UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Invitational A • 2023

GENERAL DIRECTIONS:

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

B01. In which eukaryotic organelle would the enzymes for degradation of damaged organelles or breakdown of food substance from food vacuoles be found?
A) mitochondria
B) rough endoplasmic reticulum
C) peroxisome
D) nucleus
E) lysosome

B02. In Mendelian classical genetics, the genotype Pp would be referred to as
A) homozygous.
B) homozygous dominant.
C) homozygous recessive.
D) heterozygous.
E) codominant.

B03. The process of reading a messenger RNA sequence and converting it into a protein sequence is called
A) replication.
B) regulation.
C) transduction.
D) transcription.
E) translation.

B04. Which of the following organic macromolecules is best characterized as nonpolar, hydrophobic, and found in fats and oils.
A) phospholipids
B) triglycerides
C) amino acids
D) nucleotides
E) monosaccharides

B05. The type of cell division that produces gametes is called
A) sexual reproduction.
B) mitosis.
C) meiosis.
D) fusion.
E) budding.

B06. Male birds performing intricate dancing sequences to win the interest of same-species female birds is known as
A) genetic drift.
B) sexual selection.
C) gene flow.
D) speciation.
E) hybridization.

B07. The major photosynthetic pigment that causes leaves on deciduous trees to be green is
A) chlorophyll.
B) carotenoid.
C) anthocyanin.
D) phycobillin.
E) flucoxanthin.

B08. Epithelial cells in the skin that produce pigment are called
A) keratinocytes.
B) basal cells.
C) squamous cells.
D) melanocytes.
E) mast cells.

B09. The organ system responsible for excretion of nitrogenous wastes from the human body and fluid balance is the
A) Musculoskeletal system.
B) Urinary system.
C) Reproductive system.
D) Digestive system.
E) Nervous system.

B10. Organisms in the same ____ would always be found in the same _____.
A) Domain; Kingdom
B) Kingdom; species
C) Genus; species
D) Family; Order
E) Class; Order

B11. All of the following are examples of unity in diversity except
A) all organisms are made of cells.
B) ribosomes are the cellular machinery that makes proteins for all organisms.
C) the wings of butterflies and the wings of birds are homologous structures.
D) the forelimbs of mammals (cats, bats, whales, humans) have similar structures.
E) inherited information is stored in DNA molecules for all living organisms.

B12. The process of _______ is directly linked to, and occurs before, cell division.
A) DNA replication
B) translation
C) gene expression
D) transcription
E) respiration

B13. The alleles in the following genetic cross are incompletely dominant. What percentage of the progeny will express the intermediate phenotype?

Aa x aa

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

B14. Which of the following is correctly paired with its binding site?
A) RNA polymerase - activator sequence
B) Ribosome - promoter
C) Initiator tRNA - stop codon
D) Repressor - operator
E) DNA polymerase - +1

B15. Gram-positive bacteria are differentiated from Gram-negative bacteria by
A) the presence of a thicker layer of peptidoglycan in Gram-positive bacteria.
B) Gram-positive bacteria staining purple in the Gram stain process.
C) the presence of only one membrane, the cytoplasmic membrane, in Gram-positive bacteria.
D) the absence of lipopolysaccharide (LPS) in Gram-positive bacteria.
E) all of the above.

B16. In biological hierarchy, which level immediately precedes tissues moving from smallest to largest?
A) cells
B) organ systems
C) organelles
D) organs
E) atoms

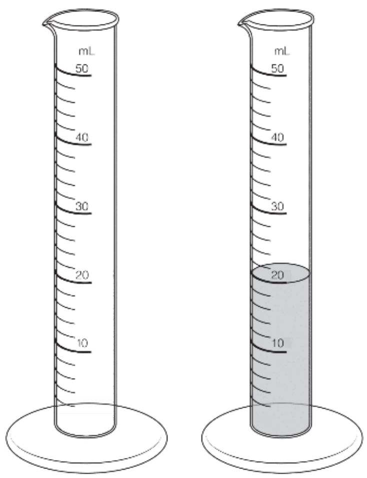
B17. In October 2022, the Centers for Disease Control and Prevention issued a Food Safety Alert and the store recalled frozen falafel due to contamination with
A) Hepatitis virus.
B) *Salmonella*.
C) *Listeria*.
D) Coronavirus.
E) Shiga-toxin producing *Escherichia coli*.

B18. Cellular components that catalyze chemical reactions and are made of amino acids are specifically called
A) inorganic catalysts.
B) organelles.
C) enzymes.
D) ribozymes.
E) proteins.

B19. In a population at Hardy-Weinberg equilibrium, 302 organisms out of 491 express the dominant phenotype. What percent of the population are homozygous recessive?
A) 29.1%
B) 38.5%
C) 61.5%
D) 62.0%
E) 78.4%

B20. The reaction in the nitrogen cycle that reduces nitrates completely to dinitrogen gas through a nitrite intermediary is called
A) denitrification.
B) nitrification.
C) ammonification.
D) nitrogen fixation.
E) anammox.

C01. If the empty 50 mL graduated cylinder shown below weighs 177.0 grams and the one with the liquid weighs 204.0 grams, what is the density of the liquid in the graduated cylinder?



A) 1.35 g/mL
B) 1.00 g/mL
C) 1.12 g/mL
D) 10.2 g/mL
E) 0.74 g/mL

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

$$Al(NO_3)_3(aq) + Na_3PO_4(aq) \rightarrow AlPO_4(s) + NaNO_3(aq)$$

A) 3
B) 4
C) 5
D) 6
E) 8

C03. How many electrons are in a neutral atom of Carbon-14?

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

C04. What type of bond holds the oxygen and hydrogen atoms together in a water molecule?

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

C05. If 0.100 moles of neon gas are placed in a 2.00 liter rigid container at 25.0 °C and then the container is heated to 190.0 °C, what will the final pressure of the gas inside the container be?

A) 1.22 atm
B) 0.78 atm
C) 1.56 atm
D) 3.80 atm
E) 1.90 atm

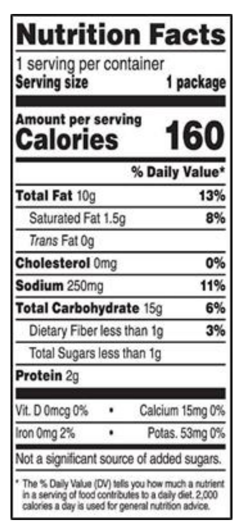
C06. What type of intermolecular forces would you expect to find in liquid methane, CH_4?

A) Ion-ion forces
B) Hydrogen bonding
C) Dipole-dipole forces
D) Dispersion Forces
E) None

C07. The amount of heat released or absorbed by a chemical reaction that occurs at constant pressure is called the

A) internal energy
B) enthalpy of reaction
C) entropy of reaction
D) spontaneous energy
E) reaction deficit energy

C08. A 1 oz snack bag of Cheetos contains 160 Calories of energy. How many grams of ice could be melted using the energy stored in one serving of Cheetos?



A) 2000 g
B) 2.00 g
C) 534 g
D) 479 g
E) 669 g

C09. What is the equilibrium constant K_P for the gas-phase reaction

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

if the gas pressures at equilibrium are found to be

Gas	Equilibrium Pressure (atm)
A	0.50
B	0.25
C	0.10
D	0.15

A) 2.4×10^{-3}
B) 420
C) 0.12
D) 8.3
E) 1.2×10^{-3}

C10. What is the pH of 300.0 mL of 0.015 M hydrochloric acid?

A) 0.300
B) 0.500
C) 1.35
D) 1.82
E) 2.00

C11. Which of these is the correct equation for calculating the K_{sp} of $Ca(OH)_2$ from the molar solubility, x?

A) $K_{sp} = 16x$
B) $K_{sp} = x^2$
C) $K_{sp} = 4x^3$
D) $K_{sp} = 27x^4$
E) $K_{sp} = 108x^5$

C12. Which of these is a possible product of a chemical reaction in which N_2 gas undergoes reduction?

A) N atoms
B) NO_2
C) NH_3
D) N_2O_4
E) N_2O

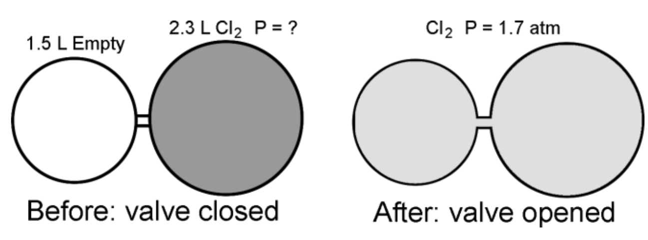
C13. The rate law for the chemical reaction between A and B is first order with respect to A and also first order with respect to B. Which of the following statements is true?

A) Sometimes A reacts first in the reaction and sometimes B reacts first.
B) Doubling the concentration of A will double the rate of the reaction.
C) Doubling the concentrations of both A and B will double the rate of the reaction.
D) Changing the concentrations of A and B will not change the rate of the reaction.
E) The rate law cannot be first order with respect to both A and B. One must be first and the other second.

C14. How many atoms are in a ball of copper wire that has a mass of 3.45 grams?

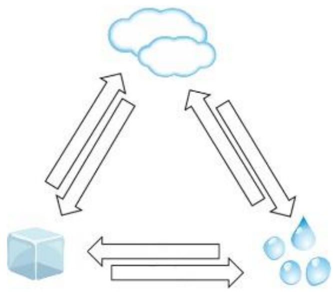
A) 3.27×10^{22}
B) 8.74×10^{22}
C) 3.27×10^{24}
D) 8.74×10^{24}
E) 8.27×10^{23}

C15. A 1.5 L bulb and a 2.3 L bulb are connected by a valve. The larger bulb contains Cl_2 gas at an unknown pressure, and the smaller bulb is empty. When the valve is opened, the pressure of the Cl_2 gas in both bulbs is 1.7 atm. What was the original Cl_2 pressure in the 2.3 L bulb? Assume the volume of the valve tube is negligible.



A) 2.8 atm
B) 0.36 atm
C) 1.7 atm
D) 1.0 atm
E) 3.3 atm

C16. Given this diagram and the information on the data sheet, what is the heat of sublimation for water?



A) 6.766 J/g
B) 1926 J/g
C) 2260 J/g
D) 2928 J/g
E) 2594 J/g

C17. How many of the following names and formulas do not match correctly?

Chemical Formula	Chemical Name
$Cr_2(SO_4)_3$	chromium(III) sulfate
CS_2	carbon disulfide
$(NH_4)_2CO_3$	ammonia carbon trioxide
$FeCl_2$	iron chloride
NI_3	nitrogen iodide

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

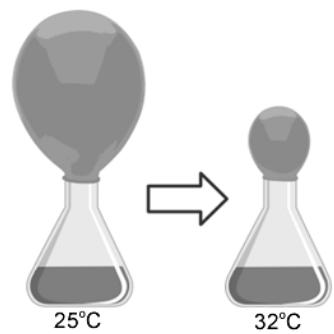
C18. Which of these is a valid set of quantum numbers?

A) $n = 1$ $\ell = 1$ $m_\ell = 0$ $m_s = -½$
B) $n = 2$ $\ell = 1$ $m_\ell = -1$ $m_s = +½$
C) $n = 3$ $\ell = 2$ $m_\ell = +2$ $m_s = +⅓$
D) $n = 4$ $\ell = 3$ $m_\ell = +3$ $m_s = -⅓$
E) $n = 5$ $\ell = 4$ $m_\ell = +5$ $m_s = +½$

C19. A 50.0 mL sample of 0.100 M HNO_3 is titrated to the equivalence point using 10.0 mL of 0.500 M NaOH. What is the final pH of the solution?

A) 1
B) 5
C) 7
D) 10
E) 60

C20. What is the sign on the change in internal energy (ΔU) for the chemical reaction carried out in a balloon-covered flask shown below?



A) $\Delta U > 0$
B) $\Delta U < 0$
C) $\Delta U = 0$
D) $\Delta U < 0$ at the top and $\Delta U > 0$ at the bottom
E) More information is needed to answer the question

Chemistry

1A 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1 H 1.01																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 La 138.9	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.20	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (293)	118 Og (294)

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Water Data

T_{mp} = 0°C
T_{bp} = 100°C
c_{ice} = 2.09 J/g·K
c_{water} = 4.184 J/g·K
c_{steam} = 2.03 J/g·K
ΔH_{fus} = 334 J/g
ΔH_{vap} = 2260 J/g
K_f = 1.86 °C/*m*
K_b = 0.512 °C/*m*

Energy Unit Conversions

1 Calorie = 1000 calories
1 calorie = 4.184 J

Constants

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

Other Data

All other necessary data for this exam is included in the problems themselves.

P01. According to Feynman, quantum electrodynamics (QED) describes all physical phenomena except two. Which two phenomena does QED not describe?
A) gravity and radioactivity
B) gravity and light
C) radioactivity and light
D) light and chemistry
E) chemistry and radioactivity

P02. According to Feynman, a ___________ is an instrument that can detect a single photon.
A) photodiode
B) photomultiplier
C) phototransistor
D) cathode ray tube
E) Geiger counter

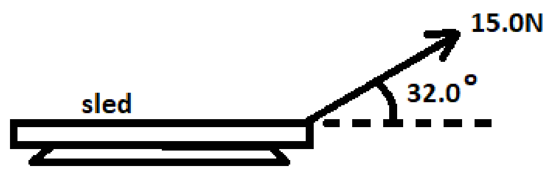
P03. According to Feynman, iridescence is the production of colors by the partial reflection of white light by two surfaces. An example of iridescence is…
A) the deep colors of stained glass
B) the rich colors of lead-based paints
C) the bright colors of cloth dyes
D) the saturated colors of television pixels
E) the brilliant colors of peacocks

P04. Though not advisable, if you did look at the Sun, what region of the Sun would you see as the disk of the Sun?
A) the Corona
B) the Chromosphere
C) the Photosphere
D) the Convection Zone
E) the Solar Wind

P05. A cube of cheese that is exactly 27.0mm on a side is melted into a circular puddle that has a diameter of 22.0cm. What is the thickness of the circular puddle of cheese?
A) 0.13 mm
B) 0.41 mm
C) 0.52 mm
D) 1.6 mm
E) 2.1 mm

P06. A small truck was initially travelling at 20.0m/s. The truck accelerated at a constant rate up to a speed of 35.0m/s. If the acceleration took a total of 6.00seconds, then how far did the truck travel while it was accelerating?
A) 45.0 m
B) 90.0 m
C) 120 m
D) 165 m
E) 210 m

P07. A sled with a mass of 7.00 kg is pulled across frictionless snow by a force of 15.0 N. The force is directed upwards at an angle of 32.0^{o} above the horizontal (as shown). What is the horizontal acceleration of the sled?



A) 1.14 m/s^2
B) 1.82 m/s^2
C) 2.14 m/s^2
D) 2.96 m/s^2
E) 3.96 m/s^2

P08. A child starts from rest at the top of a large slide, at which point her center of mass is 4.30m above the ground. Ignoring friction and air resistance, how fast is the child moving when she reaches the bottom of the slide? Note: At the bottom of the slide, the child's center of mass is 0.80m above the ground.
A) 3.96 m/s
B) 5.86 m/s
C) 6.49 m/s
D) 8.28 m/s
E) 9.18 m/s

P09. A meter stick is arranged horizontally with a fulcrum (pivot point) located exactly at the 50.0cm mark (the center of mass of the meter stick). A 60.0g mass is attached to the meter stick at the 30.0cm mark. At what location on the meter stick should a 100.0g mass be attached to balance the meter stick?

A) the 12.0cm mark
B) the 18.0cm mark
C) the 62.0cm mark
D) the 68.0cm mark
E) the 82.0cm mark

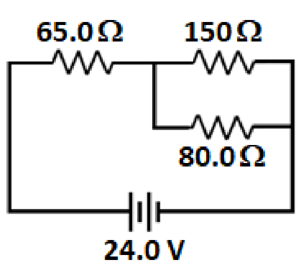
P10. A 250.0g mass is attached to a vertically hanging spring that has a spring constant of 140N/m. The mass is pulled 15.0cm from the equilibrium position and released from rest, resulting in harmonic motion. What is the speed of the mass as it passes through the equilibrium point during each oscillation?

A) 3.55 m/s
B) 15.8 m/s
C) 23.7 m/s
D) 39.4 m/s
E) 84.0 m/s

P11. A perfect Carnot engine absorbs heat energy from a 560K hot reservoir, and exhausts heat energy into a 220K cold reservoir. What is the efficiency of the Carnot engine?

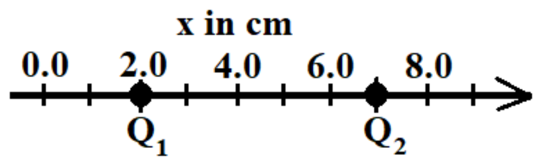
A) 16%
B) 25%
C) 39%
D) 49%
E) 61%

P12. Given the following circuit, determine the current flowing in the 65.0Ω resistor.



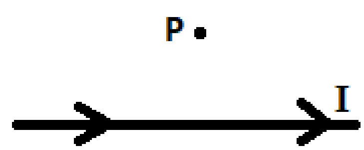
A) 81.4 mA
B) 205 mA
C) 369 mA
D) 590 mA
E) 829 mA

P13. Two charges, $Q_1 = 85.0nC$ located at x = 2.0cm, and $Q_2 = -63.0nC$ located at x = 7.0cm, are positioned on the x-axis as shown. What is the magnitude of the electric potential at the origin (x = 0.0cm) due to the presence of these two charges?



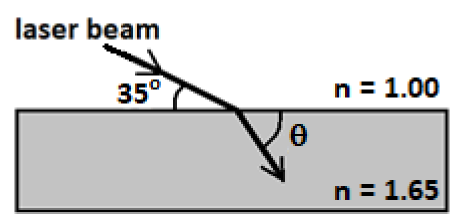
A) 18.0 kV
B) 20.3 kV
C) 30.1 kV
D) 38.5 kV
E) 46.4 kV

P14. A long straight wire carries a current of 2.25A, directed from left to right (as shown). What is the magnetic field at the point P, located 4.00cm above the wire?



A) 11.3 μT out of the page
B) 11.3 μT into the page
C) 28.1 μT out of the page
D) 28.1 μT into the page
E) 35.5 μT out of the page

P15. A laser beam travelling in air is directed onto a rectangular prism of glass, and is refracted as shown. The index of refraction of the glass is 1.65. Determine the indicated angle, θ, of the beam in the glass.



A) 20.3°
B) 29.8°
C) 45.4°
D) 60.2°
E) 71.2°

P16. A convex mirror with a radius of curvature of 28.0cm is located 11.0cm to the right of a light bulb. What is the magnification of the image of the light bulb?

A) 4.67
B) 3.16
C) 1.65
D) 0.72
E) 0.56

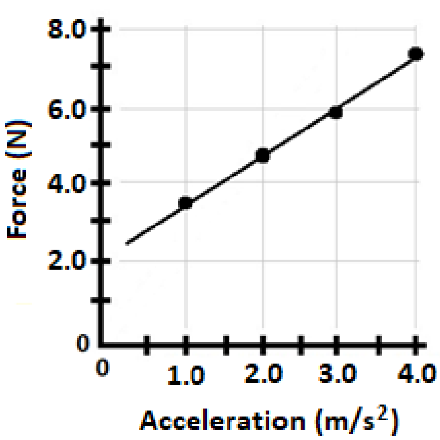
P17. A hydrogen atom undergoes a transition from the $n = 9$ state to the $n = 4$ state. What is the wavelength of the photon emitted during this transition?

A) 656 nm
B) 820 nm
C) 1220 nm
D) 1460 nm
E) 1820 nm

P18. A subatomic particle that is classified as a baryon, such as a proton, is composed of ____

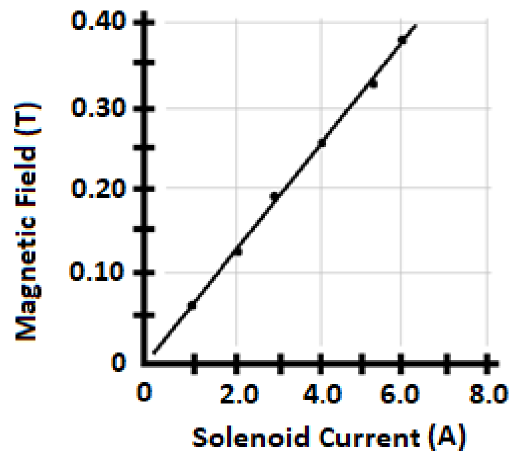
A) three quarks
B) two quarks
C) a quark and an anti-quark
D) a quark and two anti-quarks
E) two quarks and an anti-quark

P19. Shown below is a graph of the force acting on a toy car as a function of the acceleration of the car. Based on these data, what is the approximate mass of the toy car?



A) 0.75 kg
B) 1.3 kg
C) 1.8 kg
D) 2.0 kg
E) 2.7 kg

P20. The magnetic field inside a solenoid is measured as the current through the solenoid is varied. The data are plotted below. Given that the solenoid is linear and 2.00cm long, determine the approximate number of turns of wire that make up the solenoid.



A) 300 turns
B) 1000 turns
C) 3000 turns
D) 10,000 turns
E) 50,000 turns

Physics

Useful Constants

quantity	symbol	value
Free-fall acceleration	g	$9.80\ m/s^2$
Permittivity of Free Space	ε_0	$8.854 \times 10^{-12}\ C^2/Nm^2$
Permeability of Free Space	μ_0	$4\pi \times 10^{-7}\ Tm/A$
Coulomb constant	k	$8.99 \times 10^9\ Nm^2/C^2$
Speed of light in a vacuum	c	$3.00 \times 10^8\ m/s$
Fundamental charge	e	$1.602 \times 10^{-19}\ C$
Planck's constant	h	$6.626 \times 10^{-34}\ Js$
Electron mass	m_e	$9.11 \times 10^{-31}\ kg$
Proton mass	m_p	$1.67265 \times 10^{-27}\ kg$ $1.007276 amu$
Neutron mass	m_n	$1.67495 \times 10^{-27}\ kg$ $1.008665 amu$
Atomic Mass Unit	amu	$1.66 \times 10^{-27}\ kg$ $931.5\ MeV/c^2$
Gravitational constant	G	$6.67 \times 10^{-11}\ Nm^2/kg^2$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8}\ W/m^2K^4$
Universal gas constant	R	$8.314\ J/mol \cdot K$ $0.082057\ L \cdot atm/mol \cdot K$
Boltzmann's constant	k_B	$1.38 \times 10^{-23}\ J/K$
Speed of Sound (at 20ºC)	v	343 m/s
Avogadro's number	N_A	$6.022 \times 10^{23}\ atoms/mol$
Electron Volts	eV	$1.602 \times 10^{-19}\ J/eV$
Distance Conversion	miles → meters	1.00 mile = 1609 meters
Rydberg Constant	R_∞	$1.097 \times 10^7\ m^{-1}$
Standard Atmospheric Pressure	1 atm	$1.013 \times 10^5\ Pa$
Density of Pure Water	ρ_{water}	$1000.0\ kg/m^3$

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL High School Science Contest
ANSWER KEY
2023 INVITATIONAL A

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

CHEMISTRY SOLUTIONS – UIL INVITATIONAL A 2023

C01. (A) The liquid has a mass of 204.0 – 177.0 = 27.0 grams and a volume of 20.0 mL.
27.0 g/20.0 mL = 1.35 g/mL

C02. (D) $Al(NO_3)_3(aq) + Na_3PO_4(aq) \rightarrow AlPO_4(s) + 3\ NaNO_3(aq)$ 1 + 1 + 1 + 3 = 6

C03. (B) Any isotope of carbon has 6 protons, so a neutral atom of carbon will have 6 electrons.

C04. (B) Hydrogen bonds are not found within a single molecule, they are attractions between adjacent molecules.

C05. (E) $PV = nRT$, so $P = nRT/V$. T = 190.0 + 273 = 463 K. P = (0.100)(0.08206)(463)/2.00 = 1.90 atm
You do not need the initial temperature to solve this problem.

C06. (D) Methane is a non-polar molecule so its only intermolecular attractions are dispersion forces.

C07. (B) Enthalpy is defined as the heat given off or absorbed when the reaction is carried out at constant pressure.

C08. (A) 160 Calories = 160,000 cal. 160,000 cal × 4.184 J/cal = 669,440 J.
669,440 J/334 J/g = 2004 grams of ice melted.

C09. (A):

$$K_P = \frac{{P_\mathrm{C}}^3 P_\mathrm{D}}{{P_\mathrm{A}}^2 P_\mathrm{B}} = \frac{(0.10)^3(0.15)}{(0.50)^2(0.25)} = 2.4 \times 10^{-3}$$

C10. (D) pH = $-\log[H^+] = -\log(0.015)$ = 1.82. You do not need the volume to solve this problem.

C11. (C) $K_{sp} = [Ca^{2+}][OH^-]^2$. If $x = [Ca^{2+}]$, then $[OH^-] = 2x$, so $K_{sp} = (x)(2x)^2 = 4x^3$

C12. (C) The nitrogen atoms in N_2 each have an oxidation number of 0. Individual N atoms are also in a 0 oxidation state, and the oxidized forms are all positive oxidation states. Only NH_3 where N has an oxidation number of –1 is in a lower oxidation state than N_2.

C13. (B) rate = k[A][B] means that doubling either [A] or [B] will double the reaction rate. Doubling both [A] and [B] will quadruple the reaction rate.

C14. (A) 3.45 g/63.55 g/mol = 0.05429 moles × 6.02×10^{23} atoms/mole = 3.27×10^{22} atoms

C15. (A) $P_1V_1 = P_1V_2$, so $P_1 = P_2V_2/V_1$. V_2 = 1.5 + 2.3 = 3.8 L P_1 = (1.7)(3.8)/(2.3) = 2.8 atm

C16. (E) Enthalpy is a state function, which means it is path independent and depends only on the starting point and ending point. So going directly from solid to gas is the same as going from solid to liquid and then from liquid to gas.
Therefore $\Delta H_{sub} = \Delta H_{fus} + \Delta H_{vap}$ = 334 J/g + 2260 J/g = 2594 J/g.

C17. (C)

Chemical Formula	Chemical Name
$Cr_2(SO_4)_3$	chromium(III) sulfate
CS_2	carbon disulfide
$(NH_4)_2CO_3$	~~ammonia carbon trioxide~~ **ammonium carbonate**
$FeCl_2$	~~iron chloride~~ **iron (II) chloride**
NI_3	~~nitrogen iodide~~ **nitrogen triiodide**

C18. (B) In A ℓ must be 0, in C and D m_s must be + or – ½, and in E m_ℓ is outside the range of –ℓ,…,+ℓ

C19. (C) When a strong acid is neutralized with an equivalent amount of strong base the resulting pH will be neutral.

C20. (E) In this reaction the volume of the system decreases, so work is done on the system by the surroundings, and work is (+). But the reaction is giving off heat, so q = (–). $\Delta U = q + w$, but with one positive and the other negative we can't say for sure what the sign on ΔU is. (In real life q usually makes up 95% or more of the ΔU, so the most likely outcome would be that ΔU has the same sign as q, but without any numbers for q and w we can't say for sure.)

PHYSICS SOLUTIONS – UIL INVITATIONAL A 2023

P01. (A) pages 7-8: "… the vast range of phenomena that the theory of quantum electrodynamics describes: It's easier to say it backwards: the theory describes all the phenomena of the physical world except the gravitational effect…, and radioactive phenomena…."

P02. (B) page 14: "You might wonder how it is possible to detect a single photon. One instrument that can do this is called a photomultiplier, and I'll describe briefly how it works…"

P03. (E) page 35: "This phenomenon of colors produced by the partial reflection of white light by two surfaces is called iridescence, and can be found in many places. Perhaps you have wondered how the brilliant colors of hummingbirds and peacocks are produced. Now you know."

P04. (C) The deepest layer of the Sun that we can observe directly is the photosphere. This is the "solar surface" that we see when looking at the Sun in visible light.

P05. (C) The volume of the original cheese cube is $V = L^3 = (27mm)^3 = 19683mm^3$. The puddle, which is essentially a cylinder, must have the same volume. Notice that the radius of the puddle, in millimeters is $r = \frac{d}{2} = \frac{22.0cm}{2} = 11.0cm = 110mm$. Equating the volume of the cylindrical puddle to the original cube volume gives: $V = \pi r^2 h = 19683 \;\rightarrow\; \pi(110)^2 h = 38013h = 19683 \;\rightarrow\; h = 0.52mm$.

P06. (D) First, we need to find the acceleration of the truck. Using one of the kinematic equations, we get: $v_f = v_i + at \;\rightarrow\; 35.0m/s = 20.0m/s + a(6.00s) \;\rightarrow\; 6.00a = 15.0 \;\rightarrow\; a = 2.50m/s^2$. Now, we can use another of the kinematic equations to find the distance that the truck traveled: $v_f^2 = v_i^2 + 2a\Delta x \;\rightarrow\; (35)^2 = (20)^2 + 2(2.5)\Delta x \;\rightarrow\; 1225 = 400 + 5\Delta x \;\rightarrow\; \Delta x = 165m$.

P07. (B) First, we should build a free-body diagram. Since the sled is moving without friction, there are only three forces acting on the sled: the gravitational force (directed downward), the normal force (directed upward), and the pulling force (directed at 32.0° above horizontal). Breaking the pulling force into its components, we have a vertical component of $F_{pull-y} = (15.0N)\sin(32.0) = 7.95N$, and a horizontal component of $F_{pull-x} = (15.0N)\cos(32.0) = 12.72N$. We are only concerned about the horizontal acceleration, so we only need to sum up the horizontal forces (of which there is only one – the horizontal component of the pulling force). Using Newton's acceleration law, we get: $\sum F_x = F_{pull-x} = ma \;\rightarrow\; 12.72N = (7.00kg)a \;\rightarrow\; a = 1.82m/s^2$.

P08. (D) Since we are ignoring friction, this problem is simply a direct conversion of gravitational potential energy into kinetic energy. Conservation of energy requires that the initial energy equals the final energy: Thus, $E_f = E_i$. Including gravitational and kinetic energies only, this becomes: $mgh_f + \frac{1}{2}mv_f^2 = mgh_i + \frac{1}{2}mv_i^2$. Noting that the child starts from rest, we know $v_i = 0$. This reduces our expression to $mgh_f + \frac{1}{2}mv_f^2 = mgh_i$. Notice that every term includes the mass of the child, which means that we can cancel it out. This leaves: $gh_f + \frac{1}{2}v_f^2 = gh_i$. Plugging in the known values, we have: $(9.8)(0.80m) + (0.5)v_f^2 = (9.8)(4.30m) \;\rightarrow\; 7.84 + (0.5)v_f^2 = 42.14$. This gives: $(0.5)v_f^2 = 34.30 \;\rightarrow\; v_f^2 = 68.60 \;\rightarrow\; v_f = 8.28m/s$.

P09. (C) Because the fulcrum is set at the meter stick's center of mass, there will be no torque caused by the weight of the meter stick. Thus, all of the torques in this problem are created by hanging masses. To balance the meter stick, the torques must sum to zero, with counterclockwise torques being positive and clockwise torques being negative. Torque is defined as $\tau = Fr\sin\theta$. Here F is the force, which is the weight of each hanging mass; r is the "torque arm," which is the distance from the fulcrum to the location of each hanging mass; and θ is the angle between the force and the torque arm, which in an experiment like this is always 90°.
The 60.0g mass hangs to the left of the fulcrum, so it will cause a counterclockwise rotation (a positive torque). The 100.0g mass is hanging to the right of the fulcrum and will cause a clockwise rotation (a negative torque). These must sum to zero.
Mathematically, $\sum\tau = F_1r_1\sin\theta_1 - F_2r_2\sin\theta_2 = 0$, which becomes:
$m_1gr_1\sin(90) - m_2gr_2\sin(90) = 0$. The distance from the 60.0g mass to the fulcrum is $r_1 = 50.0cm - 30.0cm = 20.0cm = 0.20m$. Converting the masses to kilograms and noting that $\sin(90) = 1$ we get: $(0.060kg)(9.8)(0.20m) - (0.100kg)(9.8)r_2 = 0 \ \rightarrow$ $0.1176 - 0.98r_2 = 0 \ \rightarrow \ r_2 = 0.12m = 12.0cm$. So, the 100.0g mass must be placed to the right of the fulcrum, at a distance of 12.0cm from the fulcrum.
Thus, it should be placed at the $50.0cm + 12.0cm = 62.0cm$ mark on the meter stick.

P10. (A) First, we need to find the angular frequency of the mass-spring oscillations, a quantity given by $\omega = \sqrt{\frac{k}{m}}$. Plugging in the given quantities, we get: $\omega = \sqrt{\frac{140N/m}{0.250kg}} = \sqrt{560} = 23.66\ rad/s$. Now, the maximum velocity (which is the velocity as the mass passes through the equilibrium point) is given by: $v_{max} = \omega A$, where A is the amplitude of the motion. Converting the amplitude to meters, and putting in the values, we get $v_{max} = (23.66rad/s)(0.150m) = 3.55m/s$.

P11. (E) The efficiency of a perfect Carnot engine is based on the temperatures of the hot and cold reservoirs and is given by $e = 1 - \frac{T_c}{T_h}$. In this case, $T_c = 220K$ and $T_h = 560K$ (conveniently already provided in Kelvin). Plugging in, we get $e = 1 - \frac{220}{560} = 1 - 0.393 = 0.607 \approx 0.61 = 61\%$.

P12. (B) First, we must combine the resistors to find a singe equivalent resistance for the circuit. The 150Ω resistor and the 80.0Ω resistor are in parallel. Combining them, we get $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{150} + \frac{1}{80.0} \ \rightarrow \ R_p = 52.2\Omega$. This equivalent resistance is in series with the 65.0Ω resistor. Combining gives the total equivalent resistance for the circuit: $R_T = R_3 + R_p = 65.0 + 52.2 = 117.2\Omega$. Now, by using Ohm's Law, we can find the total current produced by the battery: $I_T = \frac{V_T}{R_T} = \frac{24.0}{117.2} = 0.205A$. Because the 65.0Ω resistor is in series with the battery, this same current must flow through the resistor. Thus, the current in the 65.0Ω resistor is $0.205A = 205mA$.

P13. (C) Fortunately, electric potential is not a vector. Thus, we can simply calculate the potential created by each charge and add them to get the total electric potential at the origin. The equation for calculating the electric potential due to a point charge is $V = \frac{kQ}{r}$ where k is the Coulomb constant. The first charge produces an electric potential at the origin of
$V_1 = \frac{kQ_1}{r_1} = \frac{(8.99\times10^9Vm/C)(85.0\times10^{-9}C)}{0.02m} = 38208V$, and the second charge produces a potential of
$V_2 = \frac{kQ_2}{r_2} = \frac{(8.99\times10^9Vm/C)(-63.0\times10^{-9}C)}{0.07m} = -8091V$. Summing these gives the total electric potential at the origin: $V = V_1 + V_2 = 38208 - 8091 = 30117 \approx 30.1kV$.

P14. (A) Since the current is flowing in a long, straight, wire, we know that the magnitude of the magnetic field produced near the wire is given by the equation $|B| = \frac{\mu_0 I}{2\pi r}$. Plugging in the values of the current, the permeability of free space, and the distance from the wire to the point P, we obtain: $|B| = \frac{(4\pi \times 10^{-7} Tm/A)(2.25A)}{2\pi(0.04m)} = 1.13 \times 10^{-5}T = 11.3\mu T$. To find the direction of the magnetic field, point your right thumb in the direction of the current and look at how your fingers curl around – this shows the direction of the field as it goes in circles around the wire. Thus, we can see that at the point P, the magnetic field above the wire would be oriented "out of the page" (that is, it points directly at your face). So, the magnetic field at the point P is $11.3\mu T$ directed out of the page.

P15. (D) This is a simple application of Snell's Law, but we must first obtain the correct incident angle. The angles for Snell's Law are measured relative to the normal line, which is perpendicular to the surface. So, the correct incident angle is $\theta_i = 90 - 35 = 55°$. Now we can use Snell's Law and the indices of refraction to obtain the refracted angle: $n_i \sin\theta_i = n_r \sin\theta_r \;\; \rightarrow$ $(1.00)\sin(55) = (1.65)\, sin\,\theta_r \;\rightarrow\; \theta_r = \sin^{-1}(0.4965) = 29.8°$. This is the refracted angle, which is also measured relative to the normal line. It relates to the angle indicated on the diagram by: $\theta = 90 - 29.8 = 60.2°$.

P16. (E) First, we will need to find the location of the image formed by the mirror. To do this, we need the focal length of the convex mirror. Recall that the focal length is related to the radius of curvature by $|f| = \frac{|R|}{2}$. This gives the magnitude of the focal length; the sign is given by the direction of the curvature. For a convex mirror, the sign of the focal length is negative. Thus, the focal length of this mirror is $f = -\frac{28.0}{2} = -14.0cm$. Now we can calculate the location of the image using: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ where p is the object location and q is the image location, both measured relative to the mirror. Here we work entirely in centimeters. Thus, $\frac{1}{11.0cm} + \frac{1}{q} = \frac{1}{-14.0cm} \;\rightarrow\; q = -6.16cm$ Note that the negative sign on the image location means that it is a virtual image. Finally, to find the magnification, we use: $M = -\frac{q}{p} = -\frac{-6.16cm}{11.0cm} = 0.56$.

P17. (E) The wavelength of a photon emitted during a transition in hydrogen is given by the Rydberg formula: $\frac{1}{\lambda} = R_\infty\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$, where R_∞ is the Rydberg constant, and n_f and n_i are the final and initial states, respectively. The final and initial states are given, and the Rydberg constant is known, so we get: $\frac{1}{\lambda} = (1.097 \times 10^7 m^{-1})\left(\frac{1}{4^2} - \frac{1}{9^2}\right) = (1.097 \times 10^7 m^{-1})\left(\frac{1}{16} - \frac{1}{81}\right)$
This gives: $\frac{1}{\lambda} = 5.502 \times 10^5 m^{-1} \;\rightarrow\; \lambda = 1.818 \times 10^{-6}m$, which, when converted to nanometers, is a wavelength of $\lambda = 1818nm \approx 1820nm$.

P18. (A) Particles composed of quarks are known as hadrons. Only two types of hadrons have been shown to exist: mesons and baryons. Mesons are composed of a quark and an anti-quark. Baryons, on the other hand, are composed of three quarks. Thus, choice A is the correct answer for baryons. Note that choices B, D, and E do not result in "color-neutral" combinations of quarks. "Color" is a property of quarks, and only color-neutral combinations are allowed to form observable particles. Thus, according to quantum chromodynamics, combinations B, D, and E are not even possible.

P19. (B) These data represent a very familiar relation - Newton's acceleration law: $F = ma$. Comparing the plot to the equation, we recognize that the mass will equal the slope of the line in the plot. So, we must choose a pair of points on the line in order to calculate the slope. I choose (1.5m/s^2, 4.0N) and (3.0m/s^2, 6.0N). The slope is then: $slope = \frac{y_2-y_1}{x_2-x_1} = \frac{6.0N-4.0N}{3.0\frac{m}{s^2}-1.5\frac{m}{s^2}} = \frac{2.0}{1.5}kg = 1.3kg = mass$.

Note: the fact that the intercept of the line is not zero is most likely a consequence of static friction; it does not affect the calculation of the mass.

P20. (B) The magnetic field inside a linear solenoid is given by the equation $B = \mu_0 \frac{N}{L} I$, where N is the number of turns of the solenoid, L is the length of the solenoid, and I is the current flowing through the solenoid. Also, μ_0 is the Permeability of Free Space, which is a constant equal to $4\pi \times 10^{-7} \frac{Tm}{A}$. Comparing the equation to the graph, we see that the slope of the line in the plot would be $slope = \mu_0 \frac{N}{L}$. Thus, we must choose a pair of points on the line in order to calculate the slope. I choose (1.5A, 0.10T) and (4.75A, 0.30T). This gives a slope of:
$slope = \frac{y_2-y_1}{x_2-x_1} = \frac{0.30T-0.10T}{4.75A-1.5A} = \frac{0.20T}{3.25A} = 0.0615\frac{T}{A} = \mu_0 \frac{N}{L} = \left(4\pi \times 10^{-7} \frac{Tm}{A}\right)\frac{N}{L}$.
This leads to $\frac{N}{L} = 49000$. Plugging in the length of the solenoid gives $\frac{N}{0.02m} = 49000$. Finally, we can obtain the total number of turns in the solenoid: $N = (49000)(0.02) = 980 \approx 1000$ turns.