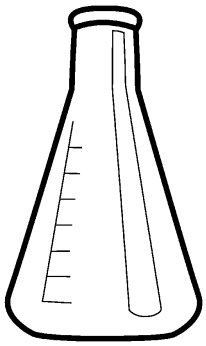
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational B • 2019



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. A student crosses a pea plant that is homozygous recessive (white flowers) with a heterozygous pea plant with the intention of obtaining offspring with white flowers. Assuming Mendelian inheritance, what percent of the offspring will have white flowers from his genetic cross?
A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B02. Which DNA technology is best described as "replication in a test tube?"
A) agarose gel electrophoresis
B) CRISPR/Cas
C) transformation
D) restriction enzyme digestion
E) PCR

B03. ATP can be hydrolyzed to transport a substance into a cell in a mechanism called
A) passive transport.
B) diffusion.
C) exocytosis.
D) active transport.
E) osmosis.

B04. All of the following contribute some way to reproductive success except
A) the ability to use both asexual and sexual reproductive cycles.
B) nutrition.
C) sexual selection (e.g. female birds that chose their mate based upon the color of their feet).
D) biological fitness.
E) All of the above contribute some way to reproductive success.

B05. The coastal redwoods of California are a type of
A) bromeliad.
B) conifer.
C) deciduous tree.
D) succulent.
E) angiosperm.

B06. Which of the following would *immediately* prevent the translation of a gene into a protein product?
A) Binding of RNA Polymerase to the promoter.
B) A small RNA that is complementary to the mRNA sequence and binds to and covers the ribosomal binding site.
C) Activators binding to gene enhancer sequences on the DNA.
D) Ribosomes binding to ribosomal binding sites.
E) A genome structure containing mostly relaxed DNA molecules.

B07. All of the following are cells found within the nervous system except
A) oocytes.
B) glial cells.
C) neurons.
D) Schwann cells.
E) astrocytes.

B08. Cell cycle regulation checkpoints occur in all of the following phases except
A) G_1
B) Mitosis
C) G_2
D) G_0
E) Checkpoints occur in all of the above phases.

B09. For a bacterial cell that can oxidize glucose both aerobically and anaerobically, which intermediate of cellular respiration marks the decision point for either fermentation or respiration processes?
A) Glucose
B) Acetyl-CoA
C) Pyruvate
D) Oxygen
E) Citrate

B10. The type of tissue found adhering muscle to bone is
A) muscle.
B) nervous.
C) connective.
D) epithelial.

B11. In terms of structure and function, the entire human genome is
A) made of both nuclear and mitochondrial genomes.
B) only comprised of the coding sequences of DNA.
C) never fully replicated during S phase.
D) mostly made of coding sequences.
E) solely contained within the nucleus.

B12. Bromeliads, ferns, air plants, and orchids can grow on tropical rainforest trees instead of at the soil/ground level. Plants that can live on trees are most specifically called
A) monophytes.
B) diphytes.
C) parasites.
D) epiphytes.
E) epibionts.

B13. All of the following generally characterize lipids except
A) they are always soluble in water.
B) they have many C-C and C-H bonds.
C) they are mostly nonpolar.
D) some lipids have ring structures.
E) they may be solid or liquid at room temperature, depending upon the degree of saturation.

B14. Romaine lettuce harvested from the Central Coast of California was contaminated with _____ in November 2018.
A) *Salmonella enterica*
B) *Escherichia coli* O157:H7
C) *Escherichia coli* O27
D) *Listeria monocytogenes*
E) *Shigella dysenteriae*

B15. Which of the following was used to separate organisms into specific Domains?
A) Physical characteristics of the organism.
B) Genetic sequences encoding ribosomal RNA.
C) Behavior and adaptations of the organism.
D) Cell structure.
E) Metabolic capabilities, such as respiration or fermentation.

B16. A reaction in which the products contain more free energy than the reactants is called a/an _____ reaction.
A) exergonic
B) catabolic
C) endergonic
D) anabolic
E) More than one answer above is correct.

B17. Transfer RNA (tRNA) and ribosomal RNA (rRNA) sequences are made through
A) transcription.
B) replication.
C) translation.
D) transduction.
E) recombination.

B18. Which of the following factors is useful in maintaining the stability of an ecosystem?
A) Genetic diversity
B) Food web structure
C) Environmental heterogeneity
D) Resilience of a system after a disturbance
E) All of the above are factors in maintaining ecosystem stability.

B19. A vaccine contains Varicella-Zoster virus. This vaccine protects against
A) measles.
B) human papillomavirus
C) HIV.
D) German measles.
E) chickenpox and shingles.

B20. All of the following are plant adaptations to their environment. Which is specific to plants living within a tropical rainforest?
A) Tumbleweeds dry out and "tumble" with the wind to disperse seeds.
B) Flowers that open up in the dark because pollinators are out during the night hours instead.
C) Plants near the ground that are adapted to high levels of light.
D) Some plants climb to acquire better light.
E) Plants that have water-conserving features such as wax coatings or hairs on the leaves.

C01. A metal oxide with the formula M_2O_5 has a molar mass of 181.88 g/mol. Which metal is M?

A) Vanadium
B) Iron
C) Ruthenium
D) Arsenic
E) Krypton

C02. What is the sum of the coefficients in the balanced equation for the explosive decomposition of nitroglycerin?

$$C_3H_5N_3O_9(\ell) \rightarrow N_2(g) + O_2(g) + CO_2(g) + H_2O(g)$$

A) 9
B) 18
C) 24
D) 32
E) 33

C03. What is the electron configuration for Mn^{2+}?

A) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^7$
B) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$
C) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5$
D) $[Ar] 4s^2 3d^6$
E) $[Ar] 4s^2 3d^3$

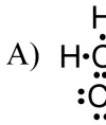
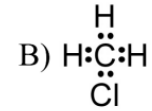
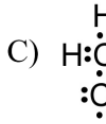
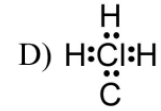
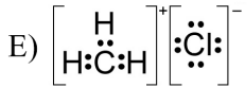
C04. Argon, with an atomic mass of 39.947680 u, has three naturally-occurring isotopes with the following masses and percent abundances:

Isotope	Mass (u)	% Abundance
Ar-36	?	0.3365
Ar-38	37.962732	0.0632
Ar-40	39.962383	99.6003

What is the mass of one atom of Ar-36?

A) 35.953320 u
B) 35.962143 u
C) 35.968556 u
D) 35.899974 u
E) 35.970028 u

C05. Which of these is the correct Lewis dot structure for chloroform, CH_3Cl?

A) 
B) 
C) 
D) 
E) 

C06. Which of the following is *not* an assumption of the kinetic theory of gases?

A) Gas particles are always moving in constant, random motion.
B) Gas particles move in a straight line until they collide with another particle or with the walls of the container.
C) The gas particles are much smaller than the distance between the particles.
D) There is no force of attraction between gas particles or between the particles and the walls of the container.
E) Gas particles exist at higher temperatures than the same compound's corresponding solid or liquid phase.

C07. When a bowl of ice cubes is left out on a table at 25 °C, a phase transition from solid to liquid occurs. ΔH_{system} for this process is positive, and $\Delta S_{universe}$ is also positive. When the resulting bowl of water is placed in a freezer at –10 °C, a phase transition from liquid to solid occurs. What are the signs on ΔH_{system} and $\Delta S_{universe}$ for this second phase transition?

A) $\Delta H_{system} > 0$ and $\Delta S_{universe} > 0$
B) $\Delta H_{system} > 0$ and $\Delta S_{universe} < 0$
C) $\Delta H_{system} < 0$ and $\Delta S_{universe} > 0$
D) $\Delta H_{system} < 0$ and $\Delta S_{universe} < 0$
E) $\Delta H_{system} = 0$ and $\Delta S_{universe} = 0$

C08. The gas phase equilibrium reaction $2A + B \rightleftharpoons 3C + D$ has the equilibrium expression

$$K = \frac{[C]^3[D]}{[A]^2[B]}$$

If the concentration of reactant A is doubled, how will *K* change?

A) *K* will be 2 times its previous value.
B) *K* will be 4 times its previous value.
C) *K* will be ½ its previous value.
D) *K* will be ¼ its previous value.
E) *K* will not change.

C09. An absent-minded professor finds a bottle in his laboratory labeled *0.25M ACID*. He vaguely recalls making up that solution earlier in the day, but he can't remember whether he used HCl, H_2SO_4, or H_3PO_4. In order to determine which acid it is, he titrates a 15 mL sample of the acid. If it takes 50.00 mL of 0.150 M NaOH to reach the endpoint, which acid is it?

A) A titration doesn't tell you which acid it is, so it could be any of these acids.
B) It is none of these acids.
C) HCl
D) H_2SO_4
E) H_3PO_4

C10. In February 2017 a heat wave in Australia set a record high temperature in New South Wales of 46.6 °C. The highest temperature measured in Texas in the July 2018 heat wave was a record 114 °F in Waco. Which place was hotter and by how much?

A) Australia by 1.88 °C.
B) Australia by 1.88 °F.
C) Waco by 1.88 °C.
D) Waco by 1.88 °F.

C11. What is the overall change in the oxidation state of the sulfur atom when a sulfide ion is oxidized to sulfate?

A) –2
B) 0
C) +2
D) +4
E) +8

C12. The experimental rate law for this reaction

$$2\ AB_2 + 2\ CD_2 \rightarrow 2\ B + C_2D_4 + A_2B_2$$

is rate = $k[AB_2]^2[CD_2]$.

If the initial concentration of AB_2 is doubled and the initial concentration of CD_2 is simultaneously decreased by a factor of 2, how will that affect the initial reaction rate?

A) The initial reaction rate will not change.
B) The new rate will be 4 times faster.
C) The new rate will be 2 times faster.
D) The new rate will be ½ as fast.
E) The new rate will be ¼ as fast.

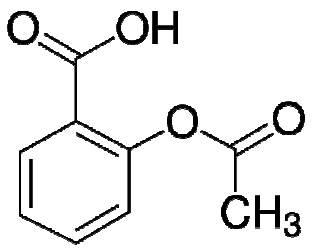
C13. A compound is 86.53% boron and 13.47% hydrogen by mass. Which of these compounds could it be?

A) BH_3
B) B_2H_6
C) B_5H_9
D) B_6H_{10}
E) $B_{10}H_{14}$

C14. How many atoms are there in one formula unit of sodium carbonate decahydrate?

A) 24
B) 32
C) 35
D) 36
E) 37

C15. What is the molar mass of acetylsalicylic acid, better known as aspirin, shown below?



A) 176.13 g/mol
B) 180.17 g/mol
C) 148.12 g/mol
D) 152.11 g/mol
E) 160.13 g/mol

C16. How many sp^2 hybridized carbon atoms are in the aspirin molecule shown in question C16?

A) Eight
B) Six
C) Two
D) Zero
E) Sixteen

C17. Table sugar, also called sucrose, has the chemical formula $C_{12}H_{22}O_{11}$. A 5.00 lb bag of sugar contains how many pounds of oxygen?

A) 1.22 lbs
B) 2.57 lbs
C) 3.15 lbs
D) 4.20 lbs
E) 5.00 lbs

C18. A certain chemical reaction has the following thermodynamic data at 25° C: $\Delta H° = 11$ kJ, $\Delta S° = 87$ J/K. What is the $\Delta G°$ for this reaction? Is this reaction spontaneous or non-spontaneous at 25° C?

A) –9.43 kJ, spontaneous
B) –14.9 kJ, non-spontaneous
C) –25920 kJ, spontaneous
D) –14.9 kJ, spontaneous
E) –14930 kJ, non-spontaneous

C19. On a molecular scale, what happens when the temperature of a solid or liquid increases?

A) The particles move farther apart and move faster.
B) The bond energies in the molecules increase.
C) The intermolecular forces grow stronger.
D) B and C both occur.
E) None of these occur.

C20. A student is disappointed when he adds solid calcium hydroxide to water and it doesn't form Ca^{2+} ions in solution. A classmate suggests adding some nitric acid to help dissolve the $Ca(OH)_2$. Another classmate suggests adding phosphoric acid instead, because the triprotic H_3PO_4 will be three times as effective as the monoprotic HNO_3 in reacting with $Ca(OH)_2$. If the student wants the highest concentration of Ca^{2+} (aq) ions he can get, what is his best course of action?

A) Add the HNO_3.
B) Add the H_3PO_4.
C) Add some of both acids.
D) Don't add any because neither acid will help.
E) Add either one because they will help equally.

P01. According to Natarajan, the mathematician Aryabhata used infinite series to develop extensive tables of values for …
A) natural logarithms.
B) exponential functions.
C) spherical Bessel functions.
D) sine and cosine functions.
E) quadratic functions.

P02. According to Natarajan, Harlow Shaply was the first astronomer to successfully apply the Cepheid variable distance method. Using this method, what did Shaply measure?
A) the size of the Milky Way galaxy
B) the size of the Andromeda galaxy
C) the distance to the Orion nebula
D) the distance to the Magellanic clouds
E) the distance to the most distant quasars

P03. According to Natarajan, the first way in which black holes were actually detected was by observing the…
A) rapid orbits of stars near a black hole.
B) gravitational lensing of radio waves.
C) X-rays emitted by gas swirling into a black hole.
D) gravitational waves from colliding black holes.
E) radio waves emitted by supernova remnants.

P04. Our Sun is currently fueled by which fusion reaction?
A) The CNO cycle (H → He)
B) The Proton-Proton cycle (H → He)
C) Double-Alpha fusion (He → Be)
D) Triple-Alpha fusion (He → C)
E) Carbon fusion (C → Na, Ne, Mg)

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

$$12.2 * [2.1822 - 1.91]$$

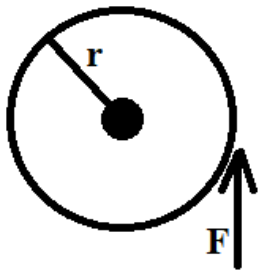
A) 3.3208
B) 3.321
C) 3.32
D) 3.3
E) 3

P06. Your frisbee is stuck in a tree. You throw a baseball directly upwards at a speed of 12.0m/s towards the frisbee to (hopefully) dislodge it from the tree. If the baseball is released exactly 4.40m below the frisbee, how fast is it moving when it strikes the frisbee?
A) 7.60 m/s
B) 8.60 m/s
C) 9.30 m/s
D) 10.0 m/s
E) 15.2 m/s

P07. A 20.0kg bag of dog food is placed on a frictionless inclined plane. If the bag accelerates down the incline at 4.21 m/s^2, what is the angle of the incline?
A) 12.2°
B) 23.2°
C) 25.4°
D) 59.2°
E) 64.6°

P08. A car with a mass of 450.0kg is travelling North at 15.0 m/s when it collides with a second car. The second car has a mass of 720.0kg and was travelling South at 20.0 m/s prior to the collision. If the two vehicles stick together after the collision, what is the speed of the wreckage immediately after the collision?
A) 12.3 m/s
B) 10.6 m/s
C) 9.38 m/s
D) 6.54 m/s
E) 5.77 m/s

P09. A solid disk with a radius of 35.0cm is spun about an axis through its center by a force of 12.0N acting tangentially on the edge of the disk (as shown). The disk starts from rest and reaches an angular speed of 18.0rad/s in 2.50 seconds. What is the mass of the disk? Note: the inertia of a solid disk is given by $I = \frac{1}{2}mr^2$.
A) 1.52 kg
B) 4.76 kg
C) 9.52 kg
D) 21.4 kg
E) 28.0 kg



P10. A travelling wave is described by the equation:

$$y = (13.0cm)\cos(0.75x - 1.55t)$$

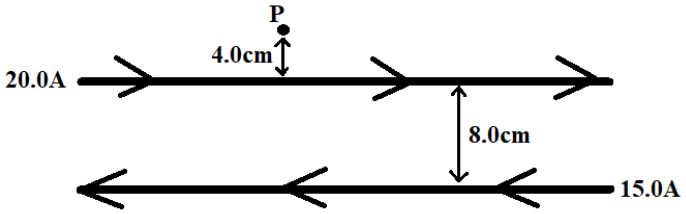
What is the wavelength of this wave?
A) 1.16 m
B) 2.07 m
C) 4.05 m
D) 4.71 m
E) 8.38 m

P11. 2.50 moles of an ideal gas start at a pressure of 1.60atm and a temperature of 77°C. The gas is then increased in temperature while holding the volume constant. If the final pressure of the gas is 2.20atm, what is the final temperature?
A) 106°C
B) 208°C
C) 255°C
D) 389°C
E) 481°C

P12. Two capacitors, a 12.0μF and a 20.0μF, are connected together in series and then hooked to a 9.00V battery. After the connections are made, what is the equilibrium charge stored on the 20.0μF capacitor?
A) 288μC
B) 180μC
C) 108μC
D) 67.5μC
E) 40.5μC

P13. Two parallel plates are connected to a battery so that there is a voltage difference of 36.0V between the plates. The plates are separated by 3.50cm. If a free electron is released between the plates, what is the acceleration of the electron?
A) 5.85×10^{9} m/s^2
B) 9.87×10^{10} m/s^2
C) 2.22×10^{13} m/s^2
D) 1.81×10^{14} m/s^2
E) 5.52×10^{15} m/s^2

P14. Two horizontal wires separated by 8.00cm carry currents of 20.0A and 15.0A in opposite directions, as shown. What is the magnitude of the magnetic field due to these currents at the point P, 4.00cm above the upper wire?



A) 25.0 μT
B) 62.5 μT
C) 75.0 μT
D) 125 μT
E) 175 μT

P15. A circular loop of wire has a radius of 23.0cm and a resistance of 2.50 Ω. A magnetic field of 850μT is directed through the loop, perpendicular to the face of the loop. If the magnetic field suddenly increases to 1350μT in a time of 100.0μs, what is the magnitude of electric current induced in the loop?
A) 332 mA
B) 565 mA
C) 831 mA
D) 897 mA
E) 1420 mA

P16. A candle that is 13.0cm tall is placed 45.0cm to the left of a concave mirror. The mirror has a radius of curvature of 30.0cm. A real, inverted image of the candle is formed by the mirror. How tall is the image of the candle?
A) 3.25cm
B) 5.20cm
C) 6.50cm
D) 9.75cm
E) 26.0cm

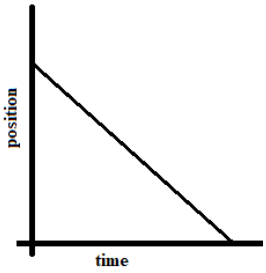
P17. Light of wavelength 486nm is incident on a metal surface that has a workfunction of 1.72eV. What is the velocity of the photoelectrons emitted from the illuminated surface?

A) 3.82×10^5 m/s
B) 5.40×10^5 m/s
C) 7.78×10^5 m/s
D) 9.47×10^5 m/s
E) 1.23×10^6 m/s

P18. The half-life of a radioactive isotope is known to be 113 days. If you begin with 240g of the isotope, how much remains after one year?

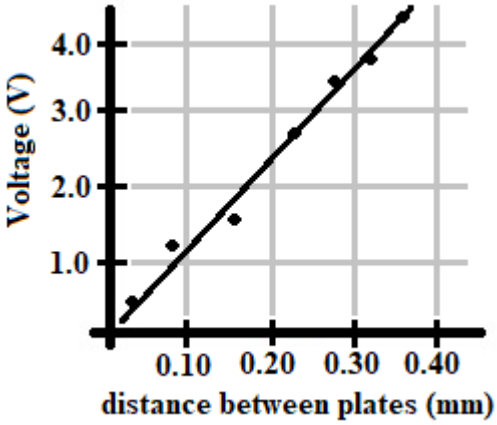
A) 120g
B) 83.6g
C) 74.3g
D) 55.0g
E) 25.5g

P19. The position-time graph for a train engine is shown below. Based on this graph, which statement best describes the motion of the train engine?



A) The engine is moving forward at constant speed.
B) The engine is moving backward at constant speed.
C) The engine is accelerating forward.
D) The engine is accelerating backward.
E) The engine is sitting still.

P20. A fixed quantity of charge is stored on an air-filled parallel plate capacitor. The voltage across the capacitor is then measured as the two plates are slowly separated. The data is shown on the graph below. If the area of the plates is 0.500cm^2, what is the quantity of charge that is stored on the capacitor?



A) 2.1 pC
B) 3.7 pC
C) 5.5 pC
D) 6.8 pC
E) 12 pC

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 = 1.602×10^{-19} C
N_A = 6.022×10^{23} mol^{-1}
k = 1.38×10^{-23} J/K
h = 6.626×10^{-34} J·s
c = 3.00×10^{8} m/s
R_H = 2.178×10^{-18} J
m_e = 9.11×10^{-31} kg

Physics

Useful Constants

quantity	symbol	value
Free-fall acceleration	g	$9.80\ m/s^2$
Permittivity of Free Space	ε_0	$8.854 \times 10^{-12}\ C^2/Nm^2$
Permeability of Free Space	μ_0	$4\pi \times 10^{-7}\ Tm/A$
Coulomb constant	k	$8.99 \times 10^{9}\ Nm^2/C^2$
Speed of light in a vacuum	c	$3.00 \times 10^{8}\ m/s$
Fundamental charge	e	$1.602 \times 10^{-19}\ C$
Planck's constant	h	$6.626 \times 10^{-34}\ Js$
Electron mass	m_e	$9.11 \times 10^{-31}\ kg$
Proton mass	m_p	$1.67265 \times 10^{-27}\ kg$
Neutron mass	m_n	$1.67495 \times 10^{-27}\ kg$
Atomic Mass Unit	u	$1.66 \times 10^{-27}\ kg$
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	$8.314\ J/mol \cdot K$
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	$1.013 \times 10^{5}\ Pa$

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2019 INVITATIONAL B

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL B 2019

C01. (A) Oxygen makes up 5 × 16.00 g/mol = 80.00 g/mol of the overall molar mass of the compound, so the two metal atoms make up the remaining 101.88 g/mol. That means each metal atom has an atomic mass of 50.94 g/mol, which is the atomic mass of vanadium.

C02. (E) The balanced equation is $4\ C_3H_5N_3O_9(\ell) \rightarrow 6\ N_2(g) + O_2(g) + 12\ CO_2(g) + 10\ H_2O(g)$

C03. (C) The first two electrons lost when forming the ion come from the 4*s* orbital.

C04. (C)

$$\text{Atomic mass} = \sum \text{isotopic mass} \times (\text{isotopic abundance}/100)$$

$$39.947680 = (\text{Ar-36})(0.003365) + (37.962732)(0.000632) + (39.962383)(0.996003)$$

$$\text{Ar-36} = \frac{39.947680\ \text{u} - (37.962732\ \text{u})(0.000632) - (39.962383\ \text{u})(0.996003)}{0.003365}$$

$$\text{Ar-36} = \frac{0.121034}{0.003365} = 35.968556\ \text{u}$$

C05. (C)

C06. (**E**)

C07. (C) The water must give up heat in order to freeze, so this is an exothermic process: $\Delta H < 0$. When you place water in a freezer it freezes spontaneously, so $\Delta S_{\text{universe}} > 0$. For some students it might be too counterintuitive to think that melting water and freezing water under these conditions both have an overall positive entropy change of the universe, so here are the calculations to back it up:

$$\Delta S_{\text{universe}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}}$$

$$\Delta S_{\text{universe}} = \frac{\Delta H_{\text{sys}}}{T_{\text{system}}} + \frac{-\Delta H_{\text{sys}}}{T_{\text{surroundings}}}$$

For melting at 0°C, $\Delta H_{\text{sys}} = \Delta H_{\text{fus}} = 334$ J/g:

$$\Delta S_{\text{universe}} = \frac{334\ \text{J/g}}{273\ \text{K}} + \frac{-334\ \text{J/g}}{298\ \text{K}} = 1.223\ \text{J/gK} - 1.121\ \text{J/gK} = +0.102\ \text{J/gK}$$

For freezing at 0°C, $\Delta H_{\text{sys}} = -\Delta H_{\text{fus}} = -334$ J/g:

$$\Delta S_{\text{universe}} = \frac{-334\ \text{J/g}}{273\ \text{K}} + \frac{334\ \text{J/g}}{263\ \text{K}} = -1.223\ \text{J/gK} + 1.270\ \text{J/gK} = +0.047\ \text{J/gK}$$

C08. (E) Changing the concentrations in an equilibrium reaction does not change the equilibrium constant.

C09. (D) Moles of acid = 0.25 M × 0.015 L = 0.00375 moles acid.
Moles OH^- = 0.05000 L × 0.150 M = 0.00750 moles OH^-.
At the equivalence point, moles OH^- = moles H^+, so there are 0.00750 moles H^+.

$$\frac{\text{Moles } H^+}{\text{Moles acid}} = \frac{0.00750}{0.00375} = \frac{2}{1}, \text{so the acid must be } H_2SO_4$$

C10. (B) $46.6\ ^\circ\text{C} \times \frac{9}{5} + 32 = 115.88\ ^\circ\text{F}$

C11. (E) The sulfide ion is S^{2-}, and the oxidation state of sulfur in SO_4^{2-} is +6, for a total difference of +8.

C12. (C) Initial rate = $k[1]^2[1] = k$
Final rate = $k[2]^2[½] = k(4 \times ½) = 2k$
The final rate will be twice the initial rate.

C13. (D) Assume 100 g of compound, that gives you 86.53 g of boron and 13.47 g of hydrogen. Dividing each by its atomic mass yields 8.00 moles of boron and 13.33 moles of hydrogen. Divide each number by the lowest of the two to get a ratio of 1 boron atom to every 1.66 hydrogens. Multiply both values by 3 to make them integers and you get 3 B atoms for every 5 H atoms. B_3H_5 is not one of the answer choices, but B_6H_{10} has the same 3:5 atomic ratio.

C14. (D) The chemical formula is $Na_2CO_3 \cdot 10H_2O$.

C15. (B) The chemical formula is $C_9H_8O_4$.

C16. (A) All the carbon atoms that have one double bond and two single bonds have three regions of electron density around them and are therefore sp^2 hybridized. There are six in the ring and additional ones.

C17. (B) The mass of one mole of sucrose is 342.34 g, and the mass of oxygen in one mole of sucrose is 176 g, so the mass ratio of oxygen to sugar is 176.00/342.34 = 0.5141.
5 lbs of sugar × 0.5141 = 2.57 lbs of oxygen.

C18. (D) Using the Gibbs free energy equation: $\Delta G = \Delta H - T\Delta S$, $\Delta G = 11{,}000\ \text{J} - (298\ \text{K})(87\ \text{J/K})$
$\Delta G = -14{,}930\ \text{J} = -14.9\ \text{kJ}$. Since ΔG is negative, the reaction is spontaneous.

C19. (**A**)

C20. (A) Nitric acid will react with the hydroxide in $Ca(OH)_2$ and increase its solubility, but $Ca_3(PO_4)_2$ is insoluble, so while the phosphoric acid will react with the $Ca(OH)_2$, the released Ca^{2+} ions will precipitate out as calcium phosphate.

PHYSICS SOLUTIONS – UIL INVITATIONAL B 2019

P01. (D) page 10: "… the mathematician Aryabhata, working in the fifth century CE, is credited with describing trigonometric functions via infinite series, enabling him to develop extensive tables of values for the sines and cosines of angles."

P02. (A) page 48: "Later he [Harlow Shapley] used the Cepheids in globular clusters to show that the Milky Way was an enormous system of stars vastly larger than anyone had previously supposed. This was the first successful application of the Cepheid variable distance method, and Shapley used it to estimate the size of our galaxy."

P03. (C) pages 90-91: "X-rays emitted by swirling gas accelerated to near the speed of light by the intense gravity of black holes reveal black holes' presence…. Early X-ray satellites scoped out the first potential black holes… The unmasking of black holes by using X-rays provided the final piece of evidence verifying the theory of the life cycle of stars."

P04. (B) The specific fusion reaction in the Sun is known as the proton-proton cycle, in which hydrogen nuclei (protons) are combined through a series of steps to form helium nuclei. The other hydrogen-to-helium fusion process, the CNO cycle, can only occur at the extremely high temperatures found in massive blue and white stars. Other fusion processes (those starting with helium or carbon) occur only when a star has exhausted it supply of hydrogen fuel – these are end-of-life processes for a star, typically when the star is in the giant or supergiant phase.

P05. (D) Consider first the subtraction inside the brackets: $2.1822 - 1.91$. The first term has 5 significant digits and four decimal places. The second number has three significant digits, but only two decimal places. When adding and subtracting, it is the fewest number of decimal places that matter – so our answer must only include two decimal places. Completing the subtraction yields $0.27[22]$. The digits in brackets are not significant, but are included while we are still in the process of doing calculations. This means, though, that this quantity has only two significant digits.
Now consider the multiplication: $12.2 * 0.27[22]$. The first number has three significant digits and the second has only two significant digits. When multiplying, the fewest number of significant digits is what matters, so our answer must only have two significant digits. Therefore, the answer is: $3.3[2084] \approx 3.3$.

P06. (A) This can be worked a couple of different ways, but let's use one-dimensional kinematics. Taking upwards to be the positive direction, we have an acceleration of $a = g = -9.8$ m/s^2. Since we are given a distance, we can use the kinematic formula: $v_f^2 = v_i^2 + 2a\Delta y = (12.0)^2 + 2(-9.8)(4.40) = 144 - 86.24 = 57.76$. Then the velocity when the ball reaches the frisbee is $v_f = \sqrt{57.76} = 7.60$ m/s.

P07. (C) Since the inclined plane is frictionless, the only forces acting on the bag of dog food are gravity (F_g, down) and the normal force (F_N, upward perpendicular to the plane). We take "down the plane" to be the positive x-direction and upward, perpendicular to the plane, to be the positive y-direction. Therefore, the normal force is entirely in the y-direction. The force of gravity must be broken into components: the x-component is $F_{gx} = mgsin\theta$ and the y-component is $F_{gy} = -mgcos\theta$. The bag does not move in the y-direction at all, so the acceleration is the y-direction is zero, giving us the equation: $\sum F_y = F_N - mgcos\theta = 0$. This equation is correct, but irrelevant for answering the question.
What we need is the equation for the acceleration in the x-direction (down the plane). From Newton's second law, we get $\sum F_x = mgsin\theta = ma_x$. This gives us $a_x = gsin\theta = (9.8)\sin\theta = 4.21$.
Therefore $sin\theta = \frac{4.21}{9.8} = 0.4296$, which gives us $\theta = sin^{-1}(0.4296) = 25.4°$.

P08. (D) This problem requires conservation of momentum, though only in one-dimension. Let's choose North to be the positive direction. Thus, the first car starts with momentum: $p_{1i} = m_1 v_{1i} = (450)(15) = 6750$ kgm/s. The second car has an initial momentum of: $p_{2i} = m_2 v_{2i} = (720)(-20) = -14400$ kgm/s. The cars stick together after the collision, so the final momentum of the wreckage is the sum of the momenta before the collision: $p_f = 6750 - 14400 = -7650$ kgm/s. The total mass of the wreckage is, similarly, the sum of the masses: $m_f = 450 + 720 = 1170$ kg. Then the velocity of the wreckage is $v_f = \frac{-7650}{1170} = -6.54$m/s or 6.54 m/s South.

P09. (C) The first thing to find in this problem is the angular acceleration, for which we need to use an angular kinematic formula: $\omega_f = \omega_i + \alpha t = 18.0 = 0 + \alpha(2.5)$. This gives $\alpha = \frac{18}{2.5} = 7.2$ rad/s^2. Now we need to find the torque on the disk provided by the tangential force. Fortunately, the force is tangential, so its angle with respect to a radial line is 90°. Thus, the torque is $\tau = Frsin\theta = (12.0)(0.350)\sin(90°) = 4.2$ Nm. Now, we can relate the angular acceleration and torque to the moment of inertia: $\tau = I\alpha = 4.2 = I(7.2)$. This gives the moment of inertia: $I = \frac{4.2}{7.2} = 0.583$ kgm^2. Now, using the inertia formula: $\frac{1}{2}mr^2 = 0.583$, which gives $m = \frac{2(0.583)}{r^2} = \frac{2(0.583)}{(0.350)^2} = 9.52$ kg.

P10. (E) The basic equation for a travelling wave is $y = Acos(kx - \omega t)$ where $k = \frac{2\pi}{\lambda}$ and $\omega = 2\pi f$. To get the wavelength we first need to extract k. Looking at the wave equation given, we can see that $k = 0.75$. This gives a wavelength of $\lambda = \frac{2\pi}{k} = \frac{2\pi}{0.75} = 8.38$ m.

P11. (B) Since the volume is constant, we do not need to use the entire ideal gas law, but can use a simpler equation derived from it. Specifically, we can use $\frac{P_1}{T_1} = \frac{P_2}{T_2}$. It is acceptable to use pressure in atmospheres, but we must convert the temperature to an absolute scale (Kelvin): $T_1 = 77 + 273 = 350$ K. Now, using the gas equation: $\frac{1.60\ atm}{350\ K} = \frac{2.20\ atm}{T_2}$ gives $T_2 = 481$ K. Converting back to Celsius: $T_2 = 481 - 273 = 208$°C.

P12. (D) First, we must find the total capacitance of the circuit. Two capacitors in series combine using their reciprocals, so $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{12} + \frac{1}{20}$, which gives $C_{total} = 7.50\ \mu F$. Now we can get the total charge: $Q_{total} = C_{total}V_{total} = (7.50)(9.00) = 67.5\ \mu C$. In a series circuit, the charge on each capacitor is the same as the total charge across the group. In other words, $Q_2 = Q_1 = Q_{total} = 67.5\ \mu C$.

P13. (D) First, we need to find the electric field strength between the plates. The electric field strength between two parallel plates is given by: $|E| = \frac{V}{d}$. This gives a field strength of $|E| = \frac{36.0}{0.035} = 1030$ N/C. Now we can get the force on the electron: $F = qE = (1.602 \times 10^{-19})(1030) = 1.65 \times 10^{-16}$ N. Finally, using Newton's second law, we can calculate the acceleration: $a = \frac{F}{m} = \frac{1.65 \times 10^{-16}}{9.11 \times 10^{-31}} = 1.81 \times 10^{14}$ m/s^2.

P14. (C) The magnitude of the magnetic field produced by a long straight wire is $|B| = \frac{\mu_0 I}{2\pi r}$, where *r* is the distance from the wire to the point P. So, the magnetic field strength due to the top wire is $|B_1| = \frac{(4\pi \times 10^{-7})(20)}{2\pi(0.04)} = 1.00 \times 10^{-4}$ T. Likewise, the magnetic field strength due to the bottom wire is $|B_1| = \frac{(4\pi \times 10^{-7})(15)}{2\pi(0.12)} = 2.50 \times 10^{-5}$ T. Note that the distance from the bottom wire to the point P is 12.0cm. The currents flow in opposite directions, and the point P is above both wires, so these magnetic fields will subtract. Specifically, the field due to the top wire is directed in the +z direction and the field due to the bottom wire is in the -z direction (directions can be found using the right-hand rule). Thus, the total magnetic field strength is $|B| = 1.00 \times 10^{-4} - 2.50 \times 10^{-5} = 7.50 \times 10^{-5}\ T = 75.0$ μT. The direction (if we care) is in the +z direction.

P15. (A) First, we use Faraday's Law to determine the voltage induced in the loop: $|\mathcal{E}| = \frac{\Delta(BA)}{\Delta t} = \frac{\pi r^2 \Delta B}{\Delta t}$. This gives $|\mathcal{E}| = \frac{\pi(0.23)^2(1350 \times 10^{-6} - 850 \times 10^{-6})}{100 \times 10^{-6}} = \frac{(0.1662)(500 \times 10^{-6})}{100 \times 10^{-6}} = 0.831$ V. Thankfully, we don't have to worry about any angles since the field is perpendicular to the face of the loop. Then we can get the current by using Ohm's Law: $V = 0.831 = IR = I(2.5)$, giving $I = 0.332\ A = 332\ mA$.

P16. (C) First, let's find the focal length of the mirror. It is concave, so the focal length is positive, and we know $f = \frac{R}{2} = \frac{30}{2} = 15.0$cm. Now we can find the location of the image using $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$. Plugging in the focal length and object distance: $\frac{1}{45} + \frac{1}{q} = \frac{1}{15}$ gives an image distance of $q = 22.5$cm. Now we can calculate the magnification: $M = -\frac{q}{p} = -\frac{22.5}{45} = -0.5$. So, the image height is $h_i = Mh_o = (-0.5)(13) = -6.50$cm. The negative sign just means it is inverted, which is given in the problem. Thus, the answer to the question of "how tall is the image" would be 6.50cm.

P17. (B) First, we need the energy of the photons of light. This can easily be found by using the relation: $E = \frac{1240}{\lambda}$ where λ is in nanometers and E is in eV. This gives us $E = \frac{1240}{486} = 2.55$ eV. Subtracting the workfunction from this will give the kinetic energy of the photoelectrons: $KE = 2.55 - 1.72 = 0.83$ eV. Assuming this will be non-relativistic (a good guess given the low energy), we can find the velocity using classical kinetic energy: $KE = \frac{1}{2}mv^2$. Converting to mks units gives:
$KE = (0.83)(1.602 \times 10^{-19}) = 1.33 \times 10^{-19}\, J = \frac{1}{2}(9.11 \times 10^{-31}\, kg)v^2$. Solving gives a velocity of $v = 5.40 \times 10^5$ m/s. (Incidentally, this is indeed non-relativistic.)

P18. (E) First, we find the decay constant of this isotope: $\lambda = \frac{\ln(2)}{T_{1/2}} = \frac{0.693}{113} = 6.13 \times 10^{-3}$ days^{-1}. Converting our time (1 year = 365 days), we can determine how much of the isotope remains by using: $N_f = N_0 e^{-\lambda t}$. This gives $N_f = (240)e^{-(6.13\times10^{-3})(365)} = (240)e^{-2.24} = 25.5$ g.

P19. (B) From the graph we see that the position of the train engine is decreasing as time increases – this means that it is moving backward. The fact that the position-time graph is a straight line indicates that the speed of the train engine is constant. Therefore, the train engine is moving backward at a constant speed.

P20. (C) We must combine a couple of capacitor equations in order to solve this problem. First, we know how voltage relates to the charge in a capacitor: $Q = CV$. We also know that for a parallel plate capacitor, the capacitance is determined by the geometry: $C = \epsilon_0 \frac{A}{d}$. Combining these two equations gives us: $Q = \epsilon_0 \frac{A}{d} V$. Solving for the voltage gives: $V = \frac{Q}{\epsilon_0 A} d$. This shows the linear relationship between the voltage, *V*, and the plate separation, *d*, that we see in the graph. The slope of the line is then: $slope = \frac{Q}{\epsilon_0 A}$. From the graph the slope is approximately $slope = \frac{y_2 - y_1}{x_2 - x_1} = \frac{3.6-1.1}{0.30-0.10} = 12.5$ V/mm. Using the known values for the area and the permittivity gives:
$slope = 12.5 \frac{V}{mm} = \frac{Q}{(8.854 \times 10^{-12}\frac{C}{Vm})(0.500\ cm^2)}$. Then, putting everything into mks units:
$slope = 12500 \frac{V}{m} = \frac{Q}{(8.854 \times 10^{-12}\frac{C}{Vm})(0.0000500\ m^2)}$, finally giving a charge of
$Q = \left(12500 \frac{V}{m}\right)\left(8.854 \times 10^{-12} \frac{C}{Vm}\right)(0.0000500\, m^2) = 5.5 \times 10^{-12} C = 5.5 pC$.

UIL Science Contest Answer Sheet

Conference _____ **Grade Level** _____ **Contestant #** _____

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

Grader Initials _____ _____ _____ **OVERALL SCORE** ☐