UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational A • 2022

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 endomembrane system of the eukaryotic cell includes all of the following except
A) rough endoplasmic reticulum.
B) Golgi apparatus.
C) nuclear envelope.
D) centrioles.
E) smooth endoplasmic reticulum.

B02. In Mendelian classical genetics, what percent of the offspring from the following genetic cross would be homozygous dominant?

Pp x pp

A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B03. All of the following are characteristic of the human genome in a somatic cell except
A) linear chromosomes.
B) associated histone proteins.
C) haploid arrangement.
D) multiple chromosomes.
E) housed within a membranous structure.

B04. Blood is the connective tissue most associated with the
A) musculoskeletal system.
B) cardiovascular system.
C) nervous system.
D) integumentary system.
E) digestive system.

B05. Which major macromolecular group contains molecules that store inherited information?
A) Proteins
B) Nucleic acids
C) Carbohydrates
D) Amino acids
E) Lipids

B06. The tissue type that provides covering and lines body cavities is classified as
A) nervous.
B) connective.
C) epithelial.
D) organs.
E) muscle.

B07. Carbon dioxide is an important substrate in photosynthesis. What is the carbon dioxide used for in photosynthesis?
A) Carbon dioxide is released by the photosynthetic organism.
B) Carbon dioxide is used as an electron donor.
C) Carbon dioxide is released during the reactions of aerobic respiration.
D) Carbon dioxide is used as an electron acceptor.
E) Carbon dioxide is used to synthesize sugars, such as glucose.

B08. The major molecular machinery that generates proteins in cells is called the
A) amino acid.
B) rough endoplasmic reticulum.
C) polymerase.
D) ribosome.
E) Golgi apparatus.

B09. In terms of evolution, what do the following terms have in common?

Mutation, recombination, migration, genetic drift

A) These are all events that occur in populations at Hardy-Weinberg equilibrium.
B) These terms are all processes that can happen to proteins.
C) These events may affect genetic diversity in a population.
D) These processes all lead to extinction events.
E) Speciation is always an outcome of these events.

B10. In a population at Hardy-Weinberg equilibrium, which value in the mathematical formula(s) represents the frequency of heterozygous individuals in the population?
A) p^2
B) p
C) q^2
D) q
E) 2pq

B11. What major event is occurring in the S-phase of the cell cycle?
A) Condensation of the chromosomes
B) DNA replication
C) Cellular growth
D) Formation of the spindle apparatus
E) Division of the cytoplasm

B12. Consider the F2 generation of Mendel's pea plants. If 16 progeny were produced in this generation from a dihybrid cross, statistically, how many of the 16 would be homozygous recessive for both traits?
A) 1
B) 3
C) 6
D) 8
E) 16

B13. Hybrids, such as mules (donkey x horse), are sterile because they do not produce functional gametes. This is evidence of
A) prezygotic barriers.
B) horses and donkeys are members of the same species.
C) postzygotic barriers.
D) mutation
E) gene flow.

B14. A DNA binding protein that binds to a sequence located upstream of the promoter and assists RNA polymerase with finding the promoter would most likely be involved in
A) repressing transcription.
B) activating transcription.
C) repressing translation.
D) activating translation.
E) negative control.

B15. Of the four supergroups found in eukaryotic classification, to which do humans belong?
A) Unikonta
B) SAR
C) Excavata
D) Archaeplastida

B16. The Centers for Disease Control and Prevention have posted several *Salmonella* outbreaks from August 2021 through the end of October 2021. Which of the following modes of transmission is most important for *Salmonella* infections?
A) parenteral (needle stick, bee sting, etc)
B) fomites
C) vectorborne
D) ingestion
E) inhalation

B17. Examine the answer choices listed below. Which answer choice is a disease not caused by a eukaryotic pathogen?
A) Hookworm disease
B) Malaria
C) Scabies
D) Amoebic dysentery
E) Chickenpox

B18. Energy-releasing reactions in the cell are
A) anabolic.
B) catabolic.
C) endergonic.
D) exergonic.
E) More than one answer above is correct.

B19. Fleas are often found feeding on the blood of animals. Which kind of organism relationship does this example represent?
A) parasitism
B) mutualism
C) commensalism
D) beneficial
E) reciprocal

B20. There are three domains of life, one of which includes the Archaea. Which of the following *best* represents this domain?
A) Eukaryotic cell types.
B) Single-celled organisms capable of causing disease.
C) Single-celled organisms that are found as part of the human microbiome, particularly in the GI tract.
D) Typically extremophiles (organisms loving extreme environments), including high salt, low or high temperatures, or high pressure.
E) Multicellular organisms capable of producing different cell types and tissues with specific function.

C01. What is the molar mass of sodium hypobromite (NaBrO)?

A) 49.80 g/mol
B) 74.44 g/mol
C) 118.89 g/mol
D) 125.89 g/mol
E) 134.89 g /mol

C02. If 100.0 g of Al reacts with excess oxygen to form Al_2O_3, how many grams of Al_2O_3 will be formed?

A) 179 g
B) 189 g
C) 199 g
D) 209 g
E) 219 g

C03. What is the energy of a photon that has a wavelength of 510 nm?

A) 3.90×10^{-19} J
B) 3.90×10^{-28} J
C) 3.90×10^{-21} J
D) 1.30×10^{-27} J
E) 1.30×10^{-25} J

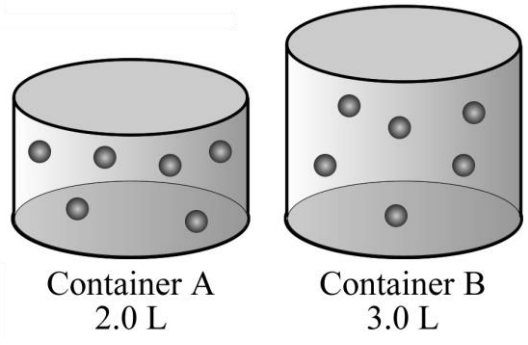
C04. What is the shape of a carbon tetrachloride (CCl_4) molecule?

A) pentagonal
B) tetrahedral
C) square planar
D) trigonal planar
E) linear

C05. Based on periodic trends, which of these ionic compounds would be expected to have the highest melting point?

A) NaCl
B) Na_2O
C) $MgCl_2$
D) MgO
E) K_2S

C06. Containers A and B are at the same temperature. If the pressure in container A is 1.50 atm, what is the pressure in container B?



A) 1.0 atm
B) 1.5 atm
C) 3.0 atm
D) 2/3 atm
E) 6.0 atm

C07. You drop a piece of sodium metal into water and the following exothermic reaction occurs:

$2\ Na(s) + 2\ H_2O(\ell) \rightarrow 2\ NaOH(aq) + H_2(g)$

What are the signs on heat (q) and work (w) for the system in this reaction, assuming constant pressure and temperature?

A) q is positive and w is negative
B) q is negative and w is positive
C) q and w are both negative
D) q and w are both positive
E) There is not enough information given

C08. How much energy would it take to melt a pound of ice (454 grams) to water at 0 degrees C?

A) 949 J
B) 1030 J
C) 1890 J
D) 152 kJ
E) 1030 kJ

C09. The reaction $A + 2B \rightleftharpoons C + 2D$ has an equilibrium constant of 1.5×10^{-5}. If the equilibrium concentrations of A, B, and C are 0.0015 M, what is the equilibrium concentration of D?

A) 1.5×10^{-5} M
B) 0.0015 M
C) 1.5×10^{-4} M
D) 2.3×10^{-8} M
E) 5.8×10^{-6} M

C10. Which of these compounds when dissolved in water would result in a solution with a neutral pH?

A) KCl
B) KCN
C) KOH
D) HCl
E) HCN

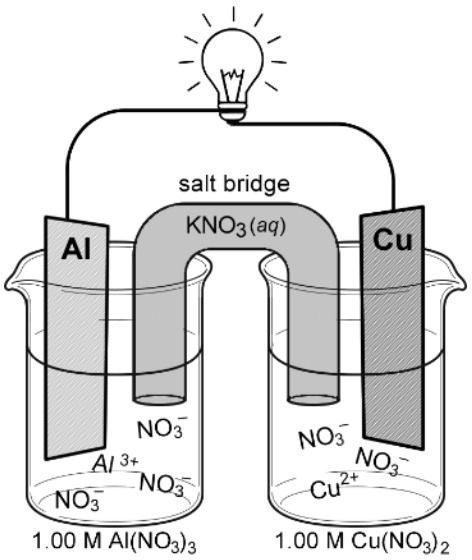
C11. A scientist slowly adds dissolved NaCl to a solution of $AgNO_3$. If a precipitate begins to form when the NaCl concentration is 5.5×10^{-4} M, what is the concentration of Ag^+ in the solution? $K_{sp} = 1.8 \times 10^{-10}$.

A) 3.3×10^{-7} M
B) 9.39×10^{-14} M
C) 3.1×10^{6} M
D) 6.0×10^{-6} M
E) 6.0×10^{-8} M

C12. A tank of compressed helium gas holds 12.8 moles of helium gas. What would the volume of this gas be if it were allowed to expand in a flexible-walled container to 1.00 atm pressure at 25.0°C?

A) 26.3 L
B) 111 L
C) 212 L
D) 313 L
E) 414 L

C13. What is the voltage of this galvanic cell that is made up of a copper cathode in 1.0 M $Cu(NO_3)_2$ solution and an aluminum anode in 1.0 M $Al(NO_3)_3$ solution?



A) +1.32 V
B) –1.32 V
C) +2.00 V
D) –2.00 V
E) +0.34 V

C14. The overall reaction $A + B_2 + C \rightarrow AB + CB$ has the following reaction mechanism:

$A + B_2 \rightarrow AB_2$
$AB_2 \rightarrow AB + B$
$B + C \rightarrow CB$

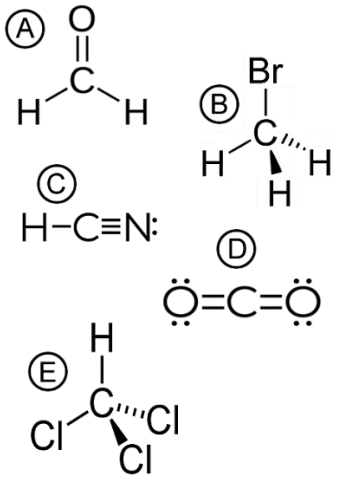
Which compound in the mechanism is a catalyst?

A) A
B) B
C) AB_2
D) B_2
E) There is no catalyst.

C15. Which of these neutral atoms has the smallest radius?

A) Al
B) Br
C) Cl
D) Db
E) Er

C16. In which one of these compounds does the carbon atom have an oxidation state of 0?



C17. How many atoms are in 100. grams of PCl_5?

A) 2.89×10^{23}
B) 1.73×10^{24}
C) 5.78×10^{23}
D) 1.45×10^{24}
E) 6.02×10^{23}

C18. Our current periodic table ends with element 118, which has a full 7*p* subshell in the ground state. What would the last term of the electron configuration be for a ground state atom of element 119?

A) $7p^7$
B) $8s^0$
C) $8s^1$
D) $8s^2$
E) $8p^1$

C19. Compound A has a vapor pressure of 18 torr and compound B has a vapor pressure of 36 torr. Which of the samples below would have the highest vapor pressure?

A) Pure Compound A
B) A mixture with a mole ratio of 0.75 A and 0.25 B
C) A 50/50 mole ratio mixture of A and B
D) A mixture with a mole ratio of 0.25 A and 0.75 B
E) Pure Compound B

C20. A little lost electron walks up to you on the street and says he has fallen out of his atom. He doesn't know what element it was, but he knows he was the outermost electron in the atom. He can remember two of his four quantum numbers: $n = 3$ $\ell = 0$. Five local +1 ions are searching for a lost electron. Which one of these might be this electron's home atom?

A) Carbon
B) Sulfur
C) Potassium
D) Magnesium
E) He could not have come from any of these atoms.

P01. According to Kaku, deep underlying physical principles about the universe are indicated by theories that are _____.
A) linear
B) non-linear
C) symmetric
D) self-consistent
E) testable

P02. According to Kaku, when William Hershel took a prism, created a rainbow, and placed a thermometer below the visible colors, in a location where there was no color at all, he discovered _____.
A) magnetic fields
B) electric fields
C) radio waves
D) infrared light
E) ultraviolet light

P03. According to Kaku, acceleration in one reference frame is identical to _____ in another reference frame.
A) the effect of gravity
B) the slowing of time
C) a constant velocity
D) the electromagnetic force
E) a quantum force

P04. Cooler regions on the Sun, called sunspots, are associated with _____.
A) strong magnetic fields
B) strong electric fields
C) strong convection currents
D) low neutrino flux
E) a weak solar wind

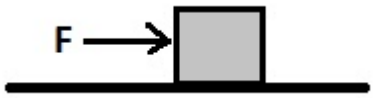
P05. What is the result of this calculation to the correct number of significant figures?

$$X = (6.18)(19.13 - 16.2)$$

A) 20
B) 18
C) 18.1
D) 18.11
E) 18.107

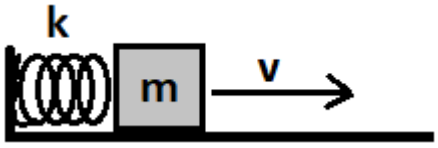
P06. A pinecone drops from a tree onto the forest floor. You estimate that the pinecone was falling for 3.5 seconds. Assuming the pinecone started from rest, and ignoring air resistance, from about what height did the pinecone drop?
A) 17 m
B) 34 m
C) 60 m
D) 84 m
E) 120 m

P07. A box of rocks having a mass of 210.0kg is pushed along a frictionless floor by a horizontal force of 65.0N (as shown). If the box started from rest, what is its velocity after 2.50 seconds?



A) 8.08 m/s
B) 3.23 m/s
C) 1.93 m/s
D) 1.29 m/s
E) 0.774 m/s

P08. A compressed spring launches a wood block horizontally across a frictionless floor (as shown). The spring has a spring constant of 390 N/m and is initially compressed by 25.0cm. The wood block has a mass of 130g. What is the velocity of the block after it is launched?



A) 9.69 m/s
B) 13.7 m/s
C) 19.4 m/s
D) 27.4 m/s
E) 43.3 m/s

P09. A carousel at a local carnival starts from rest and reaches an angular speed of 2.30 rad/s in exactly one revolution. What is the angular acceleration of the carousel?

A) 0.18 rad/s^2
B) 0.37 rad/s^2
C) 0.42 rad/s^2
D) 0.65 rad/s^2
E) 0.84 rad/s^2

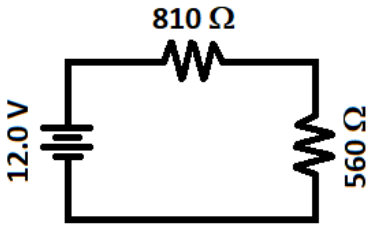
P10. An 85.0kg crate is placed on top of a vertical spring. Once it is released, the crate bounces on the spring with an oscillation period of 2.50s. What is the spring constant, k, of the spring?

A) 130 N/m
B) 210 N/m
C) 250 N/m
D) 400 N/m
E) 540 N/m

P11. A glass window is located in a room maintained at 22.0°C, while the temperature outside is a chilly −14.0°C. The window is 40.0cm wide, 1.30m tall, and 2.50cm thick. How much heat energy is lost through the window each second? The thermal conductivity of glass is 0.80 W/mK.

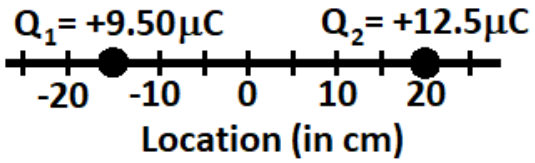
A) 230 J/s
B) 370 J/s
C) 460 J/s
D) 600 J/s
E) 750 J/s

P12. In the circuit below, what is the voltage across the 560 Ω resistor?



A) 2.14 V
B) 4.91 V
C) 7.09 V
D) 8.30 V
E) 12.0 V

P13. Two charges are located on the x-axis as shown. A +9.50μC charge (Q_1) is located at $x = -15.0$cm and a +12.5μC charge (Q_2) is located at $x = +20.0$cm. What is the magnitude of the force on Q_2 due to the presence of Q_1?



A) 3.05 N
B) 5.34 N
C) 8.71 N
D) 17.7 N
E) 26.7 N

P14. A beam of protons is directed into a region of high magnetic field such that the velocity of the beam is perpendicular to the direction of the field. In the field region, the proton beam traces out a circle with a radius of 56.0cm. If the magnetic field strength is 0.60T, then what is the velocity of the protons in the beam?

A) 1.93×10^7 m/s
B) 3.22×10^7 m/s
C) 5.37×10^7 m/s
D) 6.44×10^7 m/s
E) 8.95×10^7 m/s

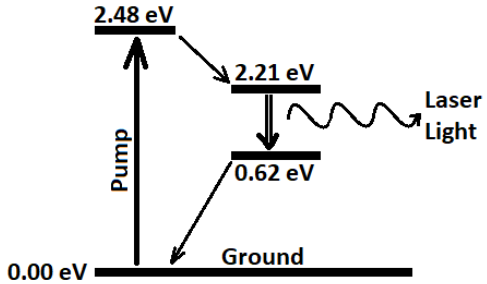
P15. A magnetic field of 0.055 Tesla passes through a square conductive loop. The field is oriented perpendicular to the face of the loop. The square loop is 40.0cm on a side, and has an internal resistance of 1.50Ω. If the magnetic field suddenly vanishes to zero in a time of 0.075 seconds, what current is induced in the conductive loop?

A) 78.2 mA
B) 117 mA
C) 196 mA
D) 293 mA
E) 489 mA

P16. You use a converging lens (a magnifier) to read some very small print. The focal length of the lens is +5.00cm, and you hold the lens 3.50cm above the print. By how much is the print magnified by the lens?

A) 1.70
B) 2.06
C) 2.33
D) 3.33
E) 11.7

P17. A four-level laser system is set up using atoms that have the energy level diagram shown. What is the wavelength of the laser light produced by this system?

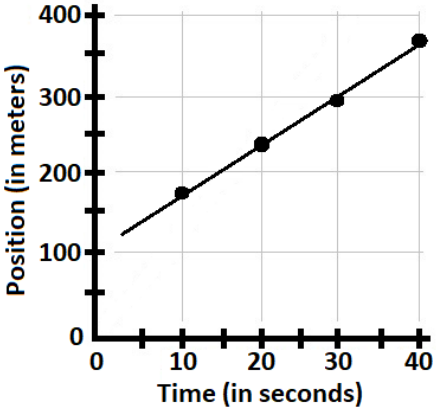


A) 335 nm
B) 500 nm
C) 561 nm
D) 667 nm
E) 780 nm

P18. You have been given an atom of Flerovium-292, $^{292}_{114}Fl$. Very rapidly, the atom emits seven alpha particles, four negative beta particles, and two gamma rays. What atom are you left with after these nuclear decays?

A) Curium-258
B) Fermium-260
C) Rutherfordium-264
D) Nobelium-262
E) Seaborgium-272

P19. The position-time graph for a marathon runner is shown below. Based on this data, what is the approximate speed of the runner?



A) 6.7 m/s
B) 8.8 m/s
C) 10.0 m/s
D) 12.5 m/s
E) 17.5 m/s

P20. You connect a zucchini into an electrical circuit. You then measure the current that flows through the zucchini as you apply different voltages to it. The following table shows the data you collected. Based on this data, what is the approximate resistance of the zucchini?

Voltage	Current
5.0 V	1.33 μA
9.0 V	8.79 μA
12.0 V	14.4 μA
15.0 V	20.0 μA

A) 3.76 MΩ
B) 1.02 MΩ
C) 833 kΩ
D) 750 kΩ
E) 535 kΩ

Chemistry

1A 1												3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H 1.01	2A 2																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	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	10	1B 11	2B 12	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
ΔH_{fus} = 334 J/g
ΔH_{vap} = 2260 J/g
K_f = 1.86 °C/*m*
K_b = 0.512 °C/*m*

Standard Reduction Potentials

$Cu^{2+} + 2e^- \rightarrow Cu(s)$ $\quad E°_{red} = +0.34$ V
$Al^{3+} + 3e^- \rightarrow Al(s)$ $\quad E°_{red} = -1.66$ V

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

Chemistry

1A 1												3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H 1.01	2A 2																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	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	10	1B 11	2B 12	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
ΔH_{fus} = 334 J/g
ΔH_{vap} = 2260 J/g
K_f = 1.86 °C/*m*
K_b = 0.512 °C/*m*

Standard Reduction Potentials

$Cu^{2+} + 2e^- \rightarrow Cu(s)$ $\quad E°_{red} = +0.34$ V
$Al^{3+} + 3e^- \rightarrow Al(s)$ $\quad E°_{red} = -1.66$ V

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

Physics

Useful Constants

quantity	symbol	value
Free-fall acceleration	g	$9.80\ m/s^2$
Permittivity of Free Space	ε_0	$8.854 \times 10^{-12}\ C^2/Nm^2$
Permeability of Free Space	μ_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	$1.67265 \times 10^{-27}\ kg$ $1.007276 amu$
Neutron mass	m_n	$1.67495 \times 10^{-27}\ kg$ $1.008665 amu$
Atomic Mass Unit	amu	$1.66 \times 10^{-27}\ kg$ $931.5\ MeV/c^2$
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	$8.314\ J/mol \cdot K$ $0.082057\ L \cdot atm/mol \cdot K$
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_∞	$1.097 \times 10^{7}\ m^{-1}$
Standard Atmospheric Pressure	1 atm	$1.013 \times 10^{5}\ Pa$
Density of Pure Water	ρ_{water}	$1000.0\ kg/m^3$

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2022 INVITATIONAL A

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL A 2022

C01. (C) 22.99 + 16.00 + 79.90 = 118.89 g/mol.

C02. (B) 100 g Al / 26.98 g/mol = 3.706 mol Al. 3.706 mol Al × 1 mol Al_2O_3/2 mol Al = 1.853 mol Al_2O_3. 1.853 mol Al_2O_3 × 101.96 g/mol = 189 g Al_2O_3.

C03. (A) $\nu\lambda = c$ and $E = h\nu$, so $E = hc/\lambda$. $E = (6.626 \times 10^{-34}\ J{\cdot}s)(3 \times 10^{8}\ m/s)/(510 \times 10^{-9}\ m) = 3.90 \times 10^{-19}\ J$

C04. (B) A central atom surrounded by four regions of electron density (a bond or a lone pair) will have tetrahedral electronic geometry. If there are no lone pairs, the molecular shape is the same as the electronic geometry.

C05. (D) Lattice energy depends on the ionic charges and the sizes of the ions. Higher ionic charges and smaller ionic radii result in higher lattice energies. Of these answer choices, MgO has the highest ionic charges (+2 ion and –2) and will have the strongest ion-ion attractions to overcome in order to melt the solid.

C06. (A) The two containers have the same temperature and the same number of moles, so the change in pressure depends only on the change in volume. $P_AV_A = P_BV_B$, $P_B = P_A(V_A/V_B) = 1.50(2.0/3.0) = 1.0$ atm

C07. (C) The problem states that the reaction is exothermic, so it is giving off heat and q is therefore negative. The reaction is producing a gas, so at constant pressure the volume is increasing. That means the system is doing work on the surroundings, therefore work is negative.

C08. (D). The heat of fusion for ice is 334 J/g and you have 454 grams, so 334 x 454 = 151,636 J = 152 kJ.

C09. (E): $K = \frac{[C][D]^2}{[A][B]^2}$ so $[D] = \sqrt{K\frac{[A][B]^2}{[C]}} = \sqrt{(1.5 \times 10^{-5}\frac{(0.0015)(0.0015)^2}{(0.0015)}} = 5.8 \times 10^{-6}$ M

C10. (A) KCl is the only neutral salt among the answer choices. KOH is a strong base and KNO_2 is a weak base and both would result in a solution with a pH greater than 7. HCl is a strong acid and HCN is a weak acid, so they would both result in a solution with a pH below 7.

C11. (A) $K_{sp} = [Ag^+][Cl^-]$, so $[Ag^+] = K_{sp}/[Cl^-] = 1.8 \times 10^{-10} / 5.5 \times 10^{-4}$ M $= 3.3 \times 10^{-7}$ M

C12. (D) PV = nRT, so V = nRT/P. n = 12.8 mol, T = 298 K, R = 0.08206 L·atm/mol·K, and P = 1.00 atm. V = (12.8)(0.08206)(298)/1.00 = 313 L total volume.

C13. (C). $E°_{cell} = E°_{reduction} - E°_{oxidation}$. Reduction occurs at the cathode and oxidation occurs at the anode, so $E°_{red}$ = +0.34 V and $E°_{ox}$ = –1.66 V. $E°_{cell}$ = (+0.34 V) – (–1.66 V) = +2.00 V

C14. (E) A catalyst appears in the reaction mechanism first as a reactant and later as a product. There are no compounds in the reaction mechanism that fit this description.

C15. (C) Atomic radii decrease as you move up and to the right on the periodic table, so Cl would have the smallest radius of these atoms.

C16. (A) Oxidation states treat every compound as if it were ionic, even when we know it's not. When determining the oxidation states of atoms in compounds, assume H is +1 except in metal hydrides, and O is –2 except in peroxides. Halides are –1 unless they are the central atom, and N is –3 unless it is the central atom. The sum of the oxidation states of a neutral molecule adds up to 0.

C17. (B) The molar mass of $PCl_5 = 1 \times 30.97 + 5 \times 35.45 = 208.22$ g/mol.
100. g / 208.22 g/mol = 0.480 mol. 0.480 mol × 6.02×10^{23} molecules/mol = 2.89×10^{23} molecules.
2.89×10^{23} molecules × 6 atoms per molecule = 1.73×10^{24} atoms

C18. (C) After the 7*p* subshell comes the 8*s* subshell, so the next electron after the 7*p* subshell would go into the 8*s* orbital and the ground state electron configuration for element 119 would end in $8s^1$.

C19. (E) The vapor pressure of a mixture is $P = \chi_A P_A + \chi_B P_B$. Since pure A has a vapor pressure of 18 torr and pure B has a vapor pressure of 36 torr, the vapor pressure of any mixture of A and B will be somewhere in between, but will never be higher than the vapor pressure of pure B.

C20. (C) n=3 means the electron is from the third energy level, and $\ell = 0$ means he is from an *s*-orbital. Since he is the outermost electron in his atom, his home atom is one in which the outermost electron is in a 3*s* orbital. That could be either potassium or calcium, but calcium is not an answer choice so it must be potassium.

PHYSICS SOLUTIONS – UIL INVITATIONAL A 2022

P01. (C) page 15: "The concept of symmetry is simple, elegant, and intuitive. Moreover, throughout this book, we will see that symmetry is not just frivolous window dressing to a theory, but in fact is an essential feature that indicates some deep, underlying physical principle about the universe."

P02. (D) page 26: "In 1800, William Hershel had asked himself a simple question: What lies beyond the colors of the rainbow, which extend from red to violet? He took a prism, which created a rainbow in his lab, and placed a thermometer below the color red, where there was no color at all. Much to his surprise, the temperature of this blank area began to rise. In other words, there was a 'color' below red that was invisible to the naked eye but contained energy. It was called infrared light."

P03. (A) page 42: "In other words, acceleration in one frame is identical to the effect of gravity in another, which is due to space being curved."

P04. (A) Measurements of the spectra from sunspot regions indicate these regions are associated with very strong magnetic fields. These strong magnetic fields shut down the convection currents and lead to the cooler, darker spots that we see. Sunspots are generally associated with increased solar activity and strong solar winds. Sunspots are not associated with electric fields and do not affect the neutrino flux coming from the solar core.

P05. (B) First, we must do the subtraction in the parentheses. When subtracting, it is the value with the fewest number of decimal places that dictates the number of decimal places of the answer. Thus, when we subtract $19.13 - 16.2 = 2.93 = [2.9]3$; we have only two significant figures. The value 16.2 limits us to the tenths place, so the significant digits in the answer are also limited to the tenths place.

Now we can do the multiplication. We keep all of the digits from the subtraction because we don't round until the end. We do need to remember that the result of the subtraction only has two significant figures – this is indicated with brackets. So, we have $(6.18)([2.9]3) = 18.1074 = [18].1074$. With multiplication, the answer is limited to the number of significant figures of the input value with the least significant figures. The value [2.9]3 has only two significant figures, while 6.18 has three. Thus, the answer will be limited to two significant figures. Therefore, our answer to the correct number of significant figures is 18.

P06. (C) Since we know the time and the acceleration (9.8 m/s^2 downward), we should utilize the kinematic equation $y_f = y_i + v_{iy}t + \frac{1}{2}a_y t^2$. The final position is the forest floor ($y_f = 0$), and the initial position is the height at which the pinecone starts ($y_i = h$). Also, the pinecone starts from rest, so the initial velocity is zero ($v_{iy} = 0$). Putting it all together, we get $0 = h + 0 + (0.5)(-9.8)(3.5)^2$ which leads to $h = (4.9)(12.25) = 60$m.

P07. (E) The free body diagram for this situation includes three forces: weight, directed downward; the normal force, directed upward; and the applied force, directed to the right. There is no vertical motion, so the weight and the normal force balance one another. However, knowing that does not help solve the problem. In the absence of friction, the only horizontal force is the applied force, F. Utilizing Newton's acceleration law for the horizontal: $\sum F_x = F = ma_x \quad \rightarrow \quad 65.0N = (210kg)a_x$. This gives a horizontal acceleration of $a_x = 0.3095$ m/s^2.
Now we turn to kinematics. The box started from rest, so its initial velocity was zero. To find the final velocity, we go to the equation $v_{fx} = v_{ix} + a_x t \quad \rightarrow \quad v_{fx} = 0 + (0.3095)(2.5) = 0.774$ m/s.

P08. (B) To solve this problem, we rely on conservation of energy. Initially, the energy is stored in the compressed spring as elastic potential energy (EPE). After launching the block, the energy has been converted into kinetic energy (KE). Since there is no friction, we can set the initial elastic potential energy (EPE) equal to the final kinetic energy (KE).
Mathematically, $EPE = \frac{1}{2}kx^2 = (0.5)(390)(0.25)^2 = 12.19\,J = KE = \frac{1}{2}mv^2$.
Thus, we calculate $(0.5)(0.130)v^2 = 12.19 \quad \rightarrow \quad v^2 = 187.5 \quad \rightarrow \quad v = 13.7$m/s.

P09. (C) To solve this, we go to our angular kinematic equations. We don't know how long it took to complete one revolution, so we will use an equation without time in it: $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$. The total angle through which the carousel went during acceleration was one revolution:
$\Delta\theta = 1rev = 2\pi$ radians. The initial angular velocity was zero, and we are given the final angular velocity. Putting it all together, we get:
$\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta = (2.30)^2 = 0 + 2\alpha(2\pi) \quad \rightarrow \quad 5.29 = 12.566\alpha \quad \rightarrow \quad \alpha = 0.42$ rad/s^2.

P10. (E) The oscillation period of a mass on a spring is given by $T = 2\pi\sqrt{\frac{m}{k}}$. Putting in the given values yields: $2.50 = 2\pi\sqrt{\frac{85}{k}}$. Solving for k gives: $\frac{2.50}{2\pi} = 0.398 = \sqrt{\frac{85}{k}} \quad \rightarrow \quad (0.398)^2 = 0.158 = \frac{85}{k}$. This gives us a spring constant of $k = \frac{85}{0.158} = 537 \approx 540$ N/m.

P11. (D) The heat transfer in this case is assumed to be entirely by conduction, so we will rely on the thermal conduction equation: $P = \frac{kA\Delta T}{L}$. We are given the thermal conductivity, k, and the thickness of the window, L. The window is rectangular, so the area of the window is given by:
$A = lw = (0.40m)(1.30m) = 0.52m^2$.
Finally, the temperature difference is $\Delta T = (22.0) - (-14.0) = 36.0$℃.
Putting this all into the thermal conduction equation, we get $P = \frac{(0.80)(0.52)(36.0)}{(0.0250)} = 599\,W \approx 600\,J/s$.
Here we recall that a Watt is a Joule per second, allowing us to conclude that this power equals the amount of heat energy lost through the window each second.

P12. (B) The two resistors are in series, so the total equivalent resistance is $R_{eq} = R_1 + R_2 = 810 + 560 = 1370\Omega$. Then, using Ohm's Law, we can find the current flowing in the circuit: $I_0 = \frac{V_0}{R_{eq}} = \frac{12.0V}{1370\Omega} = 0.00876A$. Since the two resistors are in series, this same current flows through both resistors. Now we can use Ohm's Law again to find the voltage across the 560Ω resistor: $V_2 = I_0R_2 = (0.00876A)(560\Omega) = 4.91V$.

P13. (C) This is a direct application of Coulomb's Law. The force on either charge due to the presence of the other charge is given by $F = \frac{kQ_1Q_2}{r^2}$. The distance between the charges is
$r = 20.0 - (-15.0) = 35.0cm = 0.350m$.
Thus, the force is $F = \frac{(8.99 \times 10^9)(9.50 \times 10^{-6})(12.5 \times 10^{-6})}{(0.350)^2} = 8.71\,N$.

P14. (B) The radius of the circle traced out by a charged particle in a magnetic field is given by the equation $r = \frac{mv}{qB}$. Solving for velocity in this equation yields: $v = \frac{rqB}{m}$. On the page of useful constants, we can find the charge and mass of a proton. Putting these in with the given radius and magnetic field gives us: $v = \frac{(0.560m)(1.602 \times 10^{-19}C)(0.60T)}{(1.67265 \times 10^{-27}kg)} = 3.22 \times 10^7$m/s. Although large, this is only about 1/10 of the speed of light, so we do not have to consider any relativistic effects.

P15. (A) This problem is a direct application of Faraday's Law. Using that law, we can find the voltage induced in the loop by the changing magnetic field: $\mathcal{E} = -\frac{\Delta\Phi_B}{\Delta t} = -\frac{\Delta(BA)}{\Delta t}$. The area of the loop does not change, and (in meters-squared) is equal to $A = (0.40m)^2 = 0.16m^2$. Since the magnetic field is perpendicular to the face of the loop, we don't need to worry about any angles. Therefore, we get: $\mathcal{E} = -\frac{A\Delta B}{\Delta t} = -\frac{0.16\,(B_f - B_i)}{\Delta t} = -0.16\,\frac{0\,T - 0.055\,T}{0.075\,sec} = 0.1173\,V$. This is the voltage induced in the loop. To get the current, we use Ohm's Law: $I = \frac{V}{R} = \frac{0.1173V}{1.50\Omega} = 0.0782A = 78.2mA$.

P16. (D) First, we need to find the image location of the magnified print. To do this, we use $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$. In centimeters, this gives: $\frac{1}{3.50} + \frac{1}{q} = \frac{1}{5.00} \quad \rightarrow \quad q = -11.67cm$. This is the image location. Since it is negative, we know that it is a virtual image.
Now we can calculate the magnification: $M = -\frac{q}{p} = -\frac{-11.67}{3.50} = 3.33$.

P17. (E) The fact that this is a four-level laser system is cool, but all we really need to know is the energy difference between the two levels that produce the laser light. Those levels have energies of 2.21eV and 0.62eV. So, $\Delta E = 2.21 - 0.62 = 1.59$eV. Now we can determine the wavelength of the laser light: $\lambda = \frac{1240\,eVnm}{\Delta E} = \frac{1240}{1.59} = 780nm$.

P18. (C) Alpha particles carry away four units of mass and two units of charge for every particle. This means that the emission of seven alphas will reduce the atomic mass by $7 * 4 = 28$, and reduce the atomic number by $7 * 2 = 14$. Negative beta particles do not change the atomic mass but do increase the atomic number by one; so, emitting four beta particles will increase the atomic number by $1 * 4 = 4$. Gamma rays carry away excess energy, but do not change the atomic mass nor the atomic number.

We start with an atomic mass of 292. Taking into account all of the emitted particles, then this atomic mass with change to $292 - 28 - 0 - 0 = 264$. Similarly, the atomic number starts at 114. It will change to $114 - 14 + 4 - 0 = 104$. The element with atomic number 104 is Rutherfordium, so the atom left after these decays is Rutherfordium-264.

P19. (A) On a position-time graph, a straight line indicates that the speed of the runner is constant. Furthermore, the speed of the runner is equal to the slope of the line. A best-fit line is already given, so we just need to identify two points on that line and calculate the slope. In examining the line, one point is obvious: (30s, 300m). For the second point, I will choose (15s, 200m) which also looks pretty clear. Now to calculate the slope: $slope = \frac{\Delta y}{\Delta x} = \frac{300m - 200m}{30s - 15s} = \frac{100m}{15s} = 6.7m/s = speed$.

P20. (E) Although I don't recommend connecting vegetables into electrical circuits, this problem does give us the information we need to determine the resistance of the zucchini. Unsurprisingly, the zucchini is not entirely ohmic – a threshold voltage is required before any current will flow. If you made a plot of voltage versus current for this data, the threshold voltage would appear as a non-zero y-intercept. However, once the threshold voltage is exceeded, the plot is a straight line – and the resistance equals the slope of that line. In the case of tabulated data, we don't need to make the plot, we can estimate the slope based on any two of the data points given. I will use the first and last points: $slope = R = \frac{\Delta V}{\Delta I} = \frac{15.0V - 5.0V}{20.0\mu A - 1.33\mu A} = \frac{10.0V}{18.67 \times 10^{-6} A} = 5.35 \times 10^5 \Omega = 535k\Omega$.
Note: you will get the same result using any pair of the data points given.