UNIVERSITY INTERSCHOLASTIC LEAGUE

# Science

## Region • 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. Which functional group would not be found in the structure of a nucleotide?
A) phosphate
B) hydroxyl
C) carbonyl
D) amino
E) sulfhydryl

B02. Several species of *Plasmodium* can cause malaria. Which of the following statements about malaria, or its transmission and life cycle, is incorrect?
A) *Plasmodium* requires two hosts to complete its life cycle: humans and mosquitoes.
B) *Plasmodium* is a vector-borne disease.
C) *Plasmodium* infects cells in the liver and red blood cells.
D) *Plasmodium* is a helminth.
E) Infections with *Plasmodium* can be prevented by taking certain medications before, during, and after a scheduled trip to an area where malaria is epidemic.

B03. Eudicots
A) have embryos with two cotyledons.
B) usually have net-like veins in their leaves.
C) have vascular tissue arranged in a ring structure.
D) are angiosperms.
E) are all of the above.

B04. The main function of the sarcoplasmic reticulum of muscle fibers (cells) is to store
A) ATP.
B) calcium.
C) sodium.
D) potassium.
E) myosin and actin.

B05. All of the following are examples of convergent evolution except
A) the presence of wings in insects, birds, and bats.
B) the flight ability of sugar gliders (marsupials from Australia) and mammalian North American flying squirrels.
C) the similarity in forearm skeletal structure between bats and cats.
D) the ability of whales and bats to echolocate.
E) silk production in spiders and silk worms.

B06. The investigation of the geographic distribution of species over time is referred to as
A) biogeography.
B) the fossil record.
C) gene flow.
D) succession.
E) extinction.

B07. In terms of ecology, *disturbance* is any event that changes a community and availability of resources. Which of the following events would most likely impact the ability of a savanna to become a woodland biome? Assume that climate conditions are conducive for woodland growth.
A) Overhunting of apex predators.
B) Category 5 hurricane washing away protective barrier islands.
C) Frequent fires destroying all vegetation.
D) Pests that specifically target native grasses.
E) Increased numbers of pollinating insects.

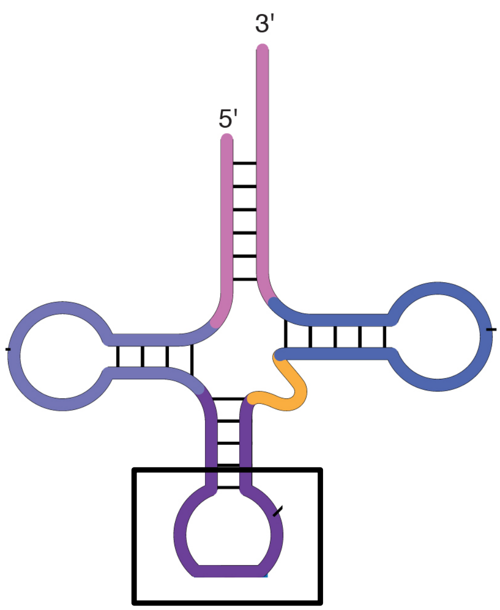
B08. DNA polymerase synthesizes _______ bonds.
A) hydrogen
B) phosphodiester
C) peptide
D) ionic
E) disulfide

B09. Which of the following precursor cells is common to basophils, neutrophils, and erythrocytes?
A) lymphoid stem cells
B) myeloid stem cells
C) platelets
D) megakaryocyte erythroid stem cells
E) monocytes

B10. Which of the following might be produced during anoxygenic photosynthesis?
A) hydrogen sulfide
B) carbon dioxide
C) oxygen
D) elemental sulfur
E) water

B11. Focusing on evolutionary change in populations, microevolution is best defined
A) as changes in allele frequencies over time.
B) solely as changes in behavior of individual members in the population as a result of changing environmental factors.
C) as a general lack of genetic diversity within a population.
D) as the mechanism that prevents speciation.
E) as a stabilizing aspect to prevent natural selection.

B12. Examine the image of a tRNA. The region identified by the box is called the




A) anticodon loop.
B) variable loop.
C) acceptor stem.
D) T-loop.
E) D-loop.

B13. Which of the following is an example of a secondary consumer?
A) cyanobacteria
B) plants
C) cattle
D) a hawk preying on a snake that primarily consumes rodents
E) a snake feeding mainly on grasshoppers

B14. Assume that Trait X is inherited in an autosomal recessive pattern. Trait X also exhibits 80% penetrance. Two people who are carriers for Trait X are expecting their first child. What is the probability of this couple having a child who exhibits Trait X?
A) 20%
B) 25%
C) 50%
D) 75%
E) 80%

B15. Genes *A* and *B* are linked. A cross between parents with genotypes *AaBb* and *aabb* yields the following progeny:

| | |
|---|---|
| *AaBb* | 302 |
| *Aabb* | 53 |
| *aaBb* | 55 |
| *aabb* | 298 |

What is the recombination frequency between the two linked loci?
A) 7.6%
B) 15.3%
C) 42.3%
D) 84.7%
E) Recombination cannot take place between two linked loci.

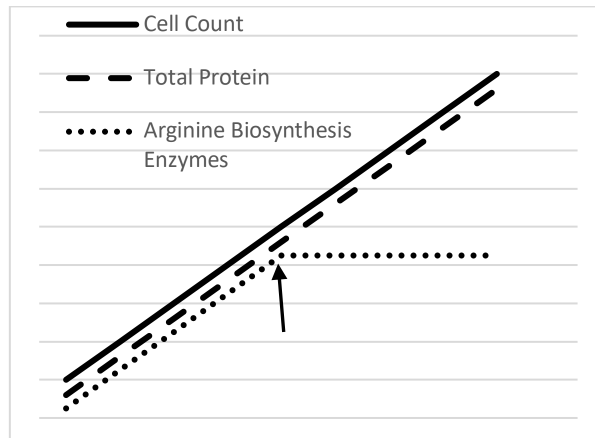
B16. Which of the following is not an example of active transport?
A) The modification of glucose to glucose-6~P upon entry into the cell through group translocation.
B) The hydrolysis of ATP to move a substance up its concentration gradient.
C) The use of a hydrogen ion gradient (proton motive force) to transport a sugar across the plasma membrane.
D) The movement of ions across the cell membrane via channel proteins.
E) All of the above are examples of active transport.

B17. In December 2019, health officials in Wuhan, China reported a number of novel coronavirus cases in the human population. These cases were originally associated with transmission from snakes to humans via bats, but the snake-origin hypothesis has since been rejected. All of the following are facts about coronaviruses, in general, except they
A) are zoonotic.
B) are the etiological agents for severe syndromes called SARS and MERS.
C) can cause respiratory symptoms.
D) have an RNA genome.
E) cannot be detected using nucleic acid amplification techniques, such as real-time RT-PCR.

B18. Species A has a 2n of 16 and the closely-related Species B has a 2n of 12. The gametes of both are able to hybridize and generate zygotes, a process called allopolyploidy. How many different types of chromosomes could a 3n zygote have from this hybridization?
A) 6 or 8
B) 12 or 16
C) 20 or 22
D) 28
E) Not enough information to determine the answer.

B19. Ribosomes form peptide bonds between adjacent amino acids. In bacteria, the peptidyltransferase activity of the ribosome is catalyzed by the
A) 5S rRNA.
B) 16S rRNA.
C) 23S rRNA.
D) 28S rRNA.
E) 30S subunit.

B20. The arginine operon of *Escherichia coli* is controlled depending on the presence or absence of arginine, an amino acid, within the growth media. Examine the graph below of *E. coli* cell count, total protein, and arginine biosynthesis enzyme concentration versus time. The solid line indicates total cell count. The dashed line indicates the total amount of cellular protein. The dotted line indicates the concentration of arginine biosynthesis enzymes in the population. The small arrow represents the addition of arginine to the bacterial growth media. Interpret the gene expression regulation mechanism for the *E. coli* arginine operon.




A) The *arg* operon is activated by the addition of arginine to the growth media.
B) The *arg* operon is under positive control and requires the presence of arginine in the media to be active.
C) The *arg* operon is constitutively (continuously) expressed.
D) The *arg* operon is under negative control and is repressed in the presence of high levels of arginine.
E) The *arg* operon is under negative control and is induced in the presence of exogenous arginine.

C01. Which of these compounds is not likely to exist?

A) Boron trichloride
B) Carbon tetrabromide
C) Nitrogen triiodide
D) Oxygen trifluoride
E) Sulfur hexafluoride

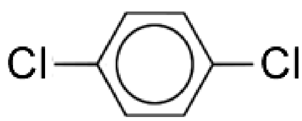
C02. What is the lowest whole-number coefficient on $H_2O$ in the balanced equation for the reaction between potassium permanganate and zinc in acidic solution?

A) 1
B) 2
C) 4
D) 6
E) 8

C03. How much energy is required to remove an electron from a hydrogen atom if that electron is in the third energy level?

A) $2.42 \times 10^{-19}$ J
B) $1.63 \times 10^{-18}$ J
C) $1.94 \times 10^{-18}$ J
D) $2.04 \times 10^{-18}$ J
E) $2.18 \times 10^{-18}$ J

C04. How many delocalized electrons are in a molecule of para-dichlorobenzene?

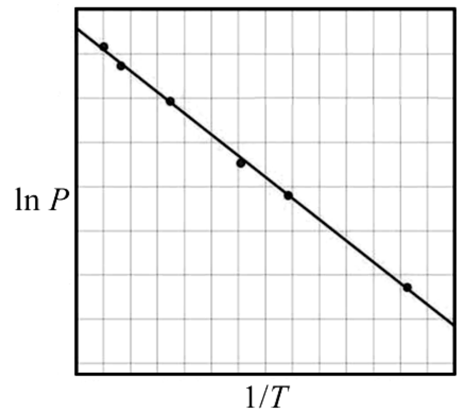



A) 2
B) 3
C) 4
D) 6
E) 12

C05. If 2.00 grams of He and 20.0 grams of $CO_2$ are placed in a flexible-walled container at 1750 torr and 15°C, what will the volume of the container be?

A) 0.51 L
B) 9.80 L
C) 11.8 L
D) 21.4 L
E) 22.4 L

C06. The vapor pressure *P* of an unknown liquid is measured at six different temperatures *T*, and ln *P* is plotted against 1/*T* (in 1/K) resulting in a straight-line graph. If the slope of the line is –4643 K, which of these liquids could it be?




A) Ethanol
B) Acetone
C) Methanol
D) Water
E) Isopropyl alcohol

C07. Four blocks of water ice, each weighing 0.25 kg and at –5°C, are added to 5.0 L of liquid ethylene glycol at 30°C. What is the final temperature of the solution?

A) 4.23 °C
B) 3.30 °C
C) 2.52 °C
D) 1.94 °C
E) 0.33 °C

C08. While having lunch at McDonald's you can't help but notice the phase changes happening all around you. Which of these processes would have the most exothermic $\Delta H$ per gram of water?

A) ice melting in your drink
B) water evaporating from a freshly-mopped floor
C) water vapor condensing on the outside of your drink cup
D) water freezing in the ice machine
E) they are all equal

C09. The enthalpy of reaction for

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

is 57.2 kJ/mol. Which of these changes will favor the reverse reaction?

A) Increasing the volume of the container at constant temperature
B) Decreasing the volume of the container at constant temperature
C) Increasing the temperature at constant pressure
D) Increasing the pressure by adding more $N_2O_4$ to the container
E) Increasing the pressure by adding helium to the container

C10. 200 grams of solid barium bromate ($K_{sp} = 2.43 \times 10^{-4}$) is added 10 L of water and shaken until the solution is saturated. A 5.55 L sample of the solution is removed from the container and is evaporated to dryness. What is the mass of the dry barium bromate?

A) 0.53 g
B) 1.58 g
C) 33.7 g
D) 85.8 g
E) 135 g

C11. What is the molarity of pure water? Assume a density of 1.00 g/mL.

A) 0.00
B) 1.00
C) 18.0
D) 33.3
E) 55.5

C12. In acidic solution, $Cr_2O_7^{2-}$ oxidizes $Fe^{2+}$ to $Fe^{3+}$ and is reduced to $Cr^{3+}$. Calculate the molarity of a $FeSO_4$ solution if 80.0 ml of this solution requires 74.80 ml of 0.0452 M $K_2Cr_2O_7$ for the reaction to go to completion.

A) 0.254 M
B) 0.0423 M
C) 0.423 M
D) 0.127 M
E) 0.0203 M

C13. Based on the reaction data below, what is the rate law for the reaction

$$2\ AB(g) + 2\ C_2(g) \rightarrow A_2(g) + 2\ C_2B(g)$$

| Experiment | [AB] (M) | [$C_2$] (M) | Initial rate (M/s) |
|---|---|---|---|
| 1 | 0.250 | 0.250 | $1.267 \times 10^{-4}$ |
| 2 | 0.400 | 0.250 | $2.027 \times 10^{-4}$ |
| 3 | 0.400 | 0.400 | $5.190 \times 10^{-4}$ |

A) rate = $k\,[AB]^2[C_2]$
B) rate = $k\,[AB]^2[C_2]^2$
C) rate = $k\,[AB][C_2]$
D) rate = $k\,[AB][C_2]^2$
E) rate = $k\,[AB][C_2]^3$

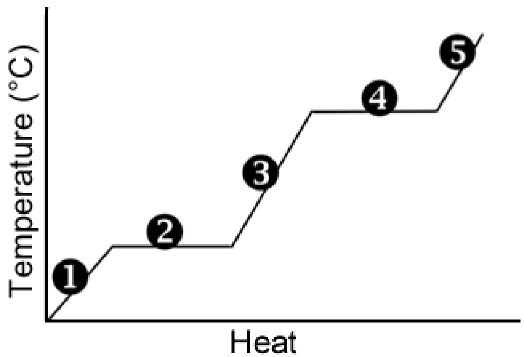
C14. When a car's tire pressure is measured with a pressure gauge, the gauge reading is equal to the *difference* in pressure between the air inside the tire and the air outside the tire. If a car's tire gauge reads 32.5 psi on a day when the barometric pressure is 29.92 inches of mercury, what is the actual pressure inside the tire?

A) 62.4 psi
B) 47.2 psi
C) 2.58 psi
D) 33.5 psi
E) 32.5 psi

C15. If 80 mL of 0.1 M HCl is added to 100 mL of 0.1 M $NH_3$ ($K_b = 1.8 \text{ x } 10^{-5}$), which answer choice below best describes the concentration ranking from most concentrated to least concentrated of these species?

A) $[NH_3] > [NH_4^+] > [OH^-] > [H^+]$
B) $[NH_3] > [NH_4^+] > [H^+] > [OH^-]$
C) $[NH_4^+] > [NH_3] > [OH^-] > [H^+]$
D) $[NH_4^+] > [NH_3] > [H^+] > [OH^-]$
E) $[NH_4^+] \approx [NH_3] > [H^+] \approx [OH^-]$

C16. Heat is applied to a sample of solid ice until the entire sample is converted to hot vapor. The heating curve for the process is shown here (not to scale). If each of the heat values given below corresponds to one line segment in the heating curve, which heat value corresponds to the line segment labeled 4?




A) 4232 J
B) 5481 J
C) 45,090 J
D) 56,484 J
E) 305,100 J

C17. A silver chloride electrode is a commonly used reference electrode in place of the standard hydrogen electrode (SHE). If the silver chloride electrode had been chosen as the 0.00 V standard instead of the SHE, what would the standard reduction potential be for the reduction of $Sn^{4+}$ to $Sn^{2+}$?

A) –0.15 v
B) –0.07 v
C) 0.00 v
D) +0.07 v
E) +0.15 v

C18. A student has 100 mL of a nitric acid solution with a pH of 2.30 and adds 50.0 mL of a nitric acid solution with a pH of 1.30. What is the pH of the resulting solution?

A) 1.70
B) 1.80
C) 1.97
D) 2.30
E) 3.60

C19. You have a closed container containing a liquid in equilibrium with its vapor. Which of these processes will result in a greater number of molecules evaporating from the liquid into the gas phase at equilibrium?

I. shaking the container
II. turning the container on its side to increase the surface area of the liquid
III. heating the container
IV. adding a solid solute to the liquid in the container
V. adding more liquid to the container

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

C20. Although the Bohr model of the atom was a major step forward, what was one drawback to the model that indicated from the outset that it was not entirely correct?

A) Energy level calculations based on the Bohr model were correct only for atoms and ions that have only one electron.
B) The energy levels in a Bohr atom get closer together as you move farther out from the nucleus instead of getting farther apart.
C) The Bohr model could still not explain the atomic emission line spectrum for any element.
D) Some energy levels in the Bohr model contained more electrons than other energy levels did.
E) In Bohr's "solar system" model atoms were flat disks, but atoms were known to be spherical.

P01. According to Rovelli, one of the principal attempts to resolve the contradictions between quantum mechanics and general relativity is the theory known as…
A) Supersymmetric quantum theory
B) Statistical mechanics
C) Multidimensional string theory
D) Loop quantum gravity
E) Quantum chromodynamics

P02. According to Rovelli, quantum mechanics describes subatomic particles as…
A) tiny, unconnected, vibrating strings.
B) great waves rippling across space-time.
C) pebble-like objects smaller than an atomic nucleus.
D) supersymmetric linked loops of space and time.
E) elementary excitations of corresponding fields.

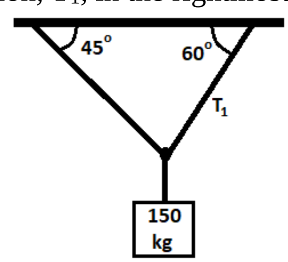
P03. According to Rovelli, heat energy flows from hot objects into cold objects because …
A) energy of any kind must always flow to regions of lower potential.
B) the second law of thermodynamics predicts that heat must flow that way.
C) experimental evidence shows it to be true.
D) the interaction of time flow and energy flow requires heat to flow that way.
E) that direction of heat flow is most probable.

P04. During the early universe (immediately following the Big Bang), nucleosynthesis produced nuclei of helium and lithium. Roughly how long did this period of nucleosynthesis last?
A) a few milliseconds
B) a few seconds
C) a few minutes
D) a few hours
E) a few hundred hours

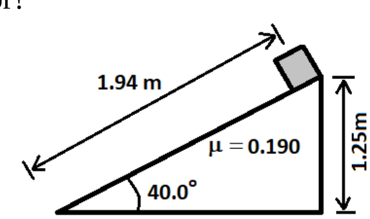
P05. On average, in the Chihuahuan desert, geologic weathering processes remove one cubic inch of rock every day from an exposed outcrop. If the average density of the rock is 2400 $kg/m^3$, what mass of rock is eroded in one year?
A) 59.8 kg/year
B) 36.6 kg/year
C) 14.4 kg/year
D) 5.67 kg/year
E) 2.23 kg/year

P06. While whitewater rafting on the Arkansas River, you are initially travelling due East at 10.5 m/s. Your raft is then pushed by a stray current, which causes a Northward acceleration of 1.91 $m/s^2$. The current accelerates your raft until you have travelled East for a distance of 13.0 m. After passing through that stray current, at what angle (relative to due East) are you now travelling?
A) 24.2°
B) 12.7°
C) 10.3°
D) 7.94°
E) 6.42°

P07. A mass of 150.0 kg is held aloft by several ropes as shown. Find the tension, $T_1$, in the rightmost rope.
A) 761 N
B) 984 N
C) 1080 N
D) 1220 N
E) 1470 N

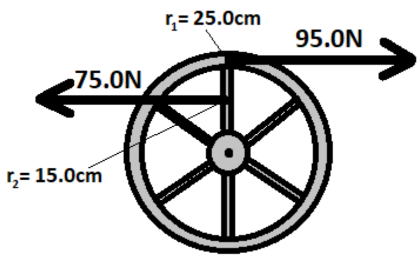



P08. A crate of coffee is placed at the top of an inclined plane, at a point that is 1.25 m above the floor. The plane is inclined at an angle of 40.0° above the horizontal; and the total length of the inclined plane is 1.94 m (as shown). The coefficient of friction between the plane and the crate is 0.190. After it is released, the crate of coffee slides down the incline. What is the speed of the crate when it reaches the floor?
A) 2.35 m/s
B) 3.08 m/s
C) 3.50 m/s
D) 4.35 m/s
E) 4.95 m/s



P09. James Bond is trying to close a wheel valve that is releasing poisonous gas. He exerts a force of 95.0N on the edge of the wheel, 25.0cm from the axle. The evil Hugo Drax is exerting an opposing force of 75.0N on one of the spokes of the wheel valve, 15.0cm from the axle. Both forces are perpendicular to the spoke, and the wheel valve has a total inertia of $6.0 kgm^2$. If the wheel valve starts from rest, and assuming the forces remain constant, then how long does it take James Bond to turn the valve by 180° to close it?

A) 1.04 s
B) 1.23 s
C) 1.37 s
D) 1.55 s
E) 1.74 s

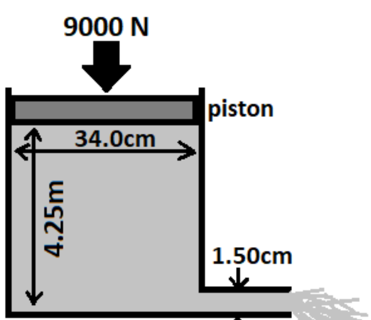



P10. You are driving along the highway at a speed of 28.0m/s. A state trooper is travelling in the opposite direction, moving towards you at an unknown speed. The siren on the trooper's car emits a frequency of 450.0Hz when stationary, but on the highway, you hear the trooper's siren at a frequency of 610.0Hz. If the air temperature is 20.0°C, then how fast is the trooper driving?

A) 69.3 m/s
B) 84.0 m/s
C) 94.0 m/s
D) 111 m/s
E) 160 m/s

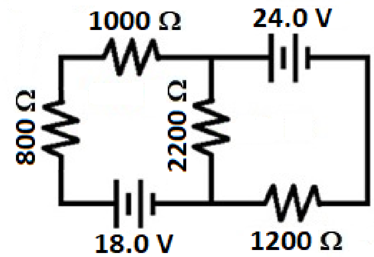
P11. A piston with a diameter of 34.0cm is pushed down by a force of 9000.0N into a cylinder full of water. The cylinder of water is 4.25m deep and has a small pipe connected at the bottom. The pipe has a diameter of 1.50cm and empties into an open pond. What is the speed of the water as it sprays out of the open end of the pipe?

A) 9.13 m/s
B) 10.1 m/s
C) 14.1 m/s
D) 16.8 m/s
E) 20.0 m/s



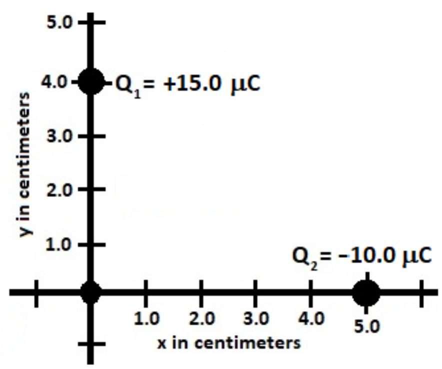

P12. In this circuit, what is the current flowing in the 1200 Ω resistor?

A) 10.9 mA
B) 7.40 mA
C) 6.44 mA
D) 2.47 mA
E) 0.959 mA

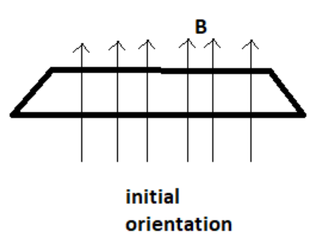


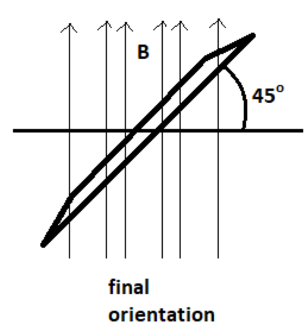

P13. Two charges are arranged as shown. A $+15.0\mu C$ charge is located at (0.0, 4.0cm) and a $-10.0\mu C$ charge is located at (5.0cm, 0.0). What is the direction (relative to the positive x-axis) of the electric field at the origin (0.0, 0.0) due to these two charges?

A) -23.1°
B) -33.7°
C) -38.7°
D) -56.3°
E) -66.9°




P14. A rectangular loop of wire is 20.0cm long and 15.0cm wide. The loop has an internal resistance of 1.80Ω. A magnetic field of 9000 Gauss passes through the loop, perpendicular to the face of the loop. If the loop is suddenly tilted to an angle of 45.0° from its original orientation in a time of 15.0ms, then what is the average current induced in the loop?

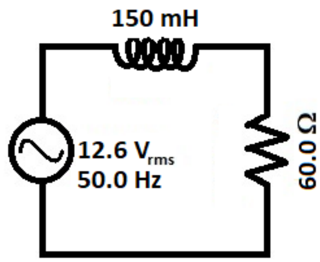



A) 0.293 A
B) 0.527 A
C) 0.707 A
D) 1.00 A
E) 1.41 A

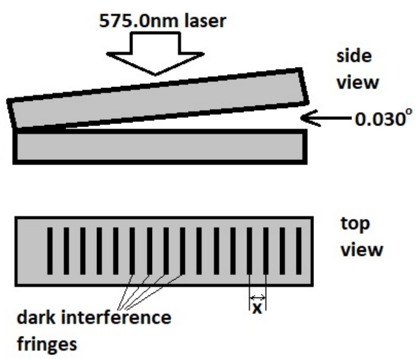
P15. For this AC circuit, determine the magnitude of the current (rms) flowing through the 60.0Ω resistor.

A) 60.0 mA
B) 102 mA
C) 130 mA
D) 165 mA
E) 210 mA




P16. An air wedge is formed between two flat plates of glass (as shown). The angle between the plates is 0.030°. A laser with a wavelength of 575.0nm is directed onto the glass plates from above. How far apart, horizontally, are the dark fringes resulting from thin film interference in the air wedge?

A) 0.55 mm
B) 1.1 mm
C) 2.2 mm
D) 4.4 mm
E) 6.6 mm




P17. After a violent supernova, a planet from the exploded star system is hurled into space at 0.77c. You are piloting a spacecraft travelling at 0.90c, flying to catch up with the runaway planet. From the surface of the planet, at what speed does your spacecraft appear to be approaching?

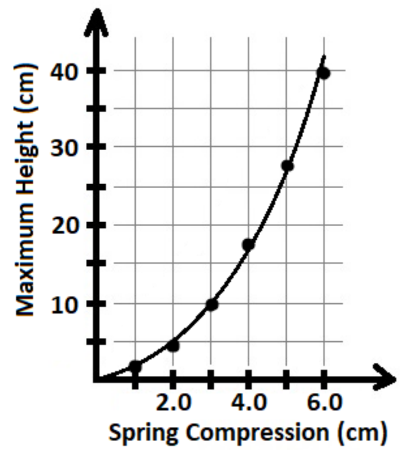
A) 0.077c
B) 0.13c
C) 0.42c
D) 0.84c
E) 0.99c

P18. What is the binding energy per nucleon of Ytterbium-164 ($^{164}_{70}Yb$)? The mass of a nucleus of this isotope of Ytterbium is 163.934489amu.

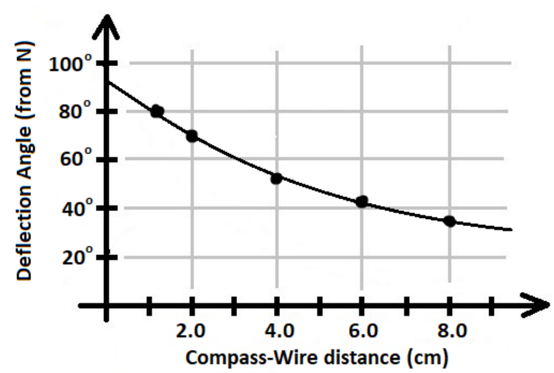
A) 7.89 MeV/nucleon
B) 8.28 MeV/nucleon
C) 12.9 MeV/nucleon
D) 13.8 MeV/nucleon
E) 18.5 MeV/nucleon

P19. A ball with a mass of 210.0g is placed on a vertical spring. The ball is pressed down, compressing the spring, and then released. The maximum height (measured from the release point) to which the ball launches is measured for different spring compression amounts. The data is graphed below. From this data, estimate the spring constant of the spring.

A) 15 N/m
B) 30 N/m
C) 110 N/m
D) 230 N/m
E) 450 N/m




P20. A wire carrying a constant DC current is arranged so that the current flows South→North. A compass is held directly above the wire, and the deflection of the compass from true North is measured as a function of the distance between the compass and the wire. The data is graphed below. From this data, estimate the current flowing in the wire. Note: the strength of Earth's magnetic field is $5.0 \times 10^{-5}$ Tesla.




A) 2.7 A
B) 7.5 A
C) 13.5 A
D) 47.3 A
E) 83.3 A

## Chemistry

| 1A 1 | 2A 2 | 3B 3 | 4B 4 | 5B 5 | 6B 6 | 7B 7 | 8B 8 | 8B 9 | 8B 10 | 1B 11 | 2B 12 | 3A 13 | 4A 14 | 5A 15 | 6A 16 | 7A 17 | 8A 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H 1.01 | | | | | | | | | | | | | | | | | 2 He 4.00 |
| 3 Li 6.94 | 4 Be 9.01 | | | | | | | | | | | 5 B 10.81 | 6 C 12.01 | 7 N 14.01 | 8 O 16.00 | 9 F 19.00 | 10 Ne 20.18 |
| 11 Na 22.99 | 12 Mg 24.31 | | | | | | | | | | | 13 Al 26.98 | 14 Si 28.09 | 15 P 30.97 | 16 S 32.07 | 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°C
$T_{bp}$ = 100°C
$c_{ice}$ = 2.09 J/g·K
$c_{water}$ = 4.184 J/g·K
$c_{steam}$ = 2.03 J/g·K
$\Delta H_{fus}$ = 334 J/g
$\Delta H_{vap}$ = 2260 J/g
$K_f$ = 1.86 °C/$m$
$K_b$ = 0.512 °C/$m$

Constants

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

Standard Reduction Potentials

| | |
|---|---|
| $Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$ | 1.36 v |
| $Ag^+(aq) + e^- \rightarrow Ag(s)$ | 0.80 v |
| $Sn^{4+}(aq) + 2e^- \rightarrow Sn^{2+}(aq)$ | 0.15 v |
| $AgCl(s) + e^- \rightarrow Ag(s) + Cl^-(aq)$ | 0.22 v |
| $2H^+(aq) + 2e^- \rightarrow H_2(g)$ | 0.00 v |

Physical data for ethylene glycol (ℓ)

specific heat = 2.41 J/gK
density = 1.113 g/mL

Enthalpy of vaporization for selected liquids

| Compound | $\Delta H_{vap}$ (kJ/mol) |
|---|---|
| Ethanol | 38.6 |
| Acetone | 31.3 |
| Methanol | 35.2 |
| Water | 40.7 |
| Isopropyl alcohol | 41.0 |

Pressure Unit Conversions

1 inch = 25.4 mm
760 mm Hg = 1 atm
1 atm = 14.7 psi

# Physics

## Useful Constants

| quantity | symbol | value |
|---|---|---|
| Free-fall acceleration | g | $9.80\ m/s^2$ |
| Permittivity of Free Space | $\varepsilon_0$ | $8.854 \times 10^{-12}\ C^2/Nm^2$ |
| Permeability of Free Space | $\mu_0$ | $4\pi \times 10^{-7}\ Tm/A$ |
| Coulomb constant | k | $8.99 \times 10^{9}\ Nm^2/C^2$ |
| Speed of light in a vacuum | c | $3.00 \times 10^{8}\ m/s$ |
| Fundamental charge | e | $1.602 \times 10^{-19}\ C$ |
| Planck's constant | h | $6.626 \times 10^{-34}\ Js$ |
| Electron mass | $m_e$ | $9.11 \times 10^{-31}\ kg$ |
| Proton mass | $m_p$ | $1.67265 \times 10^{-27}\ kg$<br>$1.007276 amu$ |
| Neutron mass | $m_n$ | $1.67495 \times 10^{-27}\ kg$<br>$1.008665 amu$ |
| Atomic Mass Unit | amu | $1.66 \times 10^{-27}\ kg$<br>$931.5\ MeV/c^2$ |
| Gravitational constant | G | $6.67 \times 10^{-11}\ Nm^2/kg^2$ |
| Stefan-Boltzmann constant | σ | $5.67 \times 10^{-8}\ W/m^2K^4$ |
| Universal gas constant | R | $8.314\ J/mol \cdot K$<br>$0.082057\ L \cdot atm/mol \cdot K$ |
| Boltzmann's constant | $k_B$ | $1.38 \times 10^{-23}\ J/K$ |
| Speed of Sound (at 20ºC) | v | 343 m/s |
| Avogadro's number | $N_A$ | $6.022 \times 10^{23}\ atoms/mol$ |
| Electron Volts | eV | $1.602 \times 10^{-19}\ J/eV$ |
| Distance Conversion | miles → meters | 1.00 mile = 1609 meters |
| Rydberg Constant | $R_\infty$ | $1.097 \times 10^{7}\ m^{-1}$ |
| Standard Atmospheric Pressure | 1 atm | $1.013 \times 10^{5}\ Pa$ |
| Density of Pure Water | $\rho_{water}$ | $1000.0\ kg/m^3$ |

**DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!**

# UIL HIGH SCHOOL SCIENCE CONTEST
# ANSWER KEY
# 2021 REGIONAL

| Biology | | Chemistry | | Physics | |
|---|---|---|---|---|---|
| B01. | E | C01. | D | P01. | D |
| B02. | D | C02. | E | P02. | E |
| B03. | E | C03. | A | P03. | E |
| B04. | B | C04. | D | P04. | C |
| B05. | C | C05. | B | P05. | C |
| B06. | A | C06. | A | P06. | B |
| B07. | C | C07. | B | P07. | C |
| B08. | B | C08. | C | P08. | D |
| B09. | B | C09. | B | P09. | E |
| B10. | D | C10. | D | P10. | A |
| B11. | A | C11. | E | P11. | D |
| B12. | A | C12. | A | P12. | C |
| B13. | E | C13. | D | P13. | E |
| B14. | A | C14. | B | P14. | A |
| B15. | B | C15. | C | P15. | D |
| B16. | D | C16. | E | P16. | A |
| B17. | E | C17. | B | P17. | C |
| B18. | C | C18. | A | P18. | A |
| B19. | C | C19. | C | P19. | E |
| B20. | D | C20. | A | P20. | C |

## CHEMISTRY SOLUTIONS – UIL REGIONAL 2021

C01. (D) Oxygen typically forms two bonds and has two lone pairs of electrons. In $OF_3$ you could put an octet on each atom and you would still have one more electron left, but nowhere to put it. Sulfur violates the octet rule in $SF_6$, but elements in $n$=3 and greater can do that.

C02. (E) The balanced equation is
$2KMnO_4(aq) + 5Zn(s) + 16H^+(aq) \rightarrow 2Mn^{2+}(aq) + 2K^+(aq) + 5Zn^{2+}(aq) + 8H_2O(\ell)$

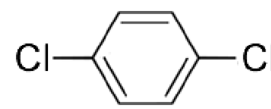
C03. (A) To calculate the energy difference between two energy levels in a hydrogen atom, use the Rydberg formula. Removing an electron entirely means moving it to the ∞ (infinity) energy level.

$$E = \mathcal{R}_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

$n_1 = 3$ and $n_2 = \infty$, so the equation becomes

$$E = 2.178 \times 10^{-18}\left(\frac{1}{9}\right) = 2.42 \times 10^{-19}\text{ J}$$

C04. (D) The delocalized electrons (represented by the circle in the benzene ring) are the three π bonds in the molecule. Since there are three π bonds in the molecule and each π bond is made up of two electrons, there are a total of six delocalized electrons in the molecule.




C05. (B) $P$ = 1750 torr = 2.30 atm $T$ = 15°C = 288 K
moles of He = (2.00 g He/4.00 g/mol) = 0.500 mol He
moles of $CO_2$ = (20.0 g/44.01 g/mol) = 0.454 mol $CO_2$
total moles of gas = 0.500 + 0.454 = 0.954 moles

$$V = \frac{nRT}{P} = \frac{(0.954)(0.08206)(288)}{2.3} = 9.80\text{ L}$$

C06. (A) The Clausius-Clapeyron equation says $\ln P = -\frac{\Delta H_{\text{vap}}}{RT} + C$, so if ln $P$ is plotted against 1/T, the slope of the line is equal to $-\Delta H_{vap}/R$. Multiplying the slope by $-R$ (–8.314 J/mol·K) gives us $\Delta H_{vap}$. $\Delta H_{vap} = -4643\text{ K}^{-1} \times 8.314$ J/mol·K = 38,602 J/mol, which matches the heat of vaporization for ethanol on the data page. Students are probably more familiar with the two-point Clausius-Clapeyron equation, but that equation is basically $\Delta\ln P = -\Delta H_{vap}/R \times \Delta 1/T$, so once again the slope of the line is rise over run ($\Delta\ln P$ over $\Delta 1/T$), and $\Delta\ln P/\Delta 1/T = -\Delta H_{vap}/R$.

C07. (B) The easiest way to solve this is to do it in two steps: first warm and melt the ice and see how much heat that requires. Then you have a mixture of liquid water at 0°C and cooled-down ethylene glycol and you can calculate the final temperature of both using the calorimetry equation.

Warming the ice to 0°C: $q = mc\Delta T$ = (1000 g)(2.09 J/gK)(5 K) = 10,450 J
Melting the ice: $q = m\Delta H_{fus}$ = (1000 g)(334 J/g) = 334,000 J
Total heat required so far = 344,450 J
Losing this much heat will cool the ethylene glycol: $q = mc\Delta T$, so $\Delta T = q/mc$

The mass of the ethylene glycol is (5000 mL)(1.113 g/mL) = 5565 g
$\Delta T = q/mc$ = (–344,450 J)/(5565 g)(2.41 J/gK) = –25.68°C. 30°C –25.68°C = 4.32°C.
The solution is now 5565 g of ethylene glycol at 4.32°C and 1000 g of water at 0°C.
$m_W c_W \Delta T_W = -m_{EG} c_{EG} \Delta T_{EG}$ (1000 g)(4.184 J/gK)($T_f$ – 0) = –(5565 g)(2.41 J/gK)($T_f$ – 4.32)
4184$T_f$ = –13,412$T_f$ + 57,938 17,596$T_f$ = 57,938 $T_f$ = 3.30°C

C08. (C) The choices here are freezing, melting, evaporation, and condensation. Freezing and condensation are exothermic. The $\Delta H$ for these processes are equal in magnitude but opposite in sign from the $\Delta H_{fus}$ and $\Delta H_{vap}$ given on the data page. Freezing is –334 J/g and condensation is –2260 J/g.

C09. (B) LeChatelier's Principle tells us that when you have a gas phase reaction and you increase the pressure, the equilibrium will shift toward the side with fewer gas moles in order to decrease the pressure. Decreasing the volume at constant temperature will increase the pressure, driving the equilibrium to the left. Choices A, C, and D will all drive the reaction forward, and answer E will have no effect.

C10. (D) $K_{sp} = [Ba^{2+}][BrO_3^-]^2$, $[BrO_3^-] = 2 \times [Ba^{2+}]$, $2.43\times10^{-4} = [x][2x]^2 = 4x^3$, $x$ = 0.03931 mol/L
0.03931 mol/L × 5.55 L = 0.2182 mol. 0.2182 mol × 393.13 g/mol = 85.8 g

C11. (E) (1000 g/L)(1 mole/18.02 g) = 55.5 mol/L

C12. (A) First write a balanced chemical equation for this oxidation-reduction reaction.

*reduction* $Cr_2O_7^{2-} + 14\,H^+ + 6\,e^- \rightarrow 2\,Cr^{3+} + 7\,H_2O$
*oxidation* $Fe^{2+} \rightarrow Fe^{3+} + e^- \quad \times \mathbf{6}$
*overall:* $Cr_2O_7^{2-} + 6\,Fe^{2+} + 14\,H^+ \rightarrow 2\,Cr^{3+} + 6\,Fe^{3+} + 7\,H_2O$

Then calculate how many moles of $K_2Cr_2O_7$ were used, use the balanced equation to determine how many moles of $FeSO_4$ this corresponds to, and divide by the volume to calculate the molarity. Moles $K_2Cr_2O_7$ = 45.2 × $10^{-3}$ M × 0.07480 L = 0.003381 moles

$$0.003381 \text{ moles } K_2Cr_2O_7 \times \frac{6 \text{ moles } Fe^{2+}}{1 \text{ mole } Cr_2O_7^{\;2-}} = 0.02029 \text{ moles } FeSO_4$$

$$\text{Molarity of } FeSO_4 = \frac{0.02029 \text{ moles } FeSO_4}{0.0800\ L} = 0.254 \text{ M}$$

C13. (D) This problem is very similar to one on the 2020 District test, except that on that exam the concentrations given were integer multiples (0.200 M and 0.400 M), making it easy to compare the concentration increase with the rate increase. In this problem the concentrations are not integer multiples (0.250 M and 0.400 M), making it more difficult to determine the relationship between concentration and rate. To determine the order with respect to AB, compare experiments 1 and 2: $([AB]_2/[AB]_1)^a = (rate_2/rate_1)$; $(0.400/0.250)^a = (2.027/1.267)$; $1.6^a = 1.6$, so $a = 1$. For $C_2$, compare experiments 2 and 3: $([C_2]_3/[C_2]_2)^b = (rate_3/rate_2)$; $(0.400/0.250)^b = (5.190/2.027)$; $1.6^b = 2.56$, so $b = 2$. The rate law is therefore rate = $k\,[AB][C_2]^2$.

C14. (B) First convert 29.92 inches of mercury to psi. Students who recognize 29.92" Hg as 1 atm will know it's 14.7 psi. Those who don't will have to convert inches of Hg to mm Hg to psi using information on the data page:
29.92" Hg × 2.54 cm/in × 10 mm/cm = 759.968 mm Hg = 1 atm = 14.7 psi.
The pressure inside the tire is equal to the gauge reading plus the outside pressure, so the actual pressure inside the tire is 32.5 psi + 14.7 psi = 47.2 psi.

C15. (C) The reaction starts with 0.010 moles of $NH_3$ and 0.008 moles of $H^+$. The $H^+$ will neutralize 0.008 mol of $NH_3$ to $NH_4^+$, leaving 0.002 mol $NH_3$ and 0.008 mol $NH_4^+$. Therefore $[NH_4^+] > [NH_3]$. The pH can be calculated using the Henderson-Hasselbalch equation, pH = p$K_a$ + log($[NH_3]/[NH_4^+]$). $K_a$ for $NH_4^+$ = $K_w/K_b = 5.56 \times 10^{-10}$, so the p$K_a$ is 9.26. The Henderson-Hasselbalch equation says pH = 9.26 + log(0.002/0.008) = 8.66. Therefore the solution is basic and $[OH^-] > [H^+]$. You don't actually need to calculate final concentrations to answer this question, but the final concentrations are $[NH_4^+]$ = 0.044 M, $[NH_3]$ = 0.011 M, $[OH^-] = 4.6 \times 10^{-6}$ $[H^+] = 2.2 \times 10^{-9}$.

C16. (E) These are the actual heat values for heating a 135 g sample of ice from –15°C to water vapor at 120°C. Line segment 4 corresponds to boiling the water, which is where the intermolecular forces in the liquid phase must be completely overcome, and this is by far the most energetically expensive part of the process. If the heating curve were drawn to scale, line 4 would be about 6.75 times as long as line 2 (45,090 J).

C17. (B) The standard reduction potential of $Sn^{4+}$ to $Sn^{2+}$ is +0.15 relative to SHE because the potential of this reaction is 0.15 v more positive than SHE. But it is 0.07 v less positive than the AgCl electrode (0.22 v), so if the AgCl electrode were 0.00, the $Sn^{4+}$ to $Sn^{2+}$ reduction potential would be –0.07 v.

C18. (A) To calculate the pH of the new solution, determine the total moles of $H^+$ and the total volume, then calculate pH from the molar concentration.
Moles of $H^+ = (0.100 \text{ L} \times 10^{-2.3}) + (0.050 \text{ L} \times 10^{-1.3}) = 5.012 \times 10^{-4} + 2.506 \times 10^{-3} = 3.007 \times 10^{-3}$ moles. Total volume = 0.150 L. $[H^+] = 3.007 \times 10^{-3}$ moles/0.150 L = $2.005 \times 10^{-2}$ M pH = 1.698 = 1.70

C19. (C) The vapor pressure above a liquid increases with increasing temperature (following the Clausius-Clapeyron equation – problem 6 should be a hint that the correct answer here must include heating the liquid). Adding a solute will lower the equilibrium vapor pressure of the liquid, but none of the other changes will have any effect.

C20. (A) Other choices: B: Yes, they do, just like they should. C: Yes it could, for hydrogen at least. D: They do, just like they should. E: Although Bohr's model is often compared to a solar system, atoms were not flat in his model, they were spherical.

## PHYSICS SOLUTIONS – UIL REGIONAL 2021

P01. (D) Page 40: "One of the principal attempts to solve the problem is a direction of research called 'loop quantum gravity'. pursued by a packed squad of researchers working in many countries. Loop quantum gravity is an endeavor to combine general relativity and quantum mechanics."

P02. (E) Page 30: "The nature of these particles, and the way they move, is described by quantum mechanics. These particles do not have a pebble-like reality but are rather the 'quanta' of corresponding fields, just as photons are the 'quanta' of the electromagnetic field. They are elementary excitations of a moving substratum similar to the field of Faraday and Maxwell."

P03. (E) Page 51: "Heat does not move from hot things to cold things due to an absolute law; it only does so with a large degree of probability. The reason for this is that it statistically more probable that a quickly moving atom of the hot substance collides with a cold one and leaves it a little of its energy, rather than vice versa."

P04. (C) Things happened rapidly in the early universe, and physics itself doesn't work until the inflationary period is finished, at about $10^{-32}$ seconds after the beginning. The four fundamental forces, as we currently understand them, were working by about $10^{-12}$ seconds after the beginning, and the first protons formed around $10^{-6}$ seconds after the beginning. Nucleosynthesis started about 10 milliseconds after the beginning and lasted for several minutes – enough time to form a significant quantity of helium, and trace amounts of lithium. After a few minutes the universe cooled enough to end the period of nucleosynthesis.

P05. (C) If one cubic inch is removed each day, then about $365\text{in}^3$ are removed each year. Now this volume needs to be converted into cubic meters using 1.0inch = 2.54cm = 0.0254m. Cubing this gives the volume conversion: $1.0\text{in}^3 = (0.0254\text{m})^3 = 1.64 \times 10^{-5}\text{m}^3$. Using this volume conversion gives an annual eroded volume of $V = 365(1.64 \times 10^{-5}) = 5.98 \times 10^{-3}\text{m}^3$. To find the mass, we use the density and the volume: $m = \rho V = (2400)(5.98 \times 10^{-3}) = 14.4\text{kg}$.

P06. (B) First, we notice that the acceleration is entirely in the Northward direction, meaning that the Eastward velocity component remains constant (there is no East-West acceleration). Mathematically, $v_{0E} = v_{fE} = 10.5\text{m/s}$. Using the Eastward velocity and Eastward distance, we find that the time it takes to travel 13.0m East is: $x = x_0 + vt = 13.0 = (10.5)t \quad \rightarrow \quad t = 1.24s$.
Now we can find the final velocity in the Northward direction after going through the stray current: $v_{fN} = v_{0N} + a_N t = 0 + (1.91)(1.24) = 2.36\text{m/s}$.
Finally, to get the angle, we use the vertical (North) and horizontal (East) velocity components: $\theta = tan^{-1}\left(\frac{v_{fN}}{v_{fE}}\right) = tan^{-1}\left(\frac{2.36}{10.5}\right) = 12.7°$.

P07. (C) This is a static equilibrium problem, meaning that all of the forces must balance in the horizontal and in the vertical. Mathematically: $\sum F_x = 0$ and $\sum F_y = 0$. The best approach is to look at the forces acting on the knot where the three ropes meet. There are three forces acting there: $T_1$ up and to the right, $T_2$ up and to the left, and $T_3$ down. It is easy to tell that the tension in the bottom rope must equal the weight of the hanging mass (based on the fact that $\sum F_y = 0$ for the hanging mass). Thus, $T_3 = mg = (150)(9.8) = 1470\text{N}$. Now, both $T_1$ and $T_2$ act at angles, so they must be broken into components. We must also be careful with the signs (left versus right, and up versus down): $T_{1x} = T_1\cos(60)$, $T_{1y} = T_1\sin(60)$, $T_{2x} = -T_2\cos(45)$, and $T_{2y} = T_2\sin(45)$. Summing up the horizontal forces gives: $\sum F_x = T_1\cos(60) - T_2\cos(45) = 0 \quad \rightarrow \quad (0.5)T_1 = (0.7071)T_2$, leading to the relation: $T_2 = 0.7071T_1$. In the vertical we have $\sum F_y = T_1\sin(60) + T_2\sin(45) - T_3 = 0$, which leads to $(0.866)T_1 + (0.7071)T_2 = T_3 = 1470$. Plugging in the relation we got from the horizontal forces, this becomes: $(0.866)T_1 + (0.7071)(0.7071)T_1 = 1470 \quad \rightarrow \quad 1.366T_1 = 1470$. Thus, the tension in the rightmost rope is $T_1 = 1076 \approx 1080\text{N}$.

P08. (D) You can solve this problem with forces/kinematics or with energy, but it is a little easier with energy, so that is how I will solve it. The crate begins entirely with gravitational potential energy and ends with kinetic energy. In between, some energy is converted to heat by friction. Let's start with the energy converted to heat – the work done by the frictional force as the crate slides down the incline. Mathematically, $W = F_f d$. The length of the incline, $d$, is given – so we just need to find the frictional force: There are three forces acting on the crate: gravity ($mg$), the normal force ($F_N$) and friction ($F_f$). Tilting our coordinate system so that the x-axis is parallel to the plane and the y-axis is perpendicular to it, we arrange it so that the normal force is in the positive y-direction and the frictional force is in the negative x-direction. Gravity must be broken into components, giving: $(mg)_x = mgsin(40°)$ (positive x-direction) and $(mg)_y = mgcos(40°)$ (negative y-direction). Noting that there is no motion in the y-direction (perpendicular to the plane), and summing up the forces gives: $\sum F_y = F_N - mgcos(40) = 0 \quad \rightarrow \quad F_N = mgcos(40)$. This allows us to determine the frictional force: $F_f = \mu F_N = \mu mgcos(40)$.

You may notice at this point that we do not know the mass of the crate. That tells us that it will probably cancel in the end, but it means that we must keep everything symbolic for now.

The work done by the frictional force is then $W = \mu mgcos(40)d$. As for the remaining two forms of energy, we start with gravitational potential energy: $GPE = mgh$ and we end with kinetic energy, $KE = \frac{1}{2}mv^2$. By conservation of energy, the kinetic energy at the end must equal the initial gravitational potential energy minus the work done by friction. Mathematically, this gives us $KE = GPE - W \quad \rightarrow \quad \frac{1}{2}mv^2 = mgh - \mu mgcos(40)d$. As expected, the mass cancels, and we get $\frac{1}{2}v^2 = gh - \mu gcos(40)d = (9.8)(1.25) - (0.19)(9.8)(1.94)\cos(40) = 12.25 - 2.767 = 9.48$. This gives a velocity of $v = \sqrt{2(9.48)} = 4.35$m/s.

P09. (E) We begin by calculating the net torque on the wheel valve. There are two forces that result in torques – the force exerted by James Bond, and the force exerted by Hugo Drax. If we take clockwise to be positive (this is not typical but makes sense for this problem) then James Bond's torque is positive and Hugo Drax's torque is negative. Noting that the forces are perpendicular to the spoke, and recalling that torque is a force multiplied by a torque-arm distance, we get:
$\sum \tau = F_{JB}R_{JB}sin\theta_{JB} - F_{HD}R_{HD}sin\theta_{HD} = (95.0)(0.25)\sin(90) - (75.0)(0.15)\sin(90) = 12.5$Nm.

Now that we know the torque, we can find the angular acceleration of the wheel valve. Torque is related to angular acceleration by: $\sum \tau = I\alpha$. Since we know the rotational inertia, we get: $12.5 = (6.0)\alpha \quad \rightarrow \quad \alpha = 2.08$rad/s$^{2}$. Finally, we use an angular kinematic equation to determine the time it takes for the value to be turned by 180° (3.14 radians):

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2 \quad \rightarrow \quad 3.14 = 0 + 0 + (0.5)(2.08)t^2 \quad \rightarrow \quad t = \sqrt{\frac{3.14}{1.04}} = 1.74\text{s}.$$

P10. (A) This is a Doppler effect problem in which both the source (the trooper) and the observer (you) are moving. The general equation for the Doppler effect is $f = f_0\left(\frac{v \pm v_o}{v \mp v_s}\right)$ where $v$ is the speed of sound, and $v_o$ and $v_s$ are the speed of the observer and source, respectively. Since the observer is moving towards the source, $v_o$ is added in the numerator. However, since the source is moving towards the observer, $v_s$ is subtracted in the denominator. At a temperature of 20.0°C, the speed of sound is 343m/s. Putting this all together, we get: $610 = (450)\left(\frac{343+28}{343-v_s}\right) \quad \rightarrow \quad \frac{610}{450} = \frac{371}{343-v_s} = 1.3556 \quad \rightarrow \quad 273.69 = 343 - v_s$. This gives a source velocity of $v_s = 69.3$ m/s.

P11. (D) This is an application of Bernoulli's equation relating the pressure at one point (A) in a connected fluid to another point (B) in the fluid: $P_A + \rho g h_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g h_B + \frac{1}{2}\rho v_B^2$. For our two points, I will choose point A to be at the piston, and point B at the opening of the pipe where it empties into the pond. We will take the height of point B to be zero, so the height of point A is 4.25m. The fluid velocity at point A is essentially zero (the piston may be moving a little, but its motion is insignificant. The absolute pressure at point B is just atmospheric pressure (it is open to air), but the pressure at point A is the sum of atmospheric pressure (the atmosphere is also pushing down on the piston) and the piston pressure resulting from the applied force. Let's begin with that applied piston pressure: Noting that the radius of the piston is 17.0cm = 0.17m, then we get $P = \frac{F}{A} = \frac{F}{\pi r^2} = \frac{9000}{\pi(0.17)^2} = 99130$ Pa. Putting this all into Bernoulli's equation, and recalling that the density of water is 1000kg/m$^3$ gives us the following result:

$P_A + \rho g h_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g h_B + \frac{1}{2}\rho v_B^2 \quad \rightarrow$

$(P_{atm} + 99130) + (1000)(9.8)(4.25) + 0 = P_{atm} + 0 + (0.5)(1000)v_B^2$. Cancelling out the atmospheric pressure and simplifying gives:

$99130 + 41650 = 500v_B^2 \quad \rightarrow \quad 140780 = 500v_B^2$. This gives a final velocity of the water as it exits the pipe of $v_B = \sqrt{281.6} = 16.8$ m/s.

P12. (C) This type of circuit, with two voltage sources, can best be solved by using Kirchhoff's Laws. To begin, I will choose currents: in the left branch will be $I_1$ directed upward through the 800Ω resistor; in the middle branch will be $I_2$ directed downward through the 2200Ω resistor, and in the right branch will be $I_3$ directed rightward through the 1200Ω resistor. Applying Kirchhoff's node rule at the topmost node gives the first equation: $I_1 + I_3 = I_2$. Now, going around the left-hand loop in a clockwise direction gives us the second equation: $18 - 800I_1 - 1000I_1 - 2200I_2 = 0$. Finally, going around the right-hand loop in a counterclockwise direction gives: $24 - 2200I_2 - 1200I_3 = 0$. Using the node equation to substitute for $I_2$ and simplifying gives the following two equations:

$4000I_1 + 2200I_3 = 18$ and $2200I_1 + 3400I_3 = 24$. Solving these two equations does take a bit of algebra, but the end result is $I_1 = 0.000959$A and $I_3 = 0.00644$A. Note that we are looking for the current through the 1200Ω resistor, which happens to be $I_3$. Thus, the answer to the question is $I = 0.00644A = 6.44mA$. By the way, $I_2 = 0.00740$A even though we don't care.

P13. (E) The total electric field at the origin is the vector sum of the individual electric fields created by the charges. So, starting with $Q_1$, and converting the distance to meters, the electric field magnitude due to the first charge is $|E_1| = \left|\frac{kQ_1}{r_1^2}\right| = \left|\frac{(8.99 \times 10^9)(15.0 \times 10^{-6})}{(0.04)^2}\right| = 8.43 \times 10^7$ N/C. And the electric field magnitude due to the second charge is $|E_2| = \left|\frac{kQ_2}{r_2^2}\right| = \left|\frac{(8.99 \times 10^9)(10.0 \times 10^{-6})}{(0.05)^2}\right| = 3.60 \times 10^7$ N/C

Now we must consider the directions of the two component fields: the field $E_1$ is directed away from the positive charge $Q_1$, so at the origin it will be pointed in the negative y-direction. The field $E_2$ is directed towards the negative charge $Q_2$, so at the origin it will be pointed in the positive x-direction. These fields are perpendicular to one another, so we don't have to do any additional combining – we can just go ahead and calculate the angle of the field at the origin: $\theta = tan^{-1}\left(\frac{E_y}{E_x}\right) = tan^{-1}\left(\frac{-|E_1|}{|E_2|}\right)$.

Plugging in the numbers, we get $\theta = tan^{-1}\left(\frac{-8.43\times10^7}{3.60\times10^7}\right) = tan^{-1}(-2.34) = -66.9°$.

P14. (A) The average current induced in the loop can be found from Faraday's Law. Since we are only concerned about the average current, we can use the difference form, as opposed to the differential form of the law. Faraday's Law gives us the induced voltage, from which we can find the induced current: $V_{ind} = \frac{\Delta\Phi_B}{\Delta t}$, and $I_{ind} = \frac{V_{ind}}{R}$.
First, we need to find the change in magnetic flux through the loop. The magnetic flux through the loop is given by $\Phi_B = |B|Acos\theta$. The magnetic field is constant, as is the shape/area of the loop. The only thing that changes is the orientation of the loop – the angle. So the change in magnetic flux is: $\Delta\Phi_B = \left||B|Acos\theta_2 - |B|Acos\theta_1\right| = \left||B|A(\cos(45) - \cos(0))\right| = 0.2929BA$. The magnetic field needs to be in units of Tesla: $B = 9000G = 0.9000T$, and since the loop is rectangular we can easily find the area (in square meters): $A = lw = (0.20m)(0.15m) = 0.030\text{m}^2$. Putting it all together, we get a change in magnetic flux of $\Delta\Phi_B = 0.2929(0.9000)(0.030) = 0.00791\text{Tm}^2$. Dividing by the time to turn the loop, we get an induced voltage of $V_{ind} = \frac{\Delta\Phi_B}{\Delta t} = \frac{0.00791}{15\times10^{-3}} = 0.527\ V$. Finally, we can determine the average induced current: $I_{avg} = \frac{0.527}{1.8} = 0.293\text{A}$.
Note: You can solve this problem with derivatives and integral averages, but you will end up with exactly the same result.

P15. (D) To begin, we need to find the reactance of the inductor. Inductive reactance is $X_L = \omega L = 2\pi f L$. For this circuit: $X_L = 2\pi(50.0)(0.150) = 47.1\Omega$. In AC circuits, reactances are treated as imaginary numbers and resistances as real numbers. The resistor and inductor are in series, so the total circuit impedance is just the sum of the imaginary reactance and real resistance. In other words, the impedance is $Z = 60.0 + 47.1i$ where $i = \sqrt{-1}$. Using the AC version of Ohm's Law, we get a total current of $I = \frac{V}{Z} = \frac{12.6}{60.0+47.1i} = 0.130 - 0.102i$. Since everything is in series in this circuit, then this same current flows through the resistor. The magnitude of this current is found by using the Pythagorean theorem:

$$|I| = \sqrt{I_{real}^2 + I_{imag}^2} = \sqrt{(0.130)^2 + (0.102)^2} = \sqrt{0.0273} = 0.165A = 165mA.$$

P16. (A) For thin film interference, a dark fringe will appear whenever the thickness of the film satisfies the equation $d = \frac{m\lambda}{2n}$ where *m* is an integer and *n* is the index of refraction of the thin film. For the air wedge in the problem, the thin film (air) has an index of refraction of 1.0. We are also given the wavelength, $\lambda = 575\text{nm}$. So, our problem is reduced to finding locations where the air wedge has a thickness of $d = \frac{m(575nm)}{2(1)} = m * 287.5$ in nanometers. This now becomes a geometry problem: The horizontal location, $x_1$, of the first dark fringe ($m = 1$) is when $tan\theta = \frac{287.5nm}{x_1}$, which gives a location for the first dark fringe of $x_1 = \frac{287.5nm}{\tan(0.030°)} = 5.5\times10^{-4}\text{m}$. Similarly, the location of the second dark fringe is $x_2 = \frac{287.5(2)}{\tan(0.030°)} = 1.1\times10^{-3}\text{m}$. And the third is $x_3 = 1.65\times10^{-3}\text{m}$. The dark fringes are equally spaced, and the separation can be found by subtracting the locations of any two adjacent dark fringes: $x = x_2 - x_1 = 5.5\times10^{-4}\text{m} = 0.55\text{mm}$.

P17. (C) Since both the planet and the spacecraft are moving at relativistic speeds, we must use the Lorentz velocity transformation to find the velocity of the spacecraft as seen from the planet. The Lorentz transform equation is $u' = \frac{u-v}{1-\frac{uv}{c^2}}$, where $u$ and $v$ are the speeds of the spacecraft and planet as measured by an outside observer. Both $u$ and $v$ are in the same direction, so we can take both to be positive. The transformed velocity, $u'$, is the velocity of the spacecraft as seen from the planet's surface. Putting in the values given, we get: $u' = \frac{0.90c-0.77c}{1-\frac{(0.90c)(0.77c)}{c^2}} = \frac{0.13c}{1-0.693} = \frac{0.13c}{0.307} = 0.42c$.

P18. (A) The binding energy of a nucleus can be found by calculating the difference between the mass of the nucleus and the mass of the constituent particles of the nucleus. Ytterbium-164 contains 70 protons and $164 - 70 = 94$ neutrons. Thus, the mass of the constituent particles in this nucleus is: $M = (70)(1.007276) + (94)(1.008665) = 165.32383$amu. Subtracting the actual mass of a ${}^{164}_{70}Yb$ nucleus gives the mass defect: $\Delta m = 165.32383 - 163.934489 = 1.3893$amu. Converting this to energy gives the total binding energy: $BE = (1.3893)(931.5) = 1294$ MeV. To get the binding energy per nucleon, we divide the total binding energy by the number of nucleons (protons plus neutrons) in this isotope: $\frac{BE}{nucleon} = \frac{1294}{164} = 7.89$ MeV/nucleon.

P19. (E) This is a conservation of energy experiment in which elastic potential energy is converted into kinetic energy and then into gravitational potential energy. For our calculations, we can actually ignore the intermediate kinetic energy and just equate the initial elastic potential energy to the final gravitational potential energy. Mathematically, this gives: $\frac{1}{2}kx^2 = mgh$. Solving for the height gives the equation of the graph shown: $h = \frac{k}{2mg}x^2$. It is probably easiest to use a data point from the graph to estimate the answer. I chose the point (5.0cm, 27.5cm). Converting into meters and plugging this point into the equation of the graph yields: $0.275 = \frac{k}{2mg}(0.05)^2$. Simplifying, and solving for the spring constant: $k = (2mg)(110) = 2(.210)(9.8)(110) = 453 \approx 450$ N/m.

P20. (C) Since the current is flowing North-South, the magnetic field (directly above the wire) produced by the current will be oriented East-West. The Earth's magnetic field is, of course, oriented North-South. Thus, these two fields – Earth's field and the current-produced field – are perpendicular to one another. These two vector fields add to give the total magnetic field, and the angle (from North) of this combined field is given by the equation $\theta = tan^{-1}\left(\frac{B_{EW}}{B_{NS}}\right)$. Also, the magnetic field of the Earth, which is the North-South field, is given: $B_e = B_{NS} = 5.0 \times 10^{-5}$ Tesla.
We can now use one of the data points from the graph to find the current-produced field strength. I'll use the point (4.0cm, 54°). Using the angle, we find:
$\tan(54°) = \frac{B_{EW}}{(5.0\times10^{-5})} \quad \rightarrow \quad B_{EW} = 6.9 \times 10^{-5}$ Tesla. This is the East-West magnetic field produced by the current in the wire. Finally, this magnetic field strength is related to the current in the wire, and the distance from the wire, by the equation $B = \frac{\mu_0 I}{2\pi r}$. Plugging in the magnetic field strength and the distance (in meters) for the data point we chose, we get:
$6.9 \times 10^{-5} = \frac{(4\pi \times 10^{-7})I}{2\pi(0.040)} = (5.0 \times 10^{-6})I \quad \rightarrow \quad I = 13.8 \approx 13.5$ A.