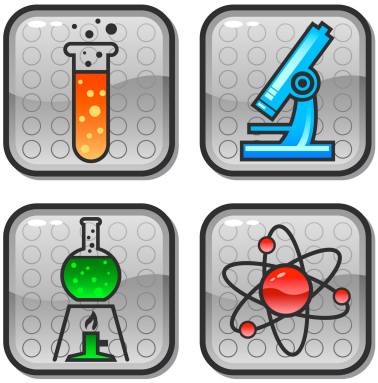
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational B • 2021



GENERAL DIRECTIONS:

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

B01. Which of the following best describes denitrification?
A) The reduction of nitrate to nitrite and then to dinitrogen gas.
B) The production of ammonium.
C) The incorporation of dinitrogen gas to produce ammonium.
D) The oxidation of ammonium to nitrate.
E) The production of ammonium by decomposers.

B02. All major animal phyla started appearing in the fossil record about 541 million years ago. The event that accounted for all this animal diversity is known as the
A) dinosaur extinction event.
B) great oxidation event.
C) K-T extinction event.
D) Cambrian explosion.
E) Holocene extinction event.

B03. A helix-turn-helix motif in a protein is indicative of
A) a DNA-binding protein.
B) a transport protein.
C) an enzyme.
D) a secreted protein.
E) a storage protein.

B04. The independent evolution of analogous structures in different species is called
A) divergent evolution.
B) adaptive radiation.
C) convergent evolution.
D) homology.
E) atavism.

B05. Which of the following events is common to fermentation and respiration?
A) citric acid cycle
B) glycolysis
C) electron transport chain
D) oxidative phosphorylation
E) chemiosmosis

B06. In November 2020, the Centers for Disease Control and Prevention, along with public health officials, began investigating three separate incidences of *Escherichia coli* O157:H7 linked to
A) deli meats.
B) onions.
C) spinach.
D) ground beef.
E) unknown sources.

B07. A biome that is dominated by warm, wet summers, cool winters, and trees that lose their leaves each year is called a
A) tropical rainforest.
B) temperate deciduous forest.
C) taiga.
D) tundra.
E) desert.

B08. The most abundant leukocyte in human blood is the
A) neutrophil.
B) basophil.
C) eosinophil.
D) lymphocyte.
E) monocyte.

B09. A protein that is destined to be modified and exported from the cell would travel a specific pathway. All of the answers below are part of that pathway. Relative to the other answers, the third item that the exported protein would travel through is the/a
A) *cis* Golgi body.
B) transport vesicle.
C) rough endoplasmic reticulum.
D) *trans* Golgi body.
E) secretory vesicle.

B10. The 50S ribosomal subunit of prokaryotes includes
A) 46 proteins plus 28S, 5.8S, and 5S rRNA.
B) 33 proteins plus 18S rRNA.
C) 33 proteins plus 23S and 5S rRNA.
D) 20 proteins plus 16S rRNA.
E) the 30S ribosomal subunit.

B11. Reproductive isolating mechanisms that occur after fertilization include all of the following except
A) post-zygotic mechanisms.
B) hybrid sterility.
C) nonviability of hybrids.
D) hybrid breakdown.
E) temporal isolation.

B12. All of the following are part of the tRNA structure except
A) variable loop.
B) T-loop.
C) D-loop.
D) codon loop.
E) acceptor stem.

B13. What is the *1n* value for a hypothetical diploid somatic cell with 40 total chromosomes?
A) 10
B) 20
C) 30
D) 40
E) 80

B14. If red (R) is dominant to white (r) and blue (B) is dominant to purple (b), what percentage of the offspring from the following genetic cross will be both white and purple?

BbRr x bbrr

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

B15. Eudicots, monocots, and magnoliids belong to
A) Kingdom Plantae.
B) Anthophyta
C) Domain Eukarya.
D) angiosperms.
E) all of the above.

B16. Muscle cells contain large calcium storage organelles specifically called
A) vacuoles.
B) Golgi bodies.
C) sarcoplasmic reticula.
D) rough endoplasmic reticula.
E) smooth endoplasmic reticula.

B17. Polymerase is to _____ as peptidyltransferase is to _____.
A) hydrogen; phosphodiester
B) peptide; hydrogen
C) phosphodiester; peptide
D) peptide; phosphodiester
E) hydrogen; peptide

B18. Arginine is an amino acid that bacteria can either biosynthesize using the enzymes encoded by the *arg* operon or they can acquire it from their environment. When arginine is plentiful in the environment, what can be hypothesized about the arginine operon?
A) The operon is activated.
B) The operon is derepressed.
C) The operon is induced.
D) The operon is repressed.
E) The arginine biosynthesis enzymes are being produced.

B19. Arthropods that can transmit pathogens are called
A) fomites.
B) helminths.
C) worms.
D) vectors.
E) protists.

B20. All of the following use an energy source during transport except
A) active transport.
B) group translocation.
C) secondary active transport.
D) moving substances against their gradients.
E) osmosis.

C01. Modern pennies are made of 97.5% zinc and 2.5% copper by weight. If a modern penny has a mass of 2.50 grams, how many copper atoms are in a 2021 penny?

A) 5.9×10^{20} Cu atoms
B) 3.3×10^{21} Cu atoms
C) 2.4×10^{22} Cu atoms
D) 9.7×10^{23} Cu atoms
E) 1.5×10^{24} Cu atoms

C02. What is the maximum number of electrons that can be found in the fourth energy level of an atom?

A) 18
B) 32
C) 36
D) 42
E) 54

C03. In any electrochemical cell, which process occurs at the anode?

A) reduction
B) precipitation
C) hydration
D) oxidation
E) deduction

C04. When carbon disulfide, CS_2, is completely combusted, the products are CO_2 and SO_2. If 2.0 moles of CS_2 are combusted, what is the total mass of the products formed?

A) 344.30 g
B) 152.30 g
C) 76.15 g
D) 248.30 g
E) 172.15 g

C05. For the endothermic gas phase equilibrium reaction $A_2 + 3\ B_2 \rightleftharpoons 2\ AB_3$, which of these actions will result in more product being formed at equilibrium?

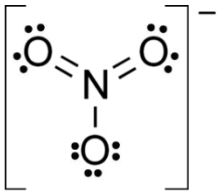
I. Heat the reaction
II. Shake the container
III. Reduce the volume of the container

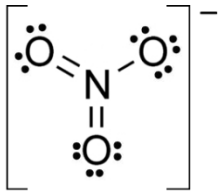
A) I only
B) I and II
C) I and III
D) II and III
E) III only

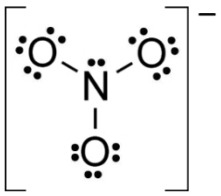
C06. What volume of 0.325 M sulfuric acid is required to neutralize 1.645 g of solid NaOH?

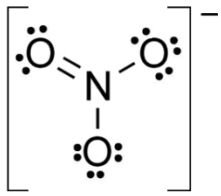
A) 127 mL
B) 31.6 mL
C) 198 mL
D) 63.3 mL
E) 99.0 mL

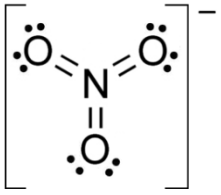
C07. Which of these is the best Lewis dot structure for the nitrate ion?

A 

B 

C 

D 

E 

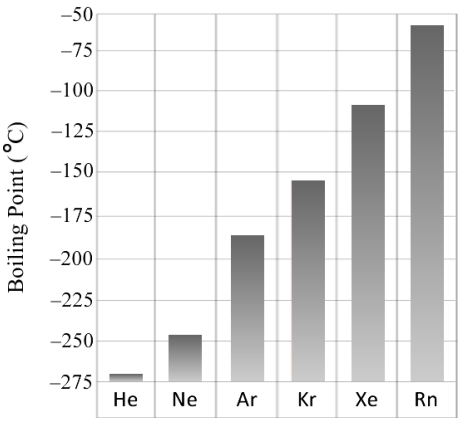
C08. Which of these is *not* an oxidation-reduction process?

A) A combustion reaction
B) A precipitation reaction
C) A decomposition reaction
D) A synthesis reaction
E) A single replacement reaction

C09. An atom of a monatomic gas at STP has an atomic mass of 39.962383 Da. How many neutrons are in the nucleus of this atom?

A) 40
B) 20
C) 18
D) 0
E) 22

C10. This chart shows the boiling points of the noble gases. How do you explain this trend?



A) The more electrons an atom has, the more bonds it can form.
B) Larger atoms with more electrons are more easily polarizable.
C) The increasing radius leads to greater ionic character in bonds between atoms.
D) Heavier atoms have a stronger gravitational attraction to earth, making them boil at higher temperatures.
E) Heavy atoms are inherently warmer internally than light atoms are, so it takes less added heat to make them boil.

C11. What is the change in volume when 2.5 moles of neon gas at 1 atm pressure and 85 °C is cooled to –40 °C and 0.60 atm pressure?

A) +39 L
B) –4.8 L
C) –11 L
D) +0.82 L
E) +6.2 L

C12. If a physical transformation is endothermic and involves an increase in entropy, when would this transformation be spontaneous?

A) Always
B) Never
C) At higher temperatures
D) At lower temperatures
E) Cannot be determined without knowing the equilibrium constant.

C13. The K_{sp} of cadmium arsenate, $Cd_3(AsO_4)_2$, is 2.2×10^{-33}. What is the concentration of Cd^{2+} in a saturated solution of cadmium arsenate?

A) 3.5×10^{-7} M
B) 1.2×10^{-7} M
C) 2.3×10^{-7} M
D) 2.9×10^{-7} M
E) 8.8×10^{-7} M

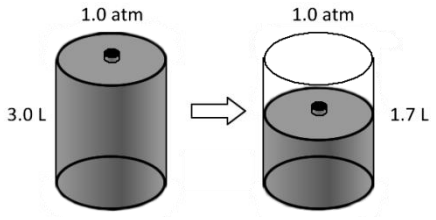
C14. The overall reaction $A_2 + 2BC \rightarrow 2BA + C_2$ proceeds by a series of steps, shown below:

Step 1: $2BC + 2D \rightarrow 2BD + 2C$
Step 2: $2C \rightarrow C_2$
Step 3: $2BD + A_2 \rightarrow 2BA + 2D$

Which species in this reaction mechanism is a catalyst?

A) A_2
B) BC
C) C
D) D
E) BD

C15. How much work is done on the system when a sample of gas is reduced from 3.0 L to 1.7 L against a constant pressure of 1 atm?
1 liter atmosphere = 101.325 joules



A) 132 J
B) –132 J
C) 172 J
D) –172 J
E) 152 J

C16. How many grams of NaCl can you make if you have 10.0 grams of sodium metal and 5.00 L of Cl_2 gas at STP?

A) 13.0 g
B) 4.12 g
C) 26.1 g
D) 13.8 g
E) 25.4 g

C17. A student adds excess KCl to a 100 mL solution of silver nitrate and precipitates out 7.6 grams of solid AgCl. What was the concentration of silver nitrate in the solution?

A) 0.70 M
B) 0.53 M
C) 0.45 M
D) 0.33 M
E) 0.26 M

C18. Which of these elements in the ground state is an exception to the aufbau principle?

A) Tin
B) Lead
C) Copper
D) Magnesium
E) Radium

C19. You have four bottles in front of you, labeled *0.10 M HBrO*, *0.10 M HClO*, *0.10 M HIO*, and *0.10 M HIP_2O*. Calculate the pH of the solution that has the lowest pH.

hypobromous acid	HBrO	$K_a = 2.0 \times 10^{-9}$
hypochlorous acid	HClO	$K_a = 3.5 \times 10^{-8}$
hypoiodous acid	HIO	$K_a = 2.0 \times 10^{-11}$
hypopotamous acid	HIP_2O	$K_a = 8.8 \times 10^{-13}$

A) 3.75
B) 4.23
C) 4.85
D) 5.85
E) 6.53

C20. A scientist needs to make 2.00 liters of 0.500 M Na_2SO_4 solution, but she only has 128.56 grams of sodium sulfate in the lab to work with. How much solution can she make?

A) 1.38 L
B) 1.46 L
C) 1.66 L
D) 1.81 L
E) 2.15 L

P01. According to Rovelli, which of the following is ***not*** one of the predictions of Einstein's General Theory of Relativity?
A) Planets orbit the Sun because space curves.
B) Light will bend around the Sun.
C) Time speeds up near a planet.
D) Space itself can ripple and sway like the surface of the sea.
E) Space itself can collapse into a bottomless hole.

P02. According to Rovelli, Einstein furthered the development of quantum theory by proposing that…
A) energy is distributed in lumps, or quanta.
B) light is made of packets, called photons.
C) electrons in atoms can only exist at certain energies.
D) objects have no definite position, except during an interaction.
E) we can only calculate the probability of an electron popping up here or there.

P03. According to Rovelli, in the Greek world view formulated by philosophers such as Pythagoras and Aristotle, the Earth was what geometric shape?
A) A flat disk
B) A flat equilateral triangle
C) An irregular stone
D) A cube
E) A sphere

P04. Ionized hydrogen regions in interstellar space (called H-II regions) are indicative of active star formation. Heated by nearby hot stars, the hydrogen in these regions generally glows what visible color?
A) Red
B) Yellow
C) Green
D) Blue
E) White

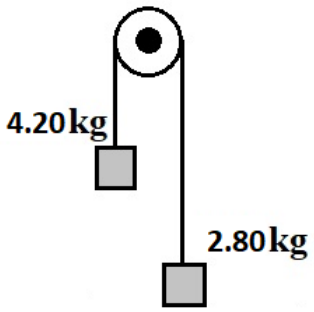
P05. For the following calculation, select the answer that has the correct number of significant figures.

$$\frac{1.98 \times 10^3 - 2.002 \times 10^3}{19.3}$$

A) -1
B) -1.1
C) -1.14
D) -1.140
E) -1.1399

P06. An evil squirrel throws a pecan directly downward with an initial velocity of 5.25m/s. The pecan is thrown from a point that is 2.29m directly above your head. How fast is the pecan moving when it hits the top of your head?
A) 6.30 m/s
B) 7.07 m/s
C) 8.51 m/s
D) 9.41 m/s
E) 13.8 m/s

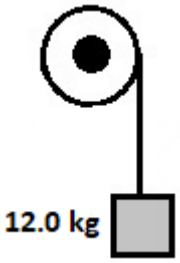
P07. An Atwood machine is set up with a 4.20kg mass on one side and a 2.80kg mass on the other (as shown). The pulley and rope for this machine are both massless and frictionless. Assuming the masses start from rest, how fast are they moving 1.30seconds after they are released?
A) 7.64 m/s
B) 5.88 m/s
C) 5.10 m/s
D) 3.92 m/s
E) 2.55 m/s



P08. A 300.0g red block slides to the right at a speed of 5.20m/s on a frictionless surface. The red block strikes a stationary green block that has a mass of 420.0g. After the collision, the red block is sliding slowly backward (to the left) at 0.850m/s. How fast (to the right) is the green block sliding after the collision?
A) 3.71 m/s
B) 4.32 m/s
C) 6.05 m/s
D) 7.28 m/s
E) 8.47 m/s

P09. A fixed pulley has a rope wrapped around it and a mass of 12.0kg attached to the end of the rope (as shown). The pulley has a rotational inertia of 0.220 kgm^2 and a radius of 30.0cm. The rope is massless and as it unwinds, it does not slip on the pulley. Once released, what is the linear acceleration of the mass?

A) 7.58 m/s^2
B) 8.14 m/s^2
C) 8.68 m/s^2
D) 9.24 m/s^2
E) 9.80 m/s^2



P10. A strong wind blows across some hollow reeds that stick up from the water at the edge of a nearby lake. As the wind blows, the reeds make a sound, resonating at a frequency of about 280.0Hz. If we assume that this sound is the fundamental frequency, and if we treat the reeds as open-closed pipes, then what is the height (above the water) of the average reed?
Assume the air temperature is 20°C.

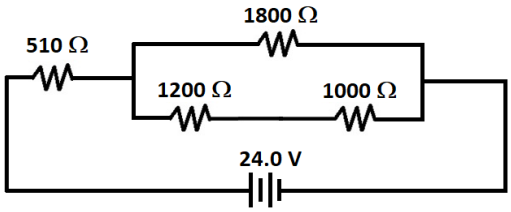
A) 61 cm
B) 41 cm
C) 31 cm
D) 20 cm
E) 9.3 cm

P11. In the summer, when the temperature is 45.0°C, the gap between sections of a bridge is only 0.50cm. Each bridge section is 12.5m is length, and the coefficient of thermal expansion of concrete is 1.0×10^{-5} °C^{-1}. How wide will the gap between the sections be in the winter when the temperature is -10.0°C?

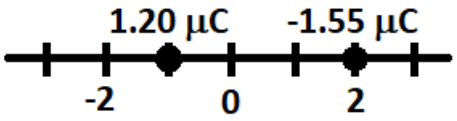
A) 0.34 cm
B) 0.59 cm
C) 0.69 cm
D) 0.84 cm
E) 1.2 cm

P12. For the circuit shown, what is the current flowing through the 1800Ω resistor?

A) 6.0 mA
B) 7.2 mA
C) 8.8 mA
D) 13 mA
E) 16 mA

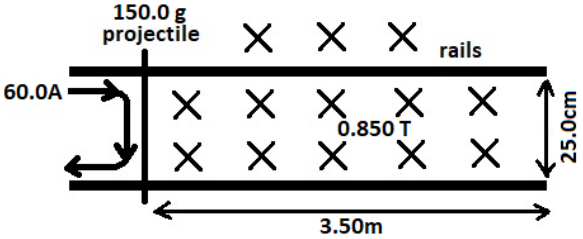


P13. Two fixed charges are located as shown. A 1.20μC charge is at $x = -1.0$cm, and a -1.55μC charge is at $x = +2.0$cm. What would be the magnitude of the force on a +0.50μC charge placed at the origin ($x = 0$) due to the two fixed charges?



A) 71.4 N
B) 56.7 N
C) 53.9 N
D) 36.5 N
E) 17.4 N

P14. A railgun is constructed as shown, with rails that are 3.50m long and separated by 25.0cm. The rails are placed in a magnetic field of 0.850 T. A 150.0g projectile is set on the rails, and a current of 60.0A is sent through the projectile. Assuming that it starts from rest, what is the speed of the projectile when it reaches the end of the rails?



A) 24.4 m/s
B) 48.8 m/s
C) 69.0 m/s
D) 244 m/s
E) 595 m/s

P15. Unpolarized light travelling in air is incident upon a polished resin tabletop. Using a polarizer, you determine that the light reflected from the tabletop is perfectly polarized when the angle of reflection is 61.0°. What is the index of refraction of the resin tabletop?

A) 1.18
B) 1.33
C) 1.48
D) 1.61
E) 1.80

P16. You are using a single converging lens as a magnifier to look at a coin. Unmagnified, the letters on the coin are about 3.00mm long. When you hold the magnifier 4.00cm above the coin, the letters appear to be about 7.00mm long. What is the focal length of the converging lens magnifier?

A) 2.33 cm
B) 2.80 cm
C) 5.60 cm
D) 7.00 cm
E) 9.33 cm

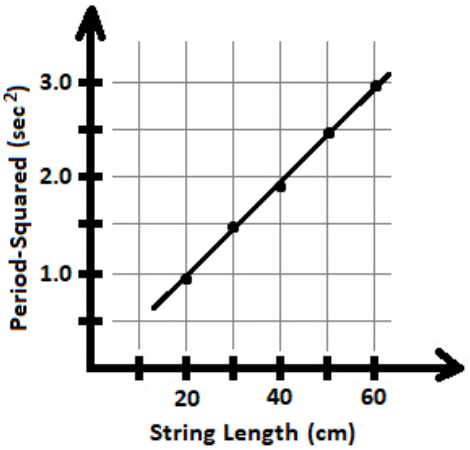
P17. The minimum rest-mass energy uncertainty of a subatomic particle is determined to be 24.0 MeV. Approximately, what is the lifetime of this particle?

A) about 10^{-26} seconds
B) about 10^{-23} seconds
C) about 10^{-20} seconds
D) about 10^{-18} seconds
E) about 10^{-12} seconds

P18. While living on Mt. Olympus, you give Zeus a 200.0g sphere of pure Uranium-235 as a birthday gift. Zeus puts the sphere on a bookshelf and forgets about it. After 280 million years, Zeus is cleaning and finds the sphere. How much mass of Uranium-235 remains in the sphere? Note: the half-life of U-235 is 700 million years.

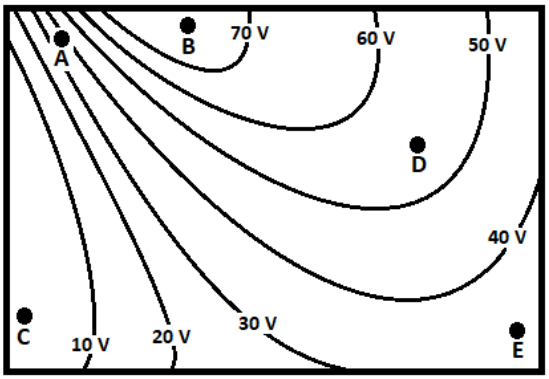
A) 152g remains
B) 134g remains
C) 120g remains
D) 103g remains
E) 80.0g remains

P19. While visiting your friend on the planet Solaria, you use a string and a 200.0g mass to make a simple pendulum. You collect data on the period of the pendulum for different lengths of the string. By graphing the period-squared versus the length of the string, you produce the linear plot shown. From this data, determine the acceleration due to gravity on the planet Solaria.



A) 4.8 m/s^2
B) 7.0 m/s^2
C) 8.2 m/s^2
D) 13 m/s^2
E) 19 m/s^2

P20. The illustration below represents the equipotential surfaces in a small region of space. At which of the labeled points is the electric field greatest in strength?



A) point A
B) point B
C) point C
D) point D
E) point E

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

There is no test-specific data for this exam.

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
2021 INVITATIONAL B

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL B 2021

C01. (A) Mass of copper in a penny = 2.50 g × (2.5/100) = 0.0625 grams.
0.0625 g / 63.55 g/mol = 9.835×10^{-4} moles Cu.
9.835×10^{-4} moles × 6.022×10^{23} atoms/mol = 5.9×10^{20} Cu atoms

C02. (B) The fourth energy level is made up of *s*, *p*, *d*, and *f* subshells, and can therefore hold a maximum of 2 + 6 + 10 + 14 = 32 electrons.

C03. (D)

C04. (A) The balanced equation for the reaction is $CS_2 + 3\ O_2 \rightarrow CO_2 + 2\ SO_2$

If 2.0 moles of CS_2 are used in the reaction, 6.0 moles of O_2 will be needed. Since the mass of the products is equal to the mass of the reactants, we can just calculate the total mass of the reactants and that will equal the total mass of the products.
(2.0 mol × 76.15 g/mol) + (6 mol × 32.00 g/mol) = 344.30 g.

C05. (C) The reaction is endothermic, which means heat can be considered a reactant. Adding more heat will therefore shift the equilibrium to the right. Shaking the container will have no effect on the equilibrium. Reducing the volume will increase the pressure, and Le Chatelier's principle says the equilibrium will shift to alleviate the increased pressure. There are fewer moles of gas among the products than there are among the reactants, so the equilibrium will shift to the right to reduce the number of moles in the gas phase and therefore reduce the pressure.

C06. (D) 1.645 g NaOH / 40.00 g/mol = 0.04113 mol NaOH. Need 0.04113 mol H^+ to neutralize this.
0.04113 mol H^+ × 1 mol H_2SO_4/2 mol H^+ = 0.02056 mol H_2SO_4 × (1 L / 0.325 mol) = 0.06327 L = 63.3 mL

C07. (D) The correct structure should have 5+6+6+6+1 = 24 valence electrons, with octets on all four atoms. A violates the octet rule on N, B has too many electrons and violates the octet rule on N and one of the O atoms, C has too many electrons, D is correct, and E violates the octet rule on N.

C08. (B) An oxidation-reduction reaction is one in which the oxidation numbers on two elements in the reaction change. Precipitation reactions and acid-base reactions do not involve changes in the oxidation states of the atoms – they just involve moving an ion from one species to another – but all other reaction types do.

C09. (E) The only monatomic gas at room temperature with an atomic mass close to 39.96 is argon, which has 18 protons. Since the atom has a mass of almost exactly 40, it must have a mass number of 40. It is therefore an argon isotope with 22 neutrons (the most common and most stable isotope of argon).

C10. (B) Larger atoms with more electrons are more easily polarizable, resulting in more dispersion forces between atoms and therefore a higher melting point and a higher boiling point. All of the other answer choices are false statements.

C11. (E) Initial volume = nRT/P = (2.5)(0.08206)(85+273)/1 = 73.44 L
Final volume = nRT/P = (2.5)(0.08206)(–40+273)/0.60 = 79.67 L
$\Delta V = V_{final} - V_{initial}$ = 79.67 – 73.44 = 6.2 L

C12. (C) $\Delta G = \Delta H - T\Delta S$, and a process is spontaneous when ΔG is negative. If the process is endothermic with an increase in entropy, ΔH and ΔS are both positive, so for ΔG to be negative, $T\Delta S$ must be larger than ΔH. The process is therefore energetically more favorable at higher temperatures. Melting ice and boiling water are both examples of this kind of physical transformation.

C13. (A) For a compound with 3:2 ion ratio, $K_{sp} = 108x^5$ where x is the molar solubility of the compound. $2.2 \times 10^{-33} = 108x^5$, so $x = 1.153 \times 10^{-7}$ M. Since one mole of $Cd_3(AsO_4)_2$ produces 3 moles of Cd^{2+} ions, $[Cd^{2+}] = 3 \times 1.153 \times 10^{-7}$ M $= 3.5 \times 10^{-7}$ M.

C14. (D) A catalyst is consumed early in a reaction mechanism and is produced later in the mechanism, and does not appear in the overall equation for the chemical reaction.

C15. (A) work = $-P\Delta V$ = –(1)(1.7 – 3.0) = 1.3 L·atm × (101.325 J)/(1 L·atm) = 132 J

C16. (E) 10.0 g Na/22.99 g/mol = 0.43497 moles of Na, enough to make 0.43497 moles of NaCl
$PV = nRT$, $n = PV/RT$, n = (5.0 L Cl_2)(1 atm)/(0.08206)(273) = 0.22319 moles of Cl_2, enough to make 0.44638 moles of NaCl.
Na is the limiting reactant. 0.43497 moles NaCl × 58.44 g/mol = 25.4 grams of NaCl.

C17. (B) 7.6 g AgCl / 143.32 g/mol = 0.05303 moles AgCl, so there must have been 0.05303 moles of Ag^+ in the solution. 0.05303 mol / 0.1000 L = 0.53 M.

C18. (C) Based on its position in the periodic table, copper should have an electron configuration ending in $4s^2\ 3d^9$, but bumping one 4*s* electron into the 3*d* subshell fills the 3*d* subshell and results in a more stable electron configuration of $4s^1\ 3d^{10}$.

C19. (B) HClO has the largest K_a, therefore since the concentrations are all equal it will have the lowest pH. Assuming $[H^+] << C_{ACID}$,

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The assumption checks out, $5.9 \times 10^{-5} << 0.10$
pH = $-\log[H^+] = -\log(5.9 \times 10^{-5})$ = 4.23.
(Hypopotamous acid and HIP_2O are not real. I made those up.)

C20. (D) 128.56 g / 142.05 g/mol = 0.90503 moles Na_2SO_4. 0.90503 moles / 0.500 mol/L = 1.81 L.

PHYSICS SOLUTIONS – UIL INVITATIONAL B 2021

P01. (C) page 9: "In short, the theory describes a colourful and amazing world where universes explode, space collapses into bottomless holes, time sags and slows near a planet, and the unbounded extensions of interstellar space ripple and sway like the surface of the sea…"

P02. (B) page 12: "It was to be Einstein once again who, five years later, came to understand that the 'packets of energy' were real. Einstein showed that light is made of packets: particles of light. Today we call these 'photons'."

P03. (E) page 23: "Soon someone (perhaps Parmenides, perhaps Pythagoras) realized that the sphere is the most reasonable shape for this flying Earth for which all directions are equal – and Aristotle devised convincing scientific arguments to confirm the spherical nature of both the Earth and of the heavens around it…"

P04. (A) H-II regions consist of about 90% hydrogen. This hydrogen is heated by nearby hot stars which excites the hydrogen atoms into various energy states. The excited atoms then decay and emit photons of specific wavelengths. These wavelengths are grouped together in named series – Lyman, Balmer, Paschen, Brackett, Pfund… The Balmer series of wavelengths are the only ones in the visible portion of the spectrum, and the strongest Balmer line has a wavelength of 656nm – which is red. Because this visible spectral line is so strong, H-II regions generally exhibit a red color.

P05. (A) First, we must consider the subtraction in the numerator. These both are multiplied by the same power of ten, so we do not need to make any adjustments for that. Also, the power of ten is irrelevant for determining the significant figures.
When adding or subtracting, the correct number of significant figures is based on the value with the least decimal places. The first value, 1.98, has two decimal places. The second value, 2.002, has three decimal places. Therefore, the result of the subtraction would have significant figures to only two decimal places. The result is: $[1.98] - [2.002] = -[0.02]2$. Stopping at two decimal places means that this result has only a single significant figure. The complete result, including the power of ten, is $-[0.02]2 \times 10^3 = -[2]2$.
Now we consider the division. When dividing or multiplying, the value with the least number of significant figures determines the number of significant figures of the result. For our case: $\frac{-[2]2}{[19.3]} = -1.139896373$. The numerator has one significant figure, and the denominator has three.
Thus, the answer will have only one significant figure: $-[1].139896373 \approx -1$.

P06. (C) We know the initial velocity, the acceleration (g), and the displacement; and we are looking for the final velocity. The best kinematic equation to use is $v_f^2 = v_i^2 + 2a\Delta x$. Taking downward to be negative, and putting in the known values, we get: $v_f^2 = (-5.25)^2 + 2(-9.8)(-2.29)$. This gives: $v_f^2 = 72.45 \;\rightarrow\; v_f = 8.51$m/s.

P07. (E) In the free-body diagram, each block has two forces acting on it – the weight, directed downward, and the tension, directed upward. In addition, each block accelerates, with the heavier block accelerating downward, and the lighter block accelerating upward. Taking upward to be positive, and summing up the forces on each block, we get two equations. For the heavier block, which accelerates downward: $\sum F_1 = T - (4.2)(9.8) = (4.2)(-a) \;\rightarrow\; T - 41.16 = -4.2a$. For the lighter block, we get: $\sum F_2 = T - (2.8)(9.8) = (2.8)(a) \;\rightarrow\; T - 27.44 = 2.8a$.

Solving for tension in the second equation: $T = 2.8a + 27.44$, and substituting this into the first equation gives the acceleration: $(2.8a + 27.44) - 41.16 = -4.2a \;\rightarrow\; -13.72 = -7.0a$ So, the acceleration is $a = 1.96$ m/s^2. Then, we can easily find the final velocity:
$v_f = v_i + at = 0 + (1.96)(1.30) = 2.55$m/s.

P08. (B) This can only be solved by considering conservation of momentum. Because we have no external forces, like friction, the total momentum before the collision will equal the total momentum after the collision. For these calculations, we will take "to the right" to be positive, and "to the left" to be negative. Before the collision, the total momentum is $p_i = m_r v_{ri} + m_g v_{gi}$. Initially, the green block isn't moving, so $v_{gi} = 0$. Putting in what we know about the initial velocity and mass of the red block, we get: $p_i = (0.300kg)(5.20m/s) = 1.56\ kgm/s$.

After the collision, both blocks are moving, so we have a final momentum of $p_f = m_r v_{rf} + m_g v_{gf}$. This equals the initial momentum, $m_r v_{rf} + m_g v_{gf} = 1.56\ kgm/s$. Putting in the known values (and being careful with signs), we get: $(0.300kg)(-0.850m/s) + (0.420kg)v_{gf} = 1.56\ kgm/s$. This leads to: $-0.255 + 0.420v_{gf} = 1.56 \ \rightarrow\ 0.420v_{gf} = 1.815 \ \rightarrow\ v_{gf} = 4.32\ m/s$.

P09. (B) We begin by considering the forces acting on the block, of which there are two: tension, T, directed upward, and weight, $m_b g$, directed downward. The block is also accelerating downward. Putting this into Newton's acceleration law: $\sum F = T - m_b g = m_b(-a) = -m_b a$. Putting in the known values gives: $T - (12)(9.8) = -(12)a = T - 117.6 = -12a$.
Now we consider the torque acting on the pulley and the rotational acceleration of the pulley. There is only one force that contributes to the rotational acceleration of the pulley: the tension, T. Mathematically, $\sum \tau = Tr = I\alpha$. Putting in the known values: $T(0.30) = (0.220)\alpha$.
Since the rope unwinds without slipping, we know that the angular acceleration of the pulley is related to the linear acceleration of the mass: $a = r\alpha$, which gives: $a = (0.30)\alpha$, or $\alpha = 3.33a$.
From these last two equations: $T = 0.733\alpha = 2.442a$. Plugging this into the first equation, we get: $T - 117.6 = 2.442a - 117.6 = -12a \ \rightarrow\ 14.442a = 117.6 \ \rightarrow\ a = 8.14$ m/s^2.

P10. (C) The frequencies resonant in an open-closed pipe are given by the equation $f_n = \frac{nv}{4L}$ (odd n). At an air temperature of 20°C, the speed of sound is $v = 343$ m/s. And for the fundamental frequency, $n = 1$. Putting this all together gives: $280 = \frac{(1)(343)}{4L} \ \rightarrow\ L = \frac{343}{(4)(280)} = 0.31\text{m} = 31\text{cm}$.

P11. (E) The equation describing linear thermal expansion is $\Delta L = \alpha L_0 \Delta T$. Between summer and winter, the temperature changes by $|\Delta T| = |45 - (-10)| = 55$°C. Thus, the contraction of each bridge section would be $\Delta L = \alpha L_0 \Delta T = (1.0 \times 10^{-5})(12.5)(55) = 0.006875\text{m}$. Since each section contracts by this amount, this is the amount by which each gap will widen. The gaps start at 0.50cm, and widen by 0.6875cm, so the width of each gap in the winter is $0.50 + 0.6875 = 1.1875 \approx 1.2$cm.

P12. (C) In order to find the current flowing in the one resistor, we must first find the total equivalent resistance of the circuit. We begin by combining the 1200Ω and 1000Ω in series: $R_A = 1200 + 1000 = 2200\Omega$. Now, this equivalent resistance is combined in parallel with the 1800Ω resistor: $\frac{1}{R_B} = \frac{1}{1800} + \frac{1}{2200} \ \rightarrow\ R_B = 990\Omega$. Finally, we combine this group resistance in series with the 510Ω resistor: $R_T = 510 + 990 = 1500\Omega$. This is the total equivalent resistance of the circuit.
From here, we can determine the current flowing from the battery: $I_T = \frac{V_T}{R_T} = \frac{24.0V}{1500\Omega} = 0.016\text{A}$. Because they are in series, this same current flows through the 510Ω resistor and the 990Ω equivalent resistance ($I_B = I_T$). This allows us to determine the voltage across the 990Ω group: $V_B = I_B R_B = (0.016)(990) = 15.84$ V.
Because they are in parallel, the voltage across the 1800Ω resistor and the voltage across the 2200Ω equivalent resistance are equal to the voltage across the group. This allows us to finally determine the current flowing through the 1800Ω resistor: $I_{1800} = \frac{V_{1800}}{R_{1800}} = \frac{15.84}{1800} = 0.0088A = 8.8mA$.

P13. (A) Coulomb's Law gives the force between two charges, but we will have to work one at a time with the fixed charges. First, let's consider the force on the +0.50μC charge at the origin due to the 1.20μC charge: $F_1 = \frac{kQ_1Q_0}{r_{10}^2} = \frac{(8.99\times10^9)(1.20\times10^{-6})(0.50\times10^{-6})}{(0.01)^2} = 53.94$ N. Since these are both positive charges, the force will be repulsive. Thus, this force on the +0.50μC charge is directed to the right. Now, we can consider the force on the +0.50μC charge at the origin due to the −1.55μC charge: $F_2 = \frac{kQ_2Q_0}{r_{20}^2} = \frac{(8.99\times10^9)|-1.55\times10^{-6}|(0.50\times10^{-6})}{(0.02)^2} = 17.42$ N. Since these charges are opposite in sign, the force will be attractive. Therefore, this force on the +0.50μC charge will also be directed to the right. The total force is the combination of these two. Since both forces are directed to the right, they add together to give the total: $F_T = F_1 + F_2 = 53.94 + 17.42 = 71.4$ N.

P14. (A) First, we need to find the force on the projectile. Since the current and the magnetic field are perpendicular, we can use the simple formula: $F = I\ell B = (60A)(0.25m)(0.85T) = 12.75$ N. Now, we can use Newton's second law to calculate the acceleration: $a = \frac{F}{m} = \frac{12.75N}{0.150kg} = 85.0$ m/s^2. Finally, we can use kinematics to determine the velocity after the projectile accelerates down the length of the rails: $v^2 = v_0^2 + 2a\Delta x = 0 + 2(85.0)(3.50) = 595 \;\rightarrow\; v = 24.4$ m/s.

P15. (E) Light reflected from a surface is maximally polarized when the light reflects at Brewster's angle. So, based on this, and on what is given in the problem, we know that Brewster's angle is $\theta_p = 61.0°$. Brewster's angle is related to the index of refraction of the surface by the equation $\frac{n_{surface}}{n_{medium}} = tan\theta_p$. The medium through which the light is travelling is air, so $n_{medium} = 1$. Thus, the index of refraction of the surface is: $n_{surface} = \tan(61.0°) = 1.80$.

P16. (D) Based on the size of the letters on the coin, we can determine the magnification provided by the lens: $M = \frac{h'}{h} = \frac{7.00mm}{3.00mm} = 2.33$. Now, we can relate this magnification to the image and object locations (and we know the object location, $p = 4.00cm$.) $M = 2.33 = -\frac{q}{p} = -\frac{q}{4.00cm}$. This allows us to determine the image location: $q = -2.33(4.00) = -9.33cm$. This is negative because the image is virtual. Finally, we can use the image and object locations to calculate the focal length of the lens: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{4.00cm} + \frac{1}{-9.33cm} = 0.143 \;\rightarrow\; f = 7.00cm$.

P17. (B) The energy/time version of Heisenberg's uncertainty principle is $\Delta E\Delta t \geq \frac{\hbar}{2}$. We can use the equality in this equation since we are given the minimum rest-mass energy uncertainty. Now, we must deal with units and constants:
First, $24.0MeV = (24.0\times10^6) * (1.602\times10^{-19}) = 3.84\times10^{-12}$ J.
Also, $\frac{\hbar}{2} = \frac{h}{4\pi} = \frac{6.626\times10^{-34}}{4\pi} = 5.27\times10^{-35}$ Js. Putting it all together, we get:
$(3.84\times10^{-12})\Delta t = 5.27\times10^{-35}$, which gives $\Delta t = 1.37\times10^{-23} \approx 10^{-23}$ seconds. This is the approximate lifetime of the subatomic particle.

P18. (A) The equation that describes radioactive decay is $N = N_0e^{-\lambda t}$. Here λ is the decay constant and is related to the half-life by $\lambda = \frac{\ln(2)}{T_{1/2}} = \frac{0.693}{700\ million\ years} = 9.90\times10^{-10}\ year^{-1}$. Putting this, and the other given values, into the decay equation gives:
$N = (200.0g)e^{-(9.90\times10^{-10})(280\times10^6)} = (200.0g)e^{-0.277} = 152g$.

P19. (C) The equation describing the period of a pendulum is $T = 2\pi\sqrt{\frac{\ell}{g}}$ where ℓ is the length of the pendulum and g is the acceleration due to gravity. Squaring both sides to get the period-squared gives: $T^2 = \frac{4\pi^2}{g}\ell$. We can see a plot of T^2 versus ℓ would be linear with a slope of $\frac{4\pi^2}{g}$. Turning our attention to the graph given, we can find the slope of the line. We need two points on the line, for which I choose (20.0cm, 1.00sec^2) and (50.0cm, 2.45sec^2). Then the slope of the line is: $slope = \frac{2.45-1.00}{50.0-20.0} = \frac{1.45}{30} = 0.0483$. Setting this equal to the slope formula from the equation gives us: $0.0483 = \frac{4\pi^2}{g} \quad \rightarrow \quad g = \frac{4\pi^2}{0.0483} = 816.8$ cm/s^2. Converting to meters gives: $g = 8.168 \approx 8.2$ m/s^2.

P20. (A) The relationship between the electric field and the electric potential can be summed up as $|E| \propto \frac{\Delta V}{\Delta x}$. This basically means that the electric field is greatest at places where the electric potential changes rapidly over a short distance. On a diagram like the one given, the strongest electric fields are located where the equipotential surfaces are spaced close together. In comparing the different points, the equipotential surfaces are closest together at point A. Thus, the greatest electric field strength is found at point A.