UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational B • 2023

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 of the following would increase the fluidity of a biological membrane?
A) Introduction of more unsaturated fatty acid tails on the phospholipids.
B) Hydrogenation of the fatty acid tails on the phospholipids.
C) Removal of double bonds within the fatty acid tails on the phospholipids.
D) Introduction of single bonds between the carbons of the fatty acid tails on the phospholipids.
E) Introduction of more saturated fatty acid tails on the phospholipids.

B02. Where would you expect a repressor, such as LacI of the *lac* operon, to bind to be most effective?
A) To an inducer molecule.
B) On DNA at a sequence located downstream of the promoter.
C) On mRNA covering the AUG start codon.
D) On mRNA covering the Shine-Dalgarno (Ribosomal Binding Site).
E) To RNA polymerase.

B03. The tissue that is often described by terms such as cuboidal, columnar, simple, and/or stratified is _____ tissue.
A) muscle
B) nervous
C) connective
D) epithelial
E) blood

B04. In the oxidation of glucose through aerobic respiration, carbon dioxide is first released during
A) the Krebs cycle.
B) glycolysis.
C) the electron transport chain.
D) chemiosmosis.
E) the transition step, pyruvate oxidation.

B05. Which of the following statements about the fossil record is incorrect?
A) The fossil record is incomplete.
B) The fossil record relies on laws that state that deeper, undisturbed rock layers are older than superficial, undisturbed rock layers.
C) Soft-bodied organisms, such as worms or jellyfish, are well-represented in the fossil record.
D) Bones, teeth, shells, footprints, and imprints of leaves are all part of the fossil record.
E) The fossil record is estimated to be between 2.3 and 3.5 billion years old.

B06. Changes of allele frequencies within a population can
A) promote natural selection.
B) influence the frequency of traits in the overall population over time.
C) induce microevolution.
D) increase reproductive success and fitness.
E) accomplish all of the above.

B07. In a population at Hardy-Weinberg equilibrium, 52% of the population are homozygous recessive. What is the frequency of the dominant allele?
A) 0.08
B) 0.28
C) 0.48
D) 0.69
E) 0.72

B08. Red algae, green algae, and land plants belong to Supergroup
A) Chromalveolata.
B) Opisthokonta.
C) Rhizaria.
D) Archaeplastida.
E) Excavata.

B09. Which of the following would be the best technique, relative to the other choices, to determine if a gene is present in a sample?
A) Western blot
B) Northern blot
C) Southern blot
D) CRISPR/Cas9
E) Transduction

B10. All of the following processes are anabolic reactions except
A) the Krebs cycle.
B) protein synthesis.
C) DNA replication.
D) the Calvin cycle.
E) gluconeogenesis.

B11. All of the following are Gram-positive bacteria that can cause disease in humans except
A) *Streptococcus pneumoniae*.
B) *Staphylococcus aureus*.
C) *Bacillus anthracis*.
D) *Clostridium tetani*.
E) *Salmonella enterica* ser. Typhimurium.

B12. An excess of potassium in the blood is called
A) hyperproteinemia.
B) hyperkalemia.
C) hypercalcemia.
D) hypernatremia.
E) metabolic alkalosis.

B13. Between early November to early December 2022, the Centers for Disease Control and Prevention issued food safety alerts and investigation notices for *Listeria* infections associated with all of the following except
A) falafel.
B) Brie cheese.
C) Camembert cheese.
D) deli meats and cheeses.
E) Enoki mushrooms.

B14. Phototropism is best observed as a plant leaning towards the sunlight. Which phytohormone is primarily responsible for phototropism?
A) auxins
B) ethylense
C) abscisic acid
D) cytokinins
E) gibberellins

B15. In which phase do cells first become haploid for organisms such as humans?
A) Prophase I
B) Metaphase II
C) After Telophase/Cytokinesis I
D) After Meiosis II
E) Interphase

B16. Eukaryotic DNA is tightly wound around proteins called
A) nucleosomes.
B) histones.
C) kinetochores.
D) cohesins.
E) shugoshin.

B17. Primary producers are
A) chemoheterotrophs.
B) chemoautotrophs.
C) photoheterotrophs.
D) photoautotrophs.
E) both chemoautotrophs and photoautotrophs.

B18. Passive transport across membranes includes all of the following except
A) transmembrane proteins.
B) the movement of lipid-soluble molecules from high to low concentration directly through the membrane.
C) the use of ATP.
D) movement of the substance from high concentration to low concentration.
E) aquaporins for the osmosis of water.

B19. Given the following genetic cross, what is the probability of having an offspring with an AAbbCcDDee genotype?

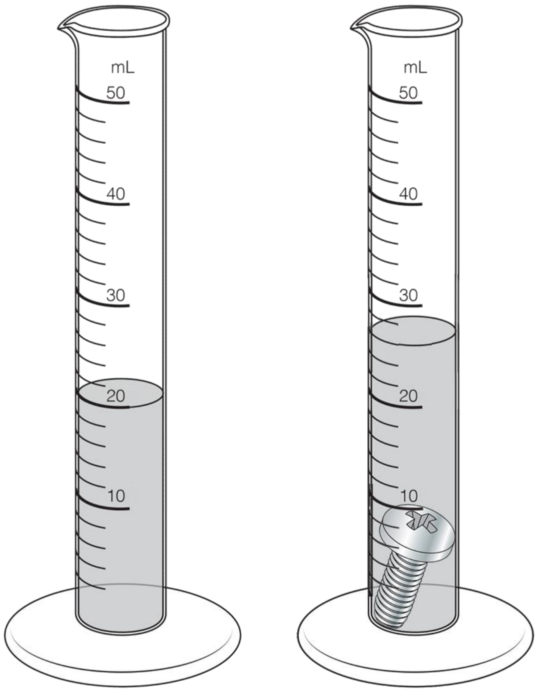
AabbCCDdEe x AABbccDDEe

A) 0
B) 1/16
C) 3/16
D) 1/32
E) 1/512

B20. A point mutation that converts a codon from CAG to UAG would be described as a/an ________ mutation.

A) silent
B) frameshift
C) missense
D) nonsense
E) inversion

C01. If the graduated cylinder with the liquid in it weighs 204.0 grams and the one with the liquid and the screw weighs 251.1 grams, what is the density of the metal screw inside the graduated cylinder?



A) 9.6 g/mL
B) 7.9 g/mL
C) 6.0 g/mL
D) 8.8 g/mL
E) 8.3 g/mL

C02. When the following equation is balanced using the smallest whole number coefficients, what is the sum of the coefficients?

__ $C_2H_4O_2(\ell)$ + __ $O_2(g)$ → __ $CO_2(g)$ + __ $H_2O(\ell)$

A) 4
B) 5
C) 6
D) 7
E) 8

C03. How many neutrons are there in a +2 ion of Carbon-14?

A) 4
B) 6
C) 8
D) 12
E) 14

C04. What type of bonds hold the phosphate ion together in a sample of solid sodium phosphate, Na_3PO_4?

A) Ionic bonds
B) Covalent bonds
C) Hydrogen bonds
D) Covalent and oxygen bonds
E) Phosphate bonds

C05. If 0.100 moles of argon gas is placed in a flexible-walled container at 25.0 °C and 1.00 atm pressure and then the container is heated at constant pressure to 190.0 °C, what will the final volume of the gas in the container be?

A) 1.35 L
B) 1.56 L
C) 2.70 L
D) 3.12 L
E) 3.80 L

C06. Which of these monatomic species would you expect to be the most polarizable?

A) He(g)
B) $I^-(g)$
C) $F^-(g)$
D) $F^+(g)$
E) Xe(g)

C07. A process that absorbs heat energy as it occurs is called

A) endothermic
B) exothermic
C) isothermic
D) ectothermic
E) hypothermic

C08. If it takes 2.50 kJ to melt a sample of ice to water at 0°C, how much energy would it take to boil the same mass of water to vapor at 100°C?

A) 5.00 kJ
B) 8.97 kJ
C) 12.9 kJ
D) 16.9 kJ
E) 20.8 kJ

C09. The equilibrium constant K_P for the gas-phase reaction

$$2A + B \rightleftharpoons 3C + D$$

is 2.40×10^{-3}. If the gases A, B, C, and D are pumped into a container at the following pressures, what will happen?

Gas	Pressure (atm)
A	0.25
B	0.25
C	0.10
D	0.15

A) The reaction will proceed until one of the reactants completely runs out.
B) The reaction will stop because it is at equilibrium
C) The forward and backward reactions will continue at the same rate
D) The reaction will proceed forward and produce more product
E) The reaction will proceed in the reverse direction and produce more reactant

C10. If you dilute 300.0 mL of 0.015 M solution of hydrochloric acid to twice the original volume, what will the pH of the final solution be?

A) 3.65
B) 2.12
C) 1.00
D) 0.25
E) 0.91

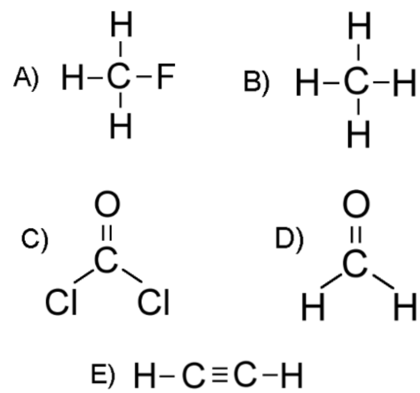
C11. If you add 25.0 grams of $Ca(OH)_2$ to 9.00 L of water and then dilute it to a final volume of 10.0 L and let it reach equilibrium, what will the final concentration of Ca^{2+} in the solution be? The K_{sp} for $Ca(OH)_2$ is 5.00×10^{-6}.

A) 0.0108 *M*
B) 0.0323 *M*
C) 0.250 *M*
D) 0.337 *M*
E) 0.374 *M*

C12. What role does a catalyst play in speeding up a chemical reaction?

A) The catalyst makes the reactant molecules move faster.
B) The catalyst makes the reactant molecules more reactive with one another.
C) The catalyst increases the equilibrium constant.
D) The catalyst decreases the activation energy.
E) The catalyst eliminates intermediates from the reaction mechanism.

C13. In which of these compounds is the carbon atom in the highest (most positive) oxidation state?



C14. How many moles of nitric acid are in 1.23 L of concentrated (15.7 *M*) HNO_3?

A) 6.4
B) 12.8
C) 15.7
D) 19.3
E) 38.6

C15. How many of the following names and formulas do not match correctly?

Chemical Formula	Chemical Name
H_2S	hydrosulfuric acid
H_2SO_3	sulfurous acid
HCl	hydrochloric acid
HClO	hypochlorous acid
$HBrO_3$	trioxybromic acid

A) 1
B) 2
C) 3
D) 4
E) 5

C16. A 1.5 L bulb and a 2.3 L bulb are connected by a valve. The larger bulb contains Cl_2 gas at 2.8 atm and the smaller bulb contains Cl_2 gas at 3.3 atm. When the valve is opened, what will the final pressure of Cl_2 be in the combined system? Assume the volume of the valve tube is negligible.

A) 2.8 atm
B) 2.9 atm
C) 3.0 atm
D) 3.1atm
E) 3.2 atm

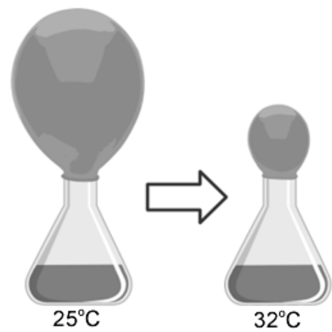
C17. Which of these is *not* a valid set of quantum numbers?

A) $n = 0$ $\ell = 0$ $m_\ell = 0$ $m_s = -½$
B) $n = 1$ $\ell = 0$ $m_\ell = 0$ $m_s = +½$
C) $n = 2$ $\ell = 1$ $m_\ell = +1$ $m_s = +½$
D) $n = 3$ $\ell = 2$ $m_\ell = -2$ $m_s = -½$
E) $n = 4$ $\ell = 3$ $m_\ell = +3$ $m_s = +½$

C18. A scientist is about to titrate a 50.0 mL sample of 0.100 M benzoic acid using 0.500 M NaOH. What is the pH of the benzoic acid solution before the titration begins? $K_a = 6.3 \times 10^{-5}$

A) 6.30
B) 5.00
C) 3.90
D) 2.60
E) 1.50

C19. How would you calculate the work done on or by the system for the reaction shown below, carried out at constant pressure?



A) $w = -P\Delta V$
B) $w = \Delta nRT$
C) $w = T_{final} - T_{initial}$
D) $w = F \cdot d$
E) none of the other answers is correct

C20. Which one of the following equations represents a formation reaction?

A) $H_2(\ell) + ½ O_2(\ell) \rightarrow H_2O(\ell)$
B) $2 H_2(g) + O_2(g) \rightarrow 2 H_2O(g)$
C) $½ N_2(g) + {}^3/_2 H_2(g) \rightarrow NH_3(g)$
D) $CO(g) + ½ O_2(g) \rightarrow CO_2(g)$
E) $2 CO_2(g) \rightarrow 2 CO(g) + O_2(g)$

P01. According to Feynman, when a quantum theory of the interaction of light and matter was finally developed in 1929, it was troubled. Attempts to use the theory to calculate quantities to a high level of accuracy would result in terms that were…

A) zero
B) very small
C) highly inaccurate
D) imaginary
E) infinite

P02. According to Feynman, what percentage of light is reflected by the front surface of a piece of glass?

A) 0%
B) 2%
C) 4%
D) 6%
E) 8%

P03. According to Feynman, when you use little arrows to do calculations in quantum electrodynamics, the probability of an event is equal to…

A) the length of the arrow.
B) the square of the length of the arrow.
C) the cube of the length of the arrow.
D) the square root of the length of the arrow.
E) the length of the arrow multiplied by pi.

P04. You discover a star cluster containing a large number of class O, B, and A stars. What must be true about this star cluster?

A) The cluster is an open cluster
B) The cluster is a Globular Cluster
C) The cluster is very old
D) The cluster is very young
E) The cluster has many white dwarf stars

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

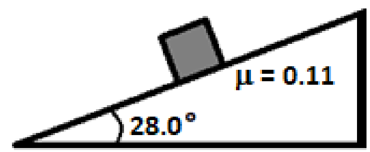
$$X = \frac{(8.2 + 5.33)}{3.142}$$

A) 4
B) 4.3
C) 4.31
D) 4.306
E) 4.3062

P06. You throw a tomato horizontally out of the window of your apartment. The initial velocity of the tomato is 8.00m/s. The tomato lands on the ground at a distance of 11.0m horizontally from the base of your apartment building. How far above the ground is your apartment window located?

A) 2.59 m
B) 7.13 m
C) 9.26 m
D) 13.9 m
E) 18.5 m

P07. A 4.80 kg can of coffee is sliding down an inclined plane. The plane is angled at 28.0° with respect to the horizontal, and the coefficient of friction between the can and the plane is 0.11. What is the acceleration of the can of coffee?



A) 4.60 m/s^2
B) 3.65 m/s^2
C) 2.45 m/s^2
D) 1.50 m/s^2
E) 0.95 m/s^2

P08. A cube of lead with a mass of 8.90 kg is launched horizontally across the floor by a spring-loaded cannon. The spring in the cannon has a spring constant of 2500.0 N/m, and it was initially compressed by 12.0 cm. What is the velocity of the cube of lead after it is launched? You may assume that the floor is frictionless.

A) 2.01 m/s
B) 3.60 m/s
C) 4.04 m/s
D) 5.81 m/s
E) 9.86 m/s

P09. The tire on a motorcycle accelerates from rest to an angular velocity of 80.0 rad/s in a time of 9.00 seconds. Through how many revolutions did the tire rotate while it was accelerating?

A) 6.37 rev
B) 8.89 rev
C) 40.0 rev
D) 57.3 rev
E) 360 rev

P10 A violin string is 42.0cm long and has a mass of 0.680g. The frequency of the fundamental harmonic of the string is exactly 588Hz. What is the tension on the string?

A) 98.7 N
B) 140 N
C) 268 N
D) 395 N
E) 560 N

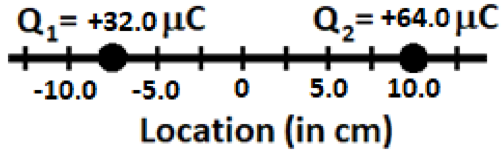
P11. A glass of room-temperature water is sitting on a table. Suddenly, heat transfers from the water into the air, cooling and freezing the water into ice, and heating the air in the room to an uncomfortably high temperature. Why don't events like this happen?

A) This event violates conservation of energy.
B) This event violates conservation of momentum.
C) Heat energy cannot flow from water into air.
D) This event results in an increase in entropy.
E) This event results in a decrease in entropy.

P12. What is the resistance of a 250.0m length of 26.0-gauge copper wire? Wire of this gauge has a diameter of 0.405mm, and the resistivity of copper is $1.70 \times 10^{-8} \Omega$m.

A) 33.0 Ω
B) 25.9 Ω
C) 16.5 Ω
D) 8.25 Ω
E) 6.48 Ω

P13. Two charges are located on the x-axis as shown. A +32.0μC charge (Q_1) is located at $x = -7.50$cm and a +64.0μC charge (Q_2) is located at $x = +10.0$cm. What is the magnitude of the force on Q_2 due to the presence of Q_1?

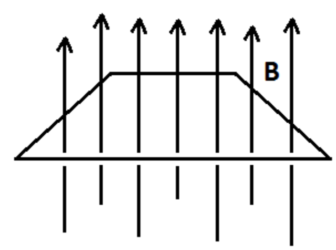


A) 2460 N
B) 601 N
C) 246 N
D) 184 N
E) 105 N

P14. A beam of singly-charged ions with a velocity of 4.6×10^5 m/s enters a region of uniform magnetic field. The field strength is 800 Gauss, and the circle traced out by the ion beam in the field region has a diameter of 84.4cm. What is the mass of the ions in the beam in atomic mass units (Note: 1 amu = 1.67×10^{-27} kg).

A) 3.0 amu
B) 4.4 amu
C) 7.0 amu
D) 10 amu
E) 14 amu

P15. A square made from conductive copper wire is 12.0cm on a side. The resistance of the wire square is 1.80Ω. The wire square is placed in a perpendicular 650 Gauss magnetic field (as shown). If the magnetic field is increased to 3250 Gauss in a time of 15.00ms, what is the current induced in the wire square?

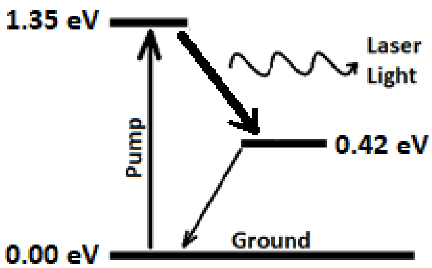


A) 34.1 mA
B) 77.2 mA
C) 116 mA
D) 139 mA
E) 170 mA

P16. You are examining a small leaf using a single converging lens as a magnifier. The lens has a focal length of 57.0cm and is held at a distance of 16.0cm from the leaf. What is the magnification of the leaf?

A) 0.22
B) 0.40
C) 0.78
D) 1.40
E) 3.56

P17. A three-level laser system utilizes atoms that have the energy levels shown in the diagram below. What is the wavelength of the laser light produced by this system?

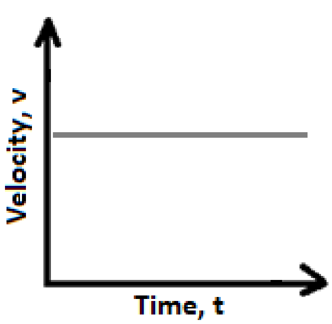


A) 2950 nm
B) 1330 nm
C) 920 nm
D) 700 nm
E) 630 nm

P18. An atom of ${}^{255}_{101}Md$ undergoes the following decay process: α , α , β^-, α , α , β^-. What is the final isotope produced after this series of radioactive emissions?

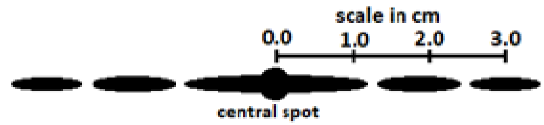
A) ${}^{237}_{91}Pa$
B) ${}^{239}_{93}Np$
C) ${}^{239}_{95}Am$
D) ${}^{241}_{93}Np$
E) ${}^{241}_{95}Am$

P19. Shown below is the velocity-time graph for a toy car moving in one dimension. Which statement best describes the motion of the car?



A) The car moves forward at constant speed.
B) The car moves backward at constant speed.
C) The car moves forward with constant acceleration.
D) The car moves backward with constant acceleration.
E) The car is stationary.

P20. A 632nm laser is directed onto a human hair, which diffracts the light like a single slit. Shown below is the diffraction pattern observed on a screen that is 1.50m away from the hair. What is the approximate diameter of the hair?



A) 110 μm
B) 76 μm
C) 54 μm
D) 38 μm
E) 27 μm

Chemistry

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8	8B 9	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)

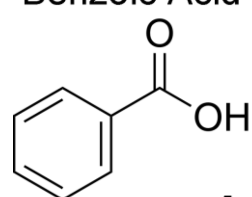
Water Data

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
ΔH_{fus} = 334 J/g
ΔH_{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
$\mathscr{F}$ = 96,485 C/mol e$^-$
1 amp = 1 C/sec
1 mol e$^-$ = 96,485 C

Benzoic Acid



$K_a = 6.3 \times 10^{-5}$

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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
2023 INVITATIONAL B

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL B 2023

C01. (B) The density is the mass of the screw (251.1 – 204.0 = 47.1 g) divided by the volume of the screw (26.0 mL – 20.0 mL = 6.0 mL). 47.1 g / 6.0 mL = 7.9 g/mL

C02. (D) The balanced equation is $C_2H_4O_2(\ell) + 2\ O_2(g) \rightarrow 2\ CO_2(g) + 2\ H_2O(\ell)$

C03. (C) Carbon has 6 protons, so an atom of carbon-14 has 14 – 6 = 8 neutrons. Changing the neutral atom to a +2 ion does not change the number of neutrons in the nucleus.

C04. (B) Although Na_3PO_4 is an ionic compound, the atoms in the polyatomic ion PO_4^{3-} are themselves covalently bonded together. The ionic bonds exist between the phosphate ion and the sodium ions, not within the phosphate ion itself.

C05. (E) $PV = nRT$. P = 1 atm, V = ?, n = 0.100 mol, R = 0.08206 L·atm/mol·K, and T = 190 + 273 = 463 K. V = (0.100)(0.08206)(463)/1 = 3.80 L. The initial temperature is not important and is not used in the calculation.

C06. (B) Generally speaking, the more volume the electrons take up, the more polarizable the species is. Xe and I^- have the same number of electrons, but I^- has a larger radius, which makes I^- more easily polarizable.

C07. (A)

C08. (D) The heat required to melt the ice is $q = m\Delta H_{fus}$, so the mass of the ice that melts is $m = q/\Delta H_{fus}$. m = (2500 J)/(334 J/g) = 7.49 g. The heat required to vaporize water is $q = m\Delta H_{vap}$, so vaporizing 7.49 g of water will take q = (7.49 g)(2260 J/g) = 16,916 J = 16.9 kJ.

C09. (E) Plugging the given pressures into the equilibrium expression yields

$$Q = \frac{C^3D}{A^2B} = \frac{(0.10)^3(0.15)}{(0.25)^2(0.25)} = 9.60 \times 10^{-3}$$

Since Q > K, there is too much product relative to the amount of reactant present, so the reaction will proceed backward toward an equilibrium ratio.

C10. (B) If you dilute the solution to twice the volume, it will have half the concentration. pH = $-\log[H^+] = -\log(0.0075) = 2.12$

C11. (A) $K_{sp} = [Ca^{2+}][OH^-]^2 = 4x^3$, where $x = [Ca^{2+}]$.

$$x = [\mathrm{Ca}^{2+}] = \left(\frac{K_{sp}}{4}\right)^{1/3} = \left(\frac{5.00\times10^{-6}}{4}\right)^{1/3} = 0.0108\ M$$

C12. (D) The catalyst provides an alternative pathway for the reaction to proceed by, and the new pathway has a lower activation energy.

C13. (C) The oxidation states on the carbon atoms in each compound are A) –2, B) –4, C) +4, D) 0, E) –1.

C14. (D) Molarity is moles per liter of solution, so 1.23 L × 15.7 mol/L = 19.3 mol.

C15. (A)

Chemical Formula	Chemical Name
H_2S	hydrosulfuric acid
H_2SO_3	sulfurous acid
HCl	hydrochloric acid
HClO	hypochlorous acid
$HBrO_3$	~~trioxy~~**bromic acid**

C16. (C) $P_1V_1 + P_1V_2, = P_{\text{FINAL}}V_{\text{TOTAL}}$. V_{TOTAL} = 1.5 L + 2.3 L = 3.8 L
P_{FINAL} = ((1.5)(3.3) + (2.3)(2.8))/3.8 = 3.0 atm

C17. (A) The allowed values for the principal quantum number *n* are integers starting with 1.

C18. (D) HBenz $\rightleftharpoons$ H^+ + $Benz^-$

$$K_\text{a} = \frac{[\text{H}^+][\text{Benz}^-]}{[\text{HBenz}]} = \frac{x^2}{(0.100 - x)}$$

Assume *x* << 0.100 (less than 5%)

$$K_a = \frac{x^2}{0.100}, so\ x = [H^+] = \sqrt{K_a \times 0.100} = \sqrt{6.3 \times 10^{-6}} = 2.51 \times 10^{-3}$$

Assumption is good: *x* = 0.00251 and is only 2.5% of 0.100, less than 5%.

$$pH = -\log[H^+] = -\log(2.51 \times 10^{-3}) = 2.60$$

Not making the assumption and solving for *x* using the quadratic formula yields the same result.

C19. (A) At constant pressure work is equal to $-P\Delta V$, and is also equal to $-\Delta nRT$. (Answer choice B is missing the negative sign.)

C20. (C) A formation reaction forms one mole of one product from its elements in their standard states (298K and 1 atm).

PHYSICS SOLUTIONS – UIL INVITATIONAL B 2023

P01. (E) pages 5-6: "So a new theory, the quantum theory of the interaction of light and matter, which is called by the horrible name 'quantum electrodynamics,' was finally developed by a number of physicists in 1929. But the theory was troubled. If you calculated something roughly, it would give a reasonable answer. But is you tried to compute it more accurately, you would find that the correction you thought was going to be small (the next term in the series, for example) was in fact very large – in fact, it was infinity!"

P02. (C) page 17: "So 'partial reflection' in this case means that 4% of the photons are reflected by the front surface of the glass, while the other 96% are transmitted."

P03. (B) page 24: "Now, what does an arrow have to do with the chance that a particular event will happen? According to the rules of 'how we count the beans,' the probability of an event is equal to the square of the length of the arrow."

P04. (D) Class O, B, and A stars are massive, hot, and short-lived. Because they are so short-lived, any cluster that contains a large number of them must be a very young cluster. Clusters can be open or compact, but the shape is largely unrelated to the classes of stars that the cluster contains. Old clusters do not contain O, B, and A stars in large numbers, and Globular Clusters are typically very old. White dwarf stars form when medium and low mass stars (like our Sun) die. These stars take many billions of years to become white dwarf stars, so you would not have many white dwarf stars in a cluster that still contains O, B, and A class stars. Thus, the best choice is that this cluster is very young.

P05. (C) Considering the order of operation, we must first do the addition in the parentheses in the numerator. When adding numbers, it is the number with the least decimal places that determines the decimal places of the sum. 8.2 is good to the tenths place, while 5.33 is good to the hundredths place. The least decimal places is the 8.2, so the sum is significant only to the tenths place. Completing the sum, we have: $8.2 + 5.33 = [13.5]3$. This sum has a total of three significant figures (indicated by the brackets).
Now we complete the division. For division, the result will have the same number of significant figures as the input value with the least number of significant figures. The numerator has three significant figures, and the denominator, 3.142, has four significant figures. Thus, the result will be the lesser of these, which is three significant figures. Completing the division, we have: $\frac{[13.5]3}{3.142} = [4.30]61744$. Rounded to three significant figures we get 4.31.

P06. (C) We know the horizontal distance that the tomato travels and the horizontal velocity of the tomato. We also know that the horizontal acceleration is zero for projectile motion. Thus, we can calculate the time that the tomato was in the air. $x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2 \;\rightarrow\; 11.0 = 0 + (8.00)t + 0$. This gives a time of $t = 1.375$sec. Because the tomato was initially thrown horizontally, the initial vertical velocity is zero. Taking the ground to be at a height of zero, plugging the time, and using the acceleration due to gravity, we get: $y_f = y_i + v_{yi}t + \frac{1}{2}a_y t^2 \;\rightarrow\; 0 = h + 0 + (0.5)(-9.80)(1.375)^2$. This gives an initial y-position for the tomato of $h = 9.26m$. This is the height of the window above the ground.

P07. (B) There are three forces acting on the box – gravity ($F_g = mg$), the normal force (F_N), and friction (F_f). Gravity is directed downward, while the normal force is directed up and to the left (perpendicular to the plane) and friction is directed up and to the right (parallel to the plane). It is customary to tilt the coordinate system to match the angle of the incline, so the x-direction is pointed down the plane and the y-direction is directed upward, perpendicular to the plane. In this coordinate system, the normal force is entirely in the positive y-direction and friction is entirely in the negative x-direction. Gravity must be broken into components: in the positive x-direction (down the plane) is $F_{gx} = mg\sin\theta$ where θ is the angle of the incline. In the negative y-direction (perpendicular into the plane) is $F_{gy} = mg\cos\theta$. There is no motion in the y-direction, so the forces in the y-direction must sum to zero: $\sum F_y = F_N - mg\cos\theta = 0 \ \rightarrow\ F_N = mg\cos\theta = (4.80)(9.80)\cos(28.0) = 41.5\text{N}$.
Now we can calculate the frictional force: $F_f = \mu F_N = (0.11)(41.5) = 4.57\text{N}$.
Finally, we sum the forces in the x-direction and use Newton's acceleration law to find the acceleration of the box: $\sum F_x = mg\sin\theta - F_f = ma \ \rightarrow\ (4.80)(9.80)\sin(28.0) - 4.57 = (4.80)a$.
This gives: $22.1 - 4.57 = 17.5 = 4.80a \ \rightarrow\ a = 3.65\text{m/s}^2$.

P08. (A) This is the conversion of the elastic potential energy stored in the spring into the kinetic energy of the cube sliding across the floor. The initial elastic potential energy is given by: $E_i = \frac{1}{2}kx^2 = (0.5)(2500)(0.12)^2 = 18.0$ J. By conservation of energy, the final kinetic energy must equal the same value as the initial energy: $E_f = \frac{1}{2}mv^2 = 18.0 \ \rightarrow\ (0.5)(8.90)v^2 = 18.0 \ \rightarrow$ $v = \sqrt{4.04} = 2.01\text{m/s}$.

P09. (D) We know the initial and final angular velocities, as well as the time. This allows us to calculate the angular acceleration of the tire: $\omega_f = \omega_i + \alpha t \ \rightarrow\ 80.0 = 0 + \alpha(9.00) \ \rightarrow\ \alpha = 8.89\text{rad/s}^2$.
Now, we can find the total angle through which the tire rotated while it was accelerating: $\theta_f = \theta_i + \omega_i t + \frac{1}{2}\alpha t^2 = 0 + 0 + (0.5)(8.89)(9.00)^2 = 360\text{rad}$. Converting the angle in radians to revolutions, we get: $\theta_f = \frac{360}{2\pi} = 57.3\text{rev}$.

P10. (D) The frequency of a wave on a string is given by: $f = \frac{nv}{2L}$. Since this is the fundamental harmonic, we know $n = 1$. Likewise, we know both the length of the string and the frequency of the wave. This gives us the velocity of the wave on the string: $588 = \frac{(1)v}{2(0.42)} \ \rightarrow\ v = 494\text{m/s}$. This velocity relates to the tension in the string by: $v = \sqrt{\frac{T}{\mu}}$ where μ is the mass per length of the string. For μ we calculate: $\mu = \frac{mass}{length} = \frac{0.680 \times 10^{-3}kg}{0.420m} = 0.00162$ kg/m. Putting it together: $494 = \sqrt{\frac{T}{0.00162}} \ \rightarrow\ (494)^2 = \frac{T}{0.00162}$.
This leads to $T = (0.00162)(494)^2 = 395\text{N}$.

P11. (E) As odd as it sounds, this kind of event does not violate conservation of energy. The energy to heat the air in the room came from the water, so the energy equation is still balanced. Likewise, there is no problem with conservation of momentum. The reason that we don't see events like this happen is because of the Second Law of Thermodynamics, which starts that entropy (a measure of the disorder of a system) cannot decrease in a closed system. The glass of water on a table in a room approximates a closed system, so this event won't happen because the event described would result in a decrease in the entropy of the system. (Side note: this event can happen if we add some additional entropy-increasing elements, such as a refrigerator. A refrigerator can cool a glass of water and simultaneously heat up the air in the room; however, by using electricity to accomplish this task, the refrigerator increases entropy enough to more than counterbalance any decrease caused by the cooling/freezing water.)

P12. (A) The relevant equation is: $R = \frac{\rho L}{A}$. Here, ρ is the resistivity of the material, L is the length of the wire, and A is the cross-sectional area of the wire. The wire's cross section is a circle, so the cross-sectional area is given by $A = \pi r^2$. The diameter of the wire is $d = 0.405mm = 4.05 \times 10^{-4}m$, so the radius is
$r = \frac{d}{2} = \frac{4.05\times10^{-4}}{2} = 2.025 \times 10^{-4}m$. Then the area is $A = \pi(2.025 \times 10^{-4})^2 = 1.288 \times 10^{-7}m^2$.
Now we can calculate the resistance: $R = \frac{(1.70 \times 10^{-8}\Omega m)(250,0m)}{1.288 \times 10^{-7}m^2} = 33.0\ \Omega$.

P13. (B) The force on one charge due to another is found by using Coulomb's Law. That is, by using $F = \frac{kQ_1Q_2}{r^2}$. The Coulomb constant is $k = 8.99 \times 10^9\ \frac{Nm^2}{C^2}$, and the charge magnitudes are $Q_1 = 32.0 \times 10^{-6}C$ and $Q_2 = 64.0 \times 10^{-6}C$. Finally, r is the distance between the charges, which can be obtained from the axis locations of the charges:
$r = 10.0cm - (-7.50cm) = 17.5cm = 0.175m$. Putting it all together, we find:
$F = \frac{kQ_1Q_2}{r^2} = \frac{(8.99\times10^9 \frac{Nm^2}{C^2})(32.0\times10^{-6}C)(64.0\times10^{-6}C)}{(0.175m)^2} = 601N$.

P14. (C) 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 the mass of the charged particle, we get $m = \frac{qBr}{v}$. Now, the ions are singly-charged, which means that they have one unit of charge, $q = 1.60 \times 10^{-19}\ C$. The magnetic field must be converted into Teslas, so $B = 800\ G = 0.0800\ T$. Finally, we must determine the radius of the ion beam path: $r = \frac{d}{2} = \frac{84.4cm}{2} = 42.2cm = 0.422m$. Now we put it together to find the mass of the ions: $m = \frac{(1.60 \times 10^{-19})(0.0800)(0.422)}{(4.6 \times 10^5)} = 1.17 \times 10^{-26}kg$. Converting to atomic mass units, we get
$m = \frac{1.17\times10^{-26}}{1.67 \text{ x } 10^{-27}} = 7.0amu$.

P15. (D) According to Faraday's Law, the voltage induced in a closed loop as a result of a changing magnetic flux is given by $\mathcal{E} = -\frac{\Delta\Phi}{\Delta t}$. The flux, Φ, is the product of the area of the loop, the magnetic field passing through the loop, and the sine of the angle between the magnetic field direction and the plane of the loop. Since the field direction is perpendicular to the plane of the loop, the angle is 90°. The area of the square loop is $A = s^2 = (0.12m)^2 = 0.0144m^2$. Thus, initially, the flux is
$\Phi_i = B_iA\sin\theta = (650\ G)(0.0144)(\sin 90°) = (0.0650\ T)(0.0144)(1) = 9.36 \times 10^{-4}\ Tm^2$. The final flux is $\Phi_f = B_fA\sin\theta = (3250\ G)(0.0144)(\sin 90°) = (0.3250\ T)(0.0144)(1) \rightarrow$
$\Phi_f = 0.00468\ Tm^2$. So, the change in flux is $\Delta\Phi = 0.00468 - 9.36 \times 10^{-4} = 0.003744\ Tm^2$.
The magnitude of the voltage induced in the loop is then $|\mathcal{E}| = \frac{\Delta\Phi}{\Delta t} = \frac{0.003744\ Tm^2}{0.01500\ sec} = 0.2496\ V$.
Finally, we use Ohm's Law to determine the induced current in the loop:
$I = \frac{\mathcal{E}}{R} = \frac{0.2496}{1.80} = 0.139A = 139\ mA$.

P16. (D) First, we need to find the location of the image of the leaf. This is found by using $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$, where *p* is the object location, *q* is the image location, and *f* is the focal length of the lens. Keeping all distances in centimeters, the image location can then be found: $\frac{1}{16.0cm} + \frac{1}{q} = \frac{1}{57.0cm} \rightarrow$
$\frac{1}{q} = -0.04496 \rightarrow q = -22.2cm$. The fact that the image location is negative is fine, and simply means that the image is virtual. Finally, we can find the magnification by using:
$M = -\frac{q}{p} = -\frac{-22.2cm}{16.0cm} = 1.40$.

P17. (B) Notice the energies of the two levels involved in the transition that produces the laser light. The difference in energy between these two levels is $\Delta E = 1.35eV - 0.42eV = 0.93eV$. From this, we can find the wavelength of the laser light: $\lambda = \frac{1240eVnm}{\Delta E} = \frac{1240eVnm}{0.93eV} = 1330nm$. This is in the near-infrared and closely matches the wavelengths commonly used for fiber optic communications.

P18. (C) Ultimately this atom of Mendelevium will emit four alpha particles and two negative beta particles. Each alpha particle lowers the atomic mass by four units and lowers the atomic number by two units. Each beta particle carries away no mass but raises the atomic number by one. Thus, the final isotope produced will have an atomic mass of $255 - 4(4) - 2(0) = 255 - 16 = 239$. Also, the final isotope will have an atomic number of $101 - 4(2) + 2(1) = 101 - 8 + 2 = 95$. So, the end product after these radioactive emissions will be an isotope of Americium: ${}^{239}_{95}Am$.

P19. (A) A horizontal line on a velocity-time graph indicates that the velocity of the car does not change with time – thus, the speed is constant. This means that the car is not accelerating. Also, note that the velocity is a positive value, thus, the car is moving forward and is not stationary nor moving backwards. So, the car described by this plot is moving forward at constant speed.

P20. (B) In order to find the diameter of the hair, we need to find the angle of diffraction for the first minimum. Based on geometry, the angle is given by $\tan\theta = \frac{x}{L}$, where *x* is the distance on the screen from the central spot to the first minimum, and *L* is the distance from the hair to the screen. Using the scale given with the diffraction pattern, we estimate the distance from the central spot to the first minimum to be $x = 1.2cm$. Thus, the diffraction angle can be found: $\tan\theta = \frac{1.2cm}{1.50m} = \frac{0.012m}{1.50m} = 0.008$ $\rightarrow \quad \theta = \tan^{-1}(0.008) = 0.46°$. Now we can turn to the single slit equation: $a \sin\theta = m\lambda$. Here λ is the laser wavelength and a is the diameter of the hair. By measuring on the screen to the first minimum, we have already chosen for $m = 1$.

Putting it together: $a \sin(0.46°) = (1)(632nm) = 0.008a$.

This gives $a = \frac{632nm}{0.008} = 79000nm = 79.0\mu m \approx 76\mu m$.