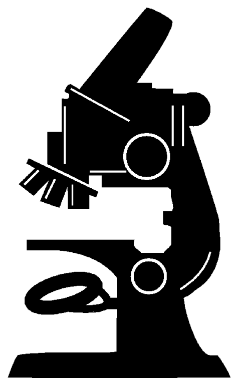
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Region • 2018



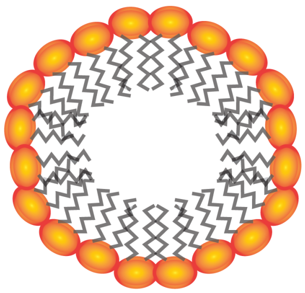
GENERAL DIRECTIONS:

- DO NOT OPEN EXAM UNTIL TOLD TO DO SO.
- Ninety minutes should be ample time to complete this contest, but since it is not a race, contestants may take up to two hours. 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.
- You may place as many notations as you desire anywhere on the test paper except 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.
- On the back of this page is printed a copy of the periodic table of the elements. You may wish to refer to this table in answering the questions, and if needed, you may use the atomic weights and atomic numbers from the table. Other scientific relationships are listed also.
- Silent hand-held calculators that do not need external wall plugs may be used. Graphing calculators that do not have built-in or stored functionality that provides additional scientific information are allowed. Small hand-held computers are not permitted. Calculators that accept memory cards or memory sticks are not permitted. Each contestant may bring one spare calculator. All memory must be cleared.

SCORING:

All questions will receive 6 points if answered correctly; no points will be given or subtracted if unanswered; 2 points will be deducted for an incorrect answer.

B01. Which of the following answers most likely explains the phospholipid arrangement in this image?



A) Phospholipids surrounding an oil droplet.
B) Phospholipids surrounding a water droplet.
C) Phospholipids at the surface of a beaker of water.
D) Phospholipids dropped into a beaker of oil.
E) None of the above.

B02. Imagine a closed system that contains all of the necessary biotic and abiotic components to run the nitrogen cycle smoothly. Predict the *immediate* effect of selectively removing all of the denitrifying bacteria.
A) Atmospheric nitrogen would increase.
B) Increased rate of nitrogen fixation.
C) Decomposers would increase production NO_2^-.
D) Ammonium concentration would decrease in the system.
E) The concentration of nitrates would increase.

B03. Methylation of histone proteins sometimes causes DNA to become condensed. If the histone is modified so that it is no longer recognized by the methyltransferase, what would happen to gene expression in that area?
A) repression of translation
B) increased gene expression in that region
C) silencing of the gene
D) decreased replication of that region
E) a genetic mutation

B04. The Unikonts include
A) Opisthokonta.
B) Amoebozoa.
C) eukaryotes with a single emergent flagellum.
D) Fungi, Animalia, and amoebas.
E) More than one answer above is correct.

B05. A population of birds migrates from Canada to Mexico every Fall, and then back again the next Spring, where they breed. In one year, early storms forced about 1% of the population to only travel as far as the United States on the return trip to Canada. This small population became isolated from the larger population. The birds mated in their new environment and raised offspring. Which mechanism would impact the allele frequencies and decrease diversity in the smaller population the *greatest*?
A) adaptation
B) distribution
C) gene flow
D) genetic drift
E) mutation

B06. Virulence factors are anything that can enhance the disease-causing ability (pathogenesis) of an organism. Which of the following would *not* be considered a virulence factor?
A) antibiotic susceptibility
B) toxin production
C) surface molecules for adhesion
D) cell-degrading enzymes
E) metabolic pathways that neutralize immune systems

B07. Examine the following genetic cross:

AaGGRRSsttVv x aaGgrrSsTtvv

Unless otherwise indicated, assume a Mendelian inheritance pattern. What is the probability of having offspring that exhibit these traits:
Terminal flowers (aa)
Green seeds (G_)
Purple dots (Rr)
Spiny stems (S_)
Tall plants (T_)
Yellow flowers (vv)

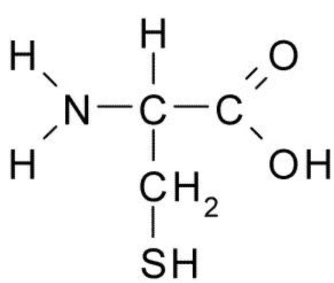
A) 0
B) 1/16
C) 1/2
D) 3/16
E) None of the above.

B08. Giant red sea urchins and purple sea urchins have overlapping ranges off the western coast of the United States. Urchins reproduce by expelling gametes into the water where sperm and egg fuse to form zygotes. The reproductive seasons for these urchins are synchronous, yet few to no hybrids exist in the wild. Which of the following best describes this phenomenon?
A) habitat isolation
B) behavioral isolation
C) mechanical isolation
D) hybrid sterility
E) gametic isolation

B09. All of the following are strategies for correcting hypocalcemia except
A) Bone resorption.
B) Increased absorption by digestive system.
C) Bone deposition.
D) Reabsorption by the kidneys.
E) Inhibition of osseous tissue production.

B10. DNA-binding proteins usually bind to DNA at
A) promoters.
B) major grooves.
C) minor grooves.
D) the ends.
E) the TATA box.

B11. Examine the image. This molecule would



A) contribute to the stability of proteins by forming disulfide bridges.
B) be metabolized by β-oxidation.
C) be found attached to a phospholipid.
D) contribute to the stability of membranes.
E) be excreted from the cell as a waste product.

B12. Transcribe and translate this DNA *template* strand. Assume the transcriptional start site is on the end.

3'-ATACATGCTCTTAATTCAT-5'

	U	C	A	G	
U	Phe	Ser	Tyr	Cys	U
	Phe	Ser	Tyr	Cys	C
	Leu	Ser	STOP	STOP	A
	Leu	Ser	STOP	Trp	G
C	Leu	Pro	His	Arg	U
	Leu	Pro	His	Arg	C
	Leu	Pro	Gln	Arg	A
	Leu	Pro	Gln	Arg	G
A	Ile	Thr	Asn	Ser	U
	Ile	Thr	Asn	Ser	C
	Ile	Thr	Lys	Arg	A
	Met	Thr	Lys	Arg	G
G	Val	Ala	Asp	Gly	U
	Val	Ala	Asp	Gly	C
	Val	Ala	Glu	Gly	A
	Val	Ala	Glu	Gly	G

A) Met-Tyr-Val-Arg-Glu-Leu-Ser
B) Tyr-Val-Arg-Glu-Leu-Ser
C) Met-Tyr-Glu-Asn
D) Met-Asn
E) Met-Leu

B13. Which characteristic do both mammals and reptiles have that is not observed in both amphibians and fishes?
A) mammary glands
B) bony skeletons
C) lungs
D) amniotic egg

B14. When considering the eukaryotic mRNA-ribosome complex, the E site is more towards the _______ end of the mRNA relative to the P site.
A) 3'
B) 5'
C) N-terminus
D) C-terminus
E) poly(A)

B15. The "iron lung" was associated with the motor neuron effects of which preventable disease?
A) poliomyelitis
B) measles
C) mumps
D) pneumonia
E) smallpox

B16. $NADP^+$ is to light-dependent reactions as _____ is to aerobic respiration.
A) H_2O
B) ATP
C) OH^-
D) O_2
E) H^+

B17. As erythrocytes within blood return to the heart from the body, which chamber do they enter first?
A) right ventricle
B) right atrium
C) left ventricle
D) left atrium
E) lungs

B18. Which one of the following enzymes overlaps both the aerobic electron transport chain and the Krebs cycle?
A) pyruvate dehydrogenase
B) pyruvate carboxylase
C) succinate dehydrogenase
D) ATPase
E) aconitase

B19. Which of the following genetic patterns is not autosomal recessive?
A) cystic fibrosis
B) sickle cell disease
C) polydactyly
D) phenylketonuria
E) polycystic kidney disease

B20. A researcher is investigating the effects of different mutations within a gene. She methodically introduces mutations and then acquires data on gene expression. From the data listed below, what is the *best* conclusion about this particular mutation?

	mRNA (copies)	Protein [nM]
Wild Type	1.99×10^8	25.6
Mutant 1	2.00×10^8	0.89

A) The mutation was introduced into a promoter region for the gene of interest.
B) The mutation was introduced into a coding region of the gene.
C) The mutation was introduced into the transcriptional termination sequence.
D) The mutation was introduced into the DNA sequence for the ribosomal binding site.
E) The mutation was introduced into a transcriptional activator site.

C01. What are the n and ℓ quantum numbers for the outermost electron in an Al^{3+} ion?

A) $n = 2, \ell = 0$
B) $n = 2, \ell = 1$
C) $n = 2, \ell = 2$
D) $n = 3, \ell = 1$
E) $n = 3, \ell = 2$

C02. What is the oxidation state of Br in the bromate ion?

A) –5
B) –3
C) –1
D) +3
E) +5

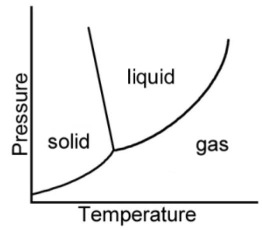
C03. Which of these best describes the lines of the Balmer series of the hydrogen atom?

A) Atomic emission lines in the visible region that are given off when an electron drops from a higher energy level to n = 2.
B) Atomic emission lines in the ultraviolet region that are given off when an electron drops from a higher energy level to n = 1.
C) Atomic emission lines in the infrared region that are given off when an electron drops from a higher energy level to n = 3.
D) Atomic emission lines in the ultraviolet region that are given off when an electron drops from a higher energy level to n = 3.
E) Atomic emission lines in the infrared region that are given off when an electron drops from a higher energy level to n = 1.

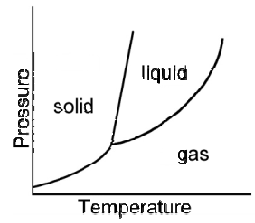
C04. If 10.0 mL of liquid bromine at 20°C is placed in a 1.00 L container and allowed to come to equilibrium with its vapor, how many grams of bromine will be in the gas phase? The vapor pressure of Br_2 at 20°C is 175 torr.

A) 0.0911 g
B) 0.755 g
C) 1.51 g
D) 3.02 g
E) 8.46 g

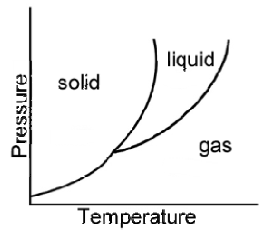
C05. Which of these best represents the phase diagram for water?



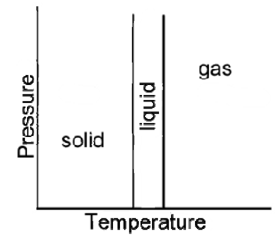
A)



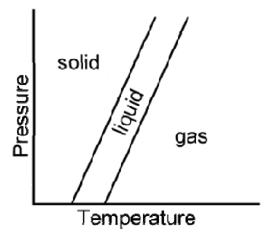
B)



C)



D)



E)

C06. Determine the empirical formula of a compound if a sample of the compound contains 3.524 g of iron, 3.034 g of sulfur, and 4.542 g of oxygen.

A) FeS_2O_3
B) $FeSO_3$
C) $FeSO_4$
D) $Fe_2(SO_3)_3$
E) $Fe_2(SO_4)_3$

C07. 75 ml of 0.10 M NaOH was added to 125 ml of a 0.20 M solution of an unknown monoprotic weak acid, and the resulting pH was 4.50. What is the K_a of the unknown acid?

A) 6.2×10^{-6}
B) 8.5×10^{-6}
C) 1.4×10^{-5}
D) 3.8×10^{-5}
E) 7.9×10^{-5}

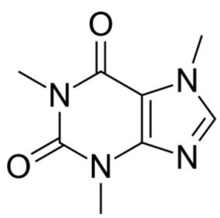
C08. For the equilibrium reaction

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

the equilibrium constant K_p is equal to 0.497 at 500 K. A gas cylinder at 500 K is filled with $PCl_5(g)$ at an initial pressure of 1.66 atm. What is the final pressure in the cylinder when the reaction reaches equilibrium?

A) 1.70 atm
B) 1.96 atm
C) 2.35 atm
D) 3.32 atm
E) 3.48 atm

C09. How many π bonds are there in a caffeine molecule, shown below?



A) 4
B) 6
C) 8
D) 12
E) 19

C10. How many grams of copper metal will be plated out of a solution of $Cu(NO_3)_2$ if 5.5 amps are passed through the solution for 12 minutes?

A) 3.9 g
B) 2.6 g
C) 1.3 g
D) 5.2 g
E) 0.021 g

C11. Sodium metal has a work function (φ) equal to 3.78×10^{-19} J. What is the longest wavelength of light (in nm) capable of removing a surface electron from sodium in a vacuum?

A) 750
B) 625
C) 570
D) 526
E) 265

C12. Is dissolving sodium chloride in water a physical change or a chemical change?

A) It is a chemical change because chemical ionic bonds between Na^+ and Cl^- are broken when dissolving the NaCl.
B) It is a chemical change because when NaCl dissolves, the Na^+ and Cl^- ions interact with H_2O molecules.
C) It is a physical change because the NaCl is Na^+ and Cl^- ions in both the solid and aqueous states.
D) It is a physical change because NaCl dissolves more readily when the solution is heated.
E) It is both a physical change and a chemical change.

C13. The reaction of ammonia with oxygen gas produces nitrogen dioxide as one of the products. What is the sum of the coefficients in the balanced equation for this reaction?

A) 6
B) 11
C) 14
D) 18
E) 21

C14. AgBr is almost completely insoluble in water, with a $K_{sp} = 5.35 \times 10^{-13}$, but it reacts with aqueous ammonia to form a complex ion:

$$AgBr(s) + 2\,NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) + Br^-(aq)$$

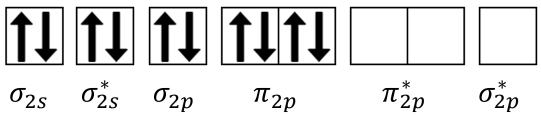
(K_f for $Ag(NH_3)_2^+ = 1.6 \times 10^7$) What is the molar solubility of AgBr in a 0.50 M NH_3 solution?

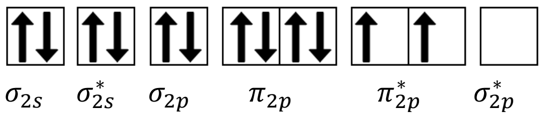
A) 2.9×10^{-3}
B) 1.5×10^{-3}
C) 7.3×10^{-7}
D) 2.1×10^{-6}
E) 9.0×10^{-5}

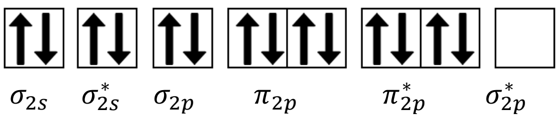
C15. What is the density of xenon gas at standard temperature and pressure?

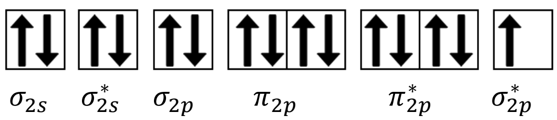
A) 0.0446 g/L
B) 2.41 g/L
C) 5.37 g/L
D) 5.86 g/L
E) 8.33 g/L

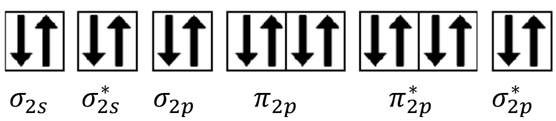
C16. Which of these molecular orbital diagrams indicates that no bond would form?

A) 

B) 

C) 

D) 

E) 

C17. Given the following thermodynamic data:

Reaction	ΔH_{rxn} (kJ/mol)
$H_2S\ (g) + 2\ O_2\ (g) \rightarrow H_2SO_4\ (l)$	–225.7
$SO_3\ (g) + H_2O\ (g) \rightarrow H_2SO_4\ (l)$	–60.5
$SO_3\ (g) + H_2O\ (l) \rightarrow H_2S\ (g) + 2\ O_2\ (g)$	205.9

Determine the heat of vaporization for water,
$H_2O\ (l) \rightarrow H_2O\ (g)$ ΔH = ?? kJ/mole

A) –492.1 kJ/mol
B) –80.3 kJ/mol
C) 40.7 kJ/mol
D) 80.3 kJ/mol
E) 205.9 kJ/mol

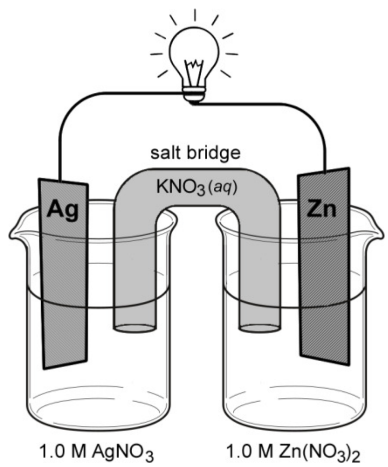
C18. What is the pH of a saturated solution of copper(II) hydroxide? $K_{sp} = 1.1 \times 10^{-15}$

A) 9.11
B) 8.81
C) 7.48
D) 5.19
E) 4.89

C19. The reaction $A + B \rightarrow C + D$ was found to be first order with respect to A and second order with respect to B. If the concentration of A is doubled and the concentration of B is cut in half, what will the overall effect be on the rate of the reaction?

A) The reaction rate will double.
B) The reaction rate will be cut in half.
C) The reaction will occur four times faster.
D) The reaction rate will drop to one fourth of the original rate.
E) The reaction rate will be unchanged.

C20. A student constructs the following galvanic cell using a zinc electrode in 1.0 M $Zn(NO_3)_2$, a silver electrode in 1.0 M $AgNO_3$, and a salt bridge containing aqueous KNO_3. What is the cell diagram for this electrochemical cell?



A) $Ag(s), Ag^+(aq) \| Zn^{2+}(aq), Zn(s)$
B) $Ag(s) | Ag^+(aq) \| Zn^{2+}(aq) | Zn(s)$
C) $Ag(s) | Ag^+(aq) \| KNO_3(aq) \| Zn^{2+}(aq) | Zn(s)$
D) $Zn(s), Zn^{2+}(aq) \| Ag^+(aq), Ag(s)$
E) $Zn(s) | Zn^{2+}(aq) \| Ag^+(aq) | Ag(s)$

P01. According to Tyson, what fraction of the atoms produced during the birth of our universe are helium atoms?
A) about 0.1%
B) about 0.5%
C) about 2.0%
D) about 5.0%
E) about 10.0%

P02. According to Tyson, which element has the least total energy per nuclear particle?
A) Lead
B) Iron
C) Carbon
D) Helium
E) Hydrogen

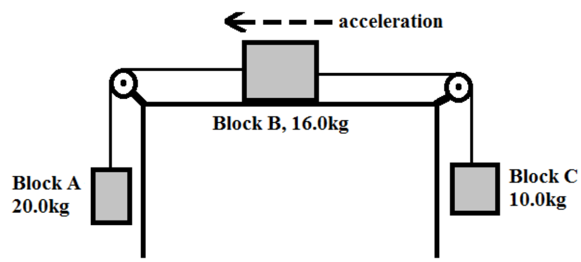
P03. According to Tyson, which part of the spectrum allows us to peek at stellar nurseries deep inside galactic gas clouds?
A) Radio waves
B) Microwaves
C) Infrared waves
D) Ultraviolet and X-rays
E) Gamma rays

P04. Where is the group of asteroids known as the "Trojans" located in the solar system?
A) between Earth's and Mars' orbits
B) between Mars' and Jupiter's orbits
C) at Jupiter's orbit
D) between Jupiter's and Saturn's orbits
E) at Saturn's orbit

P05. Taylor owns a solid gold sphere with a radius of 15.0cm. She melts the sphere and recasts the gold into a rectangular ingot that is 24.0in long and 6.0in tall. Assuming none of the metal was lost, how wide is the rectangular ingot?
A) 6.0in
B) 11in
C) 15in
D) 29in
E) 39in

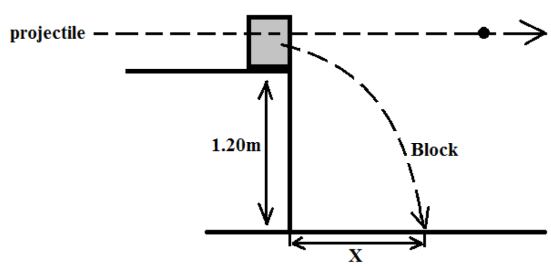
P06. Francisco uses a catapult to launch a 1200.0kg rock from atop a hill that is 150.0m higher than the plains below. He launches the rock at an angle of 35.0° above the horizontal and with a speed of 50.0m/s. How far, horizontally from the launch site, does the rock land? Ignore air resistance.
A) 631m
B) 517m
C) 460m
D) 376m
E) 227m

P07. Three blocks are connected to one another by massless strings as shown. The coefficient of friction between block B and the table is 0.21. What is the acceleration of the blocks? Ignore air resistance and assume the pulleys are massless and frictionless.



A) 1.42 m/s^2
B) 2.13 m/s^2
C) 3.25 m/s^2
D) 4.26 m/s^2
E) 4.90 m/s^2

P08. A 5.00g projectile is moving horizontally at 110.0m/s. It passes clean through a 100.0g block of wood, emerging from the wood with a velocity of 80.0m/s. The block of wood was originally sitting on the edge of a 1.20m tall table, as shown. The impact knocked the block off the table. How far from the base of the table does the block land?

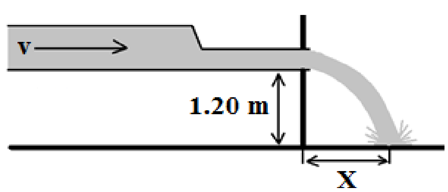


A) 36.7cm
B) 74.2cm
C) 98.0cm
D) 135cm
E) 198cm

P09. A 60.0g ball with a radius of 4.00cm is rolling without slipping across a level floor. It has an initial angular velocity of 12.0rad/s, and rolls to a stop in a distance of 9.20m. What is the angular acceleration of the ball?
A) -7.82 rad/s^2
B) -3.91 rad/s^2
C) -1.96 rad/s^2
D) -0.652 rad/s^2
E) -0.313 rad/s^2

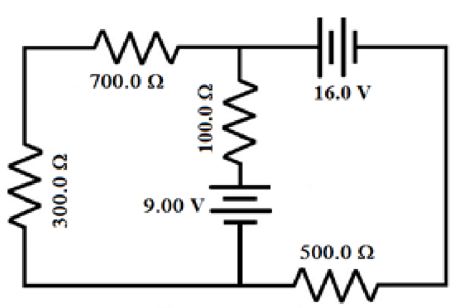
P10. A 1500.0W speaker produces a spherically expanding wave of sound. What is the sound intensity (in decibels) at a distance of 22.0m from the speaker?
A) 31.8 dB
B) 105 dB
C) 114 dB
D) 130 dB
E) 152 dB

P11. A fluid flows at 2.20m/s in a pipe with a diameter of 15.0cm. The pipe constricts to a diameter of 10.0cm and then opens to the air. The fluid streams horizontally from the open pipe and splashes on the ground 1.20m below the opening. How far, horizontally from the opening, does the fluid hit the ground?



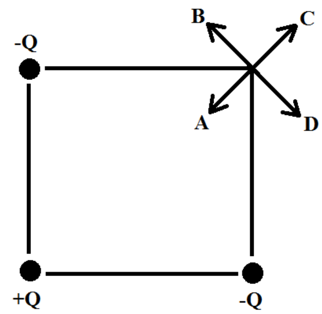
A) 0.820m
B) 1.09m
C) 1.63m
D) 1.73m
E) 2.45m

P12. For this circuit, calculate the current that passes through the 500.0 Ω resistor.



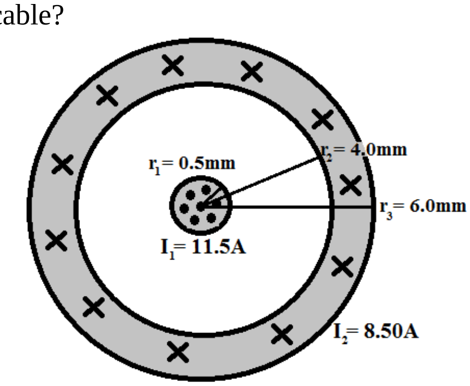
A) 9.38 mA
B) 10.7 mA
C) 11.7 mA
D) 13.2 mA
E) 14.0 mA

P13. Equal magnitude charges are placed at three of the corners of a perfect square. The charges at the upper-left and lower-right are negative, while the charge at the lower-left is positive. What is the direction of the net electric field at the remaining corner (the upper-right corner)?



A) down and left
B) up and left
C) up and right
D) down and right
E) the electric field is zero, so it has no direction.

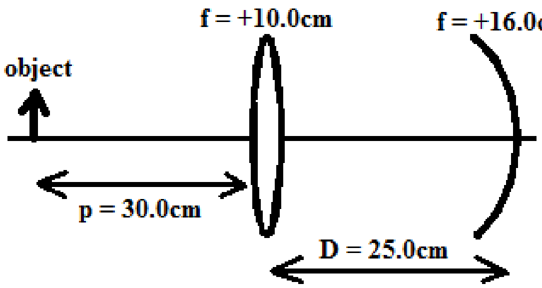
P14. A cylindrical coaxial cable carries a current of 11.50A in the inner conductor, and a current of 8.50A in the opposite direction in the outer conductor. The radius of the inner conductor is 0.5mm, and the outer conductor has radii of 4.00mm and 6.00mm (as shown). What is the magnitude of the magnetic field at a distance of 2.50mm from the center of the cable?



A) 240 μT
B) 680 μT
C) 920 μT
D) 1600 μT
E) 4600 μT

P15. A laser beam with a diameter of 3.00mm is measured to have a peak magnetic field of the electromagnetic wave of 160.0μT. What is the average power of the laser beam?
A) 21.6 W
B) 30.6 W
C) 43.2 W
D) 67.9 W
E) 86.4 W

P16. An optical system consists of a converging lens and a concave mirror separated by 25.0cm, as shown. If an object is placed 30.0cm to the left of the lens, where is the location of the final image, relative to the lens.

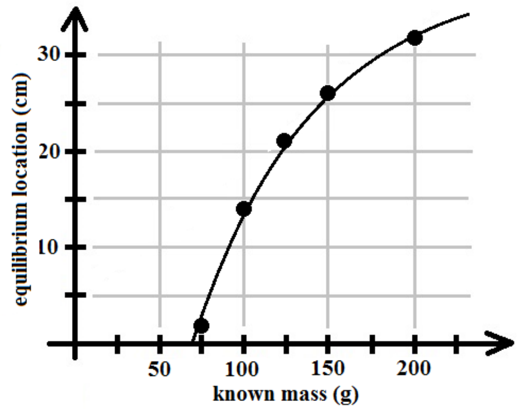


A) 2.00cm left of the lens
B) 9.60cm left of the lens
C) 12.4cm left of the lens
D) 15.0cm right of the lens
E) 26.7cm right of the lens

P17. An excited state of Rubidium has an energy 1.58eV above the ground state and has a lifetime of 230ns. Approximately, what is the magnitude of the minimum uncertainty in the frequency of a photon emitted by a Rubidium atom decaying from this excited state to the ground state?
A) 5.0 MHz
B) 500 kHz
C) 50 kHz
D) 5.0 kHz
E) 500 Hz

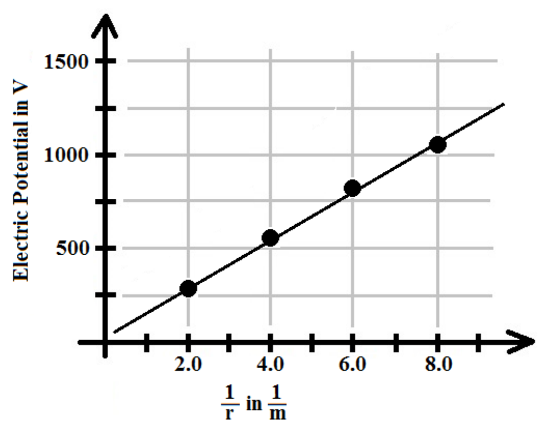
P18. What is the binding energy per nucleon for Flerovium-292 ($^{292}_{114}Fl$). The atomic number of Flerovium is 114, and the mass of a nucleus of this isotope is 4.848261×10^{-25} kg.
A) 2.65 MeV/nucleon
B) 4.92 MeV/nucleon
C) 6.78 MeV/nucleon
D) 7.69 MeV/nucleon
E) 8.07 MeV/nucleon

P19. A meter stick is set up as a balance with a pivot point at the 50.0cm mark. An unknown mass is hung from the meter stick at the 80.0cm mark. Known masses are then hung from the other end of the meter stick, and their locations are adjusted until the system achieves static equilibrium. The known masses and their equilibrium locations are plotted below. What is the value of the unknown mass?



A) 30g
B) 45g
C) 80g
D) 120g
E) 210g

P20. The electric potential (relative to ground) near a positive point charge is measured as a function of the distance r from the point charge. The potential is then plotted versus $\frac{1}{r}$, yielding the following graph. From this data, determine the magnitude of the point charge.



A) 135nC
B) 80nC
C) 60nC
D) 35nC
E) 15nC

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*

Constants

$R = 0.08206$ L·atm/mol·K
$R = 8.314$ J/mol·K
$R = 62.36$ L·torr/mol·K
$e = 1.602 \times 10^{-19}$ C
$N_A = 6.022 \times 10^{23}$ mol^{-1}
$k = 1.38 \times 10^{-23}$ J/K
$h = 6.626 \times 10^{-34}$ J·s
$c = 3.00 \times 10^{8}$ m/s
$R_H = 2.178 \times 10^{-18}$ J
$m_e = 9.11 \times 10^{-31}$ kg
1 amp = 1 C/s
96,485 C = 1 mole of electrons = 1 $\mathcal{F}$

Activity series of metals in aqueous solution

Metal	Oxidation Reaction				
Lithium	Li	⇌	Li^+	+	e^-
Rubidium	Rb	⇌	Rb^+	+	e^-
Potassium	K	⇌	K^+	+	e^-
Barium	Ba	⇌	Ba^{2+}	+	$2e^-$
Calcium	Ca	⇌	Ca^{2+}	+	$2e^-$
Sodium	Na	⇌	Na^+	+	e^-
Magnesium	Mg	⇌	Mg^{2+}	+	$2e^-$
Aluminum	Al	⇌	Al^{3+}	+	$3e^-$
Manganese	Mn	⇌	Mn^{2+}	+	$2e^-$
Zinc	Zn	⇌	Zn^{2+}	+	$2e^-$
Chromium	Cr	⇌	Cr^{3+}	+	$3e^-$
Iron	Fe	⇌	Fe^{2+}	+	$2e^-$
Cobalt	Co	⇌	Co^{2+}	+	$2e^-$
Nickel	Ni	⇌	Ni^{2+}	+	$2e^-$
Tin	Sn	⇌	Sn^{2+}	+	$2e^-$
Lead	Pb	⇌	Pb^{2+}	+	$2e^-$
Hydrogen	H_2	⇌	$2\ H^+$	+	$2e^-$
Copper	Cu	⇌	Cu^{2+}	+	$2e^-$
Silver	Ag	⇌	Ag^+	+	e^-
Mercury	Hg	⇌	Hg^{2+}	+	$2e^-$
Platinum	Pt	⇌	Pt^{2+}	+	$2e^-$
Gold	Au	⇌	Au^{3+}	+	$3e^-$

Metals at the top of the table are most easily oxidized.

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
2018 REGIONAL

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

CHEMISTRY SOLUTIONS – UIL REGIONAL 2018

C01. (B) From its position in the periodic table, Al is in period 3 (n = 3) and in the p-block (ℓ = 1), but when three electrons are removed to form the Al^{3+} ion, the outermost electrons are in the 2p orbitals (n = 2, ℓ = 1).

C02. (E) The oxidation state of each of the oxygen atoms in BrO_3^- is –2, for a total charge of –6, so to have an overall ionic charge of 1–, the oxidation state of the bromine atom must be +5.

C03. (A)

C04. (C) At equilibrium the Br_2 vapor pressure P will be 175 torr, or 175/760 = 0.2302 atm.
The available volume of the container V is 1.00 L – 0.010 L = 0.990 L
The temperature T is 20°C + 273.15 = 293.15 K
The molar mass of Br_2 is 79.90 g/mol × 2 = 159.8 g/mol

$$PV = nRT = \frac{g}{MW}RT$$

$$g = \frac{PV \cdot MW}{RT} = \frac{(0.2302)(0.990)(159.8)}{(0.08206)(293.15)} = 1.51\ \text{g}$$

This assumes that the volume of liquid bromine that evaporates can be neglected (it turns out to be about 0.5 mL). If the entire initial volume of the bromine is neglected and the volume of the gas is assumed to be 1.00 L, the answer comes out to 1.53 g, which is close enough that I hope students will still pick answer C (1.3% error).

C05. (A) The boundary line between solid and liquid for water leans slightly to the left, indicating that ice is less dense than water – applying pressure to ice will melt it.

C06. (D) First convert the grams of each element to moles, then divide each mole value by the smallest of the three to convert at least one of them to a whole number.

$$3.524\ \text{g Fe} \times \frac{1\ \text{mol Fe}}{55.847\ \text{g Fe}} = 0.06310\ \text{mol Fe}$$

$$3.034\ \text{g S} \times \frac{1\ \text{mol S}}{32.066\ \text{g S}} = 0.09462\ \text{mol S}$$

$$4.542\ \text{g O} \times \frac{1\ \text{mol O}}{15.999\ \text{g O}} = 0.2839\ \text{mol O}$$

$$\text{Fe}_{\frac{0.06310}{0.06310}}\text{S}_{\frac{0.09462}{0.06310}}\text{O}_{\frac{0.2839}{0.06310}} = \text{Fe}_{1.000}\text{S}_{1.499}\text{O}_{4.499}$$

Multiplying all of the subscripts by 2 converts the remaining two subscripts to integers while keeping the mole ratios the same. This yields $Fe_2S_3O_9$. This formula is not one of the answer choices, but $Fe_2(SO_3)_3$ has the same numbers of each type of atom in the formula.

C07. (C) initial moles of weak acid HA = 0.125 L × 0.20 M = 2.5×10^{-2} moles HA
Moles OH^- = 0.075 L × 0.10 M = 7.5×10^{-3} moles
This is also equal to the moles of conjugate base, A^-, in the solution.
Moles of HA remaining = 2.5×10^{-2} moles – 7.5×10^{-3} moles = 1.75×10^{-2} moles
Total volume = 0.075 L + 0.125 L = 0.200 L
[HA] = (1.75×10^{-2} mol)/(0.200 L) = 8.75×10^{-2} M
[A^-] = (7.5×10^{-3} mol)/(0.200 L) = 3.75×10^{-2} M
pH = 4.5, [H^+] = $10^{-4.5} = 3.16 \times 10^{-5}$ M

$$K_a = \frac{[H^+][A^-]}{[HA]} = \frac{(3.16 \times 10^{-5})(3.75 \times 10^{-2})}{(8.75 \times 10^{-2})} = 1.4 \times 10^{-5}$$

The final answer is limited to two significant digits. Note that you could also have simply used the moles of HA and moles of A^- in the K_a calculation because the volume cancels out.

C08. (C)

Reaction	PCl_5	⇌	PCl_3	+	Cl_2
Initial	1.66		0		0
Change	$-x$		$+x$		$+x$
Equilibrium	$1.66 - x$		x		x

$$K_p = \frac{P_{PCl_3} P_{Cl_2}}{P_{PCl_5}} = \frac{x^2}{(1.66 - x)} = 0.497$$

K_p is too large to assume that $1.66 - x \approx 1.66$, so we must solve for x using the quadratic formula.
$x^2 + 0.497x - 0.825 = 0$, so plugging $a = 1$, $b = 0.497$, and $c = -0.825$ into the quadratic formula yields one positive result, $x = 0.6932$. Therefore

$$P_{PCl_3} = 0.6932 \text{ atm}, P_{Cl_2} = 0.6932 \text{ atm}, \text{and } P_{PCl_5} = 1.66 - 0.6932 = 0.9668 \text{ atm}$$

The total pressure is 0.6932 + 0.6932 + 0.9668 = 2.35 atm.

C09. (A) Each single bond is a σ (sigma) bond, and each double bond is one σ bond and one π (pi) bond. There are four double bonds in the molecule, shown as parallel lines between atoms, so there are four π bonds.

C10. (C) 1 amp = 1 coulomb/sec
5.5 amps × 12 min × 60 sec/min = 3960 C
96,485 C = 1 mole of e^-

$$\frac{3960 \text{ C}}{96{,}485 \text{ C/mol}} = 4.104 \times 10^{-2} \text{ mol of } e^-$$

$$4.104 \times 10^{-2} \text{ mol of } e^- \times \frac{1 \text{ Cu atom}}{2 \text{ electrons}} = 2.052 \times 10^{-2} \text{ mol Cu formed}$$

$$2.052 \times 10^{-2} \text{ mol Cu} \times \frac{63.55 \text{ g Cu}}{1 \text{ mol Cu}} = 1.3 \text{ grams Cu}$$

C11. (D) The minimum frequency of a photon required to remove an electron is given by $h\nu = \varphi$.

$$\nu = \frac{\varphi}{h} = \frac{3.78 \times 10^{-19}\ \text{J}}{6.626 \times 10^{-34}\ \text{J} \cdot \text{s}} = 5.70 \times 10^{14}\ \text{s}^{-1}$$

The corresponding wavelength can be calculated from the frequency by rearranging $\nu\lambda = c$, as

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\text{m/s}}{5.70 \times 10^{14}\text{s}^{-1}} = 5.26 \times 10^{-7}\text{m}$$

$$5.26 \times 10^{-7}\text{m} \times \frac{1 \times 10^{9}\ \text{nm}}{1\ \text{m}} = 526\ \text{nm}$$

C12. (C) NaCl does not change its chemical formula when going from NaCl(*s*) to NaCl(*aq*), so no chemical change occurs when it dissolves in water. It is only a physical change.

C13. (E) The balanced reaction is $4\ NH_3 + 7\ O_2 \rightarrow 4\ NO_2 + 6\ H_2O$

C14. (B) Both the solubility equilibrium $AgBr(s) \rightleftharpoons Ag^+(aq) + Br^-(aq)$, $K_{sp} = 5.35 \times 10^{-13}$, and the complexation equilibrium $Ag^+(aq) + 2\ NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq)$, $K_f = 1.6 \times 10^7$, must both be satisfied at the same time. Multiplying the two equilibrium expressions together yields

$$K_{sp} \times K_f = \left([Ag^+][Br^-] \times \frac{[Ag(NH_3)_2^+]}{[Ag^+][NH_3]^2}\right) = \frac{[Ag(NH_3)_2^+][Br^-]}{[NH_3]^2} = 8.56 \times 10^{-6}$$

This is the equilibrium constant, K_{eq}, for the given reaction, so the problem can now be solved like any other equilibrium problem:

Reaction	AgBr(*s*)	+	2 $NH_3(aq)$	⇌	$Ag(NH_3)_2^+(aq)$	+	Br^- (*aq*)
Initial	—		0.50		0		0
Change	—		$-2x$		$+x$		$+x$
Equilibrium	—		$0.50 - 2x$		x		x

$$K_{eq} = 8.56 \times 10^{-6} = \frac{x^2}{(0.50 - x)^2}$$

Assume $x << 0.50$ because K_{eq} is small, so $0.50 - x \approx 0.50$.
Then $x^2 = (8.56 \times 10^{-6})(0.50)^2 = 2.14 \times 10^{-6}$ and $x = 1.46 \times 10^{-3}$ M. We are limited to two significant digits in our final answer, so the molar solubility of AgBr in 0.5 M NH_3 is 1.5×10^{-3} M.

C15. (D) Density is mass over volume, so write moles as grams of xenon over the molar mass of xenon and rearrange the ideal gas law to isolate density (*g*/*V*) on one side of the equation:

$$PV = nRT = \frac{g_{Xe}}{MM_{Xe}}RT$$

$$\frac{P \times MM_{Xe}}{RT} = \frac{g_{Xe}}{V}$$

$$\text{Density} = \frac{P \times MM_{\text{Xe}}}{RT} = \frac{1\ \text{atm} \times 131.29\ \text{g/mol}}{(0.08206)(273\ \text{K})} = 5.86\ \text{g/L}$$

C16. (E) Electrons in molecular bonding orbitals (those without an asterisk) contribute to the stability of a bond, and electrons in molecular anti-bonding orbitals (marked with *) interfere with the formation of a bond. Chemical bonds form when there are more electrons in bonding orbitals than there are in anti-bonding orbitals. If the number of electrons in anti-bonding orbitals is equal to or greater than the number of electrons in bonding orbitals, a bond does not form.

C17. (C) Reverse the second equation and change the sign on ΔH for that reaction, then add.

$H_2S(g) + 2\,O_2(g) \rightarrow H_2SO_4(l)$	$\Delta H = -225.7$ kJ/mole
$H_2SO_4(l) \rightarrow SO_3(g) + H_2O(g)$	$\Delta H = 60.5$ kJ/mole
$SO_3(g) + H_2O(l) \rightarrow H_2S(g) + 2\,O_2(g)$	$\Delta H = 205.9$ kJ/mole
$H_2O(l) \rightarrow H_2O(g)$	$\Delta H = 40.7$ kJ/mole

Alternatively, the ΔH_{vap} for water is given on the data sheet as 2260 J/g, so that value could simply be multiplied by 18.02 g/mol to get 40,725 J/mol, or 40.7 kJ/mol.

C18. (A) Solve the K_{sp} expression for $[OH^-]$, then use that to calculate pH.

$$K_{\text{sp}} = [\text{Cu}^{2+}][\text{OH}^-]^2 = [x][2x]^2 = 4x^3$$

$$x = \sqrt[3]{\frac{K_{\text{sp}}}{4}} = \sqrt[3]{\frac{1.1 \times 10^{-15}}{4}} = 6.50 \times 10^{-6}\ \text{M}$$

$$[\text{OH}^-] = 2x = 1.30 \times 10^{-5}\ \text{M}$$

$$\text{pOH} = -4.886$$

$$\text{pH} = 14 - \text{pOH} = 14 - 4.886 = 9.11$$

C19. (B) Since the reaction is first order with respect to A and second order with respect to B, the rate law expression is rate = $k[A][B]^2$. For the original rate you can assume A and B each equal 1, so the new concentrations would be [A] = 2 and [B] = 0.5.
The new rate = $k[2][0.5]^2 = k[2][0.25] = k(0.5)$, or one half the original rate.

C20. (E) The oxidation half-cell (anode) is always written on the left, and the reduction half-cell (cathode) is written on the right. The electrodes are separated from their solutions in the cell diagram by a single vertical line, and the salt bridge is represented by a double vertical line. Since silver is lower than zinc on the activity series, zinc will be oxidized and silver will be reduced. Zn therefore appears on the left in the cell diagram and Ag appears on the right.

PHYSICS SOLUTIONS – UIL REGIONAL 2018

P01. (E) page 118: "One of the pillars of big bang cosmology is the prediction that in every region of the cosmos, no less than about ten percent of all atoms are helium, manufactured in that percentage across the well-mixed primeval fireball that was the birth of our universe."

P02. (B) page 124: "With twenty-six protons and at least as many neutrons in its nucleus, iron's odd distinction comes from having the least total energy per nuclear particle of any element. This means…if you split iron atoms via fission, they will absorb energy. And if you combine iron atoms via fusion, they will also absorb energy."

P03. (C) page 163: "Want to peek at stellar nurseries deep inside galactic gas clouds? Pay attention to what infrared telescopes do."

P04. (C) A Trojan asteroid is one that shares the orbit of a major planet or moon. The most numerous and best known Trojans are those at Jupiter's orbit, though a few have been found to share Mars' and Neptune's orbits. The term typically refers exclusively to the asteroids that share Jupiter's orbit.

P05. (A) Since no gold was lost, we know the volume of the sphere and the ingot must be the same. So, first find the volume of the sphere: $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(15)^3 = 14137cm^3$. The dimensions of the ingot are in inches, so let's convert our volume into cubic inches: $V = 14137cm^3\left(\frac{1\ cm}{2.54\ in}\right)^3 = 862.7in^3$. The volume of the ingot is just the length*width*height, so we can easily solve for the width: $w = \frac{V}{lh} = \frac{862.7}{(24)(6)} = 6.0in$.

P06. (D) First, we should get the components of the initial velocity: $v_{ix} = v_i cos\theta = (50)\cos(35) = 40.96\ m/s$, and $v_{iy} = v_i \sin\theta = (50)\sin(35) = 28.68\ m/s$. Now we can consider the kinematic equations, first in the y-direction: $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 = 150 + 28.68t - 4.9t^2 = 0$. Here, our acceleration is due to gravity (a = -9.8m/s^2), the initial position is on the hill (y = 150), while the final position is on the battlefield (y = 0). This simplifies to give us the quadratic equation: $t^2 - 5.85t - 30.6 = 0$. The solutions for this are $t = -3.33,\ 9.18$. Since negative time is nonsense, we conclude that the time for the projectile to travel is 9.18s. Now we go to the x-direction kinematic equation: $x = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = 0 + 40.96t + 0$. The horizontal acceleration is zero, so we get a horizontal distance of $x = 40.96t = (40.96)(9.18) = 376m$.

P07. (A) It is easiest to consider each block separately, so let's begin with block A. There are only vertical forces acting on block A: gravity and tension. Block A is accelerating downward, therefore the force equation becomes: $m_A g - T_1 = m_A a = 20(9.8) - T_1 = 20a = 196 - T_1 = 20a$, or $T_1 = 196 - 20a$.
Now consider block C. Similarly, it only has two forces acting on it: gravity and tension. The differences are that the acceleration is upwards and the tension is different. Note that the accelerations of all the blocks must be the same. So, the force equation of block C is $T_2 - m_C g = m_C a = T_2 - (10)(9.8) = 10a = T_2 - 98 = 10a$, or $T_2 = 10a + 98$.
Now we can consider block B: it has five forces acting on it: horizontal forces are the two tensions and friction. Since the motion is to the left, friction will be directed to the right. The vertical forces on block B are gravity and the normal force. Block B does not accelerate in the y-direction, so $m_B g - F_N = 0$, or simply $F_N = m_B g = (16)(9.8) = 156.8N$. Now we can get the frictional force: $F_f = \mu F_N = (0.21)(156.8) = 32.9N$. Now consider the horizontal force equation for block B: $T_1 - T_2 - F_f = m_B a = T_1 - T_2 - 32.9 = 16a$. Plugging in from our previous equations: $(196 - 20a) - (10a + 98) - 32.9 = 16a$.
This simplifies to: $65.1 - 30a = 16a$, or $46a = 65.1$. Then the acceleration is $a = 1.42$ m/s^2.

P08. (B) This is a conservation of momentum problem followed by an easy projectile problem. First, let's consider conservation of momentum. The two objects that move are the projectile and the block, so equating the total initial and final momenta: $p_{ip} + p_{ib} = p_{fp} + p_{fb} = m_p v_{ip} + m_b v_{ib} = m_p v_{fp} + m_b v_{fb}$. Conveniently, all of the velocities are horizontal and positive (to the right). Plugging in all the masses and velocities gives $(5.00g)(110.0m/s) + (100g)(0) = (5.00g)(80.0m/s) + (100g)v_{fb}$. From this we can get the velocity of the block after the projectile passes through it: $550 + 0 = 400 + 100v_{fb}$, giving: $v_{fb} = \frac{550-400}{100} = 1.50\ m/s$.
Now we can proceed with the kinematic part of the problem. The block has a horizontal velocity of 1.50m/s when it flies off the table. From the y-direction kinematic equation we can calculate the time it takes the hit the floor: $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 = 0 = 1.20 + 0 - 4.9t^2$, which gives $t = \sqrt{\frac{1.20}{4.9}} = 0.495s$. Then we can get the horizontal distance travelled: $x = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = 0 + (1.50)(0.495) + 0 = 0.742m = 74.2cm$.

P09. (E) Rolling without slipping means there is a simple relationship between the distance rolled and the angle through which the ball turned while rolling: $\theta = \frac{d}{r} = \frac{9.20}{0.04} = 230$ radians. Knowing the initial angular velocity, that the final angular velocity is zero, and the angle through which it rolls, we can find the angular acceleration: $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta = 0 = (12)^2 + 2\alpha(230)$. This gives $\alpha = -\frac{144}{460} = -0.313$ rad/s^2.

P10. (C) This one is really easy, if you remember how to get to decibels. First, let's find the sound intensity in W/m^2. The wave expands spherically, so the intensity is the power divided by the surface area of a sphere: $I = \frac{P}{4\pi r^2}$. For a power of 1500.0W and a distance of 22.0m, we get: $I = \frac{1500}{4\pi(22)^2} = 0.247$ W/m^2. To convert to decibels we use the following: $I(dB) = 10Log(I \times 10^{12}) = 10\log(0.247 \times 10^{12}) = 10(11.39) = 114\ dB$.

P11. (E) First, we need to use the continuity equation to find the velocity of the fluid in the constricted part of the pipe: $A_1v_1 = A_2v_2 = \pi r_1^2 v_1 = \pi r_2^2 v_2$. This gives $v_2 = \frac{r_1^2}{r_2^2}v_1 = \frac{(7.5)^2}{(5)^2}(2.20) = 4.95$ m/s. It is with this velocity that the fluid streams from the open pipe. From this point, we are just doing another projectile problem – this fluid velocity is the initial horizontal velocity and the fluid falls under the influence of gravity. We can use a kinematic equation to find the time for a single drop of fluid to get from the pipe to the ground:
$y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 = 0 = 1.20 + 0 - 4.9t^2$. This gives $t = \sqrt{\frac{1.20}{4.9}} = 0.495$m/s. Now we can find the horizontal distance travelled by the fluid by using this time and the horizontal velocity of the fluid:
$x = x_i + v_{ix}t + \frac{1}{2}a_x t^2 = 0 + (4.95)(0.495) + 0 = 2.45$m.

P12. (D) This is a classic Kirchhoff problem. So, the first thing we need to do is define a current for each branch. Let's choose I_1 to be the current in the left branch, travelling down. Let I_2 be the current in the middle branch, travelling up. And let I_3 be the current in the right branch, travelling up. Now, applying Kirchhoff's node rule to the node at the top of the circuit gives $I_1 = I_2 + I_3$. We can get two equations from Kirchhoff's loop rule: going counterclockwise around the left loop we get $9.00 - 100I_2 - 700I_1 - 300I_1 = 0$. And now going counterclockwise around the right loop gives: $16.0 + 100I_2 - 9.00 - 500I_3 = 0$. Here the $100I_2$ term is positive since we are travelling around that part of the loop opposite to the direction of the current I_2. Combining two equations: $1000I_1 + 100I_2 = 9.00 = 1000(I_2 + I_3) + 100I_2 = 1100I_2 + 1000I_3 = 9$. And also we have $100I_2 - 500I_3 = -7.00$. Multiplying by 2 gives $200I_2 - 1000I_3 = -14$. Adding this to the equation we acquired previously: $1100I_2 + 1000I_3 + 200I_2 - 1000I_3 = 9 - 14 = -5 = 1300I_2$. This gives our middle branch current: $I_2 = -0.00385A$. It is OK that it is negative. What we need, however, is the right branch current, so we can go to $1100I_2 + 1000I_3 = 9 = 1100(-0.00385) + 1000I_3 = -4.23 + 1000I_3 = 9$. This gives the current we want: $1000I_3 = 13.23$, so $I_3 = 0.0132A = 13.2\ mA$.

P13. (A) To figure this out, it is helpful to consider the electric field due to each charge separately. The upper-left charge is negative, so the field created by it is directed to the left. The electric field due to the lower-right charge, which is also negative, is directed downward. The combination of these two fields is pointed diagonally down and left. The remaining charge is positive, so its field is directed diagonally up and right – the exact opposite direction of the field due to the two negative charges.

So now, we must consider the strength of the fields. The positive charge is farther away from the upper-right corner than either of the negative charges, and there is only one positive charge, while there are two negative ones. The result is that the field due to the negative charges is stronger than the field due to the positive charge. Therefore, the total electric field at the upper-right corner of the square is directed downward and to the left – direction A.

P14. (C) This is easily solved with Ampere's Law, and the symmetry and simplicity of the problem allow us to avoid doing any calculus. First, Ampere's Law states: $\oint B \cdot ds = \mu_0 I_{in}$ where I_{in} is the current passing through an area enclosed by an Amperean path. The symmetry of the problem is circular, so we choose a circular Amperean path of radius 2.50mm (the distance at which we want to know the magnetic field). By using the symmetry of the problem, we avoid having to do the integral: $\oint B \cdot ds = Bs = B(2\pi r) = \mu_0 I_{in}$. Now consider the current passing through the area enclosed by a 2.50mm radius circle. The entire inner conductor is inside that circle, but none of the outer conductor is contained inside that Amperean path. So, the outer conductor current doesn't even matter. Thus, I_{in} equals the current of the inner conductor only –
so, $I_{in} = 11.50$A. Now we can pull it all together: $B(2\pi r) = B(2\pi)(0.0025) = \mu_0 I_{in} = (4\pi \times 10^{-7})(11.50)$. Leading to $B(0.0025) = 2.3 \times 10^{-6}$, or $B = 9.2 \times 10^{-4}\ T = 920\ \mu T$.

P15. (A) The peak magnetic field is related to the intensity of the light according to an equation derived from the Poynting vector: $I = \frac{1}{2}\frac{c}{\mu_0}B^2 = \frac{1}{2}\frac{(3.00 \times 10^8)}{(4\pi \times 10^{-7})}(160 \times 10^{-6})^2 = 3.056 \times 10^6\ \frac{W}{m^2}$. Now the power of the laser is the intensity multiplied by the area of the laser spot. Since we know the diameter of the laser spot, we can calculate the area: $A = \pi r^2 = \pi\left(\frac{3.00 \times 10^{-3}}{2}\right)^2 = 7.069 \times 10^{-6}\, m^2$. Thus, the power of the laser is: $P = IA = (3.056 \times 10^6)(7.069 \times 10^{-6}) = 21.6\, W$.

P16. (C) We must work this problem one optical element at a time, with each image becoming the object for the next step. So, first consider the image made by the lens: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{30} + \frac{1}{q} = \frac{1}{10}$. This gives $q_1 = 15cm$. This image now becomes the object for the mirror, with an object distance given by: $p_2 = D - q_1 = 25 - 15 = 10cm$. Now, we can find the image formed by the mirror: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{10} + \frac{1}{q} = \frac{1}{16}$. This gives $q_2 = -26.67cm$. This is a virtual image that *appears* to be behind the mirror. The light rays, as a result of bouncing off of the mirror, have changed direction and will now go back through the lens. So, the object distance for going back through the lens is: $p_3 = D - q_2 = 25 - (-26.67) = 51.67cm$. Thus, $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{51.67} + \frac{1}{q} = \frac{1}{10}$. This last step gives the location of the final image relative to the lens: $q_3 = 12.4cm$ (positive, to the left of the lens in this case).

P17. (B) This problem requires using the Heisenberg Uncertainty Principle (HUP). In particular, using the energy-time form of the HUP: $\Delta E \Delta t \geq \frac{\hbar}{2}$. The uncertainty in time is the lifetime of the excited state, so we can get the uncertainty in energy: $\Delta E(230 \times 10^{-9}) \geq \frac{\hbar}{2} = \frac{1.054 \times 10^{-34}}{2} = 5.27 \times 10^{-35}$. The equality gives the minimum uncertainty, so $\Delta E = 2.29 \times 10^{-28}$ J. Now, to get the uncertainty in frequency, we have to consider the conversion of energy to frequency: $f = \frac{E}{h}$, so $\Delta f = \frac{\Delta E}{h} = \frac{2.29 \times 10^{-28}}{6.626 \times 10^{-34}} = 345000\ Hz \approx 500\ kHz$.

P18. (D) To find the binding energy, we must sum up the mass of the particles that make up a nucleus of Flerovium-292. It is composed of 114 protons and $292 - 114 = 178$ neutrons, so the mass of the particles is: $M = 114(1.67265 \times 10^{-27}) + 178(1.67495 \times 10^{-27}) = 4.888232 \times 10^{-25}\ kg$. Now the actual mass of a Flerovium nucleus is $4.848261 \times 10^{-25}\ kg$. This gives a mass defect of $\Delta M = 4.888232 \times 10^{-25} - 4.848261 \times 10^{-25} = 3.997 \times 10^{-27}\ kg$. Using Einstein's equation then gives us the total binding energy: $E_b = \Delta M c^2 = (3.997 \times 10^{-27})(3.00 \times 10^8)^2 = 3.60 \times 10^{-10}\, J$. Now, "per nucleon" means that we have to divide this binding energy by the total number of nucleons – 292. So, we get $E_{b/n} = \frac{1}{292}(3.60 \times 10^{-10}) = 1.23 \times 10^{-12}\, J/n = 7.69 \times 10^6\ eV/n = 7.69\ MeV/nucleon$.

P19. (D) Since the graph is not linear, it is difficult to use something like a slope to solve this problem. You could use individual points, but I find the x-intercept to be just as useful. We can see that the x-intercept is at about 70g. This is the mass that would be hung at the very end of the meter stick (at the 0.0cm mark) to balance the unknown mass at the 80.0cm mark. When the meter stick is in equilibrium, we have torques that balance. That is the force multiplied by the distance from the pivot point on each side must be equal. Mathematically, $m_1 g r_1 = m_2 g r_2$. The pivot point is at 50.0cm, so r_1 and r_2 are measured from the 50.0cm mark.
So, we get $m_1(80 - 50) = (70)(50 - 0) = 3500 = 30m_1$.
Solving for the unknown mass gives: $m_1 = 117g \approx 120g$.

P20. (E) Here the graph is a straight line, so we can utilize the slope to help answer the question. Notice the y-intercept is about zero. The slope of this graph is about $slope = \frac{1000-250}{7.5-1.8} \approx 130$ Vm. Now, to determine what this represents, we go to the formula for electric potential: $V = \frac{kQ}{r}$. On our graph V is on the y-axis, and $\frac{1}{r}$ is the x-axis, thus: $y = kQx$ is the equation of the line. Therefore, the slope of the line is kQ. Equating this: $kQ = (8.99 \times 10^9)Q = 130$. This gives us the charge: $Q = 1.45 \times 10^{-8}C = 14.5nC \approx 15nC$.
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