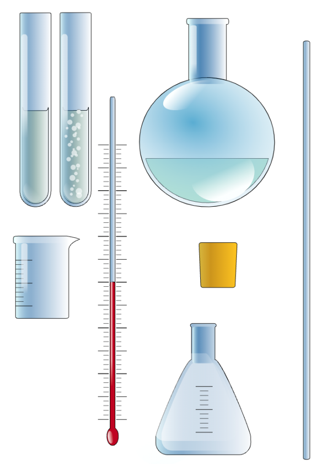
UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

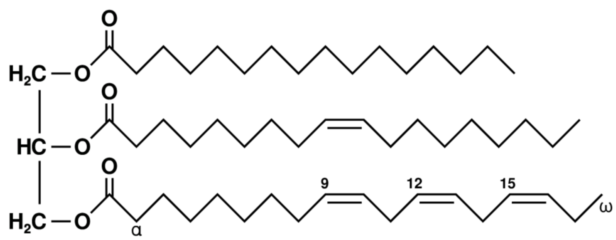
Region • 2024



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. Examine the following image. Where would this molecule be found?



A) adipocyte
B) plasma membrane
C) nuclear envelope
D) DNA sugar-phosphate backbone
E) ribosome

B02. A researcher is using the CRISPR/Cas9 system to introduce an insect gene into the chromosome of a mouse cell. Which of the following cellular repair processes would be utilized to add the new gene?
A) Non-homologous end joining
B) Homology directed repair
C) Microhomology-mediated end joining
D) Base excision repair
E) Mismatch repair

B03. *Vibrio cholerae* is a bacterium that harbors two circular chromosomes—a 2.96Mbp primary chromosome and a 1.07Mbp secondary chromosome. Based on this information and prior knowledge, which statement is correct?
A) The two circular chromosomes are identical.
B) The organism is diploid.
C) The two chromosomes pair up during meiosis.
D) This bacterium divides by binary fission.
E) More than one answer above is correct, but not all are correct.

B04. Per pyruvate, how many carbon dioxide are produced during the intermediate phase (pyruvate oxidation step) of aerobic respiration?
A) 0
B) 1
C) 2
D) 3
E) 6

B05. Examine the chromosome structures below. Which event occurred in the mutation? Note: the "*" represents the centromere.

Normal: ABCDE*FGHIJK
LMN*OPQRS

Mutant: ABCDE*OPQRS
LMN*FGHIJK

A) deletion
B) duplication
C) deletion
D) inversion
E) reciprocal translocation

B06. The organism that causes bubonic plague, *Yersinia pestis*, is present in small numbers within rodents in small, localized areas of the American Southwest. This is an example of a/an
A) pandemic.
B) subdemic.
C) epidemic.
D) endemic.
E) None of the above.

B07. When comparing *Escherichia* species with *Salmonella* species, two very similar *Enterobacteriaceae*, which statement is incorrect?
A) Both test positive for cytochrome c oxidase.
B) Both *Escherichia* and *Salmonella* are Gram-negative bacteria.
C) Both are facultative anaerobes.
D) *Salmonella* tests negative for lactose fermentation but *Escherichia* tests positive.
E) Both have an LPS layer in their cell walls.

B08. Specific causes of hypercalcemia include
A) overactive parathyroid glands.
B) cancer or other diseases.
C) certain medications.
D) taking too many supplements.
E) All of the above are specific causes.

B09. According to the Centers for Disease Control and Prevention, the most recent outbreak of Listeriosis originated from
A) enoki mushrooms.
B) leafy greens.
C) peaches.
D) cheese.
E) ice cream.

B10. Which type of epithelial cell lines kidney tubules, including collecting ducts?
A) cuboidal
B) transitional
C) squamous
D) nonciliated columnar
E) ciliated columnar

B11. A researcher examines an unknown cell from an environmental sample. Based upon the researcher's prior knowledge and access to only a microscope, which of the following would they not be able to conclude?
A) The unknown cell has a plasma membrane.
B) The researcher could determine if the cell is prokaryotic or eukaryotic.
C) The cell utilizes fermentation for its energy and carbon requirements.
D) The cell uses genes made of DNA as instructions for protein building.
E) The cell has ribosomes.

B12. Which of the following blood types is not possible from the following genetic cross?

I^Ai x I^Bi

A) A
B) B
C) AB
D) O
E) All of the above are possibilities.

B13. If the fermentation pathways listed below were the only pathways running in a cell that is fermenting, which one produces only neutral end products?
A) mixed acid fermentation.
B) 2,3-butanediol fermentation.
C) alcohol fermentation.
D) homolactic acid fermentation.
E) heterolactic acid fermentation.

B14. Right-coiling snails and left-coiling snails are reproductively isolated through _____ isolation.
A) mechanical
B) temporal
C) geographic
D) behavioral
E) ecological

B15. The *trp* operon of *Escherichia coli* harbors genes for the synthesis of the amino acid, tryptophan. Which of the following is correct regarding this regulation?
A) When tryptophan is present in the cell's environment, the operon is repressed.
B) The repressor, TrpR, binds to the operator during high concentrations of tryptophan.
C) Tryptophan serves as a co-repressor alongside TrpR.
D) The *trp* operon utilizes attenuation as a second negative feedback regulation.
E) All of the above statements are correct.

B16. Which of the following is not a characteristic of Domain Eukarya?
A) multicellular, large organism with specialized cells
B) presence of a nucleus within cells
C) presence of tissues in higher-level Eukarya
D) absence of membrane-bound organelles
E) presence of a plasma membrane

B17. Examine the image. Which of the following organelles is not correctly matched with its function?

A) 1=ribosomal RNA synthesis
B) 6=modification, packaging, and export of proteins
C) 8=synthesis of exported proteins
D) 9=citric acid cycle and oxidative phosphorylation
E) 13=microtubule organizing center

B18. Which of the replication enzymes is incorrectly paired with its main function?
A) Helicase=unwinds the double-stranded DNA
B) Primase=generates ~20 nucleotides of a DNA primer
C) DNA Polymerase III=synthesizes a majority of the DNA during replication
D) DNA Polymerase I=fills in gaps in the newly synthesized strand
E) Ligase=generates a phosphodiester bond to link DNA fragments in the new strand

B19. If the frequency of the recessive allele is 0.07, what percent of the population harbors a recessive allele?
A) 0.49%
B) 7.0%
C) 13.5%
D) 86.5%
E) 93.0%

B20. Division Coniferophyta is characterized by all of the following except they
A) contain cones as reproductive structures.
B) produce terpenes that protect against disease and herbivores.
C) produce flowers to aid in distribution of pollen.
D) harbor naked seeds (e.g., seeds not enclosed by an ovary).
E) have needles or scales instead of broad leaves.

C01. A standard latex party balloon with an empty mass of 12.0 grams is filled with helium gas to a volume of 0.55 cubic feet at 23.3°C and 750 torr. What is the overall density of the filled balloon?

A) 0.63 g/L
B) 0.73 g/L
C) 0.83 g/L
D) 0.93 g/L
E) 1.03 g/L

C02. How many grams of propanol, C_3H_7OH, could you make if you had 8.60 grams of carbon, 15.5 L of H_2 gas at STP, and 3.56×10^{23} oxygen atoms?

A) 14.3 grams
B) 10.4 grams
C) 35.5 grams
D) 5.20 grams
E) 11.9 grams

C03. I am a negative ion that has one more neutron than protons in my nucleus, and my number of electrons is equal to my number of neutrons. Which ion am I?

A) ${}^{1}_{1}H^{-}$
B) ${}^{14}_{7}N^{-}$
C) ${}^{17}_{8}O^{2-}$
D) ${}^{32}_{16}S^{2-}$
E) ${}^{19}_{9}F^{-}$

C04. What type of bond is formed when two atoms share a pair of electrons, but both electrons in the bond come from the same atom?

A) Ionic Bond
B) Metallic Bond
C) Coordinate Covalent Bond
D) Nonpolar Covalent Bond
E) Hydrogen Bond

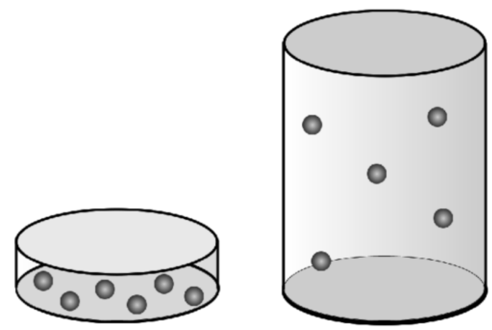
C05. How many grams of carbon are in a 325 gram sample of dry ice (solid carbon dioxide)?

A) 88.7 g
B) 108 g
C) 139 g
D) 163 g
E) 236 g

C06. What is the name of the triprotic weak acid H_3AsO_4?

A) Arsenic acid
B) Trihydrogen arsenate
C) Hydroarsenous acid
D) Hydroarsenic acid
E) Arsenacious acid

C07. What is the pressure in Container A compared to the pressure in container Z?

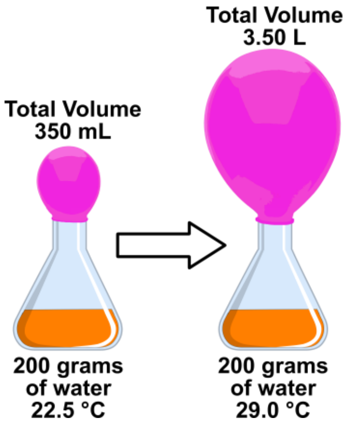


A) Both pressures are the same
B) The pressure in A is double the pressure in Z
C) The pressure in A is one half the pressure in Z
D) The pressure in A is three times the pressure in Z
E) The pressure in A is five times the pressure in Z

C08. What is the pH of the solution if 5.00 grams of NaClO is dissolved in water to make 250 mL of solution?

A) 10.02
B) 10.25
C) 10.44
D) 10.52
E) 10.67

C09. What is the value for the work done in joules on the system when this reaction is carried out at 1 atm pressure?



A) 315 J
B) 319 J
C) –3.15 J
D) –3.19 J
E) 0 J

C10. If water at 25°C has a vapor pressure of 0.0313 atm and acetone at the same temperature has a vapor pressure of 0.3030 atm, what would the vapor pressure be of a mixture containing 100 grams of water and 100 grams of acetone?

A) 0.167 atm
B) 0.334 atm
C) 0.272 atm
D) 0.111 atm
E) 0.0957 atm

C11. If a chemical reaction has an equilibrium constant of 5.6×10^{-2} at 25 °C and the enthalpy of the reaction is 23.5 kJ/mol, what will the equilibrium constant be at 125 °C?

A) 0.61
B) 7.5×10^{-2}
C) 2.2×10^{-2}
D) 0.28
E) 0.82

C12. The K_{sp} for iron(II) phosphate is 9.9×10^{-16}. What is the molar solubility of iron(II) phosphate?

A) 2.5×10^{-3} M
B) 3.9×10^{-4} M
C) 1.1×10^{-5} M
D) 7.8×10^{-5} M
E) 6.4×10^{-6} M

C13. What is the coefficient on H_2O when the equation for the following redox reaction is balanced in basic solution using the smallest whole number coefficients?

$$Sn(s) + MnO_4^-(aq) \rightarrow Sn(OH)_2(s) + MnO_2(s)$$

A) 2 B) 4 C) 6 D) 8 E) 10

C14. The reaction $A_2 + B_2 \rightarrow 2\,AB$ takes place according to the following three-step reaction mechanism:

$A_2 \rightarrow 2A$ (*slow*)
$A + B_2 \rightarrow AB + B$ (*fast*)
$A + B \rightarrow AB$ (*fast*)

If the concentration of B_2 is doubled, how will that affect the rate of the reaction?

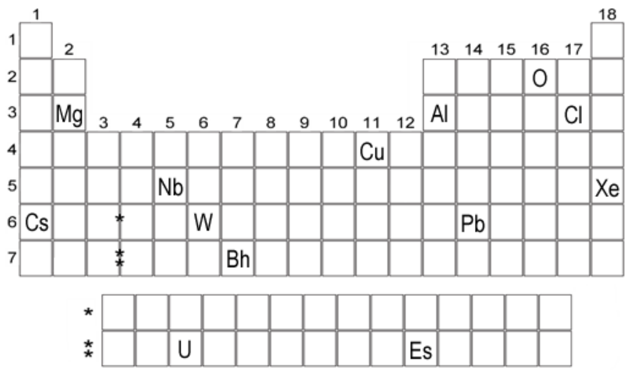
A) The reaction will occur twice as fast
B) The reaction will occur four times faster
C) The reaction will occur half as fast
D) The reaction will occur at one fourth the original rate
E) The reaction rate will not change

C15. What is the energy in joules of the ultraviolet photon given off when an electron in a hydrogen atom drops from the fourth energy level to the ground state?

A) 2.04×10^{-18} J
B) 1.98×10^{-18} J
C) 1.63×10^{-18} J
D) 2.50×10^{-18} J
E) 6.15×10^{-2} J

C16. All of the following instructions refer to the *outermost electron* in the elements shown on this table, and not to the elements themselves. (Because *atoms* and *elements* don't have quantum numbers, only *electrons* have quantum numbers.)

Start on oxygen.



1) Go to an element whose n value is one higher and whose ℓ value is one lower than oxygen's.
2) Now go to an element whose n and ℓ values are both two higher than where you are right now.
3) Now go to an element whose n value is one higher and whose ℓ value is one lower.
4) Now go to an element with the same ℓ but one lower n.

Which element are you on?

A) Pb - Lead
B) W - Tungsten
C) Cs - Cesium
D) Xe - Xenon
E) Bh - Bohrium

C17. A lab technician is asked by his boss to weigh out 127.87 grams of $CuCl_2 \cdot 2H_2O$ and dissolve it in solution up to 5.00 L, then take 1.75 L of that solution and dilute it to 0.125 M. How much water does he need to add in the dilution step?

A) 2.10 L
B) 1.25 L
C) 750 mL
D) 350 mL
E) 135 mL

C18. Which bonding theory makes use of hybridized atomic orbitals with names like *sp*, sp^3, and sp^3d^2?

A) Molecular orbital theory
B) Valence bond theory
C) Arrhenius bonding theory
D) Classical bonding theory
E) Electron tunneling theory

C19. 275 mL of 0.150 M HNO_3 is added to 725 mL of an acetic acid buffer at pH 4.74 and the pH drops to 4.35. What is the buffer capacity of the buffer solution?

A) 0.25
B) 0.20
C) 0.15
D) 0.10
E) 0.05

C20. Water has relatively strong hydrogen bonding between the molecules, but motor oil is nonpolar and the only intermolecular force between the molecules is dispersion forces. So why is motor oil more viscous than water?

A) Because viscosity is unrelated to intermolecular forces.
B) Because smaller molecules are always less viscous than larger molecules.
C) Because large molecules have a lot of dispersion forces and they add up.
D) Because that's just how motor oil is.
E) Because hydrogen bonding makes water slippery and therefore less viscous.

P01. According to Guillen, Sadi Carnot dedicated his life to the study of ________________.
A) gasoline engines
B) steam engines
C) the diesel cycle
D) energetic explosives
E) heat produced by electricity

P02. According to Guillen, the human sensation of "hotness" is produced when ______________.
A) you touch a hot material
B) your motion is converted into heat
C) electricity in your nerves produces heat
D) heat flows into your body
E) you have an excess of heat stored in your body

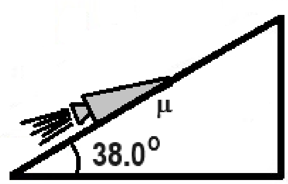
P03. According to Guillen, the theory describing the indestructibility of heat, known as caloric theory, was superseded by Clausius's theory of ….
A) thermal equilibrium
B) increasing entropy
C) statistical disorder
D) energy conservation
E) reversible processes

P04. In which type of galaxy has star formation effectively ceased?
A) spiral
B) barred spiral
C) irregular
D) peculiar
E) elliptical

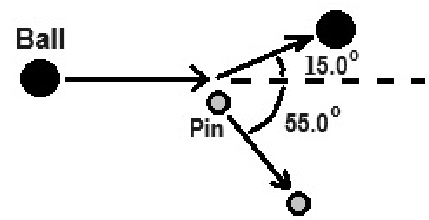
P05. During a rainstorm, you notice that each falling drop contains about 1.0mL of water. How many drops, to the nearest order of magnitude, would be needed to fill a volume of one acre·foot?
Note: 1 square kilometer equals 247acres and 1.0m equals 3.28feet.
A) $\sim 10^{6}$ drops
B) $\sim 10^{7}$ drops
C) $\sim 10^{8}$ drops
D) $\sim 10^{9}$ drops
E) $\sim 10^{10}$ drops

P06. A racing boat starts from rest and accelerates at a constant rate. After the boat travels 30.0m, a timer starts. The timer stops when the racing boat has traveled 200.0m. The time for the boat to travel from 30.0m to 200.0m is recorded as 6.65seconds. What is the acceleration of the racing boat?
A) 3.40 m/s^2
B) 4.36 m/s^2
C) 6.54 m/s^2
D) 7.69 m/s^2
E) 10.4 m/s^2

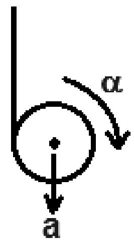
P07. An experimental jet sled is launched up an incline that is angled at 38.0° with respect to the horizontal (as shown). The mass of the jet sled is 280.0kg and the jet engine provides 4400N of force, oriented parallel to the incline. If the jet sled accelerates at 6.75m/s^2, then what is the coefficient of friction, μ, between the sled and the incline?
A) 0.30
B) 0.38
C) 0.43
D) 0.60
E) 0.69



P08. A 10.0kg bowling ball rolls at a speed of 8.70m/s towards a 3.50kg bowling pin which is initially at rest. The ball collides with the pin, after which the ball is traveling at an angle of 15.0° from its original direction. After the collision, the pin flies off at 55.0° from the bowling ball's original direction, as illustrated. What is the speed of the bowling pin after the collision?
A) 5.91 m/s
B) 6.44 m/s
C) 6.84 m/s
D) 7.58 m/s
E) 8.11 m/s



P09. A cylinder with a diameter of 24.0cm and a mass of 860g has a string wrapped around it. Starting from rest, the cylinder is released, unwinding the string as it falls (like a yo-yo, as shown). The string does not slip as it unwinds. What is the angular acceleration of the cylinder as it falls? Note: The moment of inertia of a cylinder is given by $I = \frac{1}{2}mr^2$.

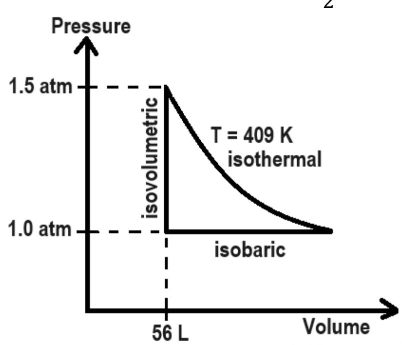


A) 6.50 rad/s^2
B) 27.2 rad/s^2
C) 40.9 rad/s^2
D) 54.4 rad/s^2
E) 81.7 rad/s^2

P10. A loudspeaker at a public park operates at a power of 60.0W, and the sound from the loudspeaker spreads out evenly in all directions. Determine the intensity of the sound (in decibels) at a distance of 35.0m from the loudspeaker?

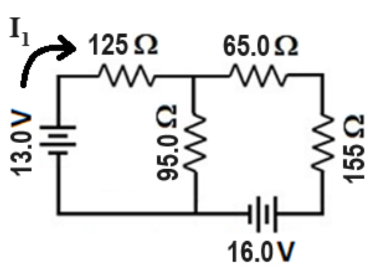
A) 108 dB
B) 102 dB
C) 96 dB
D) 90 dB
E) 84 dB

P11. 2.50 moles of a monatomic ideal gas go through the engine cycle illustrated by the PV-diagram shown below. What is the efficiency of this engine? Note: for a monatomic gas, $C_v = \frac{3}{2}R$ and $C_p = \frac{5}{2}R$.



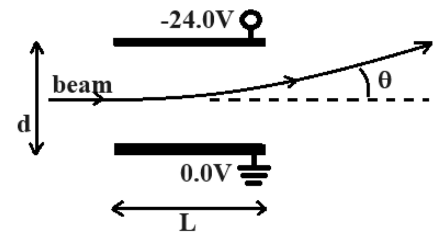
A) 3.7%
B) 4.1%
C) 5.8%
D) 6.7%
E) 8.0%

P12. For the circuit shown below, determine the magnitude of the current in the leftmost branch, I_1.



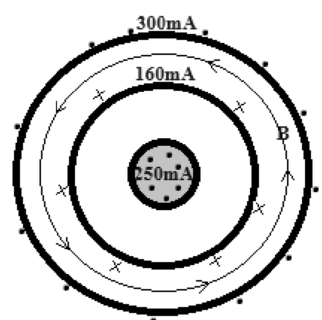
A) 93.1 mA
B) 80.6 mA
C) 42.7 mA
D) 37.9 mA
E) 32.9 mA

P13. A beam of protons is directed horizontally between two parallel plates, as shown. The protons have a horizontal velocity of 4.50×10^4m/s when they enter the field region between the plates. The plates are separated by 6.00cm (d), are 3.50cm long (L), and the voltage difference between the plates is 24.0V. At what angle, θ, does the proton beam travel when it exits the field region between the plates?



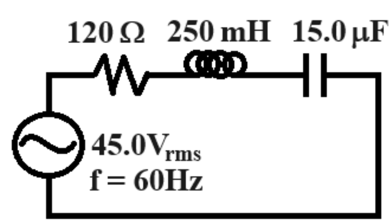
A) 62.8°
B) 56.5°
C) 48.6°
D) 33.5°
E) 27.2°

P14. A triple layer coaxial cable carries a current of 250.0mA in the +z direction in its central wire. It carries a current of 160.0mA in the −z direction in the middle layer conductor, and a current of 300.0mA in the +z direction in the outer layer conductor (as shown). The radius of the central wire is 0.500mm; the radius of the middle layer conductor is 1.30mm; and the radius of the outer layer conductor is 2.00mm. What is the magnitude of the magnetic field at a radius of 1.75mm, between the middle and outer layer conductors?



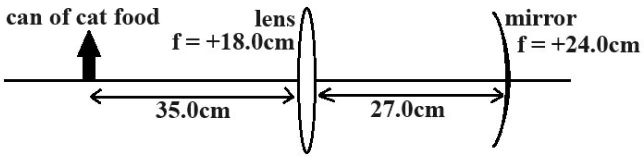
A) 10.3 µT
B) 18.3 µT
C) 24.0 µT
D) 28.6 µT
E) 44.6 µT

P15. For the AC circuit shown below, determine the magnitude of the current (rms) flowing through the resistor.



A) 0.115 A
B) 0.152 A
C) 0.309 A
D) 0.375 A
E) 1.20 A

P16. A can of cat food is placed 35.0cm to the left of a converging lens with a focal length of $18.0cm$. To the right of the lens, at a distance of $27.0cm$, sits a concave mirror with a focal length of $24.0cm$. What is the magnification of the final image of the can of cat food?



A) 0.744
B) 1.25
C) 1.83
D) 5.34
E) 7.00

P17. An X-ray with an energy of 125keV scatters from an electron. After scattering, the X-ray is travelling at an angle of 80.0° from its original direction. What is the energy of the X-ray after scattering?

A) 21 keV
B) 104 keV
C) 125 keV
D) 146 keV
E) 157 keV

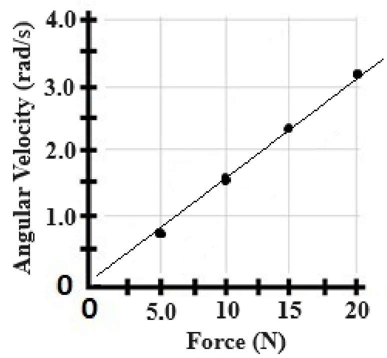
P18. The K^{-*} meson has a strangeness of -1, a charge of -1 and a spin of $+1$ (and $C = B = T = 0$). The K^{-*} meson decays into a pion and a K^- meson:

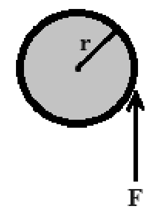
$$K^{-*} \rightarrow K^- + \pi^0$$

The K^- meson has a strangeness of -1, a charge of -1 and a spin of 0 (and $C = B = T = 0$). Based on this information, approximately what mean lifetime would the K^{-*} meson be expected to have?

A) 10^{-23} seconds
B) 10^{-19} seconds
C) 10^{-12} seconds
D) 10^{-8} seconds
E) 10^{-2} seconds

P19. A wheel with a radius of 44.0cm, and with an axis through its center, is set into rotational motion by a force acting tangentially on its edge, as illustrated. For each trial, the wheel starts from rest and the force acts for exactly 1.50seconds, after which the final angular velocity of the wheel is measured. The final angular velocity of the wheel is plotted versus the magnitude of the applied force, and the plot is shown below. Based on these data, determine the moment of inertia of the wheel about its center.

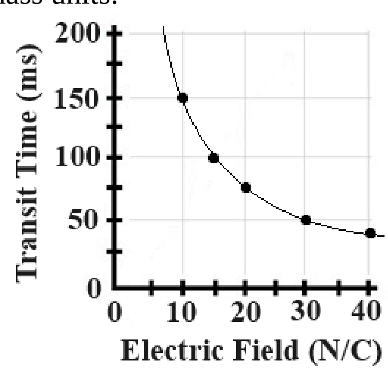




A) 0.24 kgm^2
B) 2.8 kgm^2
C) 4.2 kgm^2
D) 6.3 kgm^2
E) 9.7 kgm^2

P20. Singly charged ions with negligible velocity are injected into the top end of a 1.50m long tube. An electric field is then pulsed in the tube for exactly 1.50μs, briefly accelerating the ions. This causes the ions to drift down the tube, and they are detected when they arrive at the bottom end of the tube. Shown below is a plot of the time required for the ions to travel the length of the tube versus the strength of the pulsed electric field. From these data, determine the mass of the ions in atomic mass units.

A) 97 u
B) 145 u
C) 220 u
D) 360 u
E) 480 u



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)

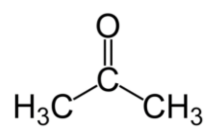
Water Data

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
$\mathscr{F}$ = 96,485 C/mol e$^-$
1 amp = 1 C/sec
1 mol e$^-$ = 96,485 C

Helpful Information



Acetone

K_a for HClO = 3.5×10^{-8}

Conversion factors

1 atm = 760 torr
1 atm = 101325 Pa
1 atm = 1.01325 bar
1 L·atm = 101.325 J
1 in = 2.54 cm
1 ft = 12 in
1 cubic foot = 28.32 L

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
2024 REGIONAL

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

CHEMISTRY SOLUTIONS – UIL REGIONAL 2024

C01. (D) Solution: Calculate the mass of the helium, add the mass of the empty balloon, and then divide by the total volume. Total volume = 0.55 cubic feet × 28.32 L/cu ft = 15.58 L. The mass of the helium is $PV = (g/MM)RT$, so $g = (PV \cdot MM)/RT$. P = 750 torr × 1 atm/760 torr = 0.9868 atm. T = 23.3 + 273 = 296.3 K.

$$\text{mass of He} = \frac{PV \cdot MM}{RT} = \frac{(0.9868)(15.58)(4.00)}{(0.08206)(296.3)} = 2.529\ \text{grams/L}$$

density = total mass/total volume = (12.0 + 2.529)/15.58 = 0.9325 g/L

C02. (B) Convert all amounts to moles to calculate how many moles of propanol you can make, then calculate grams from the lowest of these three numbers.

Carbon: 8.60 g C / 12.011 g/mol = 0.7160 mol C × 1 mol propanol/3 mol C = 0.2387 mol propanol
Hydrogen: 15.5 L H_2 / 22.4 L/mol = 0.6920 mol H_2 × 2 H atoms / 1 H_2 = 1.384 mol H atom × 1 propanol / 8 H = 0.1730 mol propanol
Oxygen: 3.56 × 1023 O atoms / 6.02 × 10^{23} atoms/mol = 0.5914 mol O atoms × 1 mol propanol / 1 mol O = 0.5914 mol propanol.
You will run out of H_2 first, after making 0.1730 mol propanol.
0.1730 mol × 60.11 g/mol = 10.40 g propanol.

(Note that H_2 is diatomic so you have to take that into account when calculating H atoms, but oxygen is given in terms of individual atoms, not as O_2, so you don't multiply by 2 for oxygen.)

C03. (E) If neutrons = protons + 1 and electrons = neutrons, then the ion has to be –1, eliminating answers C and E. ${}^{1}_{1}\text{H}^{-}$H has one *fewer* neutrons than protons, and ${}^{14}_{7}\text{N}^{-}$ has 7 of each. ${}^{19}_{9}\text{F}^{-}$ has 9 protons, 10 neutrons, and 10 electrons.

C04. (C) A coordinate covalent bond, also called a dative bond, is always polar, so the only other covalent bond choice D cannot be correct.

C05. (A) The percent carbon in CO_2 is 12.01/(12.01 + 32.00) × 100 = 27.29% The mass of carbon in 325 grams of CO_2 is (27.29/100) × 325 g= 88.7 g C

C06. (A) Acids are named based on the name of the anion. Anions that end in -*ate* become -*ic* acid, anions that end in -*ite* become -*ous* acid, and anions that end in -*ide* become *hydro*-____-*ic* acid. AsO_4^{3-} is the arsen*ate* ion, so as unlikely as it may seem, the acid formed from that ion is called arsen*ic* acid. (The naming system is the same regardless of whether the acid is strong or weak.)

C07. (E) You can solve this by taking a ratio of $PV = nRT$ for the two conditions and entering all the values to calculate the P_A/P_Z ratio, or just calculate P for each canister and take the ratio. You can use each dot to represent one mole or one molecule and you will get the same final answer either way because you are taking a ratio of the two and the units will cancel out.
For Container A, $P = nRT/V$ = (6)(0.08206)(364)/1 = 179.2 atm.
For container Z, $P = nRT/V$ = (5)(0.08206)(436)/5 = 35.78 atm.
The pressure ratio is 178.2 atm / 35.78 atm = 5.01

C08. (C) Since it is a weak base solution with a small K_b, the answer will be found somewhere in the equation $[OH^-] = \sqrt{K_b C_{base}}$ The concentration C_{base} is moles per liter, or $(g/MM)/V$ = (5.00/75.45)/0.250 = 0.2651 M. $K_b = K_w/K_a = 1 \times 10^{-14} / 3.5 \times 10^{-8} = 2.857 \times 10^{-7}$. Therefore $[OH^-] = \sqrt{(2.857 \times 10^{-7})(0.2651)} = 2.752 \times 10^{-4}$. pOH = 3.56 so pH = 14 – pOH = 10.44

C09. (D) work = $-P\Delta V$. Work = (1)(3.50 –0.350) = –3.15 L·atm. × 101.325 J/L·atm = –319.2 J. When the system volume increases, work is negative because the system expends energy pushing back against the surroundings. When the system volume decreases, work is positive.

C10. (E) $VP_{solution} = \chi_{water}\cdot VP°_{water} + \chi_{acetone}\cdot VP°_{acetone}$ χ = mole fraction. χ_{water} = moles H_2O/(moles H_2O + moles acetone) and $\chi_{acetone}$ = moles acetone/(moles H_2O + moles acetone).
100 g / 18.02 g/mol = 5.55 moles water. 100 g / 58.09 g/mol 1.72 moles acetone χ_{water} = 5.55/7.27 = 0.763. $\chi_{acetone}$ = 1.72/7.27 = 0.237. VP = (0.763)(0.0313) + (0.237)(0.3030) = 0.0957 atm

C11. (A) Equilibrium constants increase exponentially with temperature, so if you know one K/T pair you can calculate K at a different temperature using the van't Hoff equation. I won't do all the plug and chug here, I'll just say ΔH has to be in units of J/mol, not kJ/mol, so the units cancel with R, which is 8.314 J/mol·K, not 0.08206 L·atm/mol·K. (Vapor pressure and reaction rate constants also increase exponentially with temperature and have equations [the Clausius-Clapeyron equation and the Arrhenius equation] that look nearly identical to this one.)

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta H_{rxn}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

C12. (B) On the district exam we said that for a compound like this that has five ions in the compound, $K_{sp} = 108x^5$, so the molar solubility $x = (K_{sp}/108)^{1/5}$. $(9.9 \times 10^{-16}/108)^{1/5} = 3.9 \times 10^{-4}$ M. This is how many moles of the compound would dissolve in 1 liter of solution, but it is not the concentration of the Fe^{2+} ions or the phosphate ions.

C13. (B) This is the same reaction from the District exam, but on that exam it was in an acidic solution and this time it's carried out in basic solution and the products are different.
Oxidation half-reaction: $Sn(s) + 2OH^-(aq) \rightarrow Sn(OH)_2(s) + 2e^-$
Reduction half-reaction: $MnO_4^-(aq) + 2H_2O(\ell) + 3e^- \rightarrow MnO_2(s) + 4OH^-(aq)$
Multiply oxidation × 3 and reduction × 2 to equalize the electrons and then add:
$3Sn(s) + 2MnO_4^-(aq) + \mathbf{4H_2O}(\ell) \rightarrow 3Sn(OH)_2(s) + 2MnO_2(s) + 2OH^-(aq)$

C14. (E) The reaction rate is determined by the slow step of the reaction, which is step 1. The rate law for this reaction is rate = $k[A_2]$. Doubling the concentration of A_2 will double the rate, but doubling the concentration of B_2 will have no effect on the reaction rate.

C15. (A) This is a straight up Rydberg equation problem with no tricks.

$$E = \mathcal{R}\left(\frac{1}{{n_2}^2} - \frac{1}{{n_1}^2}\right)$$

$$E = 2.178 \times 10^{-18}\,J\,\left(\frac{1}{1^2} - \frac{1}{4^2}\right) = 2.04 \times 10^{-18}\text{ J}$$

C16. (D) Oxygen's outermost electron is in a 2*p* subshell, so *n*=2 and ℓ=1. 1) Move to *n*=3 and ℓ=0, that's magnesium, Mg. 2) Increasing *n* and ℓ by two puts you in *n*=5 and ℓ=2, the 5*d* subshell, that's tungsten, W. 3) Now increase to *n*=6 and decrease ℓ from 2 to 1, that's Pb in the 6*p* subshell. 4) Then go to *n*=5 and stay in ℓ=1, the 5*p* subshell, and the only element in the 5p subshell in this table is xenon, Xe.

C17. (D) First calculate the concentration of the original solution, then do the dilution problem. 127.87 g/170.49 g/mol = 0.75 mol $CuCl_2 \cdot 2H_2O$. 0.75 mol/5.00 L = 0.150 M. The dilution calculation is $M_1V_1 = M_2V_2$, where M_1 = 0.150 M, V_1 = 1.75 L, and M_2 = 0.125 M. $V_2 = M_1V_1/M_2$ = (0.150)(1.75)/(0.125) = 2.10 L. But this is the final volume and the question asks for how much water is needed, so the water needed is 2.10 L – 1.75 L = 0.350 L = 350 mL

C18. (B) In valence bond theory, two or more atomic orbitals can "hybridize" to form an equal number of hybrid orbitals which all have the same energy and are therefore capable of forming that many equal energy, symmetrical bonds around the central atom. The names of the hybrid orbitals are simply the orbitals that went not making them up – an *sp* hybrid orbital is made up of one *s* orbital and one *p* orbital, and an sp^3 hybrid orbital is a combination of one *s* orbital and three *p* orbitals.

C19. (C) Buffer capacity is defined as

$$\beta = \frac{\text{moles of acid added per liter of buffer solution}}{\Delta\text{pH}}$$

Moles of acid = 0.275 × 0.150 M = 0.04125 mol. The initial volume of the buffer is 0.725 L, and the change in pH is 4.74 – 4.35 = 0.39 pH units.

$$\beta = \frac{(0.04125/0.725)}{0.39} = 0.15$$

C20. (C) Individual dispersion forces are weaker than the hydrogen bonding in water, but when you have large molecules like the C_{18}-C_{34} compounds found in motor oil, there are multiple dispersion sites on each molecule and these add up to be stronger overall than the hydrogen bonding in water. There are other reasons for motor oil's viscosity as well, but within the context of the question it's the dispersion forces adding up to result in stronger IMF's overall.

PHYSICS SOLUTIONS – UIL REGIONAL 2024

P01. (B) page 173: "It galled young Carnot that English steam engines were more efficient than French ones… It was mainly to remedy this humiliating and dangerous disparity that Carnot had dedicated his life to the study of these marvelous machines."

P02. (D) page 183: "…scientists were forced to admit that heat was not what produced the sensation of hotness; it was the flow of heat that did so. This realization led to Heat Theory #2: "Whenever heat flows into our bodies, it produces the sensation of hotness…"

P03. (D) page 198: "This novel concept came to be called the Law of Energy Conservation….Clausius's reasoning spelled the end of the caloric theory, because it recognized energy, not heat, as being the indestructible phenomenon."

P04. (E) Elliptical galaxies are composed mostly of older, low-mass stars. They have very little interstellar gas and dust, and, thus, star formation is minimal. Spiral and barred spiral galaxies have ongoing star formation, mostly in the spiral arms. Irregular and peculiar galaxies, which result from galactic interactions, mergers, or collisions, show regions undergoing bursts of rapid star formation.

P05. (D) This is an order of magnitude calculation, so we don't need to carry more than one significant figure. Noting the conversions, we determine that 1.0 acre·foot = $\frac{1\,km^2}{247} * \frac{1\,m}{3.28} = 0.001\ km^2 m$. Converting square kilometers into square meters gives: $0.001 km^2 m * 10^6 \frac{m^2}{km^2} = 10^3\ m^3$. Now, each drop is about 1.0mL, which means that there are 10^6 drops in one cubic meter. Thus, the order of magnitude of the number of drops needed to fill one acre·foot is $10^3 m^3 * 10^6 \frac{drops}{m^3} = 10^9$ drops. Note: if you actually use a calculator, you get 1.23×10^9 drops, which is the same order of magnitude.

P06. (A) Let's define the time that the boat starts as $t = 0$, the time when it reaches 30.0m as t_1 and the time when it reaches 200.0m as t_2. Also, the initial velocity is $v_i = 0$, but we will label the velocity at the 30.0m mark as v_1 and the final velocity at the 200.0m mark as v_2. Using the kinematic equation $v_f^2 = v_i^2 + 2a\Delta x$ for the two locations, we can generate some useful relations:
$v_1^2 = 0 + 2a(30.0) = 60a \;\rightarrow\; v_1 = \sqrt{60a}$ and $v_2^2 = 0 + 2a(200.0) = 400a \;\rightarrow\; v_2 = \sqrt{400a}$.
Also, we have $v_2 = v_1 + a(t_2 - t_1) \;\rightarrow\; v_2 = v_1 + 6.65a \;\rightarrow v_2 - v_1 = 6.65a$. Squaring this last equation gives: $v_2^2 - 2v_1v_2 + v_1^2 = 44.22a^2$. Now, using the first two relations, we obtain
$v_2^2 - 2v_1v_2 + v_1^2 = 44.22a^2 \;\rightarrow\; 400a - 2\sqrt{400a}\sqrt{60a} + 60a = 44.22a^2 \;\rightarrow$
$(460 - 309.84)a = 44.22a^2$. This leads to $150.2 = 44.22a \;\rightarrow\; a = 3.40$m/s^2.

P07. (B) We start by identifying the forces on the sled. There is gravity (mg, directed downward), the normal force (F_N, directed up and left, perpendicular to the incline), friction (F_f, directed down and left, parallel to the incline), and the jet engine (F, directed up and right, parallel to the incline). As is customary for an incline, we tilt our coordinate system so that the x-axis is parallel to the incline and the y-axis is perpendicular to it. Thus, the normal force is pointed in the +y direction, the frictional force is directed in the −x direction, and the jet engine force is directed in the +x direction. Gravity is the only force that must be broken into components. Parallel to the plane and directed in the −x direction is the component $mg \sin\theta$, and perpendicular to the plane and directed in the −y direction is the component $mg\cos\theta$. The acceleration is entirely in the +x direction, and there is no motion in the y-direction. This means that the forces in the y-direction must sum to zero. Mathematically, $\sum F_y = F_N - mg\cos\theta = 0 \;\rightarrow\; F_N = mg\cos\theta = (280)(9.8)\cos(38°) = 2162\text{N}$, which is the magnitude of the normal force. In the x-direction, we do have acceleration. Thus,
$\sum F_x = F - F_f - mg\sin\theta = ma$. Putting in the known values gives:
$4400 - F_f - (280)(9.8)\sin(38°) = (280)(6.75) \;\rightarrow\; 4400 - F_f - 1689 = 1890$. This gives a frictional force of $F_f = 821\text{N}$. Finally, the frictional force is related to the normal force by the coefficient of friction: $F_f = \mu F_N \;\rightarrow\; 821 = \mu(2162) \;\rightarrow\; \mu = 0.38$.

P08. (C) This problem involves conservation of momentum in two dimensions. We must consider the initial and final momenta in both the x- and y-directions. Initially, the momentum of the bowling ball is entirely in the x-direction, and the pin has no initial momentum since it starts at rest. Mathematically, we have a total initial momentum in the x-direction of $p_{ix} = p_{ixball} + p_{ixpin} = m_b v_{ixb} + 0 = (10.0)(8.70) = 87.0$kgm/s. In the y-direction, we have no initial momentum since neither the ball, nor the pin, have any initial velocity in the y-direction. Thus, the total initial momentum in the y-direction is $p_{iy} = 0$. Now we consider the final momentum in the x- and y-directions. After the collision, the ball has velocity v_{fb} with components $v_{fxb} = v_{fb}\cos(15.0°) = 0.9659v_{fb}$ and $v_{fyb} = v_{fb}\sin(15.0°) = 0.2588v_{fb}$. Likewise, after the collision, the pin has velocity v_{fp} with components $v_{fxp} = v_{fp}\cos(-55.0°) = 0.5736v_{fp}$ and $v_{fyp} = v_{fp}\sin(-55.0°) = -0.8192v_{fp}$. [Note: the angle of motion of the pin after the collision is in the fourth quadrant, so it is technically a negative angle.]

The total final momentum in the x-direction is
$p_{fx} = m_b v_{fxb} + m_p v_{fxp} = (10.0)(0.9659v_{fb}) + (3.50)(0.5736v_{fp}) = 9.659v_{fb} + 2.008v_{fp}$.
Likewise, the total final momentum in the y-direction is
$p_{fy} = m_b v_{fyb} + m_p v_{fyp} = (10.0)(0.2588v_{fb}) + (3.50)(-0.8192v_{fp}) = 2.588v_{fb} - 2.867v_{fp}$.
By conservation of momentum, the initial momentum for each direction must equal the final momentum for that direction. Thus, for the y-direction:
$p_{iy} = p_{fy} \rightarrow 0 = 2.588v_{fb} - 2.867v_{fp} \rightarrow 2.588v_{fb} = 2.867v_{fp} \rightarrow v_{fb} = 1.108v_{fp}$.
Similarly, for the x-direction: $p_{ix} = p_{fx} \rightarrow 87.0 = 9.659v_{fb} + 2.008v_{fp}$.
Using the relation between v_{fb} and v_{fp} from the y-direction equation, and substituting it into the x-direction equation, we obtain:
$87.0 = 9.659v_{fb} + 2.008v_{fp} \rightarrow 87.0 = 9.659(1.108v_{fp}) + 2.008v_{fp} \rightarrow 87.0 = 12.71v_{fp} \rightarrow$ $v_{fp} = 6.84$m/s. This is the final speed of the pin after the collision.

P09. (D) The forces acting on the cylinder are gravity (mg, downward) and tension (T, upward). Both of these forces are vertical, and there are no horizontal forces. Using Newton's Second Law, and noting that the acceleration is downward (and thus, negative) we get $\sum F_y = T - mg = m(-a) \rightarrow$ $T - (0.860)(9.80) = -(0.860)a \rightarrow T - 8.43 = -0.860a \rightarrow T = 8.43 - 0.860a$. Now, the torque on the cylinder results from the tension acting on the edge of the cylinder (the torque arm equals the radius of the cylinder). The gravitational force acts on the center of the cylinder, so it does not produce any torque (its torque arm is zero). Thus, $\sum \tau = Tr$. Relating the torque to the angular acceleration, we get: $Tr = I\alpha$. Plugging in the moment of inertia of a cylinder gives: $Tr = \frac{1}{2}mr^2\alpha \rightarrow T = \frac{1}{2}(0.860)r\alpha$. Recalling that the linear acceleration a is related to the angular acceleration α by the equation $a = r\alpha$, our equation simplifies to $T = \frac{1}{2}(0.860)a \rightarrow T = 0.430a$. Putting together the equations we obtained from the forces with those we obtained from the torques, we get $T = 8.43 - 0.860a = 0.430a \rightarrow 1.29a = 8.43 \rightarrow a = 6.53$m/s^2. Noting the radius of the cylinder $r = \frac{1}{2}d = (0.5)(0.240) = 0.120$m, we can obtain the angular acceleration: $\alpha = \frac{a}{r} = \frac{6.53}{0.12} = 54.4$ rad/s^2.

P10. (C) If the loudspeaker sound waves spread evenly in all directions, then they spread as spherical wavefronts. The surface area of a spherical wavefront is given by $A = 4\pi r^2$. Thus, the intensity of the sound wave at a distance of 35.0m is $I = \frac{P}{A} = \frac{60.0W}{4\pi r^2} = \frac{60.0W}{4\pi(35.0m)^2} = 0.003898$ W/m^2. To convert this to decibels, we use: $I(dB) = 10Log\left(\frac{I}{I_0}\right)$ where $I_0 = 1.00 \times 10^{-12}$W/m^2. Putting in our intensity level gives: $I(dB) = 10Log\left(\frac{0.003898}{1.00\times10^{-12}}\right) = 10Log(3.898 \times 10^9) = 95.9 \approx 96$ dB.

P11. (E) To determine the efficiency of the engine, we need the total work for the cycle as well as the heat energy input into the engine. The efficiency is then determined using $e = \left(\frac{W}{Q_{in}}\right) \times 100\%$. First, we need to find P, V, and T in proper units for each vertex. For the lower left vertex (we'll call it vertex A), we already have $P_A = 1.0atm * 1.013 \times 10^5 Pa/atm = 1.013 \times 10^5 Pa$, and $V_A = 56L * 0.001m^3/L = 0.056m^3$. The temperature can be found using the ideal gas law: $PV = nRT \;\rightarrow (1.013 \times 10^5 Pa)(0.056m^3) = (2.50mol)(8.314\,J/molK)T \;\rightarrow\; T_A = 272.9K$. At the upper left vertex (let's call it vertex B), we are given all three variables: $P_B = 1.5atm * 1.013 \times 10^5 Pa/atm = 1.520 \times 10^5 Pa$ and $V_B = 56L * 0.001m^3/L = 0.056m^3$ and $T_B = 409K$. Finally, for the lower right vertex (call it vertex C), we have $P_C = 1.0atm * 1.013 \times 10^5 Pa/atm = 1.013 \times 10^5 Pa$ and $T_C = 409K$. Turning to the ideal gas law again, we obtain the volume: $PV = nRT \;\rightarrow (1.013 \times 10^5 Pa)V = (2.50mol)(8.314\,J/molK)(409K) \;\rightarrow\; V = 0.0839m^3$. Now we can find the work done by the gas and the heat flow during each process. The process $A \rightarrow B$ is isovolumetric, which means that there is no work done: $W_{AB} = 0$. The heat flow is given by $Q_{AB} = nC_v\Delta T = (2.50mol)\frac{3}{2}(8.314\,J/molK)(409K - 272.9K) = 4243\,J$. This is positive heat flow, so it represents heat flow into the gas. The process $B \rightarrow C$ is isothermal, which means that the work done by the gas equals the heat flow into the gas. Isothermal work is found using $W_{BC} = nRT\ell n\left(\frac{V_C}{V_B}\right) = (2.50mol)(8.314\,J/molK)(409K)\ell n\left(\frac{0.0839}{0.056}\right) = 3437\,J$, which means the heat flow is also $Q_{BC} = 3437\,J$. Finally, the process $C \rightarrow A$ is isobaric, and the work is $W = P\Delta V = (1.013 \times 10^5 Pa)(0.056 - 0.0839) = -2826\,J$. Isobaric heat flow is $Q_{CA} = nC_p\Delta T = (2.50)\frac{5}{2}(8.314)(272.9 - 409) = -7072\,J$. Since it is negative this represents exhaust heat leaving the gas. Now, we find the total work: $W = 0 + 3437 - 2826 = 611\,J$ and the total heat flow into the gas (the positive heat flow): $Q_{in} = 4243 + 3437 = 7680\,J$. From this we obtain the efficiency: $e = \frac{611}{7680} * 100 = 8.0\%$

P12. (C) Since there are voltage sources in two different branches of this circuit, it is best to solve this problem by using Kirchhoff's Laws. There are three branches of the circuit – the left, the middle, and the right. There are two nodes (top and bottom) and two small loops (left and right). We shall label the currents I_1 (left), I_2 (middle), and I_3 (right). We will consider I_1 to be going up on the left side (as it is illustrated), and I_2 to go down in the middle. Lastly, we will take I_3 to go up on the right side. Using Kirchhoff's node rule at the top node, we get $I_1 + I_3 - I_2 = 0$. Using Kirchhoff's loop rule for the left loop, and going clockwise around the loop, we obtain $13.0 - 125I_1 - 95.0I_2 = 0$. Now, using the loop rule for the right loop, and going counterclockwise around the loop, we get $16.0 - 155I_3 - 65.0I_3 - 95.0I_2 = 0$. From here, we just need to do some algebra. From the node equation, we note $I_2 = I_1 + I_3$. Substituting that into the loops equations gives: $13.0 - 125I_1 - 95.0I_1 - 95.0I_3 = 0 \;\rightarrow\; 220I_1 + 95.0I_3 = 13.0$, and $16.0 - 155I_3 - 65.0I_3 - 95.0I_1 - 95.0I_3 = 0 \;\rightarrow\; 95.0I_1 + 315I_3 = 16.0$. Solving for I_3 in the first loop equation gives: $95.0I_3 = 13.0 - 220I_1 \;\rightarrow\; I_3 = 0.1368 - 2.316I_1$. Substituting this into the second loop equation gives: $95.0I_1 + 315(0.1368 - 2.316I_1) = 16.0 \;\rightarrow\; -634.5I_1 + 43.1 = 16.0$. This leads to $634.5I_1 = 27.1 \;\rightarrow\; I_1 = 0.0427A = 42.7mA$.

P13. (D) To begin, we need to find the magnitude of the electric field between the plates. For parallel plates we use $|E| = \left|\frac{V}{d}\right| = \frac{24.0}{6.00 \times 10^{-2}} = 400$N/C. The electric field is entirely vertical, so the force that it exerts on the protons will also be vertical. The magnitude of the force acting on the protons can be found using $|F| = q|E| = (1.602 \times 10^{-19})(400) = 6.41 \times 10^{-17}$N. At this point, we use Newton's Second Law to find the vertical acceleration of the protons: $F = ma \;\rightarrow\; 6.41 \times 10^{-17} = (1.67265 \times 10^{-27})a \;\rightarrow\; a = 3.83 \times 10^{10}$m/s^2. Now we have a kinematic problem: the horizontal acceleration is zero, so the horizontal velocity remains constant at $v_x = 4.50 \times 10^4$m/s. The time for a proton to traverse the length of the field region (the length of the plates) is $t = \frac{L}{v_x} = \frac{0.0350}{4.50 \times 10^4} = 7.78 \times 10^{-7}s$. Using this time with the vertical acceleration allows us to find the final vertical velocity of the beam when it exits the field region:

$v_y = at = (3.83 \times 10^{10})(7.78 \times 10^{-7}) = 2.98 \times 10^4$m/s. Finally, we use the velocities to calculate the angle at which the beam exits the plates: $\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) = \tan^{-1}\left(\frac{2.98\times10^4}{4.50\times10^4}\right) = 33.5°$.

P14. (A) To solve this problem, we will utilize Ampere's Law. We'll begin with $\oint B \cdot ds = \mu_0 I_{inside}$. Fortunately, the circular symmetry of the problem allows us to avoid the path integral, reducing Ampere's Law to $Bs = \mu_0 I_{inside}$. Here, s is the path length of the magnetic field which is the circumference of the circular field line at the radius of 1.75mm. Mathematically, $s = 2\pi r = 2\pi(0.00175) = 0.0110$m. Now, the 'current inside' would include any currents enclosed by the circular magnetic field line. In this case, that includes the currents of the inner and middle conductors but excludes the current in the outer conductor. Thus, $I_{inside} = 250mA + (-160mA) = 90mA = 0.090A$. Putting it together, we get $B(0.0110) = (4\pi \times 10^{-7})(0.090) \;\; \rightarrow \;\; B = 1.03 \times 10^{-5}T = 10.3\mu T$

P15. (C) First, we need the angular frequency of the AC voltage source: $\omega = 2\pi f = 2\pi(60) = 377$rad/s. Using this, we can determine the inductive reactance: $X_L = \omega L = (377)(0.250) = 94.25\Omega$, and the capacitive reactance: $X_C = \frac{1}{\omega C} = \frac{1}{(377)(15.0 \times 10^{-6})} = 176.8\Omega$. All the elements in the circuit are in series, so the total impedance is given by: $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(120)^2 + (94.25 - 176.8)^2} = \sqrt{21220} = 145.7\Omega$. Finally, we determine the current in the circuit, which is the current passing through all the elements, including the resistor: $I = \frac{V}{Z} = \frac{45.0}{145.7} = 0.309$A.

P16. (E) In a compound optical system like this, we work through each optical element individually. Thus, we start with only the object and the lens. To find the first image, we use: $\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_L}$. This gives $\frac{1}{35.0} + \frac{1}{q_1} = \frac{1}{18.0} \;\; \rightarrow \;\; q_1 = 37.1cm$. Now, this first image becomes the object for the second element – the mirror. We begin by shifting over to the mirror's location: $p_2 = D - q_1 = 27.0 - 37.1 = -10.1cm$. The fact that this object location is negative is fine - it just means that this "object" is beyond (to the right of) the mirror. Using $\frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_M}$, we can find the location of the second image – the image formed by the mirror: $\frac{1}{-10.1} + \frac{1}{q_2} = \frac{1}{24.0} \;\; \rightarrow$ $q_2 = 7.09cm$. After reflecting from the mirror, the light must now travel back through the lens. This image formed by the mirror becomes the object for going back through the lens. Shifting over to the lens's location, we get: $p_3 = D - q_2 = 27.0 - 7.09 = 19.9cm$. Finally, we obtain the location of the final image: $\frac{1}{p_3} + \frac{1}{q_3} = \frac{1}{f_L} \;\; \rightarrow \;\; \frac{1}{19.9} + \frac{1}{q_3} = \frac{1}{18.0} \;\; \rightarrow \;\; q_3 = 187cm$. Each step of image formation also involves magnification. For the first step, we have $M_1 = -\frac{q_1}{p_1} = -\frac{37.1}{35.0} = -1.06$. For the second step, we get $M_2 = -\frac{q_2}{p_2} = -\frac{7.09}{-10.1} = 0.702$, and for the final step, the magnification is $M_3 = -\frac{q_3}{p_3} = -\frac{187}{19.9} = -9.40$. The total magnification of the final image is $M = M_1 M_2 M_3 = (-1.06)(0.702)(-9.40) = 7.00$.

P17. (B) This is an example of Compton scattering, in which the X-ray loses energy by colliding with an electron, and the angle of the scattered X-ray is used to find how much energy was lost. The equation for Compton scattering is written in terms of wavelength: $\lambda_f - \lambda_i = \frac{h}{m_e c}(1 - \cos\theta)$. To convert the initial energy into wavelength, we use $\lambda_i = \frac{hc}{E} = \frac{1240eVnm}{125 \times 10^3 eV} = 0.00992nm = 9.92pm$. Now, we calculate the final wavelength using the Compton scattering equation: $\lambda_f - 9.92pm = \frac{(6.626 \times 10^{-34}Js)}{(9.11 \times 10^{-31}kg)(3.00 \times 10^8 m/s)}(1 - \cos(80°)) = 2.00 \times 10^{-12} = 2.00pm$. This gives a final wavelength of $\lambda_f = 9.92pm + 2.00pm = 11.92pm = 0.01192nm$, and an energy for the scattered X-ray of $E = \frac{hc}{\lambda} = \frac{1240eVnm}{0.01192nm} = 104keV$.

P18. (A) From the information given, we can determine that the decay of the K^{-*} particle into a K^- particle does not involve a change in the flavor of a quark. The strangeness, charge, and other flavor quantum numbers (C, B, T) are the same between these two particles. Also, there are no leptons (electrons, muons, tauons, or neutrinos) present in the decay products. The lack of flavor changes and leptons means that this decay is not mediated by the weak force. The weak force mediates the slowest decays (up-down flavor changes at 10^{-2} seconds, strangeness-type decays at 10^{-8} seconds, and charm-type decays at 10^{-12} seconds). Furthermore, the decay of the K^{-*} particle does not involve the absorption or emission of photons, nor does it involve matter-antimatter annihilation. Thus, this decay is not mediated by the electromagnetic force, which is responsible for decays in the 10^{-16} second to 10^{-19} second range. This means that the decay of the K^{-*} particle must be mediated by the strong force, which is consistent with the change in spin when going from the K^{-*} particle to the K^- particle. Strong force decays are very fast, usually in the 10^{-23} second to 10^{-24} second range. Thus, the correct answer is 10^{-23} seconds.

P19. (C) In this problem, the applied force provides a torque that spins the wheel up to its final angular velocity. Since the force is tangential and acts on the edge of the wheel, the torque provided equals the force multiplied by the radius of the wheel: $\tau = Fr$. There are no other unbalanced forces or torques acting on the wheel, so this is the torque that causes the angular acceleration: $\tau = Fr = I\alpha$. Solving for angular acceleration gives: $\alpha = \frac{Fr}{I}$. The force acts for only a short time, t, which means that the wheel accelerates for only that short time. Using an angular kinematic equation and recalling that the wheel starts from rest for each trial, we get: $\omega = \omega_i + \alpha t = 0 + \left(\frac{Fr}{I}\right)t$. Rearranging the equation, we see that the relationship between the angular velocity and the force is linear (as illustrated on the plot): $\omega = \left(\frac{rt}{I}\right)F$. The slope can be seen to equal $slope = \frac{rt}{I}$. Now we turn to the plot and solve for the slope using two points on the best fit line. I choose the points (6.2N, 1.0rad/s) and (19N, 3.0rad/s). Calculating the slope, we get: $slope = \frac{3.0-1.0}{19-6.2} = \frac{2.0}{12.8} = 0.156$ rad/Ns. Equating this value to our derived slope formula, we can find the moment of inertia of the wheel: $slope = 0.156 = \frac{rt}{I} = \frac{(0.44)(1.50)}{I}$. This leads to $I = \frac{0.66}{0.156} = 4.2$ kgm^2.

P20. (B) The pulsed electric field results in a force acting on the ions, according to $F = qE$. This is the only significant force acting on the ions, so this force is solely responsible for the acceleration of the ions. Using Newton's Second Law, we get: $F = ma = qE$. Solving for the acceleration, we find: $a = \frac{qE}{m}$. The pulsed electric field, and thus the acceleration, only lasts for a brief time, t. Using a kinematic equation and noting that the ions initially have no significant velocity, we can find the final velocity of the ions after the electric field pulse: $v = v_i + at = 0 + \left(\frac{qE}{m}\right)t \rightarrow v = \frac{qEt}{m}$. At this point, we must consider the transit time for these ions to drift down the length of the tube. The pulse is so fast that the ions do not travel very far during the acceleration (they travel only a few micrometers during the pulse time). Thus, we can consider the ions to travel the entire length of the tube, L, at a constant velocity. Using another kinematic equation, we find: $L = vT$. Here we use T to represent the transit time (as opposed to the pulsed field duration, t). Inserting the formula for the velocity of the ions after the pulse, we get: $L = \frac{qEt}{m}T$. Now we rearrange to determine the relationship between the transit time and the pulsed electric field strength: $T = \frac{mL}{qEt} = \left(\frac{mL}{qt}\right)\frac{1}{E}$. This inverse relationship explains the shape of the plot. Noting that the ions are singly charged ($q = 1.602 \times 10^{-19}C$) and plugging in the other given values, we obtain: $T = \frac{m(1.50m)}{(1.602 \times 10^{-19}C)(1.50 \times 10^{-6}s)}\frac{1}{E} \rightarrow T = (6.24 \times 10^{24})\frac{m}{E}$. Since we do not have a straight line, all we can do is solve for mass by using one of the data points. I choose to use (10N/C, 150ms). Putting those into the equation we find: $150 \times 10^{-3} = (6.24 \times 10^{24})\frac{m}{10} \rightarrow m = 2.4 \times 10^{-25}kg = 145u$.
Note: you will get about this same value with any of the other data points.
Also Note: this problem describes a device known as a time-of-flight mass spectrometer.