = 8.8 - 2.2 = 6.6\text{J}$ .

$$\text{Equating the work to kinetic energy gives: } W = \frac{1}{2}mv^2 = 6.6 \rightarrow (0.5)(0.2)v^2 = 6.6 \rightarrow v = 8.1\text{m/s}.$$

- P09. (C) This is a conservation of angular momentum problem, in which we will primarily focus on angular velocities – and only find the angular acceleration at the end. The formula for angular momentum is  $L = I\omega$ . Initially, when the tub is empty, we have  $L_0 = (M_T R^2)\omega_0 = 5R^2(30) = 150R^2$ . We aren't given the radius of the tub, so we will just leave it as  $R$  for now. After the sand is added, the inertia increases and the angular velocity decreases. The final angular momentum is then:

$L_f = I_f\omega_f = (M_T R^2 + \frac{1}{2}M_S R^2)\omega_f$ . Here the inertia includes the tub, which is still rotating, as well as the sand which was added and is now rotating. Putting in the known values gives:

$L_f = (5R^2 + \frac{1}{2}(15)R^2)\omega_f = 12.5R^2\omega_f$ . Since there are no external forces (such as friction) acting on the tub, then angular momentum must be conserved – and the initial and final angular momenta must be the same:  $L_f = L_0 \rightarrow 150R^2 = 12.5R^2\omega_f$ . Conveniently, the radius of the tub cancels out, and we are left with the final angular velocity of the tub and sand:  $\omega_f = 12.0\text{rad/s}$ . To find the angular acceleration, we need the time it takes to fill the tub with sand. This is easy enough since the rate of filling was given:

$$\Delta t = \frac{M_s}{\text{rate}} = \frac{15.0 \text{ kg}}{1.50 \text{ kg/s}} = 10.0 \text{ s}. \text{ Finally, we can calculate the effective angular acceleration:}$$

$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_f - \omega_0}{\Delta t} = \frac{12 - 30}{10} = -1.80 \text{ rad/s}^2.$$

- P10. (D) Sound intensity is power per unit area. We have the power for each speaker, so we just need to find how much area that power spreads out over. Since the sound expands spherically from the speakers, we are spreading that power over the surface area of a sphere, given by the formula  $A = 4\pi r^2$ . The first speaker is only 30.0m from the listener, so the area is  $A_1 = 4\pi r_1^2 = 4\pi(30)^2 = 11310\text{m}^2$ . Thus, the intensity from the first speaker is  $I_1 = \frac{P_1}{A_1} = \frac{100}{11310} = 0.00884\text{W/m}^2$ .
- For the second speaker, the distance from speaker to listener is:  $r_2 = \sqrt{(20)^2 + (30)^2} = 36.06\text{m}$ . This gives an area for the second speaker of  $A_2 = 4\pi r_2^2 = 4\pi(36.06)^2 = 16336\text{m}^2$ ; and an intensity from the second speaker of  $I_2 = \frac{P_2}{A_2} = \frac{100}{16336} = 0.006121\text{W/m}^2$ .
- Since the two sources are not coherent, there are no interference effects to worry about. Thus, the total intensity is the sum of the individual intensities:  $I = I_1 + I_2 = 0.0150\text{W/m}^2$ . In order to convert this to decibels, we use the formula  $I_{dB} = 10\text{Log}(I/I_0)$  where  $I_0 = 1.0 \times 10^{-12}\text{W/m}^2$ . This gives:  $I_{dB} = 10\text{Log}(0.0150/(1.0 \times 10^{-12})) = 101.7 \approx 102\text{dB}$ .
- P11. (C) Thermodynamic engine problems can get pretty long, but a little up-front knowledge can help you avoid wasting effort. One thing we cannot avoid is that we must know the temperature at the three vertices. To find temperature, we simply use the ideal gas law:  $PV = nRT$ . We do need to be careful to use R in the correct units. For the lower-left vertex:  
 $(2.60\text{atm})(20.0\text{L}) = (1.60\text{mol})\left(0.082057 \frac{\text{Latm}}{\text{molK}}\right)T_1$ , which gives  $T_1 = 396\text{K}$ .
- Similarly, for the upper vertex we get:  $(3.75\text{atm})(20.0\text{L}) = (1.60\text{mol})\left(0.082057 \frac{\text{Latm}}{\text{molK}}\right)T_2$ . This gives a temperature at that vertex of  $T_2 = 571\text{K}$ . Because the lower process is isothermal, we know that the temperature at the lower vertices are the same. In other words, the temperature at the lower-right vertex is  $T_3 = T_1 = 396\text{K}$ . In this problem we are looking entirely for the input heat,  $Q_{in}$ . There are three processes in which heat energy might flow. For an adiabatic process, however, heat flow is zero – so we don't need to even consider that part of the cycle. For the isothermal process, the gas is being compressed while remaining at a constant temperature. This only happens if heat is expelled by the gas. This is exhaust heat flowing out of the gas,  $Q_{out}$ ; not heat flowing into the gas. Therefore, the only process in which heat flows into the gas is during the isovolumetric process. Heat flow in an isovolumetric process is given by  $Q_{isov} = nC_V\Delta T$ . The specific heat capacity at constant volume is given, but we must be sure to use the correct units:  $C_V = \frac{5}{2}R = (2.5)(8.314) = 20.785\text{ J/molK}$ . Putting it all together, we get a heat input of  $Q_{in} = nC_V(T_2 - T_1) = (1.60)(20.785)(571 - 396) = 5820\text{ J}$ .
- P12. (C) First, it is easiest to check the possibility of an “open” (infinite ohms) resistor. If any resistor fails by becoming “open,” then the current through that resistor will drop to zero. Since the measured currents at all three points are non-zero, we know that none of the resistors have failed by becoming “open.” This immediately eliminates choices D and E.
- Now, let's start to work backwards... the currents in the parallel branches allow us to calculate the voltage across those resistors:  $V_{40} = (40.0)(97.3\text{mA}) = 3.89\text{V}$  and  $V_{60} = (60.0)(64.9\text{mA}) = 3.89\text{V}$ . As expected, these are the same voltage, further confirming that nothing is wrong with the two resistors that are in parallel.
- Using the main current, we can find the voltages across the other two resistors (the main current – current A – is the same for the  $30.0\Omega$  and the  $50.0\Omega$  since they are in series.). Finding their voltages gives:  $V_{30} = (30.0)(162\text{mA}) = 4.86\text{V}$  and  $V_{50} = (50.0)(162\text{mA}) = 8.10\text{V}$ .
- If you add up all of the voltages of the resistances in series (the  $30.0\Omega$ , the  $50.0\Omega$ , and the parallel group) you get  $V = 4.86 + 8.10 + 3.89 = 16.85\text{V}$  which is greater than  $12.0\text{V}$ . Since this isn't less than  $12.0\text{V}$ , we can eliminate choice A.
- Now we do some trial-and-error: If the  $50.0\Omega$  were shorted, then its voltage would actually be zero – which gives a total voltage for the circuit of  $V = 4.86\text{V} + 3.89\text{V} = 8.75\text{V} \neq 12.0\text{V}$ . Again, this isn't  $12.0\text{V}$ , so we can eliminate choice B... If the  $30.0\Omega$  were shorted, then its voltage would be zero, and the total voltage for the circuit would be  $8.10\text{V} + 3.89\text{V} = 12.0\text{V}$ . This matches what we expect from the battery and meets all of our expected values. Thus, we can conclude that the problem is that the  $30.0\Omega$  resistor is shorted and the correct answer is C.
- Note: you can “brute-force” this problem by trying each possibility and seeing which one gives the correct main current. If you are fast on a calculator, then this option is reasonable.

- P13. (A) The easiest way to approach this problem is to look at the voltage (potential) produced at (0.0, 0.0) and at (0.0, 20.0cm) by the two fixed charges (the +6.00 $\mu\text{C}$  and the +10.0 $\mu\text{C}$ ). Conveniently, voltage is a scalar given by the formula:  $V = \frac{kQ}{r}$ .

The distances from the fixed charges to (0.0, 0.0) are  $r_1 = 0.200\text{m}$  for the +6.00 $\mu\text{C}$  and  $r_2 = 0.400\text{m}$  for the +10.0 $\mu\text{C}$ . So, the voltage at (0.0, 0.0) is:

$$V_{(0,0)} = \frac{kQ_1}{r_1} + \frac{kQ_2}{r_2} = \frac{(8.99 \times 10^9)(6.00 \times 10^{-6})}{0.200} + \frac{(8.99 \times 10^9)(10.0 \times 10^{-6})}{0.400} = 494450\text{V}.$$

The distances from the fixed charges to (0.0, 20.0cm) are  $r_3 = \sqrt{(0.200)^2 + (0.200)^2} = 0.2828\text{m}$  for the +6.00 $\mu\text{C}$ , and  $r_4 = 0.400 - 0.200 = 0.200\text{m}$  for the +10.0 $\mu\text{C}$ . Thus, the voltage at (0.0, 20.0cm) is

$$V_{(0,20)} = \frac{kQ_1}{r_3} + \frac{kQ_2}{r_4} = \frac{(8.99 \times 10^9)(6.00 \times 10^{-6})}{0.2828} + \frac{(8.99 \times 10^9)(10.0 \times 10^{-6})}{0.200} = 640207\text{V}.$$

Now, the energy needed to move the charge is given by  $U = q\Delta V$  where  $q$  is the value of the charge being moved (+2.00 $\mu\text{C}$ ). Using our voltage results, we get:  $U = (2.00 \times 10^{-6})(640207 - 494450) = 0.292\text{ J}$ .

- P14. (D) This is an Ampere's Law problem, and since the current density is not a constant, this will involve calculus. Ampere's Law states that the magnetic field along a path depends on the current passing through the area enclosed by that path. Mathematically  $\oint B \cdot ds = \mu_0 I_{\text{inside}}$ . Because of the cylindrical symmetry of both the wire and current density, we can eliminate the path integral, giving:  $Bs = \mu_0 I_{\text{inside}}$ , where  $s$  is the circumference of a circle with a radius of 1.50mm. It is finding  $I_{\text{inside}}$  that gets interesting.

To find  $I_{\text{inside}}$ , we use the integral:  $I_{\text{inside}} = \int J(r) dA$ . Again, because of the cylindrical symmetry of both the wire and the current density, this simplifies to  $I_{\text{inside}} = \int J(r) 2\pi r dr$ . Plugging in the formula for the current density gives  $I_{\text{inside}} = \int 5.0e^{-0.25r^2} 2\pi r dr$ . You can solve this with a u-substitution, letting  $u = 0.25r^2$  and  $du = 0.5r dr$ . Making the substitution puts the integral into the simplified form:  $I_{\text{inside}} = 20\pi \int e^{-u} du = -20\pi e^{-u} = -20\pi e^{-0.25r^2}$ . This is evaluated from the center of the wire ( $r = 0$ ) to the point where we want to know the magnetic field ( $r = 1.50\text{mm}$ ).

This gives:  $I_{\text{inside}} = -20\pi(e^{-0.25(1.50)^2} - e^0) = 20\pi(1 - e^{-0.5625}) = 27.03\text{A}$ .

Now, we can go back to Ampere's Law:  $Bs = B(2\pi)(1.50\text{mm}) = \mu_0 I_{\text{inside}} = \mu_0(27.03)$ . Converting units and putting in the value of  $\mu_0$ , we get:

$$B(2\pi)(0.00150) = (4\pi \times 10^{-7})(27.03) \rightarrow B = \frac{(2.0 \times 10^{-7})(27.03)}{0.00150} = 0.00360. \text{ Thus, } B = 3.60\text{mT}.$$

Note: the total current value of 49.66A is not needed.

- P15. (E) This problem is related to the previous one, but instead of actual current, this one generates a magnetic field based on the displacement current (that is, based on a changing electric field). To solve this we must use the expanded form of Ampere's Law – the Ampere-Maxwell Law. Mathematically, the Ampere-Maxwell Law looks a lot like Ampere's Law:  $\oint B \cdot ds = \mu_0(I_{\text{inside}} + I_D)$ , where the displacement current is  $I_D = \epsilon_0 \frac{d\Phi_E}{dt} \approx \epsilon_0 \frac{\Delta\Phi_E}{\Delta t}$ , and  $\Phi_E = EA$  is the electric field flux. In this problem there is no regular current ( $I_{\text{inside}}$ ), so the displacement current is all we have to worry about.

To begin, we need the electric field flux for the two different voltages. To get the flux, we need the area through which the electric field passes. For a parallel-plate capacitor, that area is simply the area of one of the plates. The plates have a radius of 12.0mm; thus,  $A = \pi r^2 = \pi(12 \times 10^{-3})^2 = 4.524 \times 10^{-4}\text{m}^2$ . The electric field in a parallel plate capacitor is given by  $|E| = \frac{V}{d}$ , where  $d$  is the distance between the plates.

For the voltages given:  $|E_1| = \frac{25.0}{0.050 \times 10^{-3}} = 5.00 \times 10^5\text{N/C}$  and  $|E_2| = \frac{35.0}{0.050 \times 10^{-3}} = 7.00 \times 10^5\text{N/C}$ . This allows us to calculate the electric field flux for the two voltages:

$$\Phi_1 = E_1 A = (5.00 \times 10^5)(4.524 \times 10^{-4}) = 226.2\text{ Nm}^2/\text{C}, \text{ and}$$

$$\Phi_2 = E_2 A = (7.00 \times 10^5)(4.524 \times 10^{-4}) = 317.7\text{ Nm}^2/\text{C}$$

So, the change in electric flux is  $\Delta\Phi_E = \Phi_2 - \Phi_1 = 317.7 - 226.2 = 90.5\text{ Nm}^2/\text{C}$ . This change occurs in a time of 100.0 $\mu\text{s}$ , giving a displacement current of:  $I_D = \epsilon_0 \frac{\Delta\Phi_E}{\Delta t} = (8.854 \times 10^{-12}) \frac{90.5}{100 \times 10^{-6}} = 8.01 \times 10^{-6}\text{A}$ .

Now, we can go back to the Ampere-Maxwell Law: Taking advantage of the cylindrical symmetry of the circular plates and the fact that  $I_{\text{inside}} = 0$ , we simplify the law to  $Bs = \mu_0 I_D$ . Because we are asked for the magnetic field at the edge of the plates,  $s$  is just the circumference of one of the circular plates. Putting it all together:  $Bs = B(2\pi r) = \mu_0 I_D = (4\pi \times 10^{-7})(8.01 \times 10^{-6}) \rightarrow B(0.012\text{m}) = 1.60 \times 10^{-12}$ . This gives an induced magnetic field at the edge of the plates of  $B = 1.34 \times 10^{-10}\text{ T}$ .

- P16. (D) In this problem, we have a refracting surface followed by a lens. When you have two optical elements, they can be treated independently - the image from the first element becoming the object for the second. So, let's begin by finding the image produced by the refracting surface:  
 The equation for image formation by a refracting surface is  $\frac{n_1}{p_1} + \frac{n_2}{q_1} = \frac{n_2 - n_1}{R}$ . The object (the fly) is in amber, so  $n_1 = 1.55$ ; and the image will form in air, so  $n_2 = 1.00$ . We are also given the object location  $p_1 = 12.0\text{cm}$ , and the radius of curvature of the surface. We do have to consider the sign of the radius of curvature. From the perspective of the object (the fly) the surface appears concave. This means that the sign of the radius of curvature is negative - so  $R = -80.0\text{mm} = -8.00\text{cm}$ . Putting this together, we can locate the image for the refracting surface:  

$$\frac{1.55}{12.0} + \frac{1.00}{q_1} = \frac{1.00 - 1.55}{-8.00} \rightarrow 0.1292 + \frac{1}{q_1} = 0.06875 \rightarrow q_1 = -16.55\text{cm}.$$
 This image then serves as the object for the lens. The distance of this object from the lens is given by  $p_2 = D - q_1 = 3.00 - (-16.55) = 19.55\text{cm}$ . Now we turn to the lens equation to find the location of the final image:  $\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f} \rightarrow \frac{1}{19.55} + \frac{1}{q_2} = \frac{1}{10.0} \rightarrow q_2 = 20.5\text{cm}$ . Since this image location is positive, then this final image is located to the right of the lens.
- P17. (C) This question is a little bit tricky - to answer it correctly, you must understand how measurement works in a quantum system. First and foremost - you will never get a measurement that isn't an eigenvalue of the system. The expectation value is an average over many measurements - and since there are different eigenvalues, the average will usually fall somewhere in-between the eigenvalues (as is the case here). However, no single measurement will ever give a number that is "in-between" eigenvalues. Therefore, choices B and D are not possible for a single measurement. Thus, they cannot be correct. That leaves the three choices that are eigenvalues. Here we have to look at the particular mixed state on which we are performing the energy measurement. Notice that the state is a mixture of  $|\psi_1\rangle$  and  $|\psi_2\rangle$ . Therefore, only the energy eigenvalues  $E_1$  and  $E_2$  are possible results for a measurement on this particular mixed state. This eliminates choice A, which is the eigenvalue  $E_3$ . Now we have to look at the coefficients for  $|\psi_1\rangle$  and  $|\psi_2\rangle$ . The probability of measuring a particular eigenvalue is equal to the coefficient squared. Thus, the probability of measuring  $E_1$  is  $P_1 = (0.6)^2 = 0.36 = 36\%$ ; and the probability of measuring  $E_2$  is  $P_2 = (0.8)^2 = 0.64 = 64\%$ . Therefore, the most likely measurement is the eigenvalue  $E_2 = 2.60\text{eV}$ , and the correct answer is C.
- P18. (B) Let's begin with a couple of observations: First, one of the particles produced in the decay is a baryon (the  $\Sigma^+$ ). Baryon number is a conserved quantity, so we must have the same number of baryons on both sides of the decay equation. Thus, since there is one baryon on the right side of the equation, then there must be exactly one baryon of the left side - which means that the original particle must be a baryon. Baryons contain three quarks. This means that choices D, E, and F are incorrect. Second, based on both its label and on conservation of charge, the original particle must have had a net charge of exact  $+1e$ . Choice A ( $uuc$ ) has a charge of  $+2e$ , so it cannot be correct. Now things get a little more challenging. The lifetime of the particle is about  $10^{-12}$  seconds. That is long lived for a massive particle. For massive particles, Strong Force decays take about  $10^{-24}$  seconds, and Electromagnetic Force decays take about  $10^{-18}$  seconds. A lifetime that is as long as  $10^{-12}$  seconds indicates that this decay is mediated by the Weak Force. We also know that Weak Force decays result in quark flavor changes. The  $\Sigma^+$  particle has a quark structure of  $uus$  - so, if the unknown particle  $X^+$  has the same quarks, then there would not be a quark flavor change. However, since this is a Weak Force decay, then there should be a quark flavor change... therefore, we can eliminate choice C as incorrect. That means the only possible option for  $X^+$  is  $udc$ . This quark structure represents a baryon, has a charge of  $+1e$ , and the decay  $udc \rightarrow uus$  does involve quark flavor changes. Thus, choice B is the most likely quark structure of the unknown particle.  
 Note: the pions constitute a particle-antiparticle pair. They carry away energy, but they represent a net sum of zero charge and zero quarks. Therefore, we can ignore them entirely in this analysis.



- P19. (B) Since the orbit is perfectly circular, we can solve this problem by equating the gravitational force of the planet on the moon to the centripetal force needed to keep the moon moving in a circle. Mathematically, this is  $\frac{GMm}{r^2} = \frac{mv^2}{r}$ , where  $m$  is the mass of the moon, and  $M$  is the mass of the planet. Simplifying gives:  $GM = rv^2$ . In order to use this, we need the velocity of the moon in its orbit. Notice that from the data, the moon completes half of an orbit in about 21 days (May 27 to June 17, or June 3 to June 24). This means that a complete orbit takes about 42 days. One complete orbit means that the moon has travelled along one circumference of the circular path.
- In other words, the moon travels  $C = 2\pi r = 2\pi(2.50 \times 10^5) = 1.57 \times 10^6$  km in 42 days. This gives an orbital velocity of  $v = \frac{1.57 \times 10^6 \text{ km}}{42 \text{ days}} = 37,400 \frac{\text{km}}{\text{day}}$ . We need to convert this to meters/second, so
- $$v = 37,400 \frac{\text{km}}{\text{day}} * 1000 \frac{\text{m}}{\text{km}} * \frac{1 \text{ day}}{24 \text{ hours}} * \frac{1 \text{ hour}}{3600 \text{ sec}} = 433 \text{ m/s.}$$
- Now we can go back to our original equation. Again, converting  $r$  into meters, we get:
- $$GM = rv^2 \rightarrow (6.67 \times 10^{-11})M = (2.50 \times 10^8)(433)^2 \rightarrow M = 7 \times 10^{23} \text{ kg.}$$
- Note: This is about 10% of the mass of the Earth

- P20. (D) Since the resistor and inductor are in series, then we know that the total impedance of the circuit is given by the sum of the resistance and the inductive reactance. Mathematically, we have  $Z = R + i\omega L$  where  $i = \sqrt{-1}$  and  $\omega = 2\pi f$ . The magnitude of this impedance is found by using the Pythagorean Theorem:  $|Z| = \sqrt{R^2 + (\omega L)^2}$ . This can be related to the data on the graph through the use of Ohm's Law:  $|Z| = \frac{V}{I}$ .
- Since we need two values (the R and the L), we will need to consider two different data points. The best one to start with is the one at  $f = 0$ . At zero frequency, we have a maximum current of 53.0mA. Also,  $f = 0$  gives  $\omega = 2\pi f = 0$ . Putting this together with our impedance formula, we get:
- $$|Z| = \frac{9.00}{0.053} = 170 = \sqrt{R^2 + (\omega L)^2} = \sqrt{R^2 + 0} = \sqrt{R^2} = R. \text{ Since } \omega = 0 \text{ at this frequency, then we easily get the resistance } |Z| = R = 170\Omega.$$
- Now we need a second data point to get the inductance: I will use (300Hz, 25.0mA) for this calculation. First, we get  $\omega = 2\pi f = 2\pi(300) = 1885 \text{ rad/s}$ . Plugging this into our impedance calculation:
- $$|Z| = \frac{9}{0.025} = 360 = \sqrt{R^2 + (\omega L)^2} = \sqrt{(170)^2 + (1885L)^2} \rightarrow 129600 = 28900 + 3553225L^2.$$
- This gives an inductance of  $L = \frac{100700}{3553225} = 0.0283H = 28\text{mH}$ . Thus, the components in the circuit are a  $170\Omega$  Resistor and a  $28\text{mH}$  inductor.

# Science Contest Answer Sheet

Conference \_\_\_\_\_

Grade Level \_\_\_\_\_

Contestant # \_\_\_\_\_

## Biology

## Chemistry

## Physics

B01 \_\_\_\_\_

C01 \_\_\_\_\_

P01 \_\_\_\_\_

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**B Score**

**C Score**

**P Score**

**Grader Initials** \_\_\_\_\_

**OVERALL SCORE**