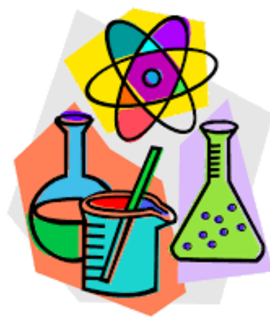
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Region • 2022



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. An organic macromolecule that contains a five-carbon sugar, a phosphate, and a nitrogenous base would best be classified as a
- A) proteins.
- B) carbohydrate.
- C) nucleic acid.
- D) lipid.
- E) monosaccharide.

B02. Which of the following answer choices would be the best example of codominance?
- A) A person with AB+ blood type.
- B) Pink flowers resulting from the cross of homozygous dominant for red and homozygous recessive for white.
- C) Changing the pH of the soil results in a change from pink to blue flowers on the same plant.
- D) The coat color of a Siamese cat.
- E) The genetics of human height.

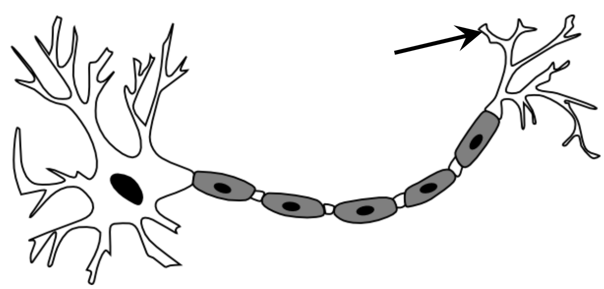
B03. Most DNA polymerases proofread as they are replicating DNA. Bacterial DNA Polymerase III has the ability to correct any mismatches that it might accidentally incorporate. Which of the following activities is employed to correct mistakes?
- A) 5′ → 3′ polymerase
- B) 3′ → 5′ polymerase
- C) 5′ → 3′ exonuclease
- D) 3′ → 5′ exonuclease
- E) 5′ → 3′ endonuclease

B04. The use of antibodies to detect a protein sequence in a polyacrylamide gel is called
- A) Northern blotting.
- B) Western blotting.
- C) Southern blotting.
- D) Electrophoretic Mobility Shift.
- E) DNA fingerprinting.

B05. A mutation that converts a codon from a threonine to an isoleucine would best be classified as a/an ______ mutation.
- A) inversion
- B) missense
- C) nonsense
- D) silent
- E) reversion

B06. Stromatolites
- A) are the earliest direct evidence of single-celled life on Earth.
- B) have been dated back to about 3.5 billion years ago.
- C) result from microbial mat layers binding to sediment.
- D) can be found in warm, shallow, and salty bays in the present day.
- E) are all of the above.

B07. Examine this microscopic image of a neuron. The cell structure identified by the arrow is a/an



- A) axon terminal.
- B) dendrite.
- C) axon.
- D) cell body.
- E) myelin sheath.

B08. In population ecology, dispersion is the pattern of spacing among individuals within the population boundaries. There are several patterns of dispersion for organisms. Which type of dispersion pattern would be expected for plants that grow from windblown seeds?
A) random
B) uniform
C) clumped
D) directed
E) dense

B09. *Plasmodium falciparum* is transmitted to humans via the ______ vector.
A) tick
B) mosquito
C) lice
D) flea
E) fly

B10. If found in the structure of a protein of unknown function, which motif would indicate that the protein could bind to DNA?
A) helix-turn-helix
B) leucine zipper
C) zinc finger
D) helix-loop-helix
E) All of the above are DNA-binding motifs.

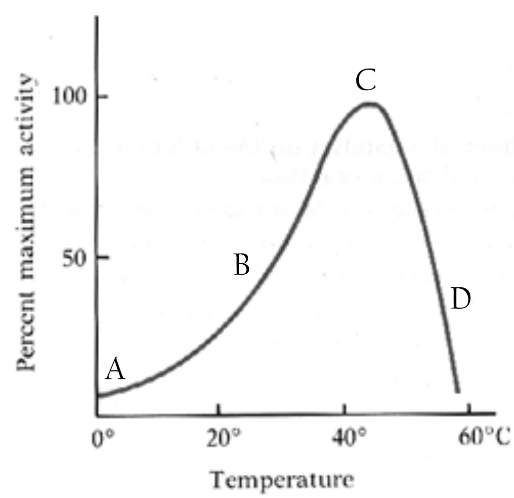
B11. Where does the Calvin cycle occur in land plants?
A) cytosol
B) thylakoid membranes
C) stroma of chloroplasts
D) thylakoid space
E) plasma membrane

B12. In biological hierarchy, the basic unit of life is the
A) organic molecule.
B) organelle.
C) tissue.
D) atom.
E) cell.

B13. Two closely related species overlap in a single geographic area and hybridization often occurs. Examination of the hybrid zone over time might yield different results. Which of the following best describes the results over time in a hybrid zone in which the reproductive barriers become weakened?
A) reinforcement of barriers
B) fusion of species
C) stability
D) speciation
E) equilibrium

B14. Which hormone is released by the body to stop hyperglycemia?
A) gastrin
B) amylin
C) glucagon
D) insulin
E) amylase

B15. Examine the following graph of enzyme activity versus temperature. At which point is the protein denatured?

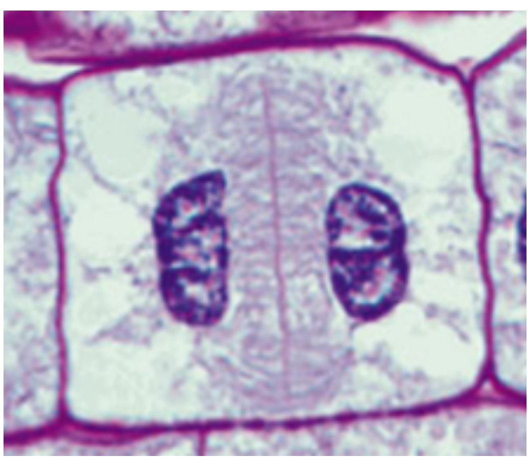


A) A
B) B
C) C
D) D
E) No denaturation occurs.

B16. The Centers for Disease Control and Prevention issued a Food Safety Alert for packaged salads made by Dole. Which organism was identified as the culprit?
A) *Escherichia coli*
B) *Salmonella* sp.
C) *Listeria* sp.
D) *Vibrio* sp.
E) *Campylobacter* sp.

B17. All of the following energy sources can be used to perform work by a cell except
A) phosphoenolpyruvate (PEP).
B) adenosine triphosphate (ATP).
C) proton motive force (PMF).
D) hydrogen ion concentration gradient.
E) all of the above can be used as energy sources by cells.

B18. Examine this image of a plant cell. If the beginning of the cell cycle is at G1 phase, which of the following events of the cell cycle has not yet occurred?



A) Chromatin has condensed.
B) DNA has been replicated.
C) Cell plate formation has not ended.
D) Sister chromatids have separated.
E) Centrioles have formed and migrated to the poles.

B19. The contributions of an individual within a population to the gene pool of subsequent generations relative to the contributions of other individuals in that same population is termed
A) relative fitness.
B) directional selection.
C) disruptive selection.
D) stabilizing selection.
E) balancing selection.

B20. In a population at Hardy-Weinberg equilibrium, 971 out of 1568 individuals in the population exhibit the dominant phenotype. What is the frequency of the recessive allele in this population?
A) 0.1467
B) 0.2130
C) 0.3829
D) 0.6170
E) 0.7869

C01. How many grams of oxygen are there in 420 grams of sodium perbromate?

A) 121
B) 134
C) 161
D) 178
E) 190

C02. How many grams of solid sodium oxide ash would result from the complete combustion of 120.0 grams of sodium acetate?

A) 30.3 g
B) 45.3 g
C) 60.5 g
D) 75.5 g
E) 90.6 g

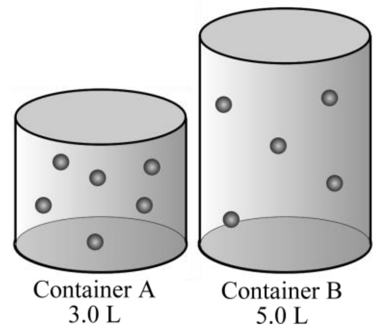
C03. The longest wavelength of light that will eject an electron from a lithium surface in a vacuum is 539.5 nm. What is the work function for lithium?

A) 1.7 eV
B) 2.0 eV
C) 2.3 eV
D) 2.6 eV
E) 2.9 eV

C04. Equal masses of two different gases, A and B, are placed in identical containers at the same temperature. The pressure of Gas A is 1.25 times the pressure of Gas B. Which one of these answer choices could possibly be Gas A and Gas B?

Answer	Gas A	Gas B
A)	O_2	Ar
B)	Ar	N_2
C)	Ne	Ar
D)	O_2	CO_2
E)	N_2	Ne

C05. The pressure in container B is 1.25 times the pressure in container A. If the temperature of container A is 300 K, what is the temperature of container B?



A) 300 K
B) 450 K
C) 600 K
D) 750 K
E) 900 K

C06. If the central carbon atom in CH_2O is sp^2 hybridized, what are the predominant intermolecular forces in the liquid?

A) Ion-ion attractions
B) Hydrogen bonding
C) Dispersion forces
D) Dipole-induced dipole forces
E) Dipole-dipole forces

C07. When would this exothermic reaction be spontaneous? $A(s) + B(\ell) \rightarrow C(s) + D(g)$

A) Always at any temperature
B) Never at any temperature
C) Only at high temperatures
D) Only at low temperatures
E) Not enough information is given

C08. If you add 85.0 mL of water at 98.0°C to a 0°C mixture of 100 mL water and 35.0 g of ice, what will the final temperature of the water be? Assume the density of water is 1.00 g/mL.

A) 15.8 °C
B) 25.2 °C
C) 20.9 °C
D) 31.4 °C
E) 35.5 °C

C09. If 200 mL of 0.010 M KF is added to 1000 L of 0.010 M $Pb(NO_3)_2$, will a precipitate form? $K_{sp} = 3.3 \times 10^{-8}$.

A) Yes, because PbF_2 is insoluble in water
B) No, because PbF_2 is soluble in water
C) Yes, because Q < K for these conditions
D) No, because Q < K for these conditions
E) Yes, because Q > K for these conditions

C10. In an abandoned laboratory you find a jar of a white crystalline solid labeled HA, $K_a = 4.4 \times 10^{-6}$. You dissolve 2.50 grams of the powder into a volume of 100.0 mL and measure the pH as 3.02. What is the molar mass of the acid?

A) 121 g/mol
B) 0.115 g/mol
C) 188 g/mol
D) 341 g/mol
E) 227 g/mol

C11. If you dissolve 200.0 grams of solid calcium chloride in water and then dilute it to 500.0 mL, what will the molality of the calcium chloride be? The density of the solution is 1.15 g/mL.

A) 5.41 m
B) 4.81 m
C) 3.60 m
D) 2.39 m
E) 2.65 m

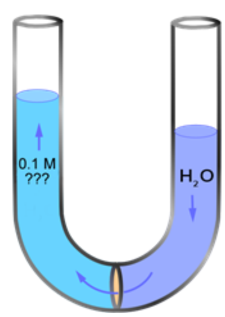
C12. If an ionic compound AB_2 has a molar solubility of 5.00×10^{-4} moles per liter in water, what is its molar solubility in 0.0200 M NaB?

A) 5.00×10^{-4} M
B) 2.50×10^{-2} M
C) 1.00×10^{-5} M
D) 2.00×10^{-7} M
E) 1.25×10^{-6} M

C13. How much solid copper would be formed by passing a 0.70 amp current through 5.0 L of a 1.20 M solution of $Cu(NO_3)_2$ for six hours?

A) An immeasurably small amount
B) About half a gram
C) A little over two and a half grams
D) Just under five grams
E) Nearly ten grams

C14. An absent-minded professor sets up an osmotic pressure apparatus with pure water on one side of the semipermeable membrane and a 0.1 molar solution on the other side, but he can't remember what solute he used when he made the solution. He measures the osmotic pressure to be 7.2 atm at 20°C. Which of these options could be the mystery solute?



A) $CaCl_2$
B) KCl
C) $AlCl_3$
D) $PbCl_2$
E) Glucose

C15. The initial rate of the reaction $A + B \rightarrow 2C + D$ was determined for three different initial conditions, with the results listed in the following table:

Run	[A] M	[B] M	Initial rate M/s
1	0.133	0.185	3.35×10^{-4}
2	0.266	0.185	1.35×10^{-3}
3	0.133	0.370	6.75×10^{-4}

Using the experimental data above, determine the rate law for this reaction.

A) $\text{rate} = k\frac{[C]^2[D]}{[A][B]}$
B) $\text{rate} = k\frac{[A]}{[B]}$
C) rate = k[A][B]
D) rate = $k[A][B]^2$
E) rate = $k[A]^2[B]$

C16. Which of these atoms would form the most polar bond when covalently bonded to a fluorine atom?

A) Si
B) N
C) O
D) Cl
E) S

C17. The label on a bottle of weak base says "Weak Base, 0.10 M pH 9.15" If you dilute the base to 0.010 M, what will the new pH be?

A) 9.15
B) 8.90
C) 8.65
D) 8.40
E) 8.15

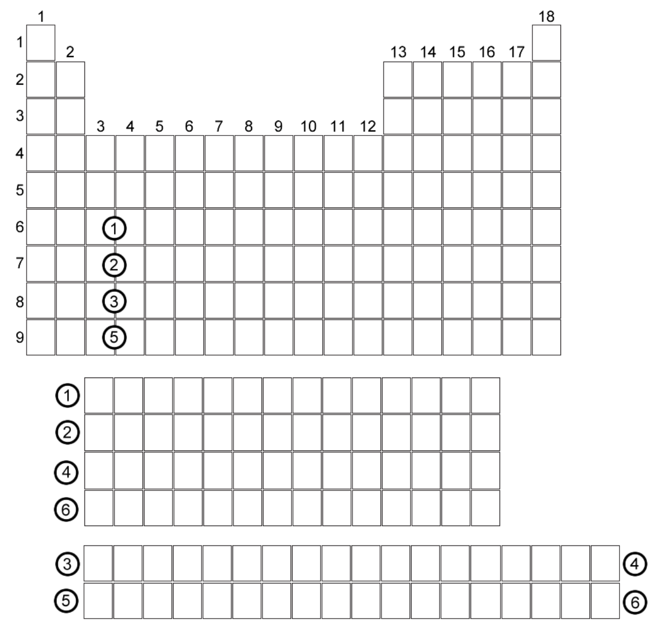
C18. How many pounds of oxygen are in a 5.0 lb bag of sugar? Sucrose is $C_{12}H_{22}O_{11}$.

A) 2.99 lbs
B) 2.57 lbs
C) 1.83 lbs
D) 1.52 lbs
E) 1.29 lbs

C19. What bond angles are present in a phosphorus pentachloride molecule?

A) 109.5°
B) 120°
C) 180°
D) 90 and 180°
E) 90, 120, and 180°

C20. Our current periodic table ends with element 118. The periodic table shown below goes 92 elements further, to element 210. How many elements in this periodic table have the principal quantum number n = 5?



A) 18
B) 32
C) 50
D) 64
E) 72

P01. According to Kaku, physicist Murray Gell-Mann used his three-quark model to arrange particles into groups. By looking at gaps in his model, Gell-Mann could predict the properties of new strongly interacting particles. Which particle, predicted by the quark model, was discovered in 1964, thus verifying the basic correctness of Gell-Mann's theory?
A) the graviton
B) the omega-minus
C) the J/psi
D) the W-minus
E) the upsilon

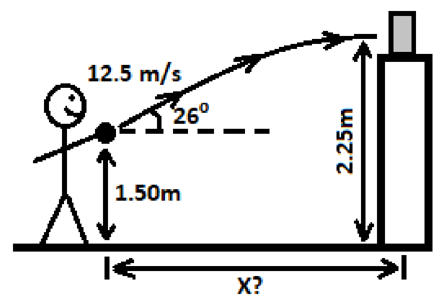
P02. According to Kaku, if you were able to create a wormhole, it would be unstable and would quickly close by itself, unless you added an exotic ingredient. What is this exotic ingredient?
A) supersymmetric matter
B) bosonic matter
C) fermionic matter
D) antimatter
E) negative matter

P03. According to Kaku, physicist Edward Witten was able to explain why there are five different string theories. He discovered a single M-theory, which is based on membranes, that can be collapsed in five different ways into the various string theories. How many dimensions are associated with Witten's M-theory?
A) three dimensions
B) four dimensions
C) ten dimensions
D) eleven dimensions
E) twenty-six dimensions

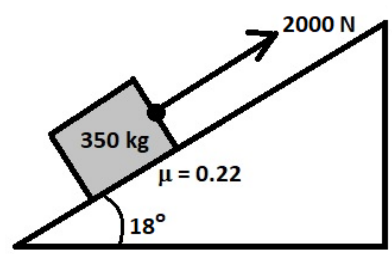
P04. From Earth, the apparent magnitude of the star Sirius (the brightest star in the Great Dog, Canis Majoris) is -1.46. The apparent magnitude of the star Procyon (the brightest star in the Lesser Dog, Canis Minoris) is $+0.38$. How many times brighter is Sirius than Procyon as seen from Earth?
A) 6.7 times brighter
B) 5.4 times brighter
C) 3.8 times brighter
D) 2.7 times brighter
E) 1.4 times brighter

P05. You watch as your teacher stacks a set of laptop computers. This makes you wonder: about how many flat stacked laptops would it take to reach the edge of space? Note: the edge of space is defined as 62 miles above the Earth's surface.
A) 3×10^3 laptops
B) 3×10^4 laptops
C) 3×10^5 laptops
D) 3×10^6 laptops
E) 3×10^7 laptops

P06. A tin can sits on top of a wall at a height of 2.25m above the ground. You throw a snowball from a height of 1.50m above the ground and perfectly hit the can. The initial velocity of the snowball was 12.5m/s at an angle of 26.0° above the horizontal (as shown). What horizontal distance, X, could you be from the wall?
A) 1.39 m
B) 1.54 m
C) 1.79 m
D) 2.00 m
E) 4.40 m



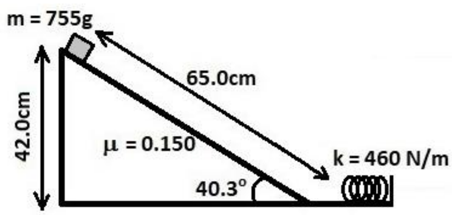
P07. A cave troll is pulling a 350.0kg crate up an inclined plane that is angled at 18.0° above the horizontal (as shown). The troll pulls with a force of 2000.0 N along a direction that is parallel to the incline. The coefficient of friction between the incline and the crate is 0.22. Assuming that it starts from rest, what is the velocity of the crate after the troll pulls it for 2.50 seconds?



A) 1.59 m/s
B) 7.57 m/s
C) 9.16 m/s
D) 10.2 m/s
E) 14.3 m/s

P08. A 755g box of paperclips slides down an incline that is 65.0cm in length. The box starts from rest at a point that is 42.0cm vertically above the floor. The coefficient of friction between the incline and the box is 0.150. After it slides off of the incline and onto the frictionless floor, the box impacts a horizontal spring and compresses it. The spring constant of the spring is 460.0N/m. By how much is the spring compressed by the box of paperclips?

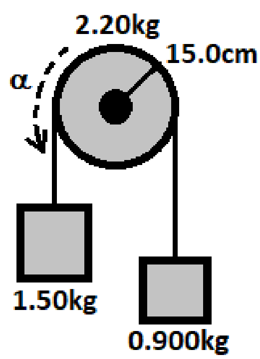
A) 9.32 cm
B) 10.5 cm
C) 11.6 cm
D) 13.0 cm
E) 14.5 cm



P09. Two masses are connected by a rope that passes over a pulley (as shown). The first mass is 1.50kg and the second is 0.900kg. The pulley itself has a mass of 2.20kg and a radius of 15.0cm; and the rope slides over the pulley without slipping. When the masses are released, what is the angular acceleration of the pulley?

Note: The rotational inertia of a disk is $I = \frac{1}{2}mr^2$.

A) 23.1 rad/s^2
B) 16.3 rad/s^2
C) 11.2 rad/s^2
D) 8.52 rad/s^2
E) 5.60 rad/s^2

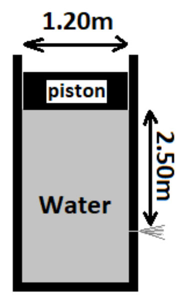


P10. A loud buzzing insect is flying directly away from you as you stand at the edge of a lake. The sound that you hear from the moving insect is at a frequency of 412 Hz. However, you know that this species of insect produces a buzzing sound at a frequency of 424 Hz. Based on this information, and knowing that the air is at 20°C, determine how fast the insect is flying away from you.

A) 4.96 m/s
B) 7.48 m/s
C) 10.0 m/s
D) 14.8 m/s
E) 19.7 m/s

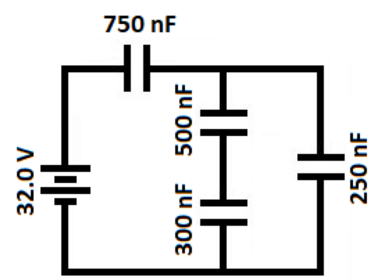
P11. A large tank filled with water is sealed at the top with a heavy, moveable piston (as shown). The piston has a diameter of 1.20m, a mass of 595.0kg, and it rests on the surface of the water, pressing down on the fluid. There is a tiny hole in the side of the tank, 2.50m below the surface of the water. What is the velocity of the water spraying out from the tiny hole?

A) 7.70 m/s
B) 7.00 m/s
C) 5.44 m/s
D) 4.95 m/s
E) 3.21 m/s

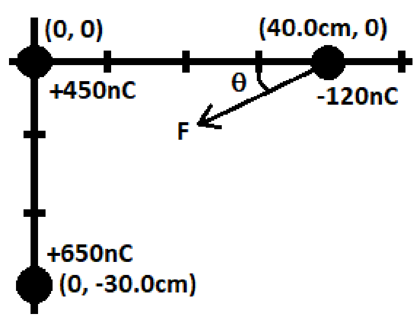


P12. What is the charge stored on the 300nF capacitor in this circuit?

A) 0.960 μC
B) 1.26 μC
C) 1.40 μC
D) 3.79 μC
E) 6.00 μC



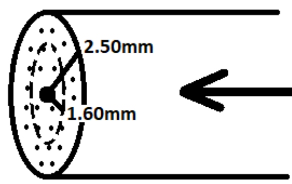
P13. Two fixed charges are placed as indicated: $Q_1 = +450\text{nC}$ is placed at the origin (0, 0), and $Q_2 = +650\text{nC}$ is placed at (0, -30.0cm). A third charge, $Q_3 = -120\text{nC}$, is then placed at (40.0cm, 0). What is the direction of the net force on the third charge due to the two fixed charges?



A) 17.7° below the x-axis
B) 25.2° below the x-axis
C) 27.9° below the x-axis
D) 38.2° below the x-axis
E) 42.8° below the x-axis

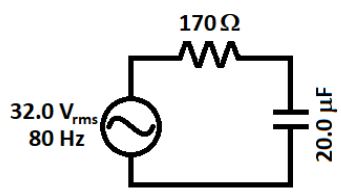
P14. A current of 18.0A flows in a wire such that the current is evenly distributed throughout the wire. The diameter of the wire is 2.50mm. What is the magnetic field strength caused by the flowing current at a distance of 1.60mm from the center of the wire?

A) 0.590 mT
B) 0.922 mT
C) 1.44 mT
D) 2.25 mT
E) 3.52 mT

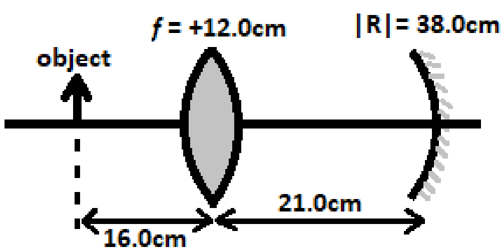


P15. What is the magnitude of the AC current (I_{rms}) in this circuit?

A) 322 mA
B) 228 mA
C) 188 mA
D) 162 mA
E) 119 mA



P16. An object is placed 16.0cm to the left of a lens-mirror optical system (as shown). The lens is a converging lens with a focal length of +12.0cm. The mirror is concave and is placed 21.0cm to the right of the lens. The magnitude of the radius of curvature of the mirror is 38.0cm. What is the location of the final image created by this optical system?



A) 9.39 cm left of the lens
B) 16.6 cm left of the lens
C) 79.0 cm left of the lens
D) 9.22 cm right of the lens
E) 54.9 cm right of the lens

P17. With regard to a quantum Particle in a Box system, under which of these circumstances would the Correspondence Principle be relevant?

A) as the box physical size becomes large
B) as the box energy depth becomes large
C) as the particle mass becomes small
D) as the particle energy becomes small
E) as the particle momentum becomes small.

P18. Two atoms of oxygen-17 fuse together to form an atom of sulfur-33 and one free neutron.

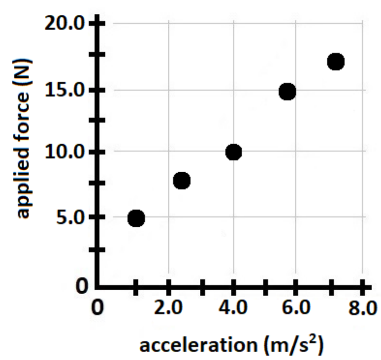
$$^{17}_{8}O + ^{17}_{8}O \rightarrow ^{33}_{16}S + ^{1}_{0}n$$

What is the energy released by this fusion reaction? The mass of $^{17}_{8}O$ is 16.99913176u, and the mass of $^{33}_{16}S$ is 32.97145891u.

A) 2.76 MeV
B) 7.51 MeV
C) 9.56 MeV
D) 12.8 MeV
E) 16.9 MeV

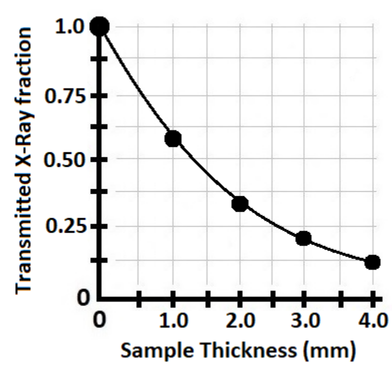
P19. You perform an experiment where you push a 2.00 kg box horizontally across a table with a known applied force. For each trial, you start the box from rest; and you measure the acceleration of the box for different values of the applied force. Your data is plotted below. Based on your data, what is the coefficient of friction between the box and the table?

A) 0.074
B) 0.13
C) 0.20
D) 0.29
E) 0.38



P20. You are testing a new material that you want to use for radiation shielding during medical imaging. You direct an X-ray beam at several samples of the new material and measure the fraction of the X-ray beam that is transmitted through the samples. Each sample has a different thickness. The data you collect is plotted below. Based on this data, what is the linear attenuation coefficient for this material?

A) 0.11 mm^{-1}
B) 0.28 mm^{-1}
C) 0.55 mm^{-1}
D) 1.1 mm^{-1}
E) 1.8 mm^{-1}



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

Conversion Factors

1 eV = 1.602×10^{-19} J
1 mol e^- = 96,485 C
96,485 C = 1 $\mathscr{F}$
1 lb = 454 grams

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

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
2022 REGIONAL

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

CHEMISTRY SOLUTIONS – UIL REGIONAL 2022

C01. (C) Molar mass of $NaBrO_4$ = 22.99 + 79.90 + 16.00 × 4 = 166.89 g/mol
420 g / 166.89 g/mol = 2.517 mol $NaBrO_4$. 2.517 mol $NaBrO_4$ × 4 mol O/1 mol $NaBrO_4$ = 10.07 mol O
10.07 mol O × 16.00 g/mol = 161.1 g O = 161 g O.

C02. (B) Molar mass of CH_3COONa = (12.01 × 2) + (1.01 × 3) + (16.00 × 2) + 22.99 = 82.04 g/mol. 120.0 g CH_3COONa / 82.04 g/mol = 1.463 moles CH_3COONa. Since there is 1 Na per molecule, this is 1.463 moles of Na. 1.463 mol Na × 1 Na_2O/2 mol Na = 0.7314 mol Na_2O. 0.7314 mol Na_2O × 61.98 g/mol = 45.3 grams Na_2O.

C03. (C) The photoelectric effect equation is $KE_{electron} = h\nu - \varphi$. If the electrons are barely ejected, they are ejected with 0 J of kinetic energy, so the equation becomes $h\nu = \varphi$. $\nu = c/\lambda = (3.00 \times 10^{8}\ m/s)/(539.5 \times 10^{-9}\ m) = 5.561 \times 10^{14}\ s^{-1}$. $\varphi = h\nu = (6.626 \times 10^{-34}\ J{\cdot}s)(5.561 \times 10^{14}\ s^{-1}) = 3.685 \times 10^{-19}$ J.
Convert to eV: $(3.685 \times 10^{-19}\ J) / (1.602 \times 10^{-19}\ eV/J) = 2.3$ eV

C04. (A) The temperature and volume are constant between the two samples, so if the pressure of Gas A is 1.25 times higher, that means Gas A has 1.25 times the number of moles as Gas B. Since the masses of the two gases are the same, the ratio of molar masses must be $MM_B/MM_A = 1.25$. This is only true for the gases in answer choice A. $MM_{Ar}/MM_{O2} = 39.95/32 = 1.248$

C05. (D) Pressure, temperature, volume, and moles are all changing in this problem. To get an equation that relates those variables, take a ratio of the ideal gas law for both containers and cancel out the gas law constant *R*:

$$\frac{P_A V_A}{P_B V_B} = \frac{n_A T_A}{n_B T_B}$$

Then rearrange to solve for T_B. Since we're using ratios and we know $P_B = 1.25 \times P_A$, we can just use $P_A = 1.00$ and $P_B = 1.25$.

$$T_B = \frac{n_A T_A V_B P_B}{n_B V_A P_A} = \frac{(6)(300)(5.0)(1.25)}{(5)(3.0)(1.00)} = 750\ K$$

C06. (E) Yes, this is the exact same question as Question 7 on Invitational B. On Invitational B you were given a picture of the molecular structure and this time you are given information about the shape of the molecule.

C07. (A) $\Delta G = \Delta H - T\Delta S$. When ΔG is negative the reaction is spontaneous. In this case the reaction is exothermic so ΔH is negative, and the reaction produces more moles of gas than it consumes, so ΔS is positive. With a negative ΔH and a positive ΔS, ΔG is negative no matter what T is.

C08. (B) There are many different approaches you can take when solving this problem. The approach I'll take here is first to melt the ice and remove that much heat from the hot water, and then mix the hot and cold water to get the final temperature. Heat required to melt the ice: $q = m\Delta H_{fus}$ = 35.0 × 334 J/g = 11,690 J
Removing that much heat from the hot water cools the water down: $q = -mc\Delta T$, so
$\Delta T = q/mc$ = 11,690/(85.0×4.184) = –32.87°C. The resulting temperature of the hot water is 98.0 – 32.87 = 65.13 °C. Now we have 135 g of water at 0°C and 85 g of water at 65.13°C. Removing all of the heat form the hot water to bring it down to 0°C releases $q = mc\Delta T$ = (85.0)(4.184)(65.13) = 23,162.83 J, and leaves us with 35+100+85 = 220 grams of water at 0°C. Adding that released heat back to the 220 grams of water at 0°C results in a final temperature of $\Delta T = q/mc$ = (23,162.83)/(220)(4.184) = 25.16°C.

C09. (D) Calculate Q = $[Pb^{2+}][F^-]2$ and compare that to K. If Q > K, a precipitate will form.
$[Pb^{2+}]$ = mol Pb^{2+}/total volume = (1000 mL)(0.010 M)/1200 mL = 0.00833 M
$[F^-]$ = mol F^-/total volume = (200 mL)(0.010 M)/(1200 mL) = 0.00167 M
Q = (0.00833)(0.00167)2 = 2.3×10^{-8}. Q < K, so the concentrations in the final mixture are not high enough to form a precipitate.

C10. (A) For a weak acid that dissociates only slightly in water (that is, $x \ll C_{acid}$), $[H^+] = \sqrt{K_a C_{acid}}$.
C_{acid} = (grams/molar mass)/volume, so

$$[H^+] = \sqrt{K_a C_{acid}} = \sqrt{\frac{K_a \cdot \text{grams}}{\text{MM} \cdot \text{V}}}$$

or

$$\text{MM} = \frac{K_a \cdot \text{grams}}{[H^+]^2 \cdot \text{V}}$$

$[H^+] = 10^{-pH} = 10^{-3.02} = 9.55 \times 10^{-4}$ M

$$\text{MM} = \frac{4.4 \times 10^{-6} \cdot 2.50}{[9.55 \times 10^{-4}]^2 \cdot 0.100} = 121 \text{ g/mol}$$

C11. (B) Molality (*m*) is moles of solute per kilogram of solvent. 200 g $CaCl_2$ / 110.98 g/mol = 1.802 moles $CaCl_2$. The solution is 500 mL × 1.15 g/mL = 575 grams. 200 grams of this is the $CaCl_2$, so the mass of the solvent is 375 g. 1.802 mol $CaCl_2$ / 0.375 kg water = 4.81 m. (200 grams of $CaCl_2$ might sound like an unrealistic amount of $CaCl_2$ to dissolve in only 375 mL of water, but it's even more soluble than that.)

C12. (E) First determine the K_{sp}, then use that to solve the problem. If the molar solubility in water x = 0.00050 M, then $K_{sp} = [A^{2+}][B^-]^2 = (0.00050)(2\times0.00050)^2 = 5.0 \times 10^{-10}$.
If $[B^-]$ = 0.020 M, then $K_{sp} = [A^{2+}](0.020)^2$, so $[A^{2+}] = (5.0 \times 10^{-10})/(0.020)^2 = 1.25 \times 10^{-6}$ M

C13. (D) $(I\times t)/\mathscr{F}$ = moles of electrons. I = 0.70 C/sec t = 6.0 hrs × 60 min/hr × 60 sec/min = 21600 seconds
$\mathscr{F}$ = 96,485 C/mol e^- Moles of electrons = (0.70)(21600)/96485 = 0.1567 moles of electrons
Since it takes 2 electrons to reduce one Cu^{2+} ion to a neutral Cu atom, moles of Cu formed = 0.1567/2 = 0.07835 moles of copper. 0.07835 × 63.55 g/mol = 4.98 grams of Cu, or just under five grams.
The volume and concentration are not important other than to ensure that you have enough Cu^{2+} ions present to begin with.

C14. (A) $\Pi = iMRT$, so $i = \Pi/MRT$. i = (7.2)/(0.1 × 0.08206 × 293) = 3. Of the answer choices, only $CaCl_2$ has i = 3. ($PbCl_2$ is not soluble in water.)

C15. (E) The rate law will be of the form $rate = k[A]^x[B]^y$ where x and y are typically integers (and can also be 0). In runs 1 and 2 the concentration of A is doubled while the concentration of B remains the same, and the rate is four times faster. This means the exponent on [A] is 2. In runs 1 and 3 where [A] is held constant and [B] is doubled, the initial rate doubles, indicating that the exponent on [B] is 1.

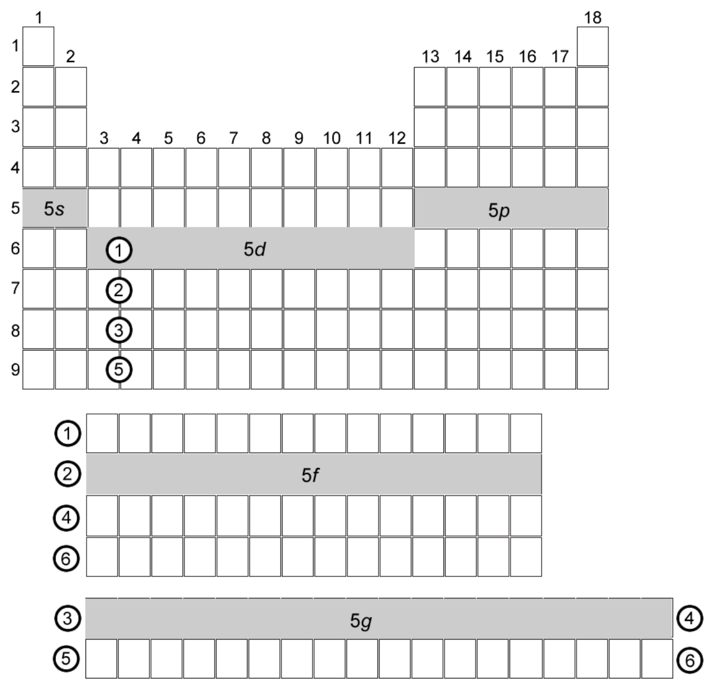
C16. (A) Since fluorine has the highest electronegativity of any atom, the one that will form the most polar bond is the atom with the lowest electronegativity. Electronegativity increases moving up and to the right on the periodic table, so the answer choice that is furthest down and to the left is Si.

C17. (C) Because it's a weak base you can't just change the pH by one unit, because weak acids and bases ionize more when they are more dilute. $[OH^-] = \sqrt{K_b C_{base}}$, so $K_b = [OH^-]^2/C_{base}$.
pOH = 14 – pH = 4.86. $[OH^-] = 10^{-pOH} = 10^{-4.85} = 1.41 \times 10^{-5}$ M. $K_b = (1.41 \times 10^{-5})^2/0.10 = 2.00\times10^{-9}$.
Knowing K_b and the new diluted concentration you can calculate $[OH^-]$ using the same equation:
$[OH^-] = \sqrt{K_b C_{base}} = \sqrt{(2.00\times10^{-9})(0.010)} = 4.47 \times 10^{-6}$. pOH = 5.35, so pH = 8.65.

C18. (B) 5.00 lb × 454 g/lb = 2270 g sucrose. Molar Mass = (12×12.01)+(22×1.01)+(11×16.00) = 342.34 g/mol. 2270 g / 342.34 g/mol = 6.6308 moles sucrose. 6.6308 mol sucrose × (11 mol O / 1 mol sucrose) = 72.939 moles O = 1167.03 g O × (1 lb/454 g) = 2.57 lbs oxygen. When you pick up a 5 lb bag of sugar, more than half of that weight of sugar is oxygen.

C19. (E) PCl_5 has five regions of electron density around the central phosphorus atom, giving it a trigonal bipyramidal structure. The bond angles in a trigonal pyramidal molecule are 90°, 120°, and 180°.

C20. (C) The fifth energy level is made up of five subshells: 5*s*, 5*p*, 5*d*, 5*f*, and 5*g*. The number of electrons in each subshell is (2 + 6 + 10 + 14 + 18) = 50, so 50 elements would have n = 5. Our current periodic table includes elements through the 5*f* subshell, but we haven't yet begun to fill the 5*g* subshell, so our current periodic table only has 32 elements with n = 5. You don't need the future periodic table in order to answer this question, but if you looked for the n = 5 elements, they would be found in the shaded squares shown here.



PHYSICS SOLUTIONS – UIL REGIONAL 2022

P01. (B) pages 90-91: "[Murray Gell-Mann] claimed that, inside the proton and neutron, there were three even smaller particles called quarks. It was a simple model, but it worked spectacularly well in arranging the particles into groups. Like Mendeleyev before him, Gell-Mann could predict the properties of new strongly interacting particles by looking at the gaps in his theory. In 1964, another particle predicted by the quark model, called the omega-minus was actually found, verifying the basic correctness of this theory…"

P02. (E) page 120: "Second, such a wormhole is going to be unstable and will close by itself, unless one adds a new, exotic ingredient, called negative matter or negative energy, which is entirely different from antimatter. Negative matter and energy are repulsive, which can keep the wormhole from collapsing."

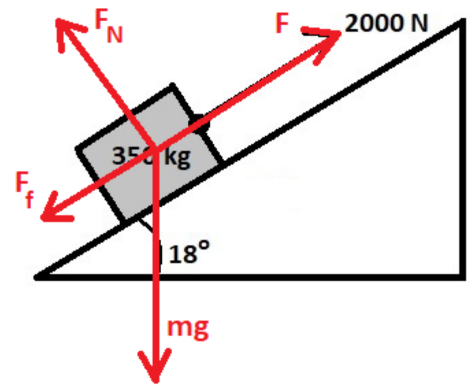
P03. (D) page 153: "Physicist Edward Witten found that there was actually a hidden eleven-dimensional theory, called M-theory, that was based on membranes (like the surfaces of spheres and doughnuts) rather than just strings. He was able to explain why there were five different string theories, because there were five ways in which to collapse an eleven-dimensional membrane to a ten-dimensional string."

P04. (B) The magnitude scale is arranged backwards - brighter stars have lower magnitude numbers and dimmer stars have higher magnitude numbers. It is also built on a logarithmic scale: a change of 5 magnitudes equals a change of brightness by a factor of 100. That is, a star of magnitude 0 is 100 times brighter than a star of magnitude 5. This also means that each magnitude step represents a change in brightness by a factor of $(100)^{1/5} = 2.512$. Thus, the brightness factor between any two stars will be $(2.512)^{\Delta m}$ where Δm is the magnitude difference between the two stars.
Looking at the specific question, we have stars with a magnitude of -1.46 and $+0.38$. The difference in their magnitudes is $\Delta m = 0.38 - (-1.36) = 1.84$. So, this means that Sirius is brighter than Procyon by a factor of $(2.512)^{1.84} = 5.4$ times.

P05. (D) Although you do not know the exact thickness of a laptop, it is on the order of about one inch. Thus, it is reasonable to say that a stack of 10 laptops would be about one foot high. One mile is about 5000 feet (technically it is 5280 feet, but we are rounding to one significant figure). Thus, you need about 50,000 = 5×10^4 laptops to make a stack that is one mile high. To go to the edge of space, you need to go up about 60 miles. So, the number of laptops needed is about
$60 * (5 \times 10^4) = 3 \times 10^6$ laptops.

P06. (C) We know the magnitude and angle of the initial velocity of the snowball; so, let's first find the components of the initial velocity. The horizontal component is given by $v_{xi} = v_i \cos\theta$. Plugging in the values gives $v_{xi} = (12.5)\cos(26.0) = 11.2$ m/s. Similarly, the vertical component is given by $v_{yi} = v_i \sin\theta$, which results in $v_{yi} = (12.5)\sin(26.0) = 5.48$ m/s. We also know all of the distances for the vertical motion, so we should be able to use the equation: $y = y_i + v_{yi}t + \frac{1}{2}a_y t^2$. Knowing that the vertical acceleration is the gravitational acceleration, and putting in all of the known values, we get:
$2.25 = 1.50 + 5.48t + (0.5)(-9.8)t^2 \quad \rightarrow \quad 4.9t^2 - 5.48t + 0.75 = 0$. Using the quadratic formula, we can determine the time from when the snowball is thrown until it hits the tin can:
$t = \frac{5.48 \mp \sqrt{(5.48)^2 - 4(4.9)(0.75)}}{2(4.9)} = \frac{5.48 \mp \sqrt{15.33}}{9.8} = \frac{5.48 \mp 3.92}{9.8} = 0.160s,\ 0.959s$. Both of these times are valid – they correspond to the snowball hitting the can on the way up or hitting it on the way down.
At this point, we will need to check both options. Fortunately, only one calculation remains: using $x = x_i + v_{xi}t + \frac{1}{2}a_x t^2$ and recalling that there no acceleration in the horizontal direction, we find that the horizontal distance from the wall is: $X = x - x_i = v_{xi}t$. Putting in the horizontal component of velocity and the two options for the time, we get: $X = (11.2)(0.160) = 1.79$m, or
$X = (11.2)(0.959) = 10.7$m. The second choice is not in our list, but the first one is. Therefore, we conclude that the correct answer is $X = 1.79$m.

P07. (A) The force diagram is shown below. There are four forces: gravity (mg, downward), the applied force (F, up and right, parallel to the plane), the normal force (F_N, up and left, perpendicular to the plane), and the frictional force (F_f, down and left, parallel to the plane).



For inclined plane problems, it is customary to tilt the coordinate system so that the x-axis is parallel to the plane, and the y-axis is perpendicular to the plane. In this tilted coordinate system, the applied force is in the positive x-direction, the frictional force is in the negative x-direction, and the normal force is in the positive y-direction. The gravitational force must be split into components: in the negative x-direction is the component $mg\sin\theta$ and in the negative y-direction is the component $mg\cos\theta$. The motion of the crate is entirely in the x-direction, so the forces in the y-direction sum to zero: $\sum F_y = F_N - mg\cos\theta = 0$. Thus $F_N = mg\cos\theta = (350)(9.8)\cos(18) = 3262\ N$. Now we can determine the magnitude of the frictional force: $F_f = \mu F_N = (0.22)(3262) = 717.7\ N$. The sum of the forces in the x-direction gives the acceleration of the crate: $\sum F_x = F - F_f - mg\sin\theta = 2000 - 717.7 - (350)(9.8)\sin(18) = ma$. Thus, $2000 - 717.7 - 1060 = 222.4 = ma = (350)a$, giving $a = 0.635$ m/s^2. Therefore, the velocity after 2.50second is: $v = v_i + at = 0 + (0.635)(2.50) = 1.59$ m/s.

P08. (B) This is most easily solved by using conservation of energy. Initially, we have only gravitational potential energy; some energy is converted to heat through the work done by friction, and the system ends with the elastic potential energy of the compressed spring. Mathematically, this is $GPE - W = EPE$. The first term, the gravitational potential energy, is easy to calculate since we know the starting height of the box: $GPE = mgh = (0.755)(9.8)(0.42) = 3.11$ J. The second term is more challenging since we must first determine the force of friction. A force diagram would have three forces: friction (F_f, directed up and left, parallel to the plane), the gravitational force (mg, directed downward), and the normal force (F_N, directed up and right, perpendicular to the plane). We rotate our coordinate system so that the x-axis is directed down the plane, and the y-axis is perpendicular to the plane. Once the coordinate system is rotated, the gravitational force must be broken into components, with $mg\sin\theta$ directed in the positive x-direction (down and right, parallel to the plane) and $mg\cos\theta$ directed in the negative y-direction (down and left, perpendicular to the plane). The motion of the box is entirely in the x-direction in the rotated coordinate system. Thus, the forces in the y-direction add up to zero: $\sum F_y = F_N - mg\cos\theta = 0$. This allows us to calculate the normal force: $F_N = mg\cos\theta = (0.755)(9.8)\cos 40.3 = 5.64$N. Now we can determine the frictional force: $F_f = \mu F_N = (0.150)(5.64) = 0.846$N. We do not need to worry about the forces in the x-direction. Since we know the length of the plane (the sliding surface), and the frictional force, we can calculate the work done by friction. This equals the energy converted to heat: $W = F_f d = (0.846)(0.650) = 0.550$ J. Returning to our conservation of energy equation: $GPE - W = EPE = 3.11 - 0.550 = 2.56$ J. Finally, we put in the equation for elastic potential energy: $EPE = \frac{1}{2}kx^2 = 2.56 \ \rightarrow\ (0.5)(460)x^2 = 2.56 \ \rightarrow\ x = \sqrt{0.0111} = 0.105m = 10.5$cm. This is the amount that the spring is compressed.

P09. (C) To solve this problem, we must consider three force diagrams: a diagram for each hanging mass, and a diagram for the pulley itself. For the left mass, there is a downward gravitational force ($m_1 g$) and an upward tension (T_1). For the right mass, there is also have a downward gravitational force ($m_2 g$) and an upward tension (T_2). The difference in these masses is that the left mass will experience a downward acceleration, while the lighter, right mass will experience an upward acceleration. For the pulley, there are four forces: acting on its left edge is the tension T_1 and acting on its right edge is the tension T_2. There is also the gravitational force $m_p g$ and the upward normal force from the axle of the pulley F_N. Because the pulley only rotates and does not fall, the gravitational force and the axle normal force balance one another $m_p g = F_N$ and do not affect the rest of the problem. The rotation of the pulley is caused by the two tension forces acting on the edge of the pulley. Each tension generates a torque: T_1 causes a counterclockwise torque equal to
$\tau_1 = T_1 r$ and T_2 causes a clockwise torque equal to $\tau_2 = T_2 r$. Here r is the radius of the pulley wheel. τ_1 will be larger, so the pulley wheel will accelerate in the counterclockwise direction with angular acceleration α. At this point we can write the acceleration equations: For the left mass:
$\sum F = T_1 - m_1 g = -m_1 a$ (negative because of the downward direction of the acceleration). For the right mass: $\sum F = T_2 - m_2 g = m_2 a$. Finally, for the torques on the pulley:
$\sum \tau = \tau_1 - \tau_2 = T_1 r - T_2 r = I\alpha = \frac{1}{2} m_p r^2 \alpha$. Lastly, because the rope slides over the pulley without slipping, we can relate the linear acceleration of the masses to the angular acceleration of the pulley wheel: $a = r\alpha$. Now for the algebra: using the force equations, we solve for the tensions:
$T_1 = m_1 g - m_1 a$, and $T_2 = m_2 g + m_2 a$. From this: $T_1 - T_2 = m_1 g - m_1 a - m_2 g - m_2 a$ which leads to $T_1 - T_2 = (1.50)(9.8) - (1.50)a - (0.900)(9.8) - (0.900)a = 5.88 - 2.40a$. Putting this in the torque equation: $T_1 r - T_2 r = (T_1 - T_2)r = (5.88 - 2.40a)r = \frac{1}{2} m_p r^2 \alpha = (0.5)(2.20)r^2 \alpha$.
Simplifying and replacing $r\alpha$ with a gives: $5.88 - 2.40a = 1.10a \rightarrow 3.50a = 5.88 \rightarrow$
$a = 1.68$ m/s². Lastly, this gives an angular acceleration of $\alpha = \frac{a}{r} = \frac{1.68}{0.150} = 11.2$ rad/s².

P10. (C) This is an example of the Doppler effect, so we will use the equation $f = f_0\left(\frac{v \pm v_o}{v \mp v_s}\right)$. Here v is the speed of sound, which is 343m/s at 20°C; v_o is the speed of the observer, and v_s is the speed of the source. The observer is not moving (you are standing still), so v_o is zero. In the denominator, we add v_s to v because the insect (source) is moving away from us (away from the observer). Putting the values into the equation, we get: $412 = 424\left(\frac{343+0}{343+v_s}\right) \rightarrow 0.9717 = \frac{343}{343+v_s} \rightarrow 343 + v_s = \frac{343}{0.9717}$. This leads to $343 + v_s = 353 \rightarrow$
$v_s = 10.0$ m/s.

P11. (A) We will rely on Bernoulli's equation to determine the velocity of the fluid at the tiny hole, based on the pressure of the fluid. Bernoulli's equation relates two points in the fluid to one another: we choose point A to be at the top of the fluid, just underneath the piston; and point B to be the location of the tiny hole in the side of the tank. Then, we have $P_A + \rho g h_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g h_B + \frac{1}{2}\rho v_B^2$. The absolute pressure at point A includes atmospheric pressure and the pressure caused by the piston's weight, while the absolute pressure at point B is just the atmospheric pressure. The velocity at point A is zero since the fluid isn't significantly moving up at the top of the tank, and we set the height at point B to be zero, so the height at point A is 2.50m.
We must take a moment to calculate the pressure provided by the piston. In this case, we will use the force (weight) of the piston divided by the area of the piston. The piston is circular, with a diameter of 1.20m, so it's radius is 0.60m. Thus, its area is $A = \pi r^2 = \pi(0.600)^2 = 1.131$m². The weight of the piston is $W = mg = (595)(9.8) = 5831$N. Therefore, the pressure caused by the weight of the piston is
$P_p = \frac{W}{A} = \frac{5831}{1.131} = 5156$ Pa.
Putting it all into Bernoulli's equation: $P_{atm} + P_p + \rho g(2.50) + \frac{1}{2}\rho(0)^2 = P_{atm} + \rho g(0) + \frac{1}{2}\rho v_B^2$.
Cancelling the atmospheric pressures of each side and ridding ourselves of terms that are zero, we have:
$P_p + \rho g(2.50) = \frac{1}{2}\rho v_B^2$ Recalling that the density of water is 1000 kg/m³ and inserting the piston pressure, we get: $5156 + (1000)(9.8)(2.50) = (0.5)(1000)v_B^2 \rightarrow 29656 = 500 v_B^2$. This gives a fluid velocity at the tiny hole of: $v_B = \sqrt{\frac{29656}{500}} = 7.70$ m/s.

P12. (D) First, we must reduce the capacitor network down to a single equivalent capacitance. We begin by combining the 300nF and 500nF, which are in series: $\frac{1}{C_A} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{300} + \frac{1}{500} \rightarrow C_A = 187.5$nF. This equivalent capacitance is in parallel with the 250nF. Combining those: $C_B = C_A + C_3 = 187.5 + 250 = 437.5$nF. Finally, we combine this capacitance with the 750nF, with which it is in series. $\frac{1}{C_T} = \frac{1}{C_B} + \frac{1}{C_4}$. This gives $\frac{1}{C_T} = \frac{1}{437.5} + \frac{1}{750} \rightarrow C_T = 276.3$nF. Now we can find the charge on this total equivalent capacitance: $Q_T = C_T V_T = (276.3)(32.0) = 8842$nC. The two capacitances in series would also have this same charge, so the charge on C_B is also $Q_B = 8842$nC. Using this, we can find the voltage on the parallel group: $V_B = \frac{Q_B}{C_B} = \frac{8842nC}{437.5nF} = 20.21$V. The voltage across each branch in parallel is the same as the voltage across the entire group, so $V_A = V_B = 20.21V$. Now we can find the charge on the equivalent capacitance C_A: $Q_A = C_A V_A = (187.5)(20.21) = 3790$nC. For the series group, the charge on the group is the same as the charge on each individual capacitor, thus $Q_1 = Q_A = 3790$nC$= 3.79$μC.

P13. (A) We know that both of the positive charges will exert an attractive force on the negative charge (Q_3). The first positive charge ($Q_1 = +450$nC) will exert a horizontal force on the negative charge, while the second positive charge ($Q_2 = +650$nC) will exert a force with both horizontal and vertical components. We begin by using Coulomb's Law to find the magnitudes of those forces. The force exerted by the first charge is: $|F_1| = \left|\frac{kQ_1Q_3}{r_1^2}\right| = \left|\frac{(8.99 \times 10^9)(450 \times 10^{-9})(-120 \times 10^{-9})}{(0.400)^2}\right| = 0.003034$ N. This force is entirely in the x-direction, so we can say: $F_{1x} = 0.003034$ N (to the left) and $F_{1y} = 0$. To find the force due to the second charge, we need the distance between the second and third charges. This is found with the Pythagorean theorem: $r_2 = \sqrt{(0.400)^2 + (0.300)^2} = 0.500$m. Now we can calculate the magnitude of the force from the second charge: $|F_2| = \left|\frac{kQ_2Q_3}{r_2^2}\right| = \left|\frac{(8.99 \times 10^9)(650 \times 10^{-9})(-120 \times 10^{-9})}{(0.500)^2}\right| = 0.002805$ N. This force has both horizontal and vertical components. We can find the components by looking at the triangle formed by the charges Q_2 and Q_3, and the origin. For the x-component, we have: $F_{2x} = F_2 \cos\phi = F_2 \frac{0.400}{0.500} = 0.002244$ N (to the left). Similarly, the y-component is $F_{2y} = F_2 \sin\phi = F_2 \frac{0.300}{0.500} = 0.001683$ N (downward). Now we can sum up the components of the two forces to find the components of the net force acting on the negative charge. $F_x = F_{1x} + F_{2x} = 0.003034 + 0.002244 = 0.005278$ N (to the left); and $F_y = F_{1y} + F_{2y} = 0 + 0.001683 = 0.001683$ N (downward). Finally, we can find the angle, θ, indicated in the diagram: $\tan\theta = \frac{F_y}{F_x} = \frac{0.001683}{0.005278} = 0.319 \quad \rightarrow \quad \theta = \tan^{-1}(0.319) = 17.7°$.
Note: we must be careful about our geometry since the forces are technically in the negative directions (left and downward), and the angle θ is defined downward from the negative x-direction.

P14. (B) To solve this problem, we will need to use Ampere's Law: $\oint B \cdot ds = \mu_0 I_{inside}$. Fundamentally, Ampere's Law is a path integral, and the best possible path will utilize the symmetry of the system. A wire is a cylindrical system, so the best path is a circle – which is already shown (dashed) on the diagram. By using this symmetry, we can greatly simplify the mathematics, reducing the path integral to a simple multiplication: $\oint B \cdot ds = Bs$ where s is the length of the path, which, in this case, is the circumference of the circle, $2\pi r$.
On the right side of Ampere's Law is the permeability of free space multiplied by the amount of current passing through the area of the dashed circle. Fortunately, the current is distributed evenly in the wire; thus, we can use a ratio of the cross-sectional areas of the wire and the dashed circle to find the current that we need. In other words: $I_{inside} = \frac{A_{inside}}{A_{wire}} I_{wire}$. The cross sections are circles, so $A_{inside} = \pi r^2 = \pi(0.00160)^2 = 8.04 \times 10^{-6}$ m^2, and $A_{wire} = \pi R^2 = \pi(0.00250)^2 = 1.96 \times 10^{-5}$ m^2.
Now we can find the current inside the dashed circle: $I_{inside} = \frac{A_{inside}}{A_{wire}} I_{wire} = \frac{8.04 \times 10^{-6}}{1.96 \times 10^{-5}}(18.0) = 7.37$A.
Finally, we can put everything together: $Bs = B(2\pi r) = \mu_0 I_{inside} = \mu_0(7.37)$.
This leads to $B(2\pi)(0.00160) = (4\pi \times 10^{-7})(7.37) \rightarrow B(0.00160) = 1.47 \times 10^{-6} \rightarrow$
$B = 9.22 \times 10^{-4}$ T, which equals $B = 0.922$ mT.

P15. (D) The first thing we need to do with this circuit is determine the angular frequency of the voltage source. We have the frequency, so the angular frequency is $\omega = 2\pi f = 2\pi(80) = 502.7$ rad/s. Now we can find the reactance of the capacitor: $X_C = \frac{1}{\omega C} = \frac{1}{(502.7)(20.0 \times 10^{-6})} = 99.5\ \Omega$. At this point we need to determine the impedance of the circuit. This is simple since there is only a resistor and a capacitor in series; thus, the total impedance is $Z = \sqrt{R^2 + X_C^2}$. Putting in the resistance and reactance values gives: $Z = \sqrt{(170)^2 + (99.5)^2} = \sqrt{38795} = 197\ \Omega$. Finally, using a form of Ohm's Law, we can determine the rms current: $I_{rms} = \frac{V_{rms}}{Z} = \frac{32.0}{197} = 0.162\ \text{A} = 162\ \text{mA}$.

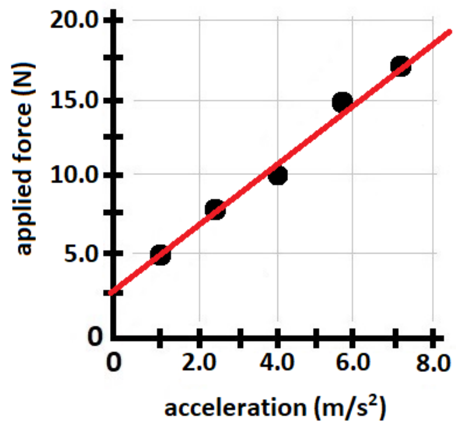
P16. (E) The light from the object will travel through the lens, reflect off of the mirror and then go back through the lens. Fortunately, in a system like this, we can complete each step separately. Thus, we first will consider light going left to right through the lens. We can use the lens formula to find the first image: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \ \rightarrow \ \frac{1}{16} + \frac{1}{q_1} = \frac{1}{12} \ \rightarrow \ q_1 = 48.0cm$ right of the lens. Now we move to the mirror. The distance of this first image from the mirror is $p_2 = D - q_1 = 21.0 - 48.0 = -27.0cm$. The fact that this is negative is important – it means that the first image would form 27cm to the right of the mirror. We need to keep the sign in the next calculation. For the mirror, we need the focal length, and since the mirror is concave, the focal length will be positive (concave mirrors are converging mirrors). Therefore, the mirror focal length is $f_m = +\frac{R}{2} = +\frac{38.0}{2} = +19.0cm$. From this we can find the location of the image formed by the light reflecting off of the mirror – this is the second image. The equation for the image location is the same for a mirror as that for a lens, so we have $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ which becomes $\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_m} \ \rightarrow \ \frac{1}{-27} + \frac{1}{q_2} = \frac{1}{19} \ \rightarrow \ q_2 = 11.2cm$. This image location is positive, but since light reflects from a mirror and is now traveling to the left, a positive image location means that the image is to the left of the mirror. The light now goes back through the lens – this time from right to left. The distance from the second image to the lens is: $p_3 = D - q_2 = 21.0 - 11.2 = 9.8cm$. Using the lens equation again: $\frac{1}{p_3} + \frac{1}{q_3} = \frac{1}{f} \ \rightarrow \ \frac{1}{9.8} + \frac{1}{q_3} = \frac{1}{12} \ \rightarrow \ q_3 = -54.9cm$. This is the location of the final image. Because it is negative, and since the light is traveling from right to left, the image is to the right of the lens. Thus, the final image is 54.9cm right of the lens.

P17. (A) The Correspondence Principle deals with the transition from a quantum system to a classical system. It states that in the classical limit, the quantum calculations will reduce to the classical results. To determine if the Correspondence Principle is relevant, we need to determine which of these circumstances would shift our system from the quantum realm into the classical realm. To enter the classical realm usually means entering the macroscopic realm – large sizes, large masses, and large energies. Based on this, we can eliminate choices C (small mass), D (small energy), and E (small momentum). As for the box itself, a larger depth allows more energy levels to exist but doesn't force the particle into a higher energy level. Increasing the energy depth really has no effect at all. Only choice A, where the physical size of the box becomes large, will shift the system into the classical realm. Thus, only for choice A is the Correspondence Principle relevant.

P18. (E) To determine the energy released, we need to determine the difference between the total mass on the left side and that on the right side. On the left, we have two atoms of ${}^{17}_{8}O$, which gives a total mass of $M_L = (16.99914176)(2) = 33.99828352$u. On the right side, we have the atom of ${}^{33}_{16}S$ and one neutron, giving a total mass of $M_R = 32.9714589 + 1.008665 = 33.9801239$u. The mass difference is then $\Delta M = M_L - M_R = 33.99828352 - 33.9801239 = 0.01816$u. Now we need to convert this mass difference into energy: $E = \Delta M(931.5\ MeV/u) = 16.9$MeV. Note: Both the mass of a neutron and the mass to energy conversion are given on the page of useful constants.

P19. (B) The forces acting on the box are as follows: the gravitational force (mg, downward), the normal force (F_N, upward), the applied force (F_a, to the right) and the frictional force (F_f, to the left). Since there is no vertical motion, we have $\sum F_y = F_N - mg = 0 \quad \rightarrow \quad F_N = mg = (2.00)(9.80) = 19.6$ N. From this we can determine an expression for the frictional force: $F_f = \mu F_N = (19.6)\mu$.
Now, for the horizontal, we get $\sum F_x = F_a - F_f = ma$. This rearranges to $F_a = (2.00)a + (19.6)\mu$.

Clearly, the relationship between the applied force and the acceleration is linear, which is apparent from the plot. On the plot we sketch in a best-fit line, which is shown to the right. Based on the equation, the slope of the best-fit line will equal the mass of the box (which we already know). It is the intercept of the line that relates to the coefficient of friction. From the best-fit line, we have a y-intercept of $F_{a0} = 2.5$ N. Relating this to the intercept term in our equation: $F_{a0} = (19.6)\mu = 2.5 \quad \rightarrow \quad \mu = \frac{2.5}{19.6} = 0.13$.



P20. (C) The equation that describes the attenuation of X-rays passing through a material is $I = I_0 e^{-\mu x}$, where I_0 is the initial beam intensity, I is the transmitted intensity, x is the material thickness, and μ is the linear attenuation coefficient. On the graph, the y-axis is the transmitted fraction, which is the ratio of the transmitted intensity to the initial beam intensity: $(fraction) = \frac{I}{I_0}$. Also, we are shown a curve fit to the data. We will read a single point from the fit to determine the linear attenuation coefficient. I have chosen the point (1.3mm, 0.50), but any point you choose on the plot will give approximately the same result. Putting it all together gives
$(fraction) = \frac{I}{I_0} = e^{-\mu x} \quad \rightarrow \quad 0.50 = e^{-\mu(1.3mm)} \quad \rightarrow \quad \ell n(0.50) = -\mu(1.3mm)$.
This leads to $-0.693 = -\mu(1.3mm) \quad \rightarrow \quad \mu = 0.53mm^{-1} \approx 0.55mm^{-1}$.

Science Contest Answer Sheet

Conference ______ Grade Level ______ Contestant # ________

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

B Score ☐ **C Score** ☐ **P Score** ☐

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