UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Study Packet 2020

This Science packet contains tests and keys from **only** 2020 Invitational A, B and District. Region and State are not available.

This item is intended for High School grade levels.

UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational A • 2020

GENERAL DIRECTIONS:

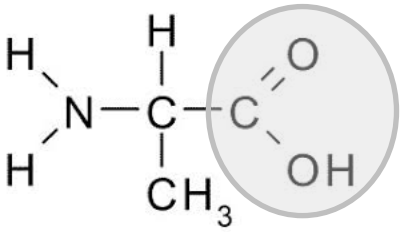
- **DO NOT OPEN EXAM UNTIL TOLD TO DO SO.**
- Contestants may take up to two hours to complete the contest. If you are in the process of actually writing an answer when the signal to stop is given, you may finish writing that answer.
- Papers may not be turned in until 30 minutes have elapsed. If you 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 photosystems of oxygenic photosynthesis use ___ as the electron donor.
A) oxygen
B) elemental sulfur
C) water
D) hydrogen sulfide
E) carbon dioxide

B02. A high level of transfer of genetic information from one population to another, called _____, generally prevents speciation of one or both of the populations.
A) gene flow
B) genetic drift
C) recombination
D) selection
E) genetic variation

B03. All of the following are diseases caused by eukaryotic organisms except
A) malaria.
B) amoebic dysentery.
C) African sleeping sickness.
D) trichinellosis.
E) cholera.

B04. The functional group identified by the circle is a/an



A) amino.
B) carboxyl.
C) alcohol.
D) ester.
E) ketone.

B05. The growth or movement of a plant towards or away from a stimulus is most specifically called
A) tropism.
B) taxis.
C) conditioning.
D) kinesis.
E) turgor.

B06. In terms of biological hierarchy, which scenario most accurately represents a community?
A) A stand of related pine trees.
B) Coastal areas including all of the living organisms and their environment.
C) All of the cells in a human body.
D) Populations of plants and animals interacting within a forest.
E) All of the oceans and land masses of plant Earth.

B07. Some RNA molecules can catalyze chemical reactions. These are collectively referred to as
A) enzymes.
B) ribonucleases.
C) ribosomes.
D) mRNAs.
E) ribozymes.

B08. The structure of an ecological community is especially maintained by the presence of a ____ ___, which has a disproportionately large effect on the environment relative to its abundance and may include apex predators as an example.
A) predator
B) keystone species
C) prey
D) primary producer
E) hybrid species

B09. The type of tissue that is found covering body surfaces and lining internal body cavities in humans is
A) skin.
B) connective.
C) muscular.
D) epithelial.
E) nervous.

B10. RNA polymerase is directly involved in which process?
A) translation
B) transcription
C) replication
D) mitosis
E) horizontal gene transfer

B11. In October 2019, the Centers for Disease and Prevention and public health officials investigated an ongoing multistate outbreak of _____ that is thought to be linked to pet turtles.
A) *Escherichia coli*
B) *Listeria*
C) Dengue fever
D) *Brucella*
E) *Salmonella*

B12. Which of the following situations is not an example of an atavism?
A) Teeth in chickens.
B) Hindlimbs in whales.
C) Reappearance of wings on stick insects.
D) Extra toes on a horse.
E) Blue eyes in a child born to parents and grandparents that also have blue eyes.

B13. Hematopoiesis is the process of making _____ in red bone marrow.
A) myeloid stem cells only
B) blood plasma
C) all cellular blood components
D) erythrocytes only
E) leukocytes only

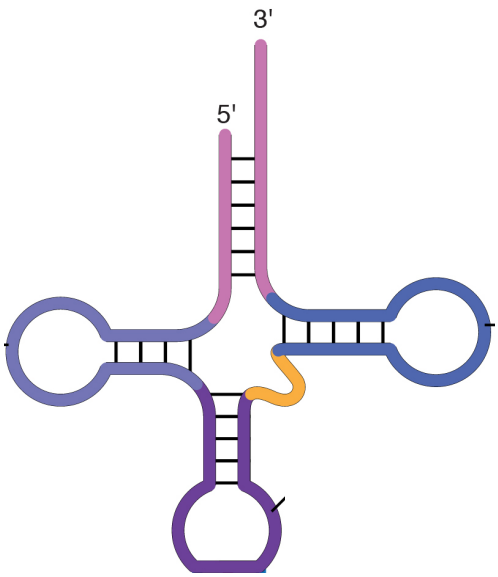
B14. If red (R) is dominant over white (r), what percentage of the offspring from this genetic cross will be white?
A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B15. All of the following are functions of biological membranes except
A) transport.
B) communication.
C) lipid biosynthesis.
D) protection.
E) attachment.

B16. The reduction of nitrates (NO_3^-) back into dinitrogen gas (N_2) in the nitrogen biogeochemical cycle is known as _____ and is generally due to anaerobically-respiring bacteria.
A) nitrification
B) ammonification
C) denitrification
D) anaerobic ammonia oxidation (anammox)
E) nitrogen fixation

B17. A prophage would only be found in which one of the following instances?
A) HIV integrates into eukaryotic host genes.
B) Lambda bacteriophage incorporates its genome into an *Escherichia coli* chromosome and is replicated in sync with binary fission.
C) A prophage is formed after biosynthesis of nucleic acids and viral protein coatings.
D) Prophages exist as complete virions outside of host cells.
E) A prophage forms during the lytic replication cycle.

B18. Examine the image of this cloverleaf-shaped molecule.



This molecule would be involved in
A) gene regulation.
B) RNA synthesis.
C) replication.
D) transcription.
E) translation.

B19. All of the following situations would indicate a Mendelian inheritance pattern except
A) a 3:1 phenotypic ratio from a monohybrid cross.
B) a dihybrid cross yielding 1 out of 16 progenies with a genotype of homozygous recessive for both traits.
C) the presence of only two alleles for a specific trait.
D) a cross between a homozygous recessive for white flowers and homozygous dominant for red flowers yielding pink flowers.
E) heterozygous and homozygous dominant always having a dominant phenotype.

B20. Which of the following is not a correct base pair in DNA-DNA or DNA-RNA interactions?
A) thymine-uracil
B) adenine-uracil
C) adenine-thymine
D) guanine-cytosine
E) All of the above are correct base pairs.

C01. Which of these is not an element?

A) Ca
B) Ce
C) Ci
D) Co
E) Cu

C02. What is the lowest whole-number coefficient on H_2O in the balanced equation for the combustion of hydrogen gas? $H_2(g) + O_2(g) \rightarrow H_2O(g)$

A) 0
B) 1
C) 2
D) 3
E) 4

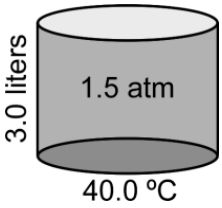
C03. What is the mass number of an atom that is made up of nine protons, ten neutrons, and nine electrons?

A) 28
B) 19
C) 18
D) 10
E) 9

C04. Which of these molecules contains a triple bond?

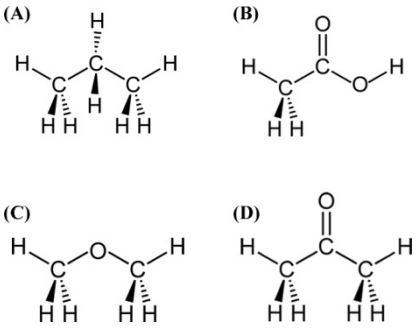
A) H_2
B) O_2
C) N_2
D) O_3
E) H_2O

C05. How would you calculate the number of moles in this gas sample?



A) $n = (0.082)(40)/(3.0)(1.5)$
B) $n = (0.082)(313)/(3.0)(1.5)$
C) $n = (3.0)(1.5)/(8.314)(40)$
D) $n = (3.0)(1.5)/(0.082)(40)$
E) $n = (1.5)(3.0)/(313)(0.082)$

C06. Arrange these compounds in order of decreasing boiling point.



A) A > C > B > D
B) D > C > B > A
C) B > D > C > A
D) D > B > C > A
E) B > C > D > A

C07. Given the following data,

$N_2(g) + 2\ O_2(g) \rightarrow 2\ NO_2(g) \quad \Delta H = 67.7$ kJ
$N_2(g) + 2\ O_2(g) \rightarrow N_2O_4(g) \quad \Delta H = 9.7$ kJ

Calculate ΔH for the dimerization of NO_2:

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

A) 77.4 kJ
B) –77.4 kJ
C) 58.0 kJ
D) –58.0 kJ
E) –29.0 kJ

C08. Which of these best describes what happens to the energy of the water molecules as a sample of ice melts?

A) The kinetic energy increases and the potential energy decreases.
B) The potential energy increases and the kinetic energy decreases.
C) The potential energy remains the same and the kinetic energy increases.
D) The kinetic energy remains the same and the potential energy increases.
E) The potential energy and the kinetic energy both increase.

C09. If the following chemical equation represents an equilibrium reaction, what symbol should replace the question mark: $2A + B_2$ ***?*** $2AB$

A) an equals sign, =
B) a double-headed arrow, ↔
C) a backward-facing arrow, ←
D) stacked forward and backward arrows, ⇌
E) the equilibrium symbol, €

C10. If equal volumes of solutions with pH 2.0 and 6.0 are added, what will be the pH of the resulting solution?

A) 4.0
B) 8.0
C) 2.3
D) 3.0
E) 5.7

C11. What is the molar solubility of barium bromate, $Ba(BrO_3)_2$? $K_{sp} = 2.43 \times 10^{-4}$

A) 0.0624 mol/L
B) 0.0393 mol/L
C) 0.0156 mol/L
D) 0.0991 mol/L
E) 0.00779 mol/L

C12. In which of these compounds is the metal atom in the highest oxidation state?

A) Cu_2O
B) SnO_2
C) PbO
D) V_2O_3
E) Fe_3O_4

C13. When the starting concentration of reactant A_2B in a chemical reaction is increased from 0.056 M to 0.112 M, the initial rate of the reaction doubles. What is the order of A_2B in the rate law for this reaction?

A) 2
B) 4
C) 0
D) 1
E) None of these

C14. Which of the elements below is a gas at room temperature?

A) An atom with 12 protons
B) An atom with 16 electrons
C) An atom whose ground state electron configuration ends with $3p^6$
D) An atom whose outermost electron has quantum numbers $n = 2$ and $\ell = 0$
E) An atom with $Z = 6$

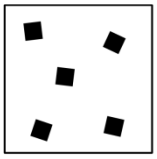
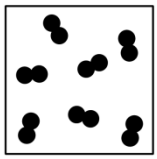
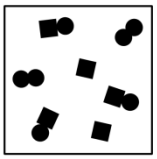
C15. The atmospheric pressure on Mars is 4.55 mm Hg. What is this pressure expressed in atmospheres?

A) 0.00599 atm
B) 0.00455 atm
C) 0.0450 atm
D) 0.167 atm
E) 0.0 atm

C16. Which of these samples contains the greatest number of solute particles?

A) 1.0 L of 0.5 M $AlCl_3$
B) 2.0 L of 0.4 M $NaNO_3$
C) 3.0 L of 0.3 M KCl
D) 4.0 L of 0.2 M $BaCl_2$
E) 5.0 L of 0.1 M Na_2SO_4

C17. If the circles and squares represent different kinds of atoms, which of these images depicts a mixture of elements?

A) 
B) 
C) 
D) 
E) 

C18. The main points of John Dalton's atomic theory are

1. Elements are made of extremely small particles called atoms.
2. Atoms cannot be subdivided, created, or destroyed.
3. The atoms of a given element are all identical in size, mass, and properties.
4. Atoms combine in simple whole-number ratios to form chemical compounds.
5. In chemical reactions, atoms are combined, separated or rearranged.

How many of these points are no longer considered to be true?

A) 0
B) 1
C) 2
D) 3
E) 4

C19. What is the mass of three moles of nitrogen triiodide?

A) 140.9 g
B) 394.7 g
C) 422.7 g
D) 1024 g
E) 1184 g

C20. A balloon with a volume of 2.35 L at 23 ºC is placed into a freezer at –5 ºC. What is the final volume of the balloon in the freezer?

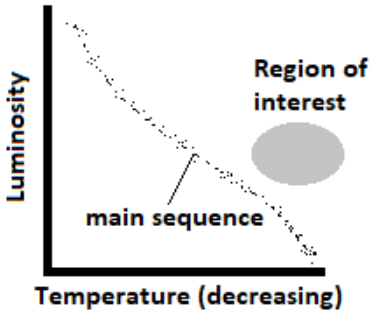
A) 2.60 L
B) 2.13 L
C) 2.05 L
D) 2.75 L
E) 2.32 L

P01. According to Orzel, physicists Clinton Davisson and Lester Germer bounced electrons off of a nickel surface and discovered _____.
A) the charge of the electron.
B) the mass of the electron.
C) the wave-like properties of the electron.
D) the intrinsic angular momentum of the electron.
E) the anti-electron (the positron).

P02. According to Orzel, the zero-point energy of empty space leads to some surprising consequences such as the…
A) spontaneous emission of photons from atoms.
B) photoelectric effect.
C) annihilation of electrons and positrons.
D) wave-like properties of electrons.
E) Heisenberg Uncertainty Principle.

P03. According to Orzel, which of these choices is NOT one of the central principles of quantum mechanics?
A) Wavefunctions
B) Allowed States
C) Probability
D) Superposition
E) Measurement

P04. A low-mass star located on a Hertzsprung-Russell diagram in the 'region of interest' generates energy primarily through the fusion of what element?
A) Hydrogen
B) Helium
C) Carbon
D) Oxygen
E) Iron



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

$$Z = \frac{13.177 + 2.10}{5.955}$$

A) 2.5654
B) 2.565
C) 2.57
D) 2.6
E) 3

P06. A cyclist starting from rest accelerates up to a speed of 12.50m/s. During the acceleration, the cyclist travels a distance of 30.0m. What is the acceleration of the cyclist?
A) 0.208 m/s^2
B) 0.417 m/s^2
C) 1.30 m/s^2
D) 2.60 m/s^2
E) 5.21 m/s^2

P07. A 3.10kg box of bananas is pushed across a frictionless floor by a constant, horizontal force. The box starts from rest and reaches a speed of 5.20m/s in 5.00seconds. What is the magnitude of the force pushing the box?
A) 8.39 N
B) 5.93 N
C) 4.19 N
D) 3.22 N
E) 1.61 N

P08. You toss a quarter into the air with an initial upward velocity of 3.71m/s. Ignoring air resistance, how high above your hand does the quarter reach before coming back down?
A) 18.9 cm
B) 37.9 cm
C) 43.5 cm
D) 61.5 cm
E) 70.2 cm

P09. A bicycle wheel starting from rest experiences an angular acceleration of 2.60 rad/s^2. If the final velocity of the wheel is 98.5 rad/s, through how many revolutions did the wheel rotate while accelerating?

A) 37.9 revolutions
B) 297 revolutions
C) 594 revolutions
D) 1866 revolutions
E) 3732 revolutions

P10. A travelling wave is described by the equation:

$$y(x,t) = (12.0cm)\cos(3.30x - 26.0t).$$

What is the oscillation frequency, f, of this wave?

A) 0.525 Hz
B) 1.90 Hz
C) 4.14 Hz
D) 7.88 Hz
E) 12.0 Hz

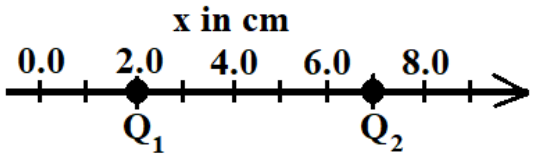
P11. A particular engine takes in 1600.0J of heat energy and exhausts 1100.0J of waste heat energy. What is the efficiency of this engine?

A) 31.3%
B) 45.5%
C) 54.5%
D) 68.8%
E) 81.5%

P12. You have a piece of wire made of an unknown metal. The wire is 30.0m long and has a diameter of 0.800mm. When you connect the wire to a 12.0V battery, a current of 320mA flows in the wire. What is the resistivity of the unknown metal from which the wire is made?

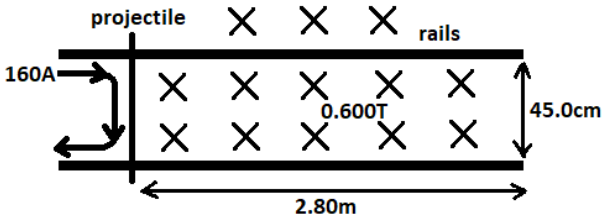
A) 4.47×10^{-7} Ωm
B) 6.28×10^{-7} Ωm
C) 1.79×10^{-6} Ωm
D) 2.51×10^{-6} Ωm
E) 1.88×10^{-5} Ωm

P13. Two charges, $Q_1 = 6.50\mu C$ and $Q_2 = -9.30\mu C$, are located on the x-axis as shown. What is the magnitude and direction of the force on Q_2 due to the presence of Q_1?



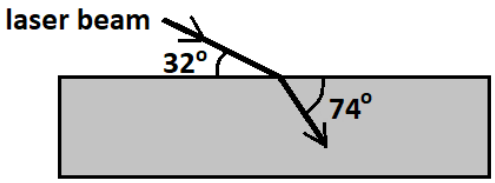
A) 10.9 N left
B) 33.5 N left
C) 33.5 N right
D) 217 N left
E) 217 N right

P14. You build a prototype railgun in which the current flowing in the rails (and projectile) is 160.0A, as shown. The rails are separated by 45.0cm, and the 120g projectile starts from rest at a point 2.80m from the end of the rails. The magnetic field is perpendicular to the rails and has a strength of 0.600T. What is the velocity of the projectile when it reaches the end of the rails and exits the railgun?



A) 14.2 m/s
B) 31.7 m/s
C) 44.9 m/s
D) 63.5 m/s
E) 318 m/s

P15. A laser beam travelling in air is directed onto a slab of transparent aluminum. The laser is refracted as shown. Based on this result, what is the index of refraction of transparent aluminum?



A) 3.49
B) 3.08
C) 1.81
D) 1.60
E) 1.13

P16. You are looking at an ant using a single converging lens as a magnifier. The lens has a focal length of 8.00cm and is held at a distance of 3.00cm from the ant. What is the magnification of the ant?

A) 0.63
B) 1.38
C) 1.60
D) 2.67
E) 4.80

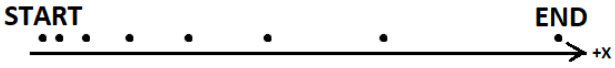
P17. Light with a wavelength of 487nm is directed onto a metal surface, resulting in the production of photoelectrons. If the workfunction of the metal is 1.42eV, what is the velocity of the emitted photoelectrons?

A) 6.29×10^5 m/s
B) 7.07×10^5 m/s
C) 9.46×10^5 m/s
D) 1.18×10^6 m/s
E) 4.45×10^6 m/s

P18. An atom of ^{249}No undergoes the following decay process: β^+ , β^+ , α , β^+ , α. What is the end product isotope after this series of radioactive emissions?

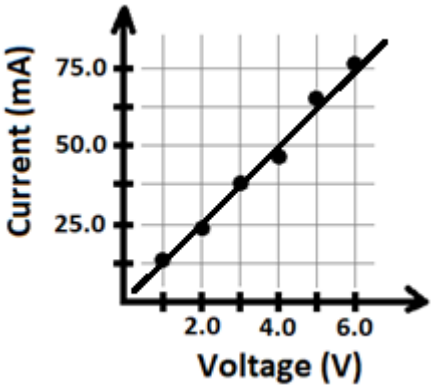
A) ^{244}Cf
B) ^{244}Md
C) ^{241}Cf
D) ^{241}Am
E) ^{238}Am

P19. A dot car, a toy car that produces dots at regular time intervals, is run in a straight line across the floor. The dot car leaves behind the following dot trail. What best describes the motion of the dot car?



A) The dot car has positive acceleration.
B) The dot car has negative acceleration.
C) The dot car has constant positive velocity.
D) The dot car has constant negative velocity.
E) The dot car has constant displacement.

P20. The current through an unknown resistor is measured as the voltage across the resistor is varied. The data is graphed below. From the graph, determine the resistance of the unknown resistor.



A) 8.00 Ω
B) 12.5 Ω
C) 20.0 Ω
D) 45.0 Ω
E) 80.0 Ω

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)

<u>Water Data</u>

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*

<u>Constants</u>

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

<u>Pressure and Volume Conversion Factors</u>

1 atm = 760 torr
1 atm = 101325 Pa
1 atm = 1.01325 bar
1 atm = 14.7 psi
1 atm = 29.92" Hg
1 torr = 1 mm Hg
1 bar = 105 Pa

1 L = 1.057 qt
1 gal = 3.785 L
1 gal = 231 in^3

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
2020 INVITATIONAL A

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL A 2020

C01. (C)

C02. (C) $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$

C03. (B) Mass number = protons + neutrons

C04. (C)

C05. (E)

C06. (C) H-bonding > dipole-dipole > less polar, so weaker dipole forces > nonpolar, dispersion forces

C07. (D) This problem is solved using Hess's Law:

$N_2(g) + 2O_2(g) \rightarrow 2\ NO_2(g)$ $\Delta H = 67.7$ kJ (1)

$N_2(g) + 2O_2(g) \rightarrow N_2O_4(g)$ $\Delta H = 9.7$ kJ (2)

Equation (2) – Equation (1):

$2\ NO_2(g) \rightarrow N_2O_4(g)$ $\Delta H = -58.0$ kJ

C08. (D) Since the temperature of a substance doesn't change during a phase change, the kinetic energy of the particles does not change. The energy that goes into the substance becomes potential energy of the particles as they are able to partially overcome the intermolecular forces between the particles.

C09. (D)

C10. (C) Assume 1 L of each solution: pH 2.0 = 0.01 moles H^+, pH 6 = 0.000001 moles H^+. Final concentration = (0.010001 moles/2 L) = 5.0005×10^{-3} *M*. $-\log(5.0005 \times 10^{-3})$ = pH 2.3.

C11. (B) $K_{sp} = [Ba^{2+}][BrO_3^-]^2$, $[BrO_3^-] = 2 \times [Ba^{2+}]$, $K_{sp} = [x][2x]^2 = 4x^3$, $x = 0.0393$ mol/L

C12. (B) The tin in SnO_2 is in a +4 oxidation state.

C13. (D) Doubling the concentration doubles the rate, so A_2B is first order in the rate law.

C14. (C) The elements in the answer choices are A) Mg, B) S, C) Ar, D) Li or Be, and E) C.

C15. (A)

C16. (D) The number of moles of solute particles = volume × concentration × ions per formula unit

C17. (D)

C18. (C) The discovery of subatomic particles and isotopes disproved numbers 2 and 3.

C19. (E) [14.01 g/mol + (126.9 g/mol × 3)] × 3 mol = 1184 g

C20. (B)

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{(2.35\ \text{L})(268\ \text{K})}{(296\ \text{K})} = 2.13\ \text{L}$$

PHYSICS SOLUTIONS – UIL INVITATIONAL A 2020

P01. (C) page 28: "In 1927, two American physicists, Clinton Davisson and Lester Germer, were bouncing electrons off of a surface of nickel, and recording how many bounced off at different angles. They were surprised when their detector picked up a very large number of electrons bouncing off at one particular angle. This mysterious result was eventually explained as the wave-like diffraction of the electrons…"

P02. (A) page 53: "Even empty space has zero-point energy, which leads to some surprising consequences, including the spontaneous emission of photons from atoms and tiny forces (called 'Casimir forces') between metal plates in a vacuum."

P03. (D) page 59 "Central Principles of Quantum Mechanics: Wavefunctions, Allowed States, Probability, Measurement"
Mentioned again on page 75: "These four ideas – wavefunctions, allowed states, probability, and measurement – are the central elements of quantum theory."

P04. (B) Stars that are located above and to the right of the main sequence are in the "giant" phase of their life cycle – these stars have lower temperature and higher luminosity (due to their size) than main sequence stars. For a low-mass star, this phase indicates that the star has run out of hydrogen in its core and has begun the fusion of helium into carbon. Thus, low-mass stars in this region of the H-R diagram are generating energy through the fusion of helium.

P05. (B) First, we must consider the addition in the numerator. During addition, it is the fewest number of decimal places of the quantities being added that determines the number of decimal places of the result. Thus, the result of the addition is: $13.177 + 2.10 = 15.27[7]$. This sum has two decimal places, and a total of four significant digits.
Now we can do the division. Here, the fewest number of significant digits of the two quantities determines the number of significant digits in the answer:

$$Z = \frac{15.27[7]}{5.955} = 2.565[407\ldots] = 2.565$$

Both the numerator and denominator have four significant digits, so the answer will also have four significant digits: $Z = 2.565$.

P06. (D) Since we know the initial and final speeds as well as the distance travelled, it is easiest to use the equation: $v^2 = v_0^2 + 2a(x_f - x_0)$. Plugging in the given values: $(12.5)^2 = (0)^2 + 2a(30 - 0)$. This leads to $156.25 = 60a$, giving an acceleration of $a = 2.60\text{m/s}^2$.

P07. (D) First, we need to find the acceleration of the box. Using the definition of acceleration, we calculate: $a = \frac{\Delta v}{\Delta t} = \frac{5.20-0}{5.00} = 1.04\text{m/s}^2$. Now, going to Newton's second law, we can calculate the net horizontal force: $F = ma = (3.10)(1.04) = 3.22$ N. In the absence of friction, this result is equal to the pushing force.

P08. (E) This is a conservation of energy problem in which linear kinetic energy is completely converted into gravitational potential energy. Setting up the equations, we have: $\frac{1}{2}mv^2 = mgh$. Notice how the mass cancels out, leaving: $\frac{1}{2}v^2 = gh \ \rightarrow \ h = \frac{v^2}{2g} = \frac{(3.71)^2}{2(9.8)} = 0.702\text{m} = 70.2\text{cm}$.

P09. (B) This is a straightforward angular kinematics problem. The best equation to use in this case is: $\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0) = (98.5)^2 = (0)^2 + 2(2.60)(\theta - 0) = 9702 = 5.20\theta \;\rightarrow\; \theta = 1866$rad. Now, we must convert this angle into revolutions: $\theta = \frac{1866}{2\pi} = 297$revolutions.

P10. (C) The general equation for a travelling wave is $y = Acos(kx \pm \omega t)$. Comparing this to the equation given, we can see that the amplitude of our wave is $A = 12.0$cm, the wave number is $k = 3.30\text{m}^{-1}$, and the angular frequency is $\omega = 26.0$rad/sec. It is this last number which helps answer the question: angular frequency, ω, and frequency, f, are related by a factor of 2π. The oscillation frequency is then: $f = \frac{\omega}{2\pi} = \frac{26.0}{2\pi} = 4.14$Hz.

P11. (A) If the engine takes in 1600J of heat, and exhausts 1100J of heat, then (because of conservation of energy) the amount of work done by the engine must be $W = 1600 - 1100 = 500$J. The efficiency is then given by: $e = \frac{Work}{Input\ Heat} = \frac{500}{1600} = 0.313 = 31.3\%$.

P12. (B) First, we use the voltage and current to find the resistance of the wire. Using Ohm's Law, we get $R = \frac{V}{I} = \frac{12.0}{0.320} = 37.5\Omega$. Now we can relate this to the resistivity by using the equation: $R = \frac{\rho L}{A}$. To use this equation, we will need the cross-sectional area of the wire. Noting that the radius of the wire is 0.400mm, and assuming a circular cross-section, we get: $A = \pi r^2 = \pi(0.400 \times 10^{-3})^2 = 5.03 \times 10^{-7}\text{m}^2$.
Now, $R = 37.5 = \frac{\rho L}{A} = \frac{\rho(30.0)}{5.03 \times 10^{-7}} = (5.97 \times 10^7)\rho$, which gives a resistivity of $\rho = 6.28 \times 10^{-7}\Omega$m.

P13. (D) This is a direct application of Coulomb's Law. First, we need the distance between the charges: $r = 7.0cm - 2.0cm = 5.0$cm. Now we can get the magnitude of the Coulomb force: $|F| = \left|\frac{kQ_1Q_2}{r^2}\right| = \left|\frac{(8.99 \times 10^9)(6.50 \times 10^{-6})(-9.30 \times 10^{-6})}{(0.050)^2}\right| = 217.4$N. Since the charges are opposite in sign, they will attract, which means that Q_2 will be pulled towards Q_1, or to the left.
Thus, the answer is $F = 217$N left.

P14. (C) First, we need to find the magnetic force on the projectile. Since everything is perpendicular (rails, projectile, and magnetic field) this is pretty easy: $F = I\ell B = (160)(0.45)(0.60) = 43.2$N. Now we can acquire the acceleration of the projectile: $a = \frac{F}{m} = \frac{43.2}{0.12} = 360\text{m/s}^2$. Finally, using kinematics, we can determine the velocity of the projectile when it reaches the end of the rails: $v^2 = v_0^2 + 2a\Delta x = 0 + 2(360)(2.8) = 2016 \;\rightarrow\; v = \sqrt{2016} = 44.9$m/s.

P15. (B) The index of refraction can be found by using Snell's Law, but first, we need the angles as measured from the normal, rather than from the surface.
The correct incident angle is $\theta_i = 90 - 32 = 58°$, and the correct angle for the refracted beam is $\theta_r = 90 - 74 = 16°$. Putting this into Snell's Law gives:
$n_i sin\theta_i = n_r sin\theta_r = (1.00)\sin(58) = n_r \sin(16) \;\rightarrow\; 0.8480 = 0.2756n_r$, giving $n_r = 3.08$.

P16. (C) First, we will need to find the location of the image of the ant. To do this we will use the lens image equation: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$. We are given that $f = 8.00$cm and $p = 3.00$cm. Plugging in: $\frac{1}{3.00} + \frac{1}{q} = \frac{1}{8.00} \;\rightarrow\; \frac{1}{q} = -\frac{5}{24} \;\rightarrow\; q = -\frac{24}{5} = -4.80$cm. Now we can determine the magnification of the ant: $M = -\frac{q}{p} = -\frac{-4.80}{3.00} = 1.60$.

P17. (A) To find the velocity, we will first find the kinetic energy of the emitted electrons. To do this, we will need the energy deposited by a single 487nm photon. Using a simple equation to convert from wavelength to energy, we get: $E = \frac{1240\ eVnm}{487nm} = 2.546$eV. Now, this energy is first used to overcome the workfunction of the metal, with any remaining energy going to the electrons as kinetic energy: $KE = E - \phi = 2.546 - 1.42 = 1.126$eV. This amount of kinetic energy is non-relativistic, so we can use the classical kinetic energy formula to acquire the velocity: $KE = \frac{1}{2}mv^2$. There are many units we could use, but I find it easiest to convert the kinetic energy to joules and solve for velocity in SI units: $KE = 1.126 * 1.602 \times 10^{-19} = 1.804 \times 10^{-19}$ J $= \frac{1}{2}(9.11 \times 10^{-31}kg)v^2$. This gives: $v^2 = 3.96 \times 10^{11} \rightarrow v = 6.29 \times 10^5$ m/s.

P18. (D) Nobelium has atomic number 102, and this isotope has an atomic mass number of 249. Now, each beta+ decay causes a drop in atomic number, and no change in the atomic mass number. Each alpha decay causes a drop of two in atomic number and a drop of four in atomic mass number. So, the ending atomic number is: $102 - 1 - 1 - 2 - 1 - 2 = 95$. Element 95 is Americium (Am). The ending atomic mass number is: $249 - 0 - 0 - 4 - 0 - 4 = 241$. Therefore, the final product of this series of radioactive emissions is Americium-241 (^{241}Am)

P19. (A) Based on the start and end locations, we can see that the dot-car is travelling in the positive direction, clearly eliminating choices D and E. Furthermore, the dots are not evenly spaced, indicating that the velocity is not constant and eliminating choice C. Finally, notice that the dots at the start are close together, but at the end are much farther apart – this indicates that the dot car is speeding up as it travels in the positive direction. Thus, the dot car has positive acceleration.

P20. (E) From the graph we can see that this data makes a straight line passing through the origin. The equation that describes this line is Ohm's law: $V = IR$. Since we have voltage as the independent variable (X) and current as the dependent variable (Y), we need to rewrite Ohm's Law as $I = \frac{V}{R}$. This is essentially: $y = \frac{1}{R}x$. Thus, the slope of the line on our graph equals $\frac{1}{R}$. To get the slope, you select two places on the best-fit line from which to calculate the slope. The two points that I selected from the line are (2.0V, 25.0mA) and (4.0V, 50.0mA). Then the slope is:

$$slope = \frac{50.0mA - 25.0mA}{4.0V - 2.0V} = \frac{25mA}{2V} = \frac{12.5mA}{V} = 0.0125\frac{1}{\Omega}$$

And the resistance is $R = \frac{1}{slope} = \frac{1}{0.0125} = 80.0\Omega$.

UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational B • 2020

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. Upon extinction of the dinosaurs 65.5 million years ago, the diversity of mammals exploded due to these animals filling the newly vacant ecological niches left behind by the dinosaurs. This process is called
A) allopatric speciation.
B) sympatric speciation.
C) extinction.
D) adaptive radiation.
E) Cambrian explosion.

B02. The DNA technology that can generate thousands of complementary DNA (cDNA) copies of a specific sequence using RNA as a template is called
A) PCR.
B) RT-PCR.
C) Multiplex-PCR.
D) quantitative PCR (qPCR).
E) DNA fingerprinting.

B03. A rooted phylogenetic tree
A) only includes the descendants of an ancestor.
B) includes a node for the most recent common ancestor.
C) does not contain the origin of the trait or gene in question.
D) is polyphyletic.
E) is none of the above.

B04. The *cis* face of the Golgi apparatus generally faces towards the
A) plasma membrane.
B) nucleus.
C) endoplasmic reticulum.
D) mitochondria.
E) nucleolus.

B05. The _____ system includes hair, skin, and nails.
A) nervous
B) muscular
C) immune
D) cardiovascular
E) integumentary

B06. In November 2019, the Centers for Disease Control and Prevention and public health officials investigated a multistate outbreak of *Salmonella* ___ _____ linked to ground beef.
A) Dublin
B) Newport
C) Uganda
D) London
E) Oranienburg

B07. Biodiversity is a measurement of two aspects/dynamics in a community setting, including
A) species richness and relative species abundance.
B) predator and prey interactions.
C) producer and consumer interactions.
D) keystone species and invasive species numbers.
E) numbers of primary producers/consumers and environmental succession.

B08. Which of the following events of cellular respiration in eukaryotes occurs within the cytosol?
A) citric acid cycle
B) pyruvate oxidation
C) electron transport chain
D) oxidative phosphorylation/chemiosmosis
E) glycolysis

B09. All of the following describe some aspect of anabolism, except
A) endergonic.
B) energy-consuming.
C) dehydration synthesis.
D) negative ΔG.
E) "building-up."

B10. The term "foundation species" usually refers to
A) consumers.
B) primary producers.
C) predators.
D) prey.
E) omnivores.

B11. Darwin's theory of evolution based on natural selection contains several basic tenets. Which of the following statements is not one of these tenets?
A) More offspring are produced than can survive.
B) Reproductive isolation promotes speciation.
C) Heritable traits better suited to the environment allow the individual to survive.
D) Phenotypic variation exists in the population and those variations are heritable.
E) Individuals evolve.

B12. A substitution mutation can never result in a(an) ___ _____ mutation.
A) silent
B) missense
C) frameshift
D) nonsense
E) None of the above are correct.

B13. Consider the events of meiotic cell division. Which event occurs first?
A) crossing over
B) Meiosis I
C) Meiosis II
D) DNA replication
E) Mitosis

B14. If red (R) is dominant to white (r) and green (G) is dominant to purple (g), what percentage of the offspring from the following genetic cross with be both white and green?

GgRr x ggrr

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

B15. A researcher examines the quantity of DNA in somatic cells growing within a flask and determines some cells contain double the amount of DNA compared to other cells. Which of the following statements about the cells containing more DNA could not be true?
A) They are in G1 phase.
B) They are in late S phase.
C) They are in G2 phase.
D) They are in prophase.
E) They are in either metaphase or anaphase.

B16. All of the following are helminths that cause disease in humans except
A) roundworms.
B) tapeworms.
C) flukes.
D) ringworm.
E) hookworms.

B17. The phospholipid bilayer is permeable to
A) gases (CO_2, N_2, O_2).
B) sugars, such as glucose and fructose.
C) ions (Ca^{2+}, Cl^-, K^+, Na^+).
D) complex carbohydrates.
E) polar molecules.

B18. The type of diabetes that forms as a result of the immune system attacking and destroying the insulin-producing cells of the pancreas is called
A) gestational diabetes.
B) neonatal diabetes mellitus.
C) Type 1 diabetes.
D) Type 2 diabetes.
E) All of the above are diabetes types called by autoimmunity.

B19. Animals containing stinging cells called nematocysts belong to Phylum
A) Chordata.
B) Nematophora.
C) Echinodermata.
D) Mollusca.
E) Cnidaria.

B20. Which of the following situations is an example of positive control in gene regulation?
A) A repressor binds to an operator and transcription is turned off.
B) A repressor binds to an inducer, which removes the repressor from the operator and transcription is turned on.
C) An activator protein binds to an inducer, which then bind to the activator sequence on DNA and promote transcription.
D) An activator binds to a corepressor and prevents transcription of genes.
E) A repressor binds to a corepressor, which then bind to the operator and prevent transcription.

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

A) CBr_4
B) NI_3
C) B_2O_3
D) H_2S
E) CF_2

C02. What is the lowest whole-number coefficient on H_2O in the balanced equation for the reaction of hydrazine with dinitrogen tetroxide?

$$N_4H_4(g) + N_2O_4(g) \rightarrow N_2(g) + H_2O(g)$$

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

C03. An atom of an element has a total of 16 electrons. An ion of the same element has a total of 18 electrons. Which statement below best describes the difference between the atom and the ion?

A) The ion is larger than the atom and has a positive charge.
B) The ion is smaller than the atom and has a positive charge.
C) The ion and the atom are the same size, but the atom has no net charge.
D) The ion is larger than the atom and has a negative charge.
E) The ion is smaller than the atom and has a negative charge.

C04. Bleegle and spleegle are miscible liquids. Pure bleegle freezes at 5°C and boils at 75°C. If a scientist adds a small amount of spleegle to a bottle of bleegle, which of these could *not* be true of the mixture?

A) The mixture freezes at –5°C and boils at 78°C
B) The mixture freezes at 0°C and boils at 76°C
C) The mixture freezes at 10°C and boils at 80°C
D) The mixture freezes at –10°C and boils at 82°C
E) The mixture freezes at 2°C and boils at 77°C

C05. Which of these molecules contains two double bonds?

A) CO_2
B) N_2O
C) HCN
D) C_2H_2
E) More than one but I'm not saying which ones.

C06. In a closed system, the temperature of a sample of gas is doubled from 100 K to 200 K. What happens to the number of moles of gas in the system?

A) n is doubled
B) n is halved
C) n is four times greater
D) n remains unchanged
E) it depends on the gas

C07. Arrange these ionic compounds in order of increasing melting point.

$BaCl_2$ CaO KI LiF

A) $CaO < BaCl_2 < KI < LiF$
B) $BaCl_2 < CaO < LiF < KI$
C) $LiF < KI < CaO < BaCl_2$
D) $BaCl_2 < CaO < KI < LiF$
E) $KI < LiF < BaCl_2 < CaO$

C08. Which of these best describes a system at equilibrium?

A) The reaction has come to a stop.
B) The forward and reverse reactions are happening at the same rate.
C) The molar concentrations of reactants and products are equal.
D) The masses of the reactants and products are equal.
E) The reaction is about to start.

C09. Fluorine and chlorine have similar chemical properties because their atoms have

A) the same shape and size
B) similar physical properties
C) electrons around the outside and protons in the nucleus
D) about a 50:50 ratio of protons to neutrons
E) the same number of valence electrons

C10. What is the molar solubility of barium bromate, $Ba(BrO_3)_2$, in grams per liter? $K_{sp} = 2.43 \times 10^{-4}$

A) 24.5 g/L
B) 15.5 g/L
C) 6.13 g/L
D) 0.287 g/L
E) 0.0955 g/L

C11. What is the missing reactant required to balance this chemical equation?

$$3HNO_2(aq) + 5H^+(aq) + \underline{\ ?\ } \rightarrow 3NO_3^-(aq) + 2Cr^{3+}(aq) + 4H_2O(\ell)$$

A) 2 Cr^{3+} (aq)
B) 2 CrO_4^- (aq)
C) $Cr_2O_7^{2-}$ (aq)
D) $Cr_2O_7^-$ (aq)
E) $Cr_2O_8^{2-}$ (aq)

C12. If the rate constant for a particular reaction is $6.33 \times 10^{-2}\ M^{-1}\ sec^{-1}$, what is the overall order of the reaction?

A) –2
B) –1
C) 0
D) 1
E) 2

C13. 100 mL of a strong acid solution at pH 4 is added to 100 mL of distilled water at pH 7. Which of these is closest to the pH of the resulting solution?

A) 4
B) 4.5
C) 5
D) 5.5
E) 6

C14. The atmospheric pressure on the surface of Venus is 93 bar. What is this pressure expressed in atmospheres?

A) 92 atm
B) 9.3 atm
C) 0.122 atm
D) 8.17 atm
E) 101 atm

C15. What is the mass of three moles of sodium chlorate?

A) 106.44 g
B) 175.20 g
C) 223.32 g
D) 271.32 g
E) 319.32 g

C16. Calculate the ΔH for the reaction between MgO and HCl using thermodynamic data on the data page.

$$MgO(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2O(\ell)$$

A) –146.6 kJ
B) –313.8 kJ
C) –1851 kJ
D) +146.6 kJ
E) +313.8 kJ

C17. What is *X* in this chemical equation?

$$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + X(aq)$$

A) hydronium ion
B) ammonium ion
C) hydroxide ion
D) hydrogen ion
E) Imodium ion

C18. On a 100 ºF Texas day, a piece of dry ice weighing 5.4 grams is placed in an empty balloon and the balloon is tied off. When the dry ice has completely sublimated what is the final volume of the balloon? (Assume ordinary atmospheric pressure.)

A) 3.13 L
B) 1.01 L
C) 0.38 L
D) 22.4 L
E) 16.7 L

C19. Which of the following aspects of Thomson's plum pudding model of the atom is also part of the modern model of the atom?

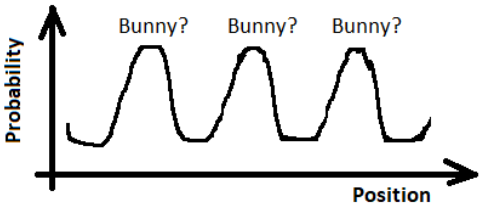
A) Atoms are composed of a small volume filled with matter that carries either a positive or a negative charge.
B) The mass of an atom is the sum of its positively-charged and negatively-charged components.
C) The positive charge in an atom is spread uniformly throughout the volume of the atom.
D) The negative charges in an atom are present in small subatomic particles that are easily removed from the atom.
E) The negative charges are embedded more or less evenly throughout the mass of the atom.

C20. If 50 mL of 0.55 M $AgNO_3$ is added to 100 mL of 0.15 M $ZnCl_2$, what mass of silver chloride will be formed?

A) 4.30 g
B) 0.70 g
C) 0.85 g
D) 3.94 g
E) 8.24 g

P01. According to Orzel, what must be true for an object to diffract around a barrier?
A) the object must be moving very fast.
B) the object's wavelength must be much smaller than the barrier.
C) the object's wavelength must be about the same size as the barrier.
D) the object must intersect the barrier at a glancing angle.
E) the object must have no mass.

P02. According to Orzel, the wavefunction shown below for a bunny in a backyard is not useful because…



A) it doesn't have a definite wavelength.
B) it doesn't provide position information.
C) it doesn't provide momentum information.
D) it isn't a continuous function.
E) it isn't a differentiable function.

P03. According to Orzel, which of the statements listed below are postulates, or apparent results, of the Copenhagen interpretation of quantum theory?

I. Microscopic and macroscopic objects follow different physical laws.
II. Wavefunctions collapse into a single state when a measurement is made.
III. Physical reality does not exist until a measurement if made.

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

P04. The arms of a spiral galaxy appear prominent because _____.
A) They contain a lot of massive, bright stars
B) They contain most all of the stars in the galaxy
C) They contain no dust to block starlight
D) They contain no gas to absorb starlight
E) They contain most of the galaxy's dark matter

P05. A rectangular container full of water measures 6.50cm by 4.00cm by 12.0cm. The water is spilled onto the floor, forming a circular puddle that is 0.200cm thick. Assuming all of the water spilled, what is the diameter of the circular puddle?
A) 15.8 cm
B) 22.3 cm
C) 31.5 cm
D) 44.6 cm
E) 63.0 cm

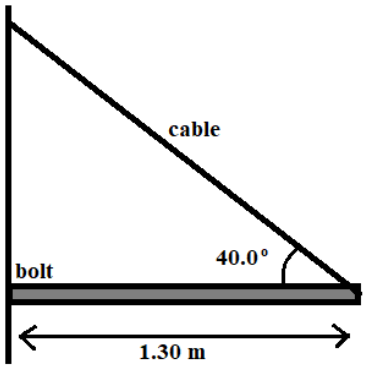
P06. A rock is thrown by a mischievous child at a speed of 15.5m/s and at an angle of 55.0° above the horizontal. At what horizontal distance from where it was thrown will the rock come back down to the ground? Assume the ground is level and ignore air resistance.
A) 7.27 m
B) 11.5 m
C) 17.3 m
D) 23.0 m
E) 28.1 m

P07. A 14.0kg crate slides down an inclined plane that is tilted at an angle of 51° with respect to the horizontal. The coefficient of friction between the crate and the plane is 0.38. What is the acceleration of the crate?
A) 2.34 m/s^2
B) 3.27 m/s^2
C) 5.27 m/s^2
D) 6.17 m/s^2
E) 7.62 m/s^2

P08. Two ice skaters, one with a mass of 60.0kg and the other with a mass of 75.0kg, are standing together on frictionless ice. Initially, the skaters are at rest. They push off of one another, after which the heavier skater has a speed of 5.68m/s. What is the final speed of the lighter skater?
A) 8.03 m/s
B) 7.10 m/s
C) 6.35 m/s
D) 5.08 m/s
E) 4.54 m/s

P09. A 3.50kg flagpole is held horizontal by a bolt at its base and a cable attached to its end (as shown). The cable makes an angle of 40.0° with respect to the horizontal flagpole. The flagpole is 1.30m long, and its mass is distributed uniformly throughout its length. What is the magnitude of the vertical component of the force acting on the bolt at the base of the flagpole?

A) 17.2 N
B) 20.4 N
C) 22.4 N
D) 26.7 N
E) 37.6 N



P10. A standing wave is set up on a guitar string. The string is 180cm long, has a mass of 3.50g, and the tension in the string is 25.0N. If the standing wave shows four anti-nodes, then what is the frequency of the wave?

A) 39.8 Hz
B) 79.6 Hz
C) 126 Hz
D) 161 Hz
E) 252 Hz

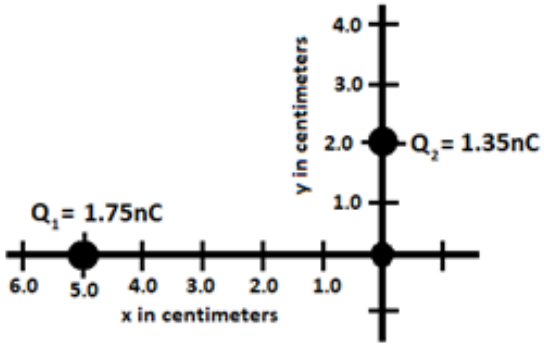
P11. You have decided to become a bare-handed blacksmith. While working in your new job, you hold a bar of steel into a furnace operating at 1300°C. The bar has a square cross-section that is 2.50cm on a side. In order to hold the bar without burning your hand, you need the power transfer through the bar to be less than 40W. What is the shortest length of steel bar, approximately, that you can safely hold?
Assume all heat transfer is via conduction and that your hand temperature is 37.0°C. The thermal conductivity of steel is 50.2 W/(m°C).

A) 4.0 cm
B) 40 cm
C) 80 cm
D) 100 cm
E) 160 cm

P12. Two circular plates, both with a diameter of 12.0cm, are arranged to form a parallel plate capacitor. The plates are separated by 2.50mm and the space between them is filled with an insulating dielectric material. When the capacitor is connected to a 9.00V battery, it builds up a charge of 1.15nC. Determine the dielectric constant of the material between the plates.

A) 4.08
B) 3.19
C) 2.50
D) 1.95
E) 1.60

P13. Two charges are located as shown: $Q_1 = 1.75$nC is at $(-5.0cm, 0.0)$, and $Q_2 = 1.35$nC is at $(0.0, 2.0cm)$. What is the electric potential, V, at the origin $(0.0, 0.0)$ due to these charges?



A) 290 V
B) 920 V
C) 9620 V
D) 24,100 V
E) 36, 700 V

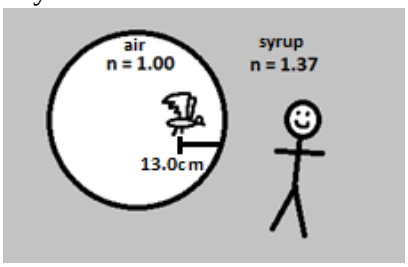
P14. A beam of Helium ions is directed into a region with a uniform magnetic field. The ions have a mass of 4.0026amu, a charge of $1e$, and the ions are travelling at a velocity of 4.30×10^5 m/s. The magnetic field is perpendicular to the velocity of the ion beam. If the circle traced out by the beam has a diameter of 44.0cm, what is the strength of the magnetic field?

A) 405 Gauss
B) 650 Gauss
C) 810 Gauss
D) 1300 Gauss
E) 4050 Gauss

P15. One way to send cargo into space involves directing a high-power laser onto a perfectly reflective disk. The resulting radiation pressure produces a force that can overcome gravity. For a test run, the laser is set to a power of 65.0GW, and the laser beam diameter is 20.0cm. The mass of the disk and its cargo totals 21.0kg. What is the net acceleration of the disk when it is near the surface of the Earth?

A) 1.03 m/s^2
B) 9.80 m/s^2
C) 10.8 m/s^2
D) 20.6 m/s^2
E) 30.4 m/s^2

P16. A hummingbird is hovering inside a spherical air bubble that has a diameter of 45.0cm. The air bubble is surrounded by corn syrup that has an index of refraction of 1.37. A scuba diver is outside the bubble looking at the hummingbird in the bubble (see diagram). If the hummingbird is hovering 13.0cm from the edge of the bubble, how far into the bubble is the image of the hummingbird located, as seen by the scuba diver?

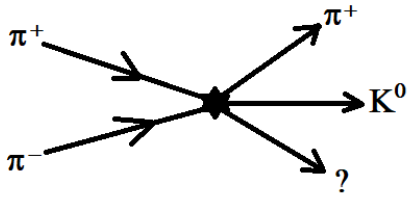


A) 10.7 cm
B) 12.1 cm
C) 14.7 cm
D) 16.5 cm
E) 22.7 cm

P17. A group of atoms is observed to strongly absorb light with a wavelength of 510nm. These same atoms then immediately drop to a lower energy state by emitting light with a wavelength of 781nm. Finally, these atoms decay back to the ground state through a non-radiative process. Taking the ground state to have an energy of zero, what are the energies of the two excited states involved in this three-state absorption-emission cycle?

A) 1.59 eV and 0.844 eV
B) 2.43 eV and 0.844 eV
C) 2.43 eV and 1.59 eV
D) 4.02 eV and 2.43 eV
E) 4.02 eV and 1.59 eV

P18. Two high-energy pions collide, producing a shower of particles as illustrated. One of the particles is unidentified. Using the table provided, determine the identity of the unidentified particle.



A) K^-
B) η^0
C) K^0
D) π^-
E) π^0

PARTICLE TABLE:

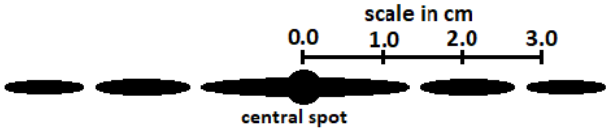
π^0	$\bar{u}u$ or $\bar{d}d$
π^+	$u\bar{d}$
π^-	$\bar{u}d$
K^0	$\bar{s}d$
K^+	$\bar{s}u$
K^-	$s\bar{u}$
η^0	$\bar{s}s$

P19. Several samples of the same mineral are weighed in air, and then weighed again while submerged in water. The data is tabulated below. From this data, determine the density of the mineral.

Sample	Weight in air	Weight in water
A	3.20 N	2.84 N
B	5.68 N	5.04 N
C	11.8 N	10.5 N
D	13.2 N	11.7 N

A) 6300 kg/m^3
B) 7900 kg/m^3
C) 8900 kg/m^3
D) 11,300 kg/m^3
E) 12,700 kg/m^3

P20. A laser with a wavelength of 575nm 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) 10 μm
B) 30 μm
C) 40 μm
D) 60 μm
E) 80 μm

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)

<u>Water Data</u>

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*

<u>Constants</u>

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
$\mathcal{R}_H = 2.178 \times 10^{-18}$ J
$m_e = 9.11 \times 10^{-31}$ kg

Pressure and Volume <u>Conversion Factors</u>

1 atm = 760 torr
1 atm = 101325 Pa
1 atm = 1.01325 bar
1 atm = 14.7 psi
1 atm = 29.92" Hg
1 torr = 1 mm Hg
1 bar = 105 Pa

1 L = 1.057 qt
1 gal = 3.785 L
1 gal = 231 in^3

<u>Enthalpy of Formation</u>

<u>Compound</u>	<u>ΔH_f (kJ/mol)</u>
MgO(*s*)	–601.7
HCl(*aq*)	–167.2
$MgCl_2$ (*aq*)	–796.9
$H_2O(\ell)$	–285.8

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
2020 INVITATIONAL B

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL B 2020

C01. (E) Carbon does not have an octet in CF_2, and the compound would not be stable.

C02. (B) The balanced equation is $2\ N_4H_4(g)\ + N_2O_4(g)\ \rightarrow 5\ N_2(g)\ + 4\ H_2O(g)$

C03. (D)

C04. (C) A solution has a lower freezing point and a higher boiling point than the pure solvent.

C05. (A)

C06. (D) No matter is allowed to enter or leave a closed system, so the moles of gas would remain the same. The pressure or volume (or both) would have to change when the temperature is changed.

C07. (E) Higher ionic charges and smaller ion sizes will lead to greater lattice energies of ionic compounds, requiring greater energy to break the lattice.

C08. (B) Equilibrium is achieved when the rates of the forward and reverse reactions are the same.

C09. (E)

C10. (B) $K_{sp} = [Ba^{2+}][BrO_3^-]^2$, $[BrO_3^-] = 2 \times [Ba^{2+}]$, $K_{sp} = [x][2x]^2 = 4x^3$, $x = 0.0393$ mol/L
0.0393 mol/L × 393.13 g/mol = 15.5 g/L

C11. (C)

C12. (E) The reaction must be second order in order for the rate in the rate law to have units of M/sec^{-1}: $M^{-1}\ sec^{-1} \times M^2 = M/sec$.

C13. (B) 0.100 L pH 4 solution = 1.00×10^{-5} moles H^+. 0.100 L pH 7 solution = 1.00×10^{-8} moles H^+.
Total moles $H^+ = 1.001 \times 10^{-5}$ moles / 0.200 L = 5.005×10^{-5} M H^+ = pH 4.3.

C14. (A) 93 bar × (1 atm/1.01325 bar) = 92 atm

C15. (E) Sodium chlorate is $NaClO_3$ 22.99 + 35.45 + (16.00 × 3) = 106.44 g/mol × 3 mol = 319.32 g

C16. (A) $\Delta H_{rxn} = \sum n\Delta H_{f_{products}} - \sum n\Delta H_{f_{reactants}}$
$\Delta H_{rxn} = \Delta H_{f_{MgCl2}} + \Delta H_{f_{H2O}} - \Delta H_{f_{MgO}} - 2\Delta H_{f_{HCl}}$
$\Delta H_{rxn} = -796.9 + -285.8 - (-601.7) - 2(-167.2)$
$\Delta H_{rxn} = -146.6$ kJ

C17. (C) This is a hydrolysis reaction. NH_3 accepts a proton from water, leaving a hydroxide ion, OH^-, behind.

C18. (A) P = 1 atm. T = 100 ºF = 37.8 ºC = 310.8 K. Moles of CO_2 = 5.4 g/44.01 g/mol = 0.123 mol
$PV = nRT$ so $V = nRT/P$ = (0.123 mol)(0.082 L·atm/mol·K)(310.8 K)/(1 atm) = 3.12 L

C19. (D)

C20. (D) moles of Ag^+ = (0.050 L)(0.55 mol/L) = 0.0275 mol Ag^+.
Moles of Cl^- = (0.100 L)(0.15 mol/L) 2 Cl^-/1 $ZnCl_2$) = 0.0300 mol Cl^-. Ag^+ is the limiting reactant, so 0.0275 mol of AgCl will be formed. 0.0275 mol × 143.32 g/mol = 3.94 g

PHYSICS SOLUTIONS – UIL INVITATIONAL B 2020

P01. (C) page 10: "You need your wavelength to be comparable to the size of the tree – maybe ten centimeters – in order to diffract around it…"

P02. (B) page 42: "This wavefunction doesn't meet our requirements, either. The wavelength is easy to define – just measure the distance between two points where the probability is largest – so we have a well-defined momentum, but we can't identify a specific position for the bunny. The bunny is spread out over the entire yard, with a good probability of finding it at lots of different places."

P03. (E) I. page 76: "The Copenhagen interpretation tries to avoid the problems of superposition and measurement by drawing a strict line between microscopic and macroscopic physics. Microscopic objects…are governed by the rules of quantum mechanics, but macroscopic objects… are governed by classical physics."
II. page 76 "Quantum measurement involves the interaction of a macroscopic measurement apparatus with a microscopic object, and that interaction changes the state of the microscopic object. The usual description is that the wavefunction 'collapses' into a single state. This 'collapse,' in the Copenhagen interpretation, is an actual change of the wavefunction …"
III. page 78: "The Copenhagen interpretation also seems to be saying that physical reality does not exist until a measurement is made…"

P04. (A) The arms of a spiral galaxy are places where there are large amounts of gas and dust, and extremely active star-forming regions. Although the majority of stars in a galaxy are in the central bulge, the arms are the only places to find young, short-lived, very luminous, massive stars. This is why the arms are so prominent: it is in the arms that you will find the brightest stars, which are young and massive.

P05. (D) First, we need to find the total volume of water. For the rectangular container:
$V = lwh = (6.50)(4.00)(12.0) = 312\ cm^3$
The puddle is a cylinder but contains the same total volume. So, using the formula for the volume of a cylinder: $V = \pi r^2 H = 312 = \pi r^2(0.200)$, which gives: $r^2 = 496.6$, or $r = 22.3$cm. Thus, the diameter of the puddle is $d = 2r = 44.6$cm.

P06. (D) First, we must consider the two components of the initial velocity:
$v_{0x} = v_0 cos\theta = (15.5)\cos(55) = 8.89$m/s, and $v_{0y} = v_0 sin\theta = (15.5)\sin(55) = 12.7$m/s. Since we know the rock starts and ends at approximately ground level, we let $y_f = y_0 = 0$. Now, using a kinematic equation for the y-direction: $y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = 0 = 0 + (12.7)t + \frac{1}{2}(-9.8)t^2$. This results in the factorable quadratic equation: $4.9t^2 - 12.7t = 0$, which gives times of $t = 0, 2.59$seconds. Since a time of zero is clearly the starting point, we take the ending point (the landing) to be at $t = 2.59$seconds.

Now we can use the horizontal component of velocity to determine the horizontal distance travelled in this time: $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 = 0 + (8.89)(2.59) + \frac{1}{2}(0)(2.59)^2 = 23.0$m.

P07. (C) In this situation there are three forces acting on the crate: friction (directed upward parallel to the plane), the normal force (directed upward perpendicular to the plane), and gravity (directed downward). As is customary, we tilt our coordinate system so that "down the plane" is the positive x-direction, and upward perpendicular to the plane is the y-direction. This means that the normal force goes in the positive y-direction, and the frictional force goes in the negative x-direction. Gravity, on the other hand, is directed at an angle with respect to our tilted coordinate system and must be broken into components.
In the tilted x-direction, the gravitational force is $F_{gx} = mgsin\theta = (14.0)(9.8)\sin(51) = 106.6\text{N}$.
In the tilted y-direction, we get $|F_{gy}| = mgcos\theta = (14.0)(9.8)\cos(51) = 86.34\text{N}$.

We now consider the forces in the y-direction. The crate does not accelerate in the y-direction (perpendicular to the plane), so the forces in that direction must sum to zero:
$\sum F_y = F_N - F_{gy} = F_N - 86.34 = 0$. This gives us the normal force: $F_N = 86.34\text{N}$. Knowing the normal force allows us to find the frictional force: $F_f = \mu F_N = (0.38)(86.34) = 32.8\text{N}$.

Since the crate accelerates in the x-direction, we have $\sum F_x = ma_x = F_{gx} - F_f$. Plugging in our calculated forces: $ma_x = 106.6 - 32.8 = 73.8\text{N} = (14.0)a_x$. This gives us an acceleration down the plane of $a_x = 5.27\text{m/s}^2$.

P08. (B) This is essentially a one-dimensional perfectly inelastic collision in reverse, so we will use conservation of momentum to solve it. Initially, the skaters are at rest, so their total momentum is zero. In other words, $p_1 + p_2 = 0$.
After they push apart, the momentum of the heavier skater is $p_1 = m_1 v_1 = (75)(5.68) = 426\text{kgm/s}$.
Since momentum must be conserved, we still require $p_1 + p_2 = 0$, which means $p_2 = -426\text{kgm/s}$.
Using the mass of the lighter skater, we determine $m_2 v_2 = -426 = (60)v_2 \;\rightarrow\; v_2 = -7.10\text{m/s}$.
Thus, the speed of the lighter skater is 7.10m/s (the sign provides the direction, which isn't needed).

P09. (A) First, we should list all of the forces acting on the flagpole along with the location at which they are acting. At the bolt we have forces that are horizontal (F_h), acting to the right, and vertical (F_v), acting upward. The weight (mg) of the flagpole is vertical (down) acting at a point halfway along the flagpole. Finally, at the end we have the cable tension (T) acting up-and-left at an angle of 40.0°.

The flagpole is in static equilibrium, so all forces and all torques sum to zero. We begin with the torques: we take the pivot point to be at the base of the flagpole. Then the torques are as follows:
$\sum \tau = F_h(0)\sin(0) + F_v(0)\sin(90) - mg(0.65)\sin(90) + T(1.30)\sin(40) = 0$. The first two terms vanish, and the last two terms have opposite signs since they would cause rotations in opposite directions. Simplifying: $0.8356T = (0.65)(3.50)(9.8) = 22.3 \;\rightarrow\; T = 26.7\text{N}$.

Considering the sum of horizontal forces, we have: $\sum F_H = F_h - Tcos(40) = 0$, which gives us the horizontal component of the bolt force: $F_h = Tcos(40) = (26.7)\cos(40) = 20.4\text{N}$ (which, by the way, we do not care about). Similarly, for the vertical forces: $\sum F_V = F_v + Tsin(40) - mg = 0$.
This leads to the vertical component of the bolt force:
$F_v = mg - Tsin(40) = (3.50)(9.8) - (26.7)\sin(40) = 17.2\text{N}$, which is the answer we seek.

P10. (C) First, we should find the velocity of the waves on the string. In order to do this, we need the mass-per-length of the string itself: $\mu = \frac{M}{L} = \frac{3.50 \times 10^{-3}\ kg}{1.80\ m} = 1.94 \times 10^{-3}$ kg/m. Now we can get the wave velocity for this string: $v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{25.0\ N}{1.94 \times 10^{-3} kg/m}} = 113.4\text{m/s}$.
In order to relate the velocity to the frequency, we need the wavelength of the standing wave. The wave shows four anti-nodes, so the mode of the standing wave is $n = 4$. This allows us to use the length of the string to find the wavelength: $\lambda = \frac{2L}{n} = \frac{2(1.80)}{4} = 0.90\text{m}$.
Now, we can find the frequency using $v = \lambda f = 113.4 = (0.90)f \;\rightarrow\; f = 126\text{Hz}$.

P11. (D) If the heat is only transferred through conduction, then the equation is $P = \frac{kA\Delta T}{L}$. The only number we do not have is the cross-sectional area, which we can calculate easily enough: $A = s^2 = (0.0250)^2 = 6.25 \times 10^{-4}$ m^2. Now, we plug all of the values into the conduction formula: $P = 40.0 = \frac{(50.2)(6.25 \times 10^{-4})(1300-37)}{L} = \frac{39.63}{L} \rightarrow L = 0.990\text{m} = 99.0 \approx 100\text{cm}$.

P12. (B) Using the charge and voltage, we can find the capacitance of the device: $C = \frac{Q}{V} = \frac{1.15 \times 10^{-9}}{9.00} = 1.28 \times 10^{-10}$ F $= 128$ pF. Now we can relate this capacitance to the geometry of the device, and the dielectric constant: $C = 128pF = \frac{\kappa\varepsilon_0 A}{d}$. In order to use this equation, we do need the area of the plates: $A = \pi r^2 = \pi(0.06)^2 = 0.01131\text{m}^2$.
Plugging in, we get $128 \times 10^{-12} = \frac{\kappa(8.854 \times 10^{-12})(0.01131)}{2.50 \times 10^{-3}} \rightarrow 128 = \kappa(40.055) \rightarrow \kappa = 3.19$.

P13. (B) The electric potential of a point charge is given by the equation $V = \frac{kQ}{r}$. Furthermore, since electric potential is a scalar, we can add the potentials from each point charge to get the total electric potential at the origin. The potential from the first charge is: $V_1 = \frac{kQ_1}{r_1} = \frac{(8.99 \times 10^9)(1.75 \times 10^{-9})}{(0.05)} = 315\text{V}$. The potential from the second charge is: $V_2 = \frac{kQ_2}{r_2} = \frac{(8.99 \times 10^9)(1.35 \times 10^{-9})}{(0.02)} = 607\text{V}$. Thus, the total electric potential at the origin is $V = V_1 + V_2 = 315 + 607 = 922 \approx 920\text{V}$.

P14. (C) The equation for the radius of the circle traced out by a charged particle in a magnetic field is $r = \frac{mv}{qB}$. Using this equation but solving for the magnetic field gives: $B = \frac{mv}{qr}$. Before using this equation, we need to convert the mass: $m = (4.0026)(1.66 \times 10^{-27}) = 6.64 \times 10^{-27}$kg, and find the radius of the circular path: $r = \frac{d}{2} = \frac{0.44}{2} = 0.22\text{m}$. Noting that the charge is $1e = 1.602 \times 10^{-19}C$, we get a magnetic field of $B = \frac{mv}{qr} = \frac{(6.64 \times 10^{-27})(4.30 \times 10^5)}{(1.602 \times 10^{-19})(0.22)} = 0.081T = 810Gauss$.

P15. (C) This solution will include a bit of mathematical redundancy, but since the problem specifically mentions radiation pressure, we will start with that. We begin with the intensity of the laser, which means we need the area of the beam. Noting that the radius is 10.0cm, we get an area of: $A = \pi r^2 = \pi(0.10)^2 = 0.0314\text{m}^2$.
Then the beam intensity is $I = \frac{Power}{A} = \frac{65.0 \times 10^9}{0.0314} = 2.07 \times 10^{12}\text{W/m}^2$.
Now the radiation pressure for a perfectly reflective surface onto which the entire laser is incident is: $P = \frac{2I}{c} = \frac{4.14 \times 10^{12}}{3.00 \times 10^8} = 13793\text{Pa}$. To calculate the force on the disk, we once again use the area of the laser beam, since that is the only part of the disk the experiences the radiation pressure: $F = PA = (13793)\pi(0.10)^2 = 433.3\text{N}$. Note: we could have arrived here more quickly, but I think the method we used is more intuitive.

Now we consider the force diagram: upwards is the laser pressure force, and downward is gravity. Since we are near the surface of the Earth, the gravitational force is just mg. Using Newton's second law and taking upward to be positive: $\sum F_y = F - mg = ma = 433.3 - (21.0)(9.8) = (21.0)a$. This gives: $227.5 - 21a \rightarrow a = 10.8\text{m/s}^2$.

P16. (C) As weird as this situation seems, it is really just a simple refracting surface problem. We have a bird in an air bubble (index $n_1 = 1.00$) being observed from outside the bubble, in corn syrup (index $n_2 = 1.37$). Since the diameter of the bubble is 45.0cm, then the radius of the bubble is $R = 22.5$cm. The object location, *p*, is 13.0cm. To find the image location, we use the refracting surface equation: $\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$. The object (the bird) sees the surface as concave, so the radius of curvature is taken to be negative. Thus, plugging in the given values: $\frac{1.00}{13.0} + \frac{1.37}{q} = \frac{1.37-1.00}{-22.5} \rightarrow 0.07692 + \frac{1.37}{q} = -0.01644 \rightarrow \frac{1.37}{q} = -0.09337$. This gives an image location of $\frac{q}{1.37} = -10.71 \rightarrow q = -14.7$cm. Thus, the image of the hummingbird appears at a point 14.7cm inside the bubble.

P17. (B) This is a three-state atom in which we set the ground state to be at $E = 0$. The first absorption will take the atom into the highest of the three states. Given the wavelength, we can calculate the energy of that level above ground: $E_1 = \frac{1240\ eV{\cdot}nm}{510nm} = 2.43eV$. Now the next step is from this highest state down to the middle state. In other words, the next photon has an energy equal to $E_1 - E_2$. Thus, $E_1 - E_2 = 2.43 - E_2 = \frac{1240\ eV{\cdot}nm}{781nm} = 1.59eV \rightarrow E_2 = 2.43 - 1.59 = 0.844$eV. So, the states of this atom are at energies of $E_0 = 0, E_1 = 2.43eV, and\ E_2 = 0.844eV$.

P18. (A) When two high energy particles collide, they can produce additional quark-antiquark pairs which combine in various way to make new particles. Importantly, though, the types of quarks must be balanced on each side of the collision, since weak-force flavor changes are too slow to occur during high-energy collisions.
In this collision, the two pions that interact are antiparticles of one another – thus the total quark count on the left side is zero ($\pi^+ = u\bar{d}$ and $\pi^- = \bar{u}d$, so the left side has a quark count of $\bar{u}u\bar{d}d$. Since each quark in that list has a corresponding antiquark, the total quark count is zero). This means that every quark on the right side must also be accompanied by its corresponding antiquark.
The two particles that we know about give us quarks of $\pi^+ = u\bar{d}$, and $K^0 = \bar{s}d$. This gives a partial quark count on the right side of $u\bar{d}d\bar{s}$. The down-quarks balance, but the up quark and the antistrange quark do not – thus the unknown particle must be made up of the missing partners: a strange quark and an antiup quark. In other words, the missing particle must have a quark structure of $? = s\bar{u}$. Looking at the table, we can see that this particle is a K^-particle.

P19. (C) Although there is an entire table of data, you really only need one sample's data to calculate the density. I'll start with Sample A. The difference between the weight in air and the weight in water is equal to the buoyant force on the mineral. Mathematically: $F_B = W_a - W_w = \rho_w g V_m$. Here, ρ_w is the density of the water, which is 1000.0kg/m^3, and V_m is the volume of the mineral – which is what we need from this equation. For sample A: $F_B = 3.20 - 2.84 = 0.36 = (1000)(9.8)V_m$. This gives $V_m = 3.67 \times 10^{-5}$ m^3. The mass can be found from the weight in air: $m = \frac{W_a}{g} = \frac{3.20}{9.8} = 0.3265$kg. So, the density of Sample A is: $\rho_m = \frac{m}{V} = \frac{0.3265}{3.67 \times 10^{-5}} = 8890 \approx 8900$kg/m^3. The other samples give similar densities: Sample B = 8880kg/m^3, Sample C = 9080kg/m^3, and Sample D = 8800kg/m^3.

P20. (D) Looking at the pattern, we can use the scale to estimate the distance from the central spot to the first minimum. That distance is approximately $y = 1.4$cm. This gives the tangent of the diffraction angle to be $tan\theta = \frac{y}{L} = \frac{1.4cm}{1.50m} = \frac{0.014}{1.50} = 0.0093$. This is small enough to use the small-angle approximation, giving $sin\theta \approx tan\theta = 0.0093$. Now, using the equation for a single slit, and noting that we measured to the first minimum ($m = 1$), we have: $m\lambda = asin\theta = (1)(575nm) = a(0.0093)$. This gives a hair diameter of $a = \frac{575 \times 10^{-9}}{0.0093} = 6.2 \times 10^{-5}$m $= 62\mu$m $\approx 60\mu$m.

UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

District • 2020

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 is not evidence for evolution?
A) Fossil record.
B) Direct observations of evolutionary change.
C) Homology in different organisms.
D) Geographic distribution of species.
E) More offspring produced than the environment can support.

B02. In genetics, the term *penetrance* refers to
A) the percent of individuals who express the expected phenotype for their genotype.
B) the degree with which a trait is expressed.
C) the same thing as dominance.
D) the presence of lethal alleles.
E) an organism having a heterozygous genotype but expressing a recessive trait.

B03. Modified proteins leaving the Golgi apparatus in secretory vesicles would do so on the _____ side of the Golgi body.
A) cytoplasmic
B) exocytosis
C) endocytosis
D) *cis*
E) *trans*

B04. Where would sarcoplasmic reticulum be found in the human body?
A) liver cells
B) skin cells
C) neurons
D) muscle cells
E) vitreous humor

B05. Communities with high diversity are
A) less productive.
B) more stable.
C) more prone to diseases or environmental stress.
D) less resistant to invasive species.
E) more likely to be destroyed by fires or other natural phenomena.

B06. Some organisms can modify and run the citric acid cycle in reverse. This process
A) is catabolic.
B) is exergonic.
C) is a form of autotrophy.
D) generates ATP.
E) has a negative ΔG.

B07. Which of the following represents a challenge in attempting to organize the diversity of life into a phylogenetic tree?
A) Analogy from convergent evolution.
B) Morphological and molecular homologies.
C) Descent with modification.
D) Changes in DNA sequences of universal genes.
E) Presence of mutations in analyzed sequences.

B08. In triglycerides, the bonds that forms between the fatty acid tails and the glycerol backbone are _____ bonds/linkages.
A) ionic
B) ether
C) ester
D) hydrogen
E) phosphodiester

B09. The oxidation of ammonium (NH_4^+) into nitrite (NO_2^-) and then nitrate (NO_3^-) is called
A) ammonification.
B) nitrification.
C) denitrification.
D) nitrogen fixation.
E) assimilation.

B10. The ribosome is classified as a
A) ribozyme.
B) catabolic enzyme.
C) ribonuclease.
D) structural protein.
E) DNA-binding protein.

B11. *Drosophila persimilis* and the closely-related *Drosophila pseudoobscura* inhabit the same geographic area in Hawaii. *D. persimilis* breeds early in the morning and *D. pseudoobscura* breeds in the afternoon. The type of reproductive isolation mechanism for these two *Drosophila* species is
A) post-zygotic.
B) hybridization, since both species are closely related.
C) behavioral isolation.
D) temporal isolation.
E) gametic isolation.

B12. Examine the answer choices. Assuming that the cell cycle begins at G1, determine which event would occur second in relation to the other events listed.
A) Formation of a cleavage furrow.
B) Sister chromatids lining up along the "equator" of the cell.
C) DNA synthesis.
D) Replication and migration of the centrioles to the poles of the cell.
E) Separation of sister chromatids and movement towards the poles.

B13. *Taenia* is a genus of helminths that can cause tapeworm infections (Taeniasis). The individual segments containing the reproductive structures on the tapeworm body are called
A) scolex.
B) rostellum.
C) suckers.
D) bursae.
E) proglottids.

B14. If a cell has a 2n of 30, how many different types of chromosomes are there?
A) 60
B) 45
C) 30
D) 15
E) Not enough information to solve the problem.

B15. Examine the following wild type (WT) and mutated (MU) DNA *coding* sequences. Predict the type of mutation based on the information given.

```
WT: 5′-CCATGTTCTCCTAACG-3′
MU: 5′-CCATGTTTCTCCTAACG-3′
```

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

B16. Red is dominant to white. A cross between a red-flowered plant and a white-flowered plant results in 52 progeny with red flowers and 49 progeny with white flowers. What is the genotype of the red-flowered plant?
A) RR
B) Rr
C) rr
D) Ww
E) Not enough information to determine the answer.

B17. In December 2019, the Centers for Disease Control and Prevention began issuing warnings for hard-boiled eggs from a specific company that might be contaminated with
A) *Salmonella*.
B) *Listeria*.
C) 2019-nCoV.
D) *Escherichia*.
E) *Campylobacter*.

B18. The operator sequence of the *lac* operon of *Escherichia coli* is an example of _____ regulation.
A) negative inducible
B) negative repressible
C) positive inducible
D) positive repressible

B19. Hematopoietic stem cells can differentiate into lymphoid stem cells or myeloid stem cells. Myeloid stem cells are the progenitors of all of the following except
A) basophils.
B) neutrophils.
C) platelets.
D) erythrocytes.
E) natural killer cells.

B20. Which of the following traits is found exclusively in angiosperms?
A) pollen
B) apical meristems
C) ovaries
D) seeds
E) xylem and phloem

C01. 50 g of solid barium bromate is added to 2.0 L of water, and 31 g of the solid dissolves. If an additional 2.0 L of water is added to the solution, how much more barium bromate will dissolve?

A) 0 g
B) 9.5 g
C) 19 g
D) 31 g
E) 50 g

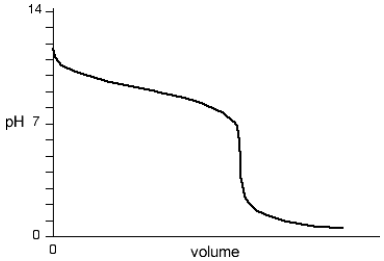
C02. For a 3.0 L sample of sulfur dioxide gas at 40.0ºC and 1.5 atm pressure, how would you calculate the mass of SO_2 in the sample?

A) mass = (0.082)(40)(64.07)/(3.0)(1.5)
B) mass = (0.082)(313)/(3.0)(1.5)(64.07)
C) mass = (3.0)(1.5)(64.07)/(8.314)(40)
D) mass = (3.0)(1.5)/(0.082)(40)(64.07)
E) mass = (64.07)(1.5)(3.0)/(313)(0.082)

C03. What is the lowest whole-number coefficient on H_2O in the balanced equation for the combustion of ethanol?

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

C04. What kind of experiment is represented by the graph below?

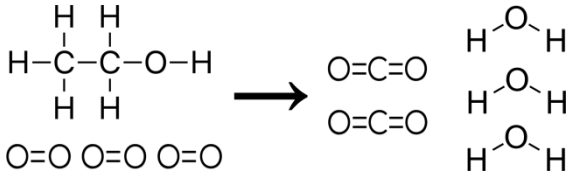


A) Titration of a strong acid with a strong base
B) Titration of a weak acid with a strong base
C) Titration of a strong base with a strong acid
D) Titration of a weak base with a strong acid
E) Titration of a weak acid with a strong acid

C05. Which of these compounds in the liquid state would you expect to have the highest surface tension?

A) CH_4
B) C_3H_6
C) C_3H_8
D) CH_3OCH_3
E) C_2H_5OH

C06. Estimate the ΔH for this reaction using the bond energies provided on the data page.



A) –1248 kJ/mol
B) 816 kJ/mol
C) –1594 kJ/mol
D) 2309 kJ/mol
E) –2309 kJ/mol

C07. What is the mass of three moles of sodium hydrogen phosphate dihydrate?

A) 178.00 g
B) 155.01 g
C) 534.00 g
D) 465.03 g
E) 136.99 g

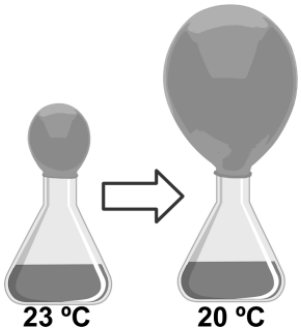
C08. Which of the following is true when the reaction $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ is at equilibrium?

A) The number of moles of NO_2 is twice the number of moles of N_2O_4.
B) The concentrations of N_2O_4 and NO_2 are equal.
C) The pressure of the N_2O_4 gas is twice the pressure of the NO_2 gas.
D) The concentrations of N_2O_4 and NO_2 are constant.
E) The rate of the forward reaction is double the rate of the reverse reaction.

C09. What is the total mass of solute in 1.00 kg of solution that has a concentration of 7.5 ppm?

A) 7.5 g
B) 0.75 g
C) 75 mg
D) 7.5 mg
E) 750 µg

C10. Two aqueous reactants are mixed in a flask with a balloon over the top and the following change is observed.



What are the signs on q and w for the system?

A) $q > 0, w > 0$
B) $q > 0, w < 0$
C) $q < 0, w > 0$
D) $q < 0, w < 0$
E) $q < 0, w = 0$

C11. Which of these acids at 0.075 M would have the lowest pH?

A) H_2SO_3
B) H_2SO_4
C) H_3PO_3
D) H_3PO_4
E) HNO_3

C12. What is the freezing point of the solution that results from adding 0.80 moles of $BaCl_2$ to 4.0 L of water? Assume 1 L H_2O = 1 kg.

A) 0.37 °C
B) –0.37 °C
C) –1.9 °C
D) –4.4 °C
E) –1.1 °C

C13. What is the reducing agent in this reaction?

$$3HNO_2(aq) + 5H^+(aq) + Cr_2O_7^{2-}(aq) \rightarrow 3NO_3^-(aq) + 2Cr^{3+}(aq) + 4H_2O(\ell)$$

A) HNO_2
B) H_2O
C) $Cr_2O_7^-$
D) NO_3^-
E) Cr^{3+}

C14. Which of these compounds is not likely to exist?

A) NaO
B) KBr
C) Sr_3N_2
D) ZnO
E) AgF

C15. U.S. weather reports typically give the atmospheric pressure in units of inches of mercury, reported to two decimal places. High pressure usually means that the weather will likely remain the same, and low pressure indicates that the weather will soon change. What is 1 atm expressed in units of inches of mercury? (1 inch = 2.54 cm)

A) 29.92" Hg
B) 31.02" Hg
C) 28.15" Hg
D) 30.55" Hg
E) 31.98" Hg

C16. Using the data below, determine the rate law for this 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	0.200	0.200	2.06×10^{-4}
2	0.400	0.200	8.24×10^{-4}
3	0.400	0.400	1.65×10^{-3}

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

C17. Which of these could not be explained by the Rutherford model of the atom?

A) The gold foil experiment
B) Ionization of atoms
C) Atomic emission line spectra
D) Atoms of different elements having different masses
E) The electrical neutrality of atoms

C18. Nitrogen and oxygen form four different binary gaseous compounds. For a given mass of oxygen, the ratio of the masses of nitrogen in any two of the compounds is a small whole number ratio:

Compound	Mass of N	Mass of O
NO_2	7	16
N_2O_4	7	16
NO	14	16
N_2O	28	16

This is an example of

A) Dalton's Law
B) The Law of Atomic Ratios
C) The Law of Molecular Masses
D) The Law of Definite Proportions
E) The Law of Multiple Proportions

C19. Which bond type below best describes the type of bond formed between the Zn and N atoms in $Zn(NH_3)_4^{2+}$?

A) ionic bond
B) nonpolar covalent bond
C) polar covalent bond
D) coordinate covalent bond
E) hydrogen bond

C20. In the year 2075 your granddaughter is doing her chemistry homework and asks you which atomic orbital comes after the 6*g*. What do you tell her?

A) 7*d*
B) 7*f*
C) 5*f*
D) 8*s*
E) In my day we didn't have *g* orbitals. And we were happy that way!

P01. According to Orzel, macroscopic objects do not exhibit quantum effects because their wavefunctions quickly interact with the environment, causing…
A) interference
B) wave superposition
C) diffraction
D) dispersion
E) decoherence

P02. According to Orzel, when photons that are going through an interferometer interact with the environment, they end up with different wavefunctions, and they will each produce a different interference pattern. The cumulative effect – the sum of all of the different interference patterns – results in _____.
A) a pattern showing very strong interference.
B) a pattern showing barely any interference.
C) a pattern showing diffraction.
D) a standing wave pattern.
E) a coherence pattern.

P03. According to Orzel, if you set up a photon on the left side of a quantum Zeno apparatus, with a very small chance of leaking to the right side of the apparatus; and if the photon is later measured to still be on the left side of the apparatus, then it is most likely true that _____.
A) the photon has become decoherent.
B) the photon was absorbed and re-emitted by a group of atoms.
C) the wavefunction of the photon remains in a superposition of states after a measurement.
D) there is a photon-absorbing object on the right side of the apparatus.
E) the quantum state of the photon is entangled with the wavefunction of the apparatus.

P04. The most intense radiation belt in the solar system is a torus of plasma around Jupiter. This torus is associated with which moon of Jupiter?
A) Amalthea
B) Callisto
C) Ganymede
D) Io
E) Europa

P05. In the Elven nation of Doriath, the standard unit of length is the "Endie," which is exactly 0.814meters. The standard unit of force is the "Mauime," which is exactly 3.614Newtons. The Elvish kingdom uses the same unit of time – the second – that we use. The Elvish unit of mass is the "quin." Use the information above to determine how many kilograms are in one quin.
A) 1.0 quin = 0.225 kg
B) 1.0 quin = 0.340 kg
C) 1.0 quin = 1.64 kg
D) 1.0 quin = 2.94 kg
E) 1.0 quin = 4.44 kg

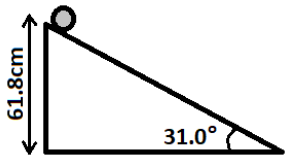
P06. A child kicks a soccer ball from ground level with a velocity of 13.0m/s at an angle of 24.0° above the horizontal. The ball strikes the goal's crossbar. If the child kicked the ball at a horizontal distance of 9.50m from the goal, how high above the ground is the crossbar?
A) 0.310 m
B) 0.737 m
C) 1.09 m
D) 1.40 m
E) 2.04 m

P07. A heavy crate of Orcish battleaxes is being dragged across a horizontal floor by two goblins. The crate has a mass of 195.0kg, and the coefficient of friction between the crate and the floor is 0.420. The goblins exert a combined horizontal force of 1050N on the crate. What is the acceleration of the crate?
A) 1.27 m/s^2
B) 1.85 m/s^2
C) 2.26 m/s^2
D) 4.12 m/s^2
E) 5.38 m/s^2

P08. A brick with a mass of 3.25kg is pressed up against a horizontal spring, compressing the spring by 16.0cm. Once released, the brick slides across the floor, coming to rest 6.55m from where it started. If the coefficient of friction between the brick and the floor is 0.29, then what is the spring constant of the spring?
A) 148 N/m
B) 756 N/m
C) 1660 N/m
D) 4730 N/m
E) 16300 N/m

P09. You roll a 5.50g quarter down an inclined plane that is angled at 31.0° above the horizontal (as shown). The quarter starts from rest at a point that is 61.8cm above the floor, and the diameter of the quarter is 2.50cm. If the quarter does not slip while rolling, then what is its angular velocity at the bottom of the inclined plane? Note: The moment of inertia for a solid disk is $I = \frac{1}{2}mr^2$.

A) 114 rad/s
B) 227 rad/s
C) 278 rad/s
D) 317 rad/s
E) 646 rad/s



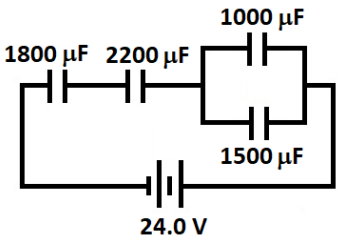
P10. You are using an empty soda bottle as a musical instrument. Two adjacent resonances of the bottle can be heard at 245Hz and at 735Hz. By treating the bottle as an open-closed pipe, determine the length of the bottle. The air temperature is 20.0°C.

A) 17.5 cm
B) 23.3 cm
C) 35.0 cm
D) 46.7 cm
E) 70.0 cm

P11. 1.80mols of an ideal gas is at a volume of 25.0L and a temperature of 450K. The gas is expanded to 35.0L while the pressure is held constant. How much work is done by the gas during this isobaric expansion?

A) 2700 J
B) 3770 J
C) 6730 J
D) 9430 J
E) 13200 J

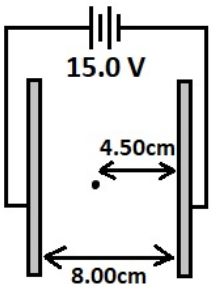
P12. In the following capacitor circuit, what is the charge stored on the 1500μF capacitor?



A) 6.81 mC
B) 10.2 mC
C) 11.6 mC
D) 14.2 mC
E) 17.0 mC

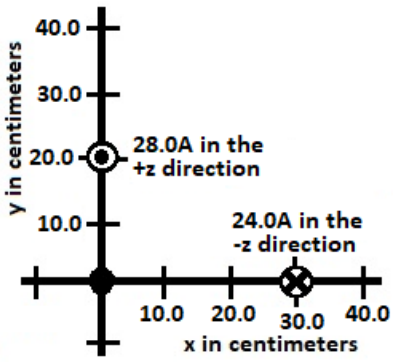
P13. A particle of dust has a mass of 0.200g and a charge of +15.0μC. The particle of dust is located between two parallel plates that are separated by 8.00cm and connected to a voltage supply of 15.0V (as shown). If the particle of dust starts from rest at a distance of 4.50cm from the negative plate, then what is the speed of the particle when it reaches the negative plate?

A) 0.356 m/s
B) 0.795 m/s
C) 1.13 m/s
D) 1.27 m/s
E) 1.50 m/s



P14. Two long straight wires carry currents in the ±z-direction, as shown. The wires pass through the xy-plane: 28.0A at (0, 20.0cm) and 24.0A at (30.0cm, 0). What is the magnitude of the magnetic field at the origin (0, 0) due to these currents?

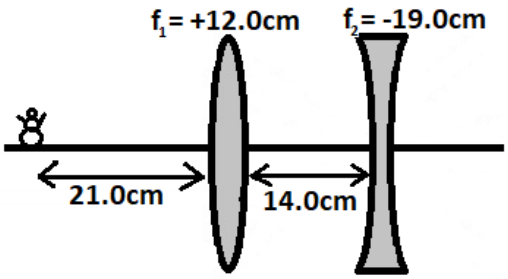
A) 12.0 μT
B) 16.0 μT
C) 23.0 μT
D) 32.2 μT
E) 44.0 μT



P15. You stand 1.75m away from a 200.0W light bulb. At your location, what is the amplitude of the magnetic field associated with the light produced by the bulb?

A) 0.209 μT
B) 0.417 μT
C) 0.653 μT
D) 0.923 μT
E) 1.31 μT

P16. A decorative snowman sits 21.0cm to the left of the first lens in a double lens system (as shown). The first lens has a focal length of $+12.0$cm, and the second lens has a focal length of -19.0cm. The lenses are separated by 14.0cm. Relative to the second lens, where is the final image of the snowman located?



A) 11.3 cm left of the second lens
B) 59.1 cm left of the second lens
C) 14.0 cm right of the second lens
D) 28.0 cm right of the second lens
E) 53.2 cm right of the second lens

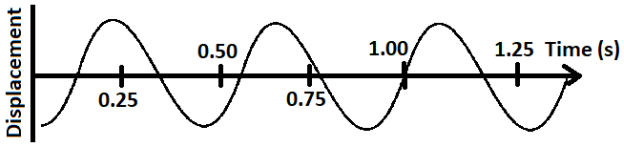
P17. An electron starting from rest is accelerated through an electric potential, V. After the acceleration, the deBroglie wavelength of the electron is 0.100nm. Through what magnitude of electric potential was the electron accelerated?

A) 300 V
B) 150 V
C) 47.7 V
D) 15.2 V
E) 3.81 V

P18. The $K^*(892)^0$ meson has a lifetime of about 7×10^{-24}s, and a dominant decay mode of: $K^*(892)^0 \rightarrow K^0 + \pi^0$. Which fundamental force is responsible for the decay of the $K^*(892)^0$ meson?

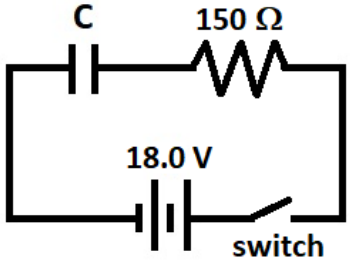
A) The strong force
B) The weak force
C) The electromagnetic force
D) The gravitational force
E) The electroweak force

P19. A mass of 200.0g is attached to a spring. The mass is pulled and released so that the system oscillates with simple harmonic motion. The graph below shows the displacement of the mass from equilibrium as a function of time. Use this data to determine the spring constant of the spring.



A) 10 N/m
B) 20 N/m
C) 40 N/m
D) 80 N/m
E) 150 N/m

P20. For the series DC-RC circuit shown, the switch was closed at $time = 0$. You measured the current flowing in the circuit at fixed intervals after the switch was closed. The data collected, along with a useful calculated quantity, are given in the table below. I_0 is the initial (and maximum) current of 120mA. Based on this data, determine the value of the capacitor in the circuit.



Time, t	Current, I	ln(I_0/I)
0.00 s	120 mA	0.0
0.20 s	65 mA	0.61
0.40 s	35 mA	1.2
0.60 s	20 mA	1.8
0.80 s	11 mA	2.4
1.00 s	6 mA	3.0

A) 320 µF
B) 800 µF
C) 2200 µF (2.2 mF)
D) 4600 µF (4.6 mF)
E) 20,000 µF (20 mF)

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*

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

Equilibrium constants at 25°C

$N_2O_4(g) \rightleftharpoons 2NO_2(g)$ $K_C = 4.6 \times 10^{-3}$

Single Bond Energies (kJ/mol of bonds)

	H	C	N	O	S	F	Cl	Br	I
H	436								
C	413	346							
N	391	305	163						
O	463	358	201	146					
S	347	272	—	—	226				
F	565	485	283	190	284	155			
Cl	432	339	192	218	255	253	242		
Br	366	285	—	201	217	249	216	193	
I	299	213	—	201	—	278	208	175	151

Multiple Bond Energies (kJ/mol of bonds)

C=C 602	C=N 615	C=O 799
C≡C 835	C≡N 887	C≡O 1072
N=N 418	N=O 607	
N≡N 945	O=O 498	

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
2020 DISTRICT

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

CHEMISTRY SOLUTIONS – UIL DISTRICT 2020

C01. (C) If 31 grams of $Ba(BrO_3)_2$ dissolves in 2 L, then the solubility is 15.5 g/L. Adding 2 more liters of water would allow an additional 31 grams to dissolve, but there is only 19 grams of solid $Ba(BrO_3)_2$ remaining, so all of it will dissolve.

C02. (E) $PV = nRT = (g/MM)RT$ $T = 40.0$ ºC = 313 K $g = PV(MM)/RT$
The molar mass (MM) of SO_2 = 64.07 g/mol, so g = (64.07)(1.5)(3.0)/(313)(0.082)

C03. (C) The balanced equation is $C_2H_5OH(\ell) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g)$ (This reaction is shown in question 7.)

C04. (D) The pH begins above 7, so the solution is basic. The pH initially drops quickly, then as a buffer is formed the pH drop becomes more gradual, which is characteristic of a weak base titration curve.

C05. (E) Stronger intermolecular forces will lead to higher surface tension. Ethanol has hydrogen bonding, and will have the strongest IMF's of the compounds listed here.

C06. (A)

$$\Delta H = \sum B.E._{\text{reactants}} - \sum B.E._{\text{products}}$$

ΔH = (5×C–H) + C–C + C–O + O–H + (3×O=O) – (4×C=O) – (6×O–H)
ΔH = (5×413) + 346 + 358 + 463 + (3×498) – (4×799) – (6×463)
ΔH = (2065) + 346 + 358 + 463 + (3×498) – (4×799) – (6×463)
ΔH = –1248 kJ/mol (Note that bond energies are rough averages since not all C–O bonds, for example, have the same energy, so bond energies can provide only a ballpark estimate of the reaction enthalpy. The accepted ΔH value for this reaction is about 9% greater, –1360 kJ/mol.)

C07. (C) $Na_2HPO_4 \cdot 2H_2O$ (2×22.99) + 1.01 + 30.97 + (4×16.00) + (4×1.01) + (2×16.00) = 178.00 g/mol
178.00 g/mol × 3 mol = 534.00 g.

C08. (D) At equilibrium the forward and reverse reactions occur at the same rate, so the concentrations of all species in the reaction are constant.

C09. (D) 7.5 ppm = 7.5 micrograms of solute per gram of solution. 7.5 µg/g × 1000/1000 = 7.5 mg/kg.
7.5 mg/kg × 1.00 kg = 7.5 mg.

C10. (B) This can be tricky because the system is the reactants and products, but the water they are dissolved in is part of the *surroundings*. So when the temperature of the solution drops, that is the temperature of the surroundings dropping as the system absorbs heat ($q > 0$). The reaction is generating a gas that is increasing the volume of the system. Since the system is doing work on the surroundings, work for the system is negative ($w < 0$).

C11. (B) A, C, and D are all weak acids and only partially ionize. B and E are strong acids and ionize completely, but B has a second acidic proton that will also partially ionize, so B will have the highest $[H^+]$ and therefore the lowest pH.

C12. (E) $\Delta T = -imk_f$ 1 $BaCl_2 \rightarrow$ 1 Ba^{2+} + 2 Cl^-, so $i = 3$. m = moles $BaCl_2$/kg solvent = 0.80 mol/4 kg = 0.20 molal $k_f = 1.86$ °C/m $\Delta T = -(3)(0.20)(1.86) = -1.1$ °C.

C13. (A) The nitrogen atom in HNO_2 starts out in the +3 oxidation state and ends up in NO_3^- in the +5 oxidation state. That means each N atom in HNO_2 gives up two electrons, so HNO_2 is the reducing agent.

C14. (A) Sodium typically forms a +1 ion and oxygen forms a –2 ion, so the expected ratio of the neutral compound would be Na_2O.

C15. (A) 1 atm = 760 mm Hg. 760 mm Hg ÷ 25.4 mm/in = 29.92" Hg.

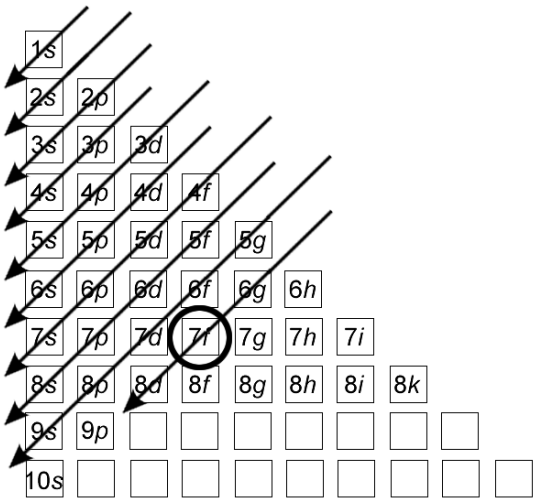
C16. (C) Compare experiments 1 and 2: doubling [AB] while keeping $[C_2]$ constant quadruples the initial reaction rate, so the reaction is second order with respect to AB. Compare experiments 2 and 3: doubling $[C_2]$ while keeping [AB] constant doubles the initial reaction rate, so the reaction is first order with respect to C_2. The rate law is therefore rate = $k[AB]^2[C_2]$.

C17. (C) The energies of the electrons in the Rutherford model were not quantized, so all atoms regardless of which element they belong to would have a continuous emission spectrum.

C18. (E) The Law of Multiple Proportions says that when two elements can combine with each other to form more than one compound, the weights of one element that combine with a fixed weight of the other are in a ratio of small whole numbers. In this case the weight of oxygen is constant and the weights of nitrogen that combine with that specific mass of oxygen are all whole number multiples of 7.

C19. (D) The lone pair of electrons on the nitrogen atom in ammonia is used to form a shared electron bond with the zinc ion. When both electrons in a covalent bond come from the same atom, it's called a coordinate covalent bond or a dative bond.

C20. (B) Probably the easiest way to answer this question is to expand an orbital filling diagram beyond where our periodic table currently stands. If you do this you can see that the subshell that follows the 6*g* is the 7*f*. (The subshells are named alphabetically after the *g* orbital: *h*, *i*, *k*, ℓ, *m*,... and so on, skipping *j*.)



PHYSICS SOLUTIONS – UIL DISTRICT 2020

P01. (E) Page 100: "…macroscopic objects like cats in boxes do obey quantum rules, and show superposition and interference effects. We don't see those effects because of decoherence caused by interactions with the environment."

P02. (B) Page 98: "We can't guarantee exactly the same interaction between the photon and the environment every time… As a result, the second photon sent in will interfere with itself according to a different wavefunction…The third photon has yet another different wavefunction… The cumulative effect is to trace out a pattern that is the sum of many different interference patterns… which barely shows any interference at all."

P03. (D) page 113, "We start with a photon on the left-hand side of the apparatus, bouncing back and forth between two mirrors. There is a small chance of the photon leaking through the central mirror, so over time, the photon will shift into the right-hand side of the apparatus. If there is an absorbing object (a bunny, say) on the right-hand side, though, it will prevent the photon from moving, through the quantum Zeno effect."

P04. (D) Jupiter has an intense magnetic field, and a magnetosphere similar in behavior to Earth's (though much stronger and larger). Jupiter's volcanically active moon, Io, is caught up in this intense magnetic field. Volcanoes on Io load Jupiter's magnetosphere with up to 1000kg of new material per second. This material is ionized by solar radiation to produce the most intense radiation belt in the solar system, known as the Io plasma torus.

P05. (E) We know that force is equal to mass*acceleration which equals mass*distance/(time-squared). Putting this into an equation, of sorts: $F \propto \frac{mx}{t^2}$. From the perspective of units we can write both the metric form and the Elvish form of this equation: $[Newton] = \frac{[kilogram][meter]}{[second]^2}$ and for the Elvish nation: $[Mauime] = \frac{[quin][Endie\}}{[second]^2}$. Now, in the Elvish form we can put in the known conversions: $[Mauime] = 3.614[Newton] = \frac{[quin]*0.814[meter]}{[second]^2}$, or $[Newton] = (0.2252)\frac{[quin][meter]}{[second]^2}$. Equating this to the metric Newton: $[Newton] = (0.2252)\frac{[quin][meter]}{[second]^2} = \frac{[kilogram][meter]}{[second]^2}$. Cancelling out meters and seconds gives: $(0.2252)[quin] = [kilogram]$. Solving for the Elvish unit of mass gives: $[quin] = 4.44[kilogram]$, so 1.0quin = 4.44kg.

P06. (C) Since we are given the initial speed and angle, we should begin by finding the horizontal and vertical components of the initial velocity: $v_{0x} = v_0 cos\theta = (13.0)\cos(24.0) = 11.88$m/s and $v_{0y} = v_0 sin\theta = (13.0)\sin(24.0) = 5.29$m/s. What we need to find is the time that the ball was in the air – we can do this by using the horizontal distance to the goal along with the horizontal component of the velocity. Remember, also, that there is no acceleration in the horizontal direction: $x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \ \rightarrow\ 9.50 = 0 + (11.88)t + 0 \ \rightarrow\ t = 0.800$s. Now we can find the height to which the ball rises by using this time and the vertical component of velocity, recalling that the acceleration in the vertical direction is due to gravity and directed downward:
$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 = 0 + (5.29)(0.800) + (0.5)(-9.8)(0.800)^2 = 1.09$m

P07. (A) First, let's consider the forces acting on the crate: we have gravity acting downwards, the normal force acting upwards, the exerted force acting to the right, and friction acting to the left. Notice all of the forces are either horizontal or vertical, so there are no angles to worry about. Also note that the crate has an acceleration to the right (horizontal), and zero vertical acceleration. Thus, summing the forces in the vertical direction: $\sum F_y = F_N - mg = 0 \ \rightarrow\ F_N = mg = (195)(9.8) = 1911$N.
From this we can calculate the frictional force: $F_f = \mu F_N = (0.42)(1911) = 802.6$N.
Now, summing the horizontal forces: $\sum F_x = F_{exert} - F_f = ma = 1050 - 802.6 = (195)a$. This gives: $195a = 247.4 \ \rightarrow\ a = 1.27$m/s^2.

P08. (D) This is a conservation of energy problem where the energy converts from elastic potential energy into kinetic energy, and then into heat through the work done by the frictional force. We will need to find the work done by friction and equate that to the original elastic potential energy. To find the work done, we need to look at the forces while sliding across the floor. There are three forces – gravity acting downward, the normal force acting upward, and the frictional force acting to the left (assuming the motion is to the right). There is no acceleration in the vertical direction, so the sum of forces in the vertical is: $\sum F_y = F_N - mg = 0 \;\rightarrow\; F_N = mg = (3.25)(9.8) = 31.85\text{N}$.
This allows us to calculate the frictional force: $F_f = \mu F_N = (0.29)(31.85) = 9.24\text{N}$.
Now, the work done by the frictional force is $W = F_f d = (9.24)(6.55) = 60.5\text{J}$. Converting the spring compression to meters, and equating the work done by friction to the initial elastic potential energy gives: $W = 60.5 = \frac{1}{2}kx^2 = (0.5)k(0.16)^2 = 0.0128k \;\rightarrow\; k = 4727 \approx 4730\text{N/m}$.

P09. (B) This is another conservation of energy problem, but in this case, we also have to consider rotational kinetic energy. Specifically, we have the conversion of gravitational potential energy into linear and rotational kinetic energy. Mathematically, this is: $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$. Because the quarter does not slip while rolling, we can relate the linear velocity to the angular velocity: $v = r\omega$. Also, we can put in the formula for the moment of inertia for a solid disk. This gives: $mgh = \frac{1}{2}m(r\omega)^2 + \frac{1}{2}\left(\frac{1}{2}mr^2\right)\omega^2 = \frac{1}{2}mr^2\omega^2 + \frac{1}{4}mr^2\omega^2$. Simplifying: $mgh = \frac{3}{4}mr^2\omega^2$. Notice that the mass doesn't really matter – it cancels out. Cancelling the mass, noting that the radius of the quarter is 1.25cm = 0.0125m, and converting the height into meters gives:
$gh = (9.8)(0.618) = \frac{3}{4}(0.0125)^2\omega^2 = 6.06 = (1.172 \times 10^{-4})\omega^2 \;\rightarrow\; \omega = 227$ rad/s.

P10. (C) The equation for the resonances in an open-closed pipe is $f_n = \frac{nv}{4L}$ where *n* is an odd integer. We don't know exactly which n values are represented by those two resonances, but that doesn't matter if we consider the difference between adjacent resonant frequencies. The difference between adjacent odd integers is always exactly two. So, looking at the differences:
$f_a - f_b = \frac{(n+2)v}{4L} - \frac{nv}{4L} = \frac{2v}{4L} = \frac{v}{2L} \;\rightarrow\; 735Hz - 245Hz = 490Hz = \frac{343m/s}{2L}$.
This gives a length for the bottle of $L = 0.350m = 35.0cm$.

P11. (A) The work done by a gas expanding under constant pressure (an isobaric expansion) is $W = P\Delta V$. To use this equation, we need to find the pressure of the gas. We will use the ideal gas law and the initial conditions. After converting our quantities into the appropriate units, we get:
$PV = nRT = P(0.025m^3) = (1.80mol)\left(8.314\frac{J}{mol\,K}\right)(450K) = 6734\,J \;\rightarrow\; P = 269370\text{Pa}$.
After again converting to appropriate units, we can calculate the work done by the gas:
$W = P(V_2 - V_1) = (269370Pa)(0.035m^3 - 0.025m^3) = 2694J \approx 2700\text{J}$.

P12. (B) First, we need to find the total equivalent capacitance of this circuit. Combining the two capacitors in parallel gives $C_p = 1000 + 1500 = 2500\mu\text{F}$. Now this is in series with the other two capacitors. Combining those three series capacitances, we get to total capacitance for the circuit:
$\frac{1}{C_{Total}} = \frac{1}{1800} + \frac{1}{2200} + \frac{1}{2500} \;\rightarrow\; C_{Total} = 709.2\mu\text{F}$. To get the total charge stored, we use $Q = CV$.
For the combined capacitance: $Q_{Total} = (709.2)(24.0) = 17000\mu C = 17.0\text{mC}$. For capacitances in series, the total charge is the same as the charge on each individual capacitance. Thus, the charge on the 1800µF capacitor is 17.0mC, and the charge on the 2200µF capacitor is 17.0mC. Likewise, the net charge on the parallel group of capacitors is 17.0mC. From this we can determine the voltage on the parallel group: $V_p = \frac{Q_p}{C_p} = \frac{17.0mC}{2500\mu F} = \frac{17000\mu C}{2500\mu F} = 6.81\text{V}$. Since objects in parallel all have the same voltage, we can use this voltage to calculate the charge stored on the 1500µF capacitor:
$Q_{1500} = CV = (1500)(6.81) = 10200\mu C = 10.2\text{mC}$.

P13. (C) First, we need to determine the electric field between the plates: For parallel plates, we know $|E| = \frac{V}{d} = \frac{15.0V}{8.00cm} = \frac{15.0V}{0.0800m} = 187.5\,V/m$. Now we can find the force on the particle of dust: $|F| = |qE| = (15.0 \times 10^{-6}C)(187.5\,V/m) = 2.81 \times 10^{-3}N$. And now we can go to Newton's Second Law to find the acceleration: $|F| = m|a| = 2.81 \times 10^{-3}N = (0.200 \times 10^{-3}kg)a$, which gives $a = 14.1\text{m/s}^2$. Finally, we can use a kinematic equation to find the velocity of the particle of dust when it reaches the negative plate:
$v^2 = v_0^2 + 2a(x - x_0) = 0 + 2(14.1m/s^2)(0.0450m) = 1.27 \;\rightarrow\; v = 1.13m/s.$

P14. (D) The magnitude of the magnetic field created by a current-carrying, long, straight wire is given by the equation $|B| = \frac{\mu_0 I}{2\pi r}$. Applying this to our two current-carrying wires, after converting the distances to meters, gives: $|B_1| = \frac{(4\pi \times 10^{-7})(28.0)}{2\pi(0.20)} = 2.8 \times 10^{-5}T$, and $|B_2| = \frac{(4\pi \times 10^{-7})(24.0)}{2\pi(0.30)} = 1.6 \times 10^{-5}T$. To find the directions of each of these magnetic fields, we must use the right-hand rule. Point your thumb in the direction of the current and curl your fingers to see the way in which the magnetic field will point. The field will form circles around the wire, and your right-hand fingers will show you whether the field goes around clockwise or counterclockwise. From this we determine that the 28.0A current produces a counterclockwise field, and the 24.0A current produces a clockwise field. This means that the field at the origin due to the 28.0A current is pointed to the right, and the field at the origin due to the 24.0A current is pointed upward. This means that B_1 and B_2 are oriented perpendicular to one another. When the two fields you are combining are perpendicular, you find the total magnitude of the field by using the Pythagorean theorem, thus:
$|B| = \sqrt{(2.8 \times 10^{-5}T)^2 + (1.6 \times 10^{-5}T)^2} = 3.22 \times 10^{-5}T = 32.2\mu T.$

P15. (A) First, we need to find the intensity of the light at our location. Intensity is power per area: $I = \frac{P}{A}$. Assuming that the light goes in all directions from the bulb, then it spreads out spherically – and the surface area of a sphere is $A = 4\pi r^2$. Thus, the intensity is $I = \frac{P}{4\pi r^2} = \frac{200.0W}{4\pi(1.75)^2} = 5.20\text{W/m}^2$. Now, the intensity is related to the magnetic field by $I = \frac{c}{2\mu_0}|B|^2 \;\rightarrow\; 5.20\,W/m^2 = \frac{(3.0 \times 10^8\,m/s)}{2(4\pi \times 10^{-7}\,Tm/A)}|B|^2$. This gives a magnetic field amplitude of $|B| = 2.09 \times 10^{-7}T = 0.209\mu T$.

P16. (E) Double lens systems like this can be calculated one lens at-a-time, so let's first look at the image formed by the first lens. We have an object location of 21.0cm and a focal length of +12.0cm, so the image location can be found using: $\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_1} \;\rightarrow\; \frac{1}{21} + \frac{1}{q_1} = \frac{1}{12} \;\rightarrow\; q_1 = 28.0cm$. This positive image location means that the image is to the right of the first lens. Now, we need to shift over to the second lens. The image from the first lens becomes the object for the second lens. Shifting over, we can find the location of the object for the second lens: $p_2 = D - q_1 = 14.0cm - 28.0cm = -14.0cm$. The fact that the object distance is negative isn't anything to worry about. Now we can return to the lens equation, but this time using the second lens and the second object:
$\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_2} \;\rightarrow\; \frac{1}{-14} + \frac{1}{q_2} = \frac{1}{-19} \;\rightarrow\; q_2 = 53.2cm$. Since this final image location is positive, the image is located to the right of the second lens.

P17. (B) Since we are given the deBroglie wavelength, we should start with that. The deBroglie wavelength is related to the electron momentum by the equation: $\lambda = \frac{h}{p}$. Plugging in the wavelength and Planck's constant: $0.100 \times 10^{-9} m = \frac{6.626 \times 10^{-34} Js}{p} \rightarrow p = 6.626 \times 10^{-24} kgm/s$. This is a non-relativistic momentum (a fact that will be confirmed shortly), so we can just use the classical momentum formula: $p = mv = 6.626 \times 10^{-24} = (9.11 \times 10^{-31})v = 6.626 \times 10^{-24}$ which gives a velocity of $v = 7.27 \times 10^{6}$ m/s. This speed is much less than the speed of light – confirming our assumption that this problem is non-relativistic.
In order to calculate the potential, we need the kinetic energy of the electron. Since this is non-relativistic, we can use: $KE = \frac{1}{2}mv^2 = \frac{1}{2}(9.11 \times 10^{-31})(7.27 \times 10^{6})^2 = 2.41 \times 10^{-17}$J. This energy was imparted to the electron by the electric potential; thus, by conservation of energy we have $KE = Electric\ Potential\ Energy \rightarrow 2.41 \times 10^{-17} J = qV = (1.602 \times 10^{-19})V$. This gives an electric potential of $V = 150V$.

P18. (A) The biggest clue to the answer is the lifetime of the $K^*(892)^0$ meson. Stronger forces result in faster decays. The typical lifetime for a weak force decay is about $10^{-8}s$, while an electromagnetic decay has a typical lifetime of $10^{-16}s$. The only force that can work as fast as $10^{-24}s$ is the strong force.

Another clue is that there is no quark flavor change involved in this decay. The $K^*(892)^0$ contains the same quark flavors as the K^0. The π^0 is a flavor-neutral quark-antiquark pair, so it is inconsequential. The weak force causes flavor changes; therefore, since there are no quark flavor changes, the weak force cannot be responsible for this decay. This logic also eliminates the electroweak force since that is a convolution of the weak and electromagnetic forces. The gravitational force has not been shown to be responsible for any particle decay processes, and the electromagnetic force would involve one or more photons in the decay. Thus, we have more evidence that this decay must be caused by the strong force.

P19. (C) The spring constant of the spring is related to the period of oscillation by the equation $T = 2\pi\sqrt{\frac{m}{k}}$. The period can be found from the plot, as the time difference between adjacent crests (or between adjacent troughs, if you prefer). Looking at the first two crests, I estimate them to be at times of $t_1 = 0.22s$ and $t_2 = 0.65s$. This gives a period of approximately $T = 0.65 - 0.22 = 0.43s$. Plugging this into the equation with the mass (converted to kg) gives:
$0.43 = 2\pi\sqrt{\frac{0.200}{k}} \rightarrow 0.00468 = \frac{0.200}{k} \rightarrow k = 42 \approx 40$ N/m.

P20. (C) The current equation for a DC-RC circuit like this is $I = I_0 e^{-\frac{t}{RC}}$. However, since the table already does some calculations, we can do the same. Consider a rearrangement of this equation: $\frac{I}{I_0} = e^{-\frac{t}{RC}} \rightarrow \frac{I_0}{I} = e^{\frac{t}{RC}} \rightarrow \ln\left(\frac{I_0}{I}\right) = \frac{t}{RC}$. So, a plot of $\ln\left(\frac{I_0}{I}\right)$ versus time would give a straight line with a slope of $\frac{1}{RC}$. Since we don't have a graph, I will have to use the tabulated data to estimate what the slope of a best-fit line would be. I will use the second and last rows of the table to acquire the slope. Here the x-values are time, and the y-values are the quantity $\ln\left(\frac{I_0}{I}\right)$.
$slope = \frac{y_2 - y_1}{x_2 - x_1} = \frac{3.0 - 0.61}{1.00 - 0.20} = \frac{2.39}{.80} = 2.99\frac{1}{s}$. Finally, relating this to the capacitance, we get:
$\frac{1}{RC} = 2.99 = \frac{1}{(150)C} \rightarrow C = \frac{1}{(150)(2.99)} = 0.00223F \approx 2.2mF = 2200\mu F$.