UNIVERSITY INTERSCHOLASTIC LEAGUE

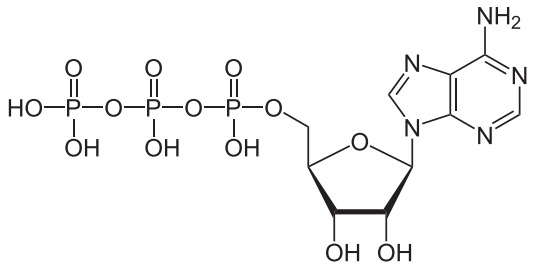
Science

Region • 2025

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 structure below and identify the correct statement regarding this molecule.



A) This molecule is not found in all cells.
B) This molecule is a monomer for a macromolecule that is responsible for long-term storage of inherited information.
C) This molecule contains a region that forms two hydrogen bonds with its complement and would only be found in RNA.
D) This molecule base pairs with guanine.
E) This molecule is a pyrimidine.

B02. Which of the following is a hormone that is produced by the pituitary gland and targets the kidneys to support osmoregulation?
A) ADH
B) FSH
C) oxytocin
D) progesterone
E) thyroxin

B03. In terms of metabolism, which one of the following processes is anabolic?
A) glycolysis
B) fermentation
C) Calvin cycle
D) citric acid cycle
E) hydrolysis

B04. In terms of natural selection and evolution, what is meant by *relative fitness*?
A) *Relative fitness* is the contribution an individual within a population—relative to the contribution of all others in the population—makes to the gene pool of the next generation.
B) *Relative fitness* is the contribution that all members of a population make to the gene pool of the next generation.
C) *Relative fitness* refers to solely the type of natural selection that results in direct combat, such as male species locking horns in combat for mating.
D) *Relative fitness* refers to the sexual selection by females for specific male characteristics, such as colorful male birds.
E) *Relative fitness* refers to all members of a population having a specific trait that is not inheritable.

B05. Of the following enzymes/proteins involved in DNA replication, which one functions first in the process?
A) DNA Polymerase I
B) Single-strand binding protein
C) DNA ligase
D) RNA primase
E) DNA helicase

B06. How many glucose molecules are made per 6 CO_2 in photosynthesis?
A) 1/2
B) 1
C) 2
D) 4
E) 6

B07. The organ system that stores most of the human body's calcium reserves is the _____ system.
A) respiratory
B) nervous
C) digestive
D) skeletal
E) endocrine

B08. In February 2025, the World Health Organization issued recommendations on the composition of the 2025-2026 Northern Hemisphere influenza seasonal vaccine. The recommendations include
A) a trivalent egg-based vaccine of two influenza A and two influenza B strains.
B) a trivalent cell-/recombinant protein-/nucleic acid-based vaccine of two influenza B and one influenza A strain.
C) a quadrivalent egg- or cell-/recombinant protein-/nucleic acid-based vaccine of two influenza A and two influenza B strains.
D) only a single strain of influenza.
E) a divalent egg-based vaccine of one influenza A and one influenza B strain.

B09. A comparison of the wings of bats and butterflies is an example of
A) unity in diversity.
B) convergent evolution.
C) homologous structures.
D) relative fitness.
E) sexual selection.

B10. Bacteriophage replicate inside _____ cells.
A) animal
B) fungal
C) all types of
D) bacterial
E) plant

B11. Which of the following contains seedless, vascular plants?
A) Lycophyta
B) Coniferophyta
C) Cycadophyta
D) Angiosperm
E) Gymnosperm

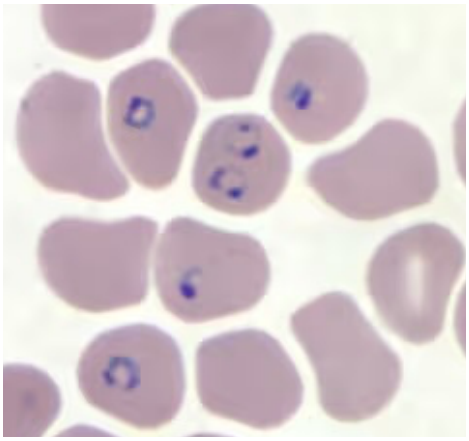
B12. Mutations in the p53 gene lead to
A) loss of tumor suppressor function.
B) an increase in the risk of cancer.
C) loss of apoptosis of damaged cells.
D) genome instability.
E) all of the above.

B13. Which of the following is used to edit a genome?
A) CRISPR/Cas9
B) Zinc Finger Nucleases
C) Transcription Activator-Like Effector Nucleases
D) Meganucleases
E) All of the above.

B14. In which biogeographical situation would there be an expectation of high endemism?
A) islands
B) oceans
C) large tropical rainforests at one elevation
D) deserts
E) continental mainland

B15. The 40S subunit of the eukaryotic ribosome contains
A) 46 proteins plus 28S, 5.8S, and 5S rRNA.
B) 33 proteins plus 18S rRNA.
C) 33 proteins plus 23S and 5S rRNA.
D) 19 proteins plus 16S rRNA.
E) the 50S ribosomal subunit.

B16. Identify the information in this image.



A) Leukocytes containing *Plasmodium falciparum* gametocytes.
B) Hepatocytes containing *Plasmodium falciparum* merozoites.
C) Mosquito gut cells containing *Plasmodium falciparum* sporozoites.
D) Mosquito salivary gland cells containing *Plasmodium falciparum* sporozoites.
E) Erythrocytes containing *Plasmodium falciparum* ring-form trophozoites.

B17. In biological hierarchy, tissues are made of
A) organelles.
B) cells.
C) organisms.
D) organs.
E) organ systems.

B18. In a population at Hardy-Weinberg equilibrium, 2532 express the dominant phenotype out of a total population of 3200. What is the frequency of the recessive allele?
A) 0.2087
B) 0.2949
C) 0.4569
D) 0.5431
E) 0.8895

B19. Small, hydrophobic molecules
A) require active transport.
B) require water to move across any membrane.
C) can only move across a biological membrane if a channel or carrier protein assists.
D) can easily move across the plasma membrane.
E) would require an energy source, such as ATP, to move across a membrane.

B20. What is the probability of having an offspring that is AaBbccDDEeFF from the following genetic cross?

AAbbccDDeeFf x AaBbccDdEEFf

A) 0
B) 1/2
C) 1/16
D) 1/32
E) 1/64

C01. Aqueous solutions of potassium carbonate and copper(II) sulfate are mixed, producing one solid product and one aqueous product. In the balanced equation for this reaction, which species has the largest coefficient?

A) The potassium carbonate
B) The copper(II) sulfate
C) The solid product
D) The aqueous product
E) They are all the same

C02. Which of these equilibrium expressions never has a denominator?

A) K_a (weak acid dissociation)
B) K_b (weak base ionization)
C) K_f (complex ion formation)
D) K_{sp} (solubility product)
E) K_{eq} (general equilibrium constant)

C03. Which of these samples would you expect to have the lowest vapor pressure?

A) 100 mL of water at 25°C
B) 50 mL of water at 50°C
C) 100 mL of ethanol (CH_3CH_2OH) at 25°C
D) a 50/50 mixture of water and ethanol (CH_3CH_2OH) at 25°C
E) a 10% solution of sugar in water at 25°C

C04. If 500.0 mL of 2.00 M HCl is added to 45.0 g of $CaCO_3$, how many liters of CO_2 gas will be produced at STP?

A) 3.46 L B) 7.52 L C) 10.1 L
D) 11.2 L E) 22.4 L

C05. Which of these oxidations states on nitrogen is *NOT* represented in any of the compounds shown below?

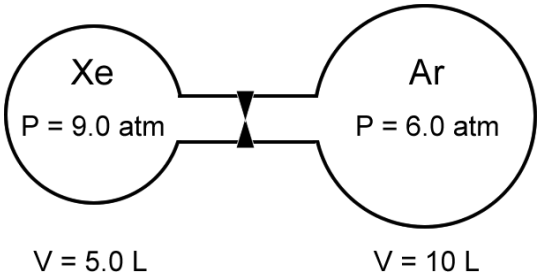
NO NO_2 N_2O N_2O_4 HNO_3

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

C06. Your lab partner mistakenly pours 375 mL of 0.50 M $CaCl_2$ solution and 475 mL of 0.75 M NaCl into a jar containing 825 mL of 0.25 M $AlCl_3$. What is the chloride ion concentration in the mixed solution?

A) 0.750 M B) 0.806 M C) 1.25 M
D) 1.88 M E) 2.03 M

C07. In the following two-bulb gas system at 0°C, the bulb on the left has a volume of 5.0 L and contains 9.0 atm of xenon gas. The bulb on the right has a volume of 10 L and contains 6 atm of argon gas. After the value is opened and the gases are allowed to mix, how many moles of gas will be in the smaller bulb?



A) 1.56 B) 1.78 C) 1.92 D) 2.24 E) 2.36

C08. What is the molar mass of the solid compound that is formed when aqueous potassium phosphate reacts with aqueous calcium bromate?

A) 134.07 g/mol
B) 175.13 g/mol
C) 198.12 g/mol
D) 266.34 g/mol
E) 310.18 g/mol

C09. Which species in this reaction mechanism is a catalyst?

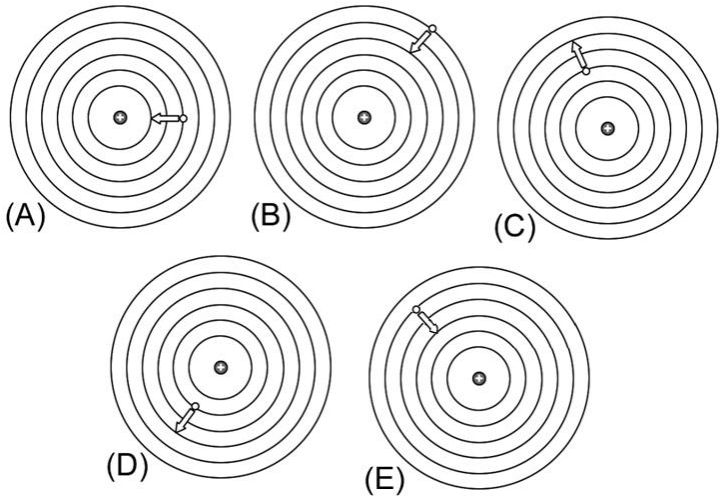
Step 1: $A + B_2 \rightarrow AB_2$
Step 2: $AB_2 + C \rightarrow AC + B_2$

A) A B) B_2 C) C D) AC E) AB_2

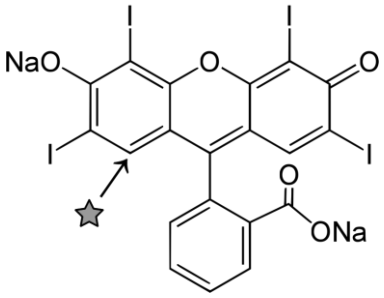
C10. A 65.0 gram sample of an unknown fuel is burned and 2887 kJ of heat are released. Which of these could be the unknown fuel?

A) Methane, CH_4 B) Methanol, CH_3OH
C) Acetylene, C_2H_2 D) Octane, C_8H_{18}
E) Hydrogen gas, H_2

C11. This graphic shows five hydrogen atoms whose electron is making a transition from one energy level to another. Which of these transitions will result in the emission of a photon with the highest energy?



C12. Red dye number 3, also known as erythrosine, has the chemical formula $C_{20}H_6I_4Na_2O_5$ and is shown below. It is a petroleum product that is added to foods to provide a red color, although it has recently been linked to cancer and to hyperactivity in children. What is the orbital hybridization of the carbon atom marked with the star?



A) sp B) sp^2 C) sp^3 D) sp^3d E) sp^3d^2

C13. An iron cylinder with a mass of 24.5 g at a temperature of 83.0°C is dropped into 125 grams of water at a temperature of 25.0°C. If the change in temperature of the iron is –56.8°C, what is the change in temperature of the water? c_{Fe} = 0.451 J/g°C

A) 0.50 °C B) 0.90 °C C) 1.0 °C
D) 1.1 °C E) 1.2 °C

C14. The gas phase equilibrium reaction $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ is exothermic. You want to shift the equilibrium to the right in order to produce as much HI as possible using the H_2 and I_2 you have available. Your colleague suggests making the following changes to the reaction process to produce more HI gas:

1. heat the reaction
2. increase the pressure in the reaction vessel by reducing the volume
3. decrease the pressure in the reaction vessel by increasing the volume
4. add a catalyst
5. shake the container

How many of these suggestions will increase the equilibrium constant and result in more HI at equilibrium?

A) None of them
B) One of them
C) Two of them
D) Three of them
E) Four of them

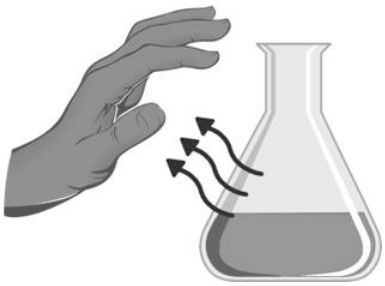
C15. If 1.78×10^{24} molecules of propane (C_3H_8) are burned and the products of the reaction are captured and cooled to 25°C, how many milliliters of liquid water will be produced?

A) 52.3 mL B) 137 mL C) 213 mL
D) 273 mL E) 312 mL

C16. A frustrated chemist said "Alright,
Here's fluoride and chlorate and bromite,
And iodate too,
But I've looked through and through,
And I can't find the sodium _____!"

A) chlorite B) nitrite
C) fluorite D) sulfite
E) phosphite

C17. Another student tells you "If the reaction flask of an aqueous reaction feels hot, that means the chemical reaction is endothermic because it's absorbing heat and getting warmer." Is his statement true or false, and why?



A) True, because endothermic reactions absorb heat and make the water in the flask warmer.
B) True, because breaking chemical bonds releases energy as heat.
C) False, because exothermic reactions give off heat and endothermic reactions give off cold.
D) False, because endothermic reactions absorb heat from the water and make the water feel cold, not hot.
E) False, because endothermic reactions do not absorb or release heat, they are thermally neutral.

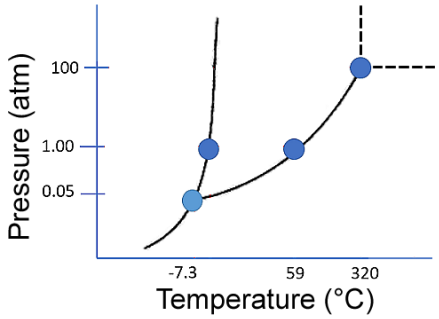
C18. If each of the compounds below has a molar solubility of 7.60×10^{-6}, for which one is the anion concentration at equilibrium equal to 2.28×10^{-5}?

A) A_2B B) AB_2 C) A_3B D) AB_3 E) A_3B_2

C19. This is the phase diagram for an unknown compound. A sample of the compound starts at ordinary laboratory conditions and then undergoes the following changes:

1) The pressure is lowered to 0.001 atm
2) The temperature is increased to 400°C
3) The pressure is increased 120 atm
4) The temperature is lowered to 60°C

How many phase changes has the sample undergone in this process?



A) 0 B) 1 C) 2 D) 3 E) 4

C20. You prepare a 300 L vat of barium hydroxide solution with a pH of 9.6 and then head home for the night. Overnight a saboteur sneaks into your lab and spikes your solution with some additional barium hydroxide. When you test the pH in the morning, it reads 11.5. How many grams of barium hydroxide did the saboteur add to your solution? (Assume there was no volume change from the added solid.)

A) 61.8 g
B) 80.2 g
C) 141.5 g
D) 160.5 g
E) 172.2 g

P01. According to Orzel, as your speed through space increases, your speed through time...
A) increases
B) decreases
C) stays constant below the speed of light
D) stays constant at the speed of light
E) stays constant above the speed of light

P02. According to Orzel, for every 800 million proton-proton collisions occurring in the Large Hadron Collider at CERN, how many of those collisions (on average) produce a top-antitop quark pair?
A) one
B) two
C) three
D) five
E) ten

P03. According to Orzel, there are some striking predictions that we can make about the effects of gravity, based on the theory of general relativity. Which of the following statements are correct predictions?

I. light bends due to gravity
II. vertical beams of light vertically change frequency
III. clocks run fast in a gravitational field

A) only statement I is correct
B) only statement III is correct
C) statements I and II are correct
D) statements I and III are correct
E) statements I, II, and III are all correct

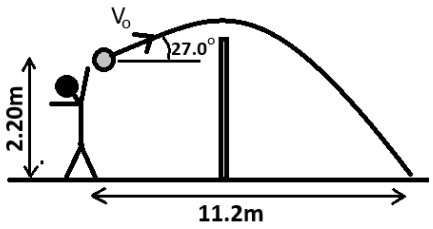
P04. A large group of asteroids orbit the Sun along the same path as Jupiter but remain either just ahead or just behind the gas giant. These asteroids have stable orbits at the Lagrange points L_4 (the leading group) and L_5 (the trailing group). What are these asteroids called?
A) The Trojans
B) The Centaurs
C) The Amor Asteroids
D) The Kuiper Asteroids
E) The Pallas Asteroids

P05. In the following formula, the units of B are [Teslas], the units of m are [kilograms], the units of t are [seconds], and the units of I are [Amperes]. What are the units of the quantity Z?

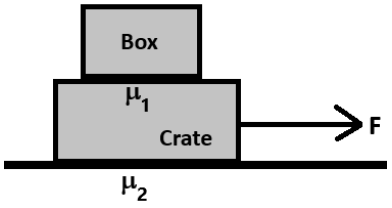
$$Z = \frac{I^2 B}{m} t^3$$

A) [Volts]/[meter]
B) [Newtons]/[second]
C) [Amperes]
D) [Coulombs]
E) [Volts]

P06. You hit a volleyball from a height of 2.20m above the ground and at an angle of 27.0° above the horizontal. The volleyball goes over the net and lands on the ground at a point that is 11.2m horizontally from you (as shown). What was the speed of the volleyball immediately after it was hit?
A) 7.79 m/s
B) 9.90 m/s
C) 10.9 m/s
D) 12.6 m/s
E) 14.0 m/s



P07. A 5.50kg Box rests on top of a 9.60kg crate which sits on a horizontal floor. The coefficient of friction between the Box and the crate is 0.28, and the coefficient of friction between the crate and the floor is 0.17. Using a rope attached to the crate, you pull the crate with a horizontal force of 80.0N (as shown). What is the acceleration of the *Box?*
A) 14.5 m/s²
B) 5.30 m/s²
C) 4.14 m/s²
D) 3.63 m/s²
E) 2.74 m/s²

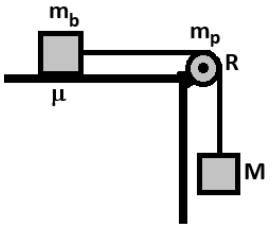


P08. A melon with a mass of 2.40kg is connected to a 1.70m long rope, the other end of which is tied to a tree branch. This forms a simple pendulum. A 55.0g arrow is launched horizontally into the melon, in which it sticks. Due to the impact, the melon-pendulum swings upward, reaching a maximum angle of 22.0° with respect to vertical. What was the velocity of the arrow just prior to its impact with the melon?

A) 49.2 m/s
B) 54.1 m/s
C) 69.5 m/s
D) 108 m/s
E) 158 m/s

P09. A 34.0kg box sits on a horizontal table. A cable that is attached to the box passes over a pulley and connects to a freely hanging 76.0kg mass (as shown). The coefficient of friction between the box and the table is 0.32. The pulley is a solid disk, has a radius of 25.0cm, and a mass of 24.0kg. The cable moves over the pulley without slipping. What is the acceleration of the box on the table once the system is released?

A) 8.68 m/s^2
B) 7.60 m/s^2
C) 6.77 m/s^2
D) 5.80 m/s^2
E) 5.23 m/s^2



P10. A violin string that is 36.0cm long is tightened until the frequency of the fourth harmonic ($n = 4$) is 780.0Hz. If the string has a mass of 0.900g, then what is the tension to which the string is tightened?

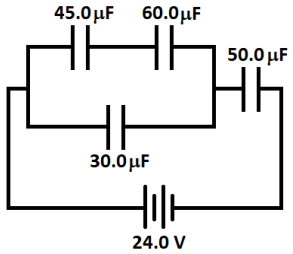
A) 0.0025 N
B) 0.351 N
C) 49.3 N
D) 140 N
E) 562 N

P11. What is the root-mean-square (rms) velocity of a molecule of water vapor at room temperature (20.0°C)?

A) 293 m/s
B) 368 m/s
C) 406 m/s
D) 520 m/s
E) 637 m/s

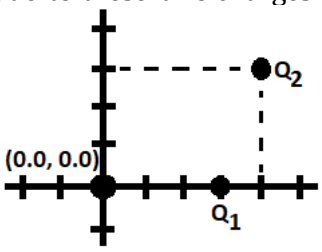
P12. For the capacitor circuit shown, determine the charge stored on the 45.0μF capacitor.

A) 632 μC
B) 341 μC
C) 292 μC
D) 72.7 μC
E) 11.4 μC

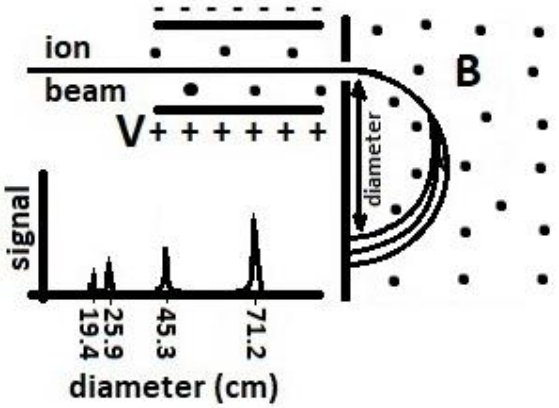


P13. Two charges are arranged as illustrated below. $Q_1 = -50.0nC$ is at (30.0cm, 0.0cm) and $Q_2 = +60.0nC$ is at (40.0cm, 30.0cm). What is the magnitude of the total electric field at the origin (0.0, 0.0) due to these two charges?

A) 7150 N/C
B) 5440 N/C
C) 4990 N/C
D) 3510 N/C
E) 2830 N/C



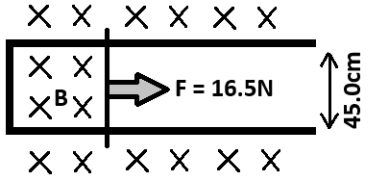
P14. An unknown compound is ionized, and the ions are directed into a velocity selector and mass spectrometer, as shown. The plates of the velocity selector are separated by 10.0cm and have a voltage of 5.00V across them. The magnetic field for both the velocity selector and the mass spectrometer has a strength of 8000.0μT. Four different ion signals appear in the spectrum. Using these data, determine the chemical structure of the original compound. Assume all ions, molecular and atomic, are singly ionized.



A) CO_2
B) CH_4
C) O_2
D) CO
E) CH_2OH

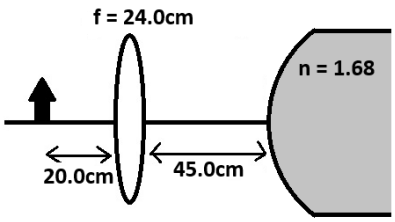
P15. A conductive bar is placed across two rails that are separated by 45.0cm. The rails are electrically connected at the left end and have negligible internal resistance. The bar has a resistance of 1.30Ω. Oriented perpendicular to the bar and rails is a magnetic field with a magnitude of 1.90T. The bar is pulled along the rails by a constant force of 16.5N. What is the terminal speed reached by the bar?

A) 13.2 m/s
B) 15.4 m/s
C) 21.5 m/s
D) 25.1 m/s
E) 29.3 m/s



P16. A converging lens with a focal length of 24.0cm is placed 45.0cm to the left of a spherical refracting surface (as shown). The refracting surface is convex and has a radius of curvature of 40.0cm. The refracting material has an index of refraction of 1.68. An object is placed 20.0cm to the left of the lens. How far beyond the refracting surface is the final image located?

A) 91.4 cm
B) 120 cm
C) 154 cm
D) 165 cm
E) 194 cm



P17. A battleship of the UrQuan empire is moving to the right at 0.65c relative to an observer on the Moon. The battleship is pursuing an Earth federation cruiser that is moving to the right at 0.81c relative to the observer. A missile fired from the UrQuan battleship travels towards the cruiser at a speed of 0.92c relative to the battleship. At what speed is the missile approaching the Earth Federation cruiser as seen by the captain of the cruiser?

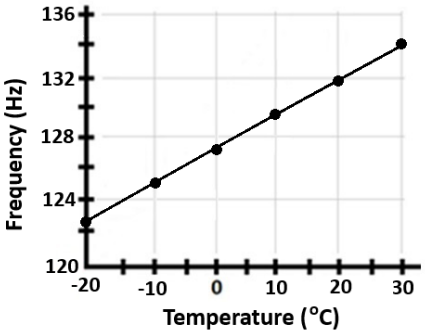
A) 0.34c
B) 0.43c
C) 0.76c
D) 0.84c
E) 0.98c

P18. A recently discovered particle is known to be a baryon with a strangeness number of -1, and a charm number of $+1$. The particle also has a charge of $+1$. Which of the following options would be an allowed decay for this particle?

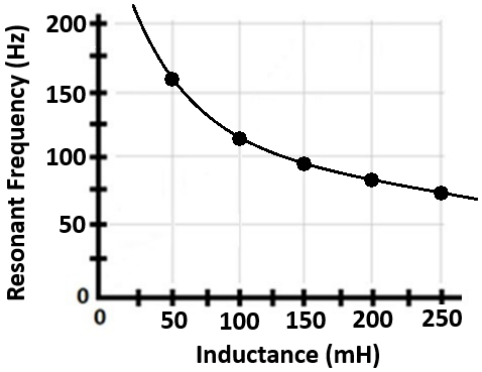
A) $X \rightarrow K^+ + \pi^0 + \pi^0$
B) $X \rightarrow K^+ + \pi^0 + \pi^-$
C) $X \rightarrow \Sigma^0 + \pi^+ + \pi^-$
D) $X \rightarrow \Sigma^0 + \pi^+ + \pi^0$
E) $X \rightarrow \Sigma^+ + p^+ + \pi^-$

P19. You measure the frequency of the sound produced by the fundamental resonance of an open-closed pipe for different air temperatures. The data are plotted below. Based on these data, what is the length of the pipe?

A) 45 cm
B) 65 cm
C) 85 cm
D) 110 cm
E) 150cm



P20. You construct an AC-RLC series circuit using a variable inductor. As you vary the inductance, you record the resonant frequency for the circuit. The data are plotted below. Using these data, determine the value of the capacitor in the RLC circuit.



A) 7 μF
B) 20 μF
C) 40 μF
D) 60 μF
E) 130 μF

Chemistry

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

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

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

Heats of Combustion (kJ/mol)

hydrogen gas	286
acetylene	1300
methane	890
methanol	726
octane	5074.9

Density of water at 25°C = 1.00 g/mL

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 inches → centimeters	1.0 mile = 1609 meters 1.00 inch = 2.54 centimeters
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}	$1000.0\ kg/m^3$
Magnetic Field Conversion	Gauss → Tesla	10^4 Gauss = 1.00 Tesla

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2025 REGIONAL

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

CHEMISTRY SOLUTIONS – UIL REGIONAL 2025

C01. (E) $K_2CO_3(aq) + CuSO_4(aq) \rightarrow CuCO_3(s) + K_2SO_4(aq)$

C02. (D) Not having a denominator in the equilibrium expression (also called the mass action expression or the law of mass action) means that all of the reactants are solid. The only equilibrium situation in which this is always the case is in solubility equilibrium, K_{sp}.

C03. (E) The volume is irrelevant in each case. As long as the sample is in a closed container and some liquid is present, the vapor pressure does not depend on the amount of liquid. Vapor pressure increases with temperature, so B is higher than A. Ethanol has weaker intermolecular forces than water does, so it will have a higher VP than water at the same temperature, so C is also higher than A. D is a mixture of water with a more volatile liquid – as a mixture it will have a lower VP than the higher VP pure liquid, but a higher VP than the lower VP liquid, so this is also a higher VP than A. E is just like A except that is has a non-volatile solute in it. This reduces the vapor pressure, so E will have a lower VP than A.

C04. (C) The balanced equation is $2\ HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(\ell) + CO_2(g)$
Moles of HCl = 0.500 L × 2.00 M = 1.00 mol. Moles of $CaCO_3$ = 45.0 g / 100.091 g/mol = 0.4496 mol. Since it requires 2 mol HCl for every mole of $CaCO_3$, you would need 0.8992 mol HCl to react away all the $CaCO_3$. You have slightly more than this, so HCl is in excess and $CaCO_3$ is the limiting reactant. Reacting 0.4496 mol of $CaCO_3$ results in 0.4496 mol of CO_2. At STP the volume of a mole of gas is 22.4 L, so 0.4496 mol × 22.4 L/mol = 10.07 L = 10.1 L.

C05. (C) Oxygen in compounds is almost always in a –2 oxidation state, and H in compounds is almost always +1. With this information the oxidation state of nitrogen in these compounds is NO: +2, NO_2: +4, N_2O: +1, N_2O_4: +4, HNO_3: +5. The oxidation state among the answer choices that is not found here is +3.

C06. (B) Moles of Cl^- from NaCl = (0.475)(0.75)(1) = 0.356 moles. Moles of Cl^- from $CaCl_2$ = (0.375)(0.50)(2) = 0.375 moles. Moles of Cl^- from $AlCl_3$ = (0.825)(0.25)(3) = 0.619 moles
Total moles Cl^- = 1.350 moles. Total volume = 1.675 L. Final Cl^- concentration = 0.806 M

C07. (A)There are many ways to solve this problem. One way is to calculate the final pressure when the valve is opened (that was the District problem, and the answer was 7.0 atm), then use $n=PV/RT$ to solve for moles in the 5.0 L bulb. Doing it that way n = (7.0 × 5.0)/(0.08206 × 273) = 1.56 moles. Or you could solve for the total number of moles of gas, knowing that one third of the moles (5 L/15 L total) will be in the smaller bulb. This way

$$n_{\mathrm{Xe}} = \frac{(9.0)(5.0)}{(0.08206)(273)} = 2.01 \text{ moles} \quad \text{and} \quad n_{\mathrm{Ar}} = \frac{(6.0)(10.0)}{(0.08206)(273)} = 2.68 \text{ moles}$$

Total moles = 4.69. 4.69 × (5/15) = 1.56 moles of gas in the smaller bulb.

C08. (E) The balanced equation is $2\ K_3PO_4(aq) + 3\ Ca(BrO_3)_2(aq) \rightarrow Ca_3(PO_4)_2(s) + 3KBrO_3(aq)$, but you don't need that, you just need to know that the calcium and phosphate will form a precipitate with the chemical formula $Ca_3(PO_4)_2$. Molar mass = 3 × Ca + 2 × PO_4 = 3 × 40.08 + 2 × (30.97+64) = 310.18 g/mol

C09. (B) A catalyst is consumed as a reactant in an early step of the mechanism and produced as a product in a later step of the mechanism. This is true of B_2. A and C are reactants, AC is a product, and AB_2 is an intermediate.

C10. (D) Solving this problem is going to require some trial and error because you are not just solving for one variable, you actually need two corresponding variables to complete the equation. The equation typically used to solve this kind of problem is Moles × heat of combustion = heat released. You also know that moles = grams/molar mass, so

$$\frac{\text{grams}}{\text{molar mass}} \times \Delta H_{\text{combustion}} = \text{heat released}$$

You don't have the molar mass or the heat of combustion, but these are related. There are a couple ways you could approach this, either by sequentially plugging in the molar mass and ΔH_{comb} for each fuel to see which one gives you 2887 kJ, or you can divide the heat generated by the mass (2887 kJ/65 g) = 44.4 kJ/g and then compare this ratio to the ratio for each fuel. Either way you hit the right answer when you get to octane:

$$\frac{65}{114.26} \times 5074.9\,\text{kJ/mol} = 2887\,\text{kJ}$$

Or

$$\frac{2887\,\text{kJ}}{65\,\text{g}} = 44.4\,\text{kJ/g} \quad \text{and for octane} \quad \frac{5074.9\,\text{kJ/mol}}{114.26\,\text{g/mol}} = 44.4\,\text{kJ/g}$$

C11. (A) In each of these atoms the electron is jumping or falling two energy levels. In C and D the electron is moving away from the nucleus and is therefore going to a higher energy level, so these will absorb a photon, not emit one. A, B, and E will all emit a photon. Although the energy levels in an atom are often shown equally spaced as they are here, the energy difference between adjacent energy levels starts out large near the nucleus and grows increasingly smaller as you move away. Therefore the transition between energy levels nearest the nucleus will have the largest energy difference and will emit the photon with the highest energy. In A the transition is n=3 → n=1, in B it is n=6 → n=4, and in E it is n=5 → n=3. A is nearest the nucleus and will have the greatest energy difference.

C12. (B) There are three regions of electron density surrounding that carbon atom: the single bond to the left to another carbon atom, the double bond to the right to another carbon atom, and the single bond to a hydrogen atom which is not shown in the structure because carbon-hydrogen bonds are not shown in these shorthand molecular structures. Since there are three regions of electron density around that carbon atom, three hybrid orbitals are involved in the bonding: *s*, *p*, and *p*, are hybridized into three sp^2 hybrid bonds.

C13. (E) Since the iron and the water will end up at the same temperature, the final temperature of the iron is the same as the final temperature of the water. The final temperature of the iron is 83.0 – 56.8 = 26.2°C, so the water increased in temperature from 25.0°C to 26.2°C, a change of 1.2°C. None of the other information provided is necessary to solve the problem. If you didn't see the shortcut and you did this problem the hard way, it would look like this:

$$-m_{\text{Fe}}c_{\text{Fe}}(T_{\text{final}} - T_{\text{Fe}}) = m_{\text{water}}c_{\text{water}}(T_{\text{final}} - T_{\text{water}})$$

c_{Fe} = 0.451 J/g°C T_{Fe} = 83.0 °C m_{water} = 125 g c_{water} = 4.184 J/g°C T_{water} = 25.0 °C

$$T_{\text{final}} = \frac{m_{\text{w}}c_{\text{w}}T_{\text{w}} + m_{\text{Fe}}c_{\text{Fe}}T_{Fe}}{m_{\text{w}}c_{\text{w}} + m_{\text{Fe}}c_{\text{Fe}}} = \frac{(125)(4.184)(25.0) + (24.5)(0.451)(83.0)}{(125)(4.184) + (24.5)(0.451)} = 26.2°\text{C}$$

$$\Delta T_{\text{water}} = 26.2 - 25.0 = 1.2°\text{C}$$

C14. (A) Heating the reaction will result in *less* HI at equilibrium because the reaction is exothermic. Changing the pressure by changing the volume will not affect the equilibrium either way because the number of moles of gas does not change in the reaction. Adding a catalyst would make the reaction reach equilibrium faster, but it would not increase the amount of product at equilibrium. Shaking the container will also not change the equilibrium constant.

C15. (C) The balanced equation is 1 C_3H_8 + 5 O_2 → 3 CO_2 + 4 H_2O. Calculate moles of propane, multiply by four to get moles of water, then multiply by 18.02 g/mol to get grams of water. Since the density of water 25°C is 1.00 g/mL, the mass of water in grams is also the volume in milliliters.
$(1.78 \times 10^{24} / 6.022 \times 10^{23}) \times 4 \times 18.02 = 213$ g = 213 mL

C16. (C) There is no such compound as sodium fluorite because the fluorite ion does not exist. Chlorite, bromite, and iodite are ClO_2^-, BrO_2^-, and IO_2^- respectively, so fluorite would be FO_2^-, but fluorine only forms one single bond and you can't draw a stable Lewis dot structure for a fluorite ion. (Geologists call the mineral CaF_2 *fluorite*, but there is no sodium fluorite.)

C17. (D) Endothermic reactions absorb heat energy from the surroundings and use it to break chemical bonds, so the surroundings, which includes the flask and the water (and your hand) would all feel colder.

C18. (D) The ratio of the anion concentration at equilibrium to the molar solubility is $2.28 \times 10^{-5} / 7.60 \times 10^{-6} = 3.0$, so you are looking for a compound that releases 3 moles of anions for each mole of compound that dissolves. The only answer choice that has three anions per formula unit is AB_3.

C19. (B) Yes, the sample starts out as a liquid, undergoes one phase change (vaporization) and ends up as a liquid. Moving through the supercritical fluid region is not considered a phase change because there is no discontinuity of phase. The only phase change occurred when crossing the solid line between liquid and gas.

C20. (B) calculate the moles of hydroxide in the initial solution and in the final solution to determine how many moles of hydroxide were added.
Initial concentration of OH^-: pOH = 14 – pH = 14 – 9.6 = 4.4. $[OH^-] = 10^{-4.4} = 3.981 \times 10^{-5}$ M.
3.981×10^{-5} M × 300 L = 0.01194 moles OH^-.
Final concentration of OH^-: pOH = 14 – pH = 14 – 11.5 = 2.5 $[OH^-] = 10^{-2.5} = 3.162 \times 10^{-3}$ M.
3.162×10^{-3} M × 300 L = 0.9486 moles OH^-.
Added moles of hydroxide = 0.9486 – 0.01194 = 0.9367 moles OH^-.
Each mole of $Ba(OH)_2$ yields 2 moles of OH^-, so the moles of $Ba(OH)_2$ added are *half* the moles of hydroxide added. Grams of $Ba(OH)_2$ added = 0.4683 moles $Ba(OH)_2$ × 171.35 g/mol = 80.2 grams.

PHYSICS SOLUTIONS – UIL REGIONAL 2025

P01. (A) page 161: "When you add the speed through space and the speed through time, you square them both and subtract the time part. So, as your speed through space increases, your speed through time also increases…"

P02. (B) page 181: "Well, the LHC produces about 800 million collisions between protons every second. Only about two of those collisions produce a top and antitop quark with a combined mass of about 350 GeV/c^2."

P03. (C) page 209: "This recipe… lets us make three striking predictions: light bends due to gravity, vertical beams of light vertically change frequency, and clocks run slow in a gravitational field."

P04. (A) The two large groups of asteroids that share Jupiter's orbit around the Sun and remain stable at Lagrange points ahead of (L_4) or behind (L_5) the gas giant are known collectively as the Jupiter Trojans, or simply as the Trojans. The group that leads Jupiter is call the "Greek camp" while those asteroids lagging behind Jupiter are called the "Trojan camp."

P05. (D) First, we convert the equation into dimensional representation: $[Z] = \frac{[Amperes]^2[Teslas]}{[kg]}[seconds]^3$. Now we expand the composite units: $[Amperes] = \frac{[Coulombs]}{[second]}$ and $[Teslas] = \frac{[seconds][Newtons]}{[Coulomb][meter]}$. Inserting those and simplifying: $[Z] = \frac{[Coulombs]^2}{[second]^2}\frac{[seconds][Newtons]}{[Coulomb][meter]}\frac{[seconds]^3}{[kg]} = \frac{[Coulombs][seconds]^2[Newtons]}{[meter][kg]}$. Now we use $[Newtons] = \frac{[kg][meters]}{[second]^2}$ and get: $[Z] = \frac{[Coulombs][seconds]^2[kg][meters]}{[meter][kg][second]^2} = [Coulombs]$.

P06. (B) We begin with the horizontal: $x = x_i + v_{ix}t + \frac{1}{2}a_x t^2$. There is no acceleration in the horizontal direction ($a_x = 0$), and the initial velocity in the horizontal direction can be written in terms of the total initial velocity ($v_{ix} = v_i \cos\theta$). Thus, $x = x_i + v_i \cos\theta\, t + \frac{1}{2}(0)t^2 \;\rightarrow$ $11.2 = 0 + v_i \cos(27.0)\, t \;\rightarrow\; 11.2 = 0.8910\, v_i t$. This gives us the relation: $v_i t = 12.57$. Now we consider the vertical: $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2$. We know the vertical acceleration is due to gravity ($a_y = -g$), and we again write the velocity component in terms of the total initial velocity ($v_{iy} = v_i \sin\theta$). This gives $y = y_i + v_i \sin\theta\, t + \frac{1}{2}(-g)t^2 \;\rightarrow$ $0 = 2.20 + v_i \sin(27.0)\, t - (0.5)(9.80)t^2$. This leads to $-2.20 = 0.4540 v_i t - 4.9t^2$. Now we use the relation that we found from the horizontal: $-2.20 = 0.4540(12.57) - 4.9t^2 \;\rightarrow$ $-7.907 = -4.9t^2$ which gives us a time of flight of $t = 1.27$seconds. Going back to the horizontal relation, we can find the total initial velocity of the volleyball to be: $v_i t = 12.57 \;\rightarrow\; v_i(1.27) = 12.57 \;\rightarrow\; v_i = 9.90\, m/s$.

P07. (E) The force diagram for the box includes gravity ($m_b g$, downward) the normal force (F_{N1}, upward) and the frictional force (f_1, to the right). The force diagram for the crate includes gravity ($m_c g$, downward), the top normal force (F_{N1}, downward), the bottom normal force (F_{N2}, upward), the top frictional force (f_1, to the left), the bottom frictional force (f_2, to the left), and the applied force (F, to the right). We'll focus on the box: there is no vertical acceleration, so the vertical forces must sum to zero: $\sum F_{yb} = 0 = F_{N1} - m_b g$. This gives $F_{N1} = m_b g = (5.50)(9.80) = 53.9N$. From this we determine the frictional force on the box to be $f_1 = \mu_1 F_{N1} = (0.28)(53.9) = 15.1N$. Then, the acceleration of the box is $\sum F_{xb} = m_b a \;\rightarrow\; f_1 = 15.1 = (5.50)a \;\rightarrow\; a = 2.74$m/s^2. For this to be valid, the crate must have an equal or greater acceleration. A quick calculation gives an acceleration of 4.14m/s^2 for the crate. Since this is greater than what we found for the box, our previous calculations are valid, and the result is a box acceleration of $a = 2.74$m/s^2.

P08. (C) First, let's find how high the melon rose after being impacted by the arrow. Based on the length of the rope and the angle to which the melon rose, we find the maximum height to be $h = L(1 - \cos\theta) = (1.70)(1 - \cos(22.0)) = 0.1238m$. By using conservation of energy, we can now find the velocity of the melon immediately after impact: $Mgh = \frac{1}{2}Mv_B^2 \;\rightarrow\; (9.80)(0.1238) = (0.5)v^2$. This gives a velocity of the melon, immediately after impact, of $v_B = 1.558$m/s. Note: $M = m_A + m_m$ is the combined mass of the melon and arrow since

they are stuck together during this part. Now we turn to conservation of momentum and examine the impact itself. Before the impact, only the arrow had momentum since the melon was initially stationary. After the impact, the melon and arrow (which get stuck together) had a velocity of $v_B = 1.558$m/s. By conservation of momentum: $m_A v_A = (m_A + m_m)v_B$. This leads to $(0.055kg)\,v_A = (0.055 + 2.40)(1.558) \;\rightarrow\; v_A = 69.5$m/s.

P09. (E) We begin with free body diagrams – one diagram for the mass, one for the box, and one for the pulley. For the hanging mass, we have two forces: gravity ($M_m g$, downward), and tension (T_1, upward). For the box, we have four forces: gravity ($m_b g$, downward), the normal force (F_N, upward), friction (F_f, left), and tension (T_2, right). For the pulley, we are more concerned with the torques created by the forces, so we list them differently. The pulley has two forces acting on it that can cause a torque: tension one (T_1, clockwise, acting at the pulley's edge), and tension two (T_2, counterclockwise, acting at the pulley's edge). All other forces acting on the pulley act at the axle, so they do not contribute to the torque and may be ignored. The acceleration of each object is as follows: the mass accelerates downward, the box accelerates to the right, and the pulley accelerates in the clockwise direction.
For the box, there is no acceleration in the vertical. This means that the vertical forces sum to zero, giving: $\sum F_{y-box} = F_N - m_b g = 0 \;\rightarrow\; F_N = m_b g = (34.0)(9.80) = 333.2$N. This allows us to calculate the frictional force: $F_f = \mu F_N = (0.32)(333.2) = 106.6$N. Now we can sum the horizontal forces acting on the box: $\sum F_{x-box} = T_2 - F_f = m_b a \;\rightarrow\; T_2 - 106.6 = (34.0)a$. This simplifies to $T_2 = 34a + 106.6$. For the mass, there are no horizontal forces at all. The sum of the vertical forces gives: $\sum F_{y-mass} = M_m g - T_1 = M_m a \;\rightarrow\; (76.0)(9.80) - T_1 = (76.0)a$. This simplifies to $T_1 = 744.8 - 76a$. Finally, there is the torque equation for the pulley. Both tensions act at the edge of the pulley, so the torque arm for both tensions is the radius of the pulley, r. Thus, we have $\sum \tau = T_1 r - T_2 r = I\alpha$. The moment of inertia for a solid disk pulley is $I = \frac{1}{2}m_p r^2$. Also, since the cable does not slip on the pulley, the angular acceleration is related to the linear acceleration by $a = r\alpha$. Putting it all together in the torque equation gives: $T_1 r - T_2 r = \frac{1}{2}m_p r^2 \alpha$, which simplifies to $T_1 - T_2 = \frac{1}{2}m_p r\alpha = \frac{1}{2}m_p a = (0.5)(24.0)a = 12.0a$. Now we combine all three equations:
$T_1 - T_2 = 12a \;\rightarrow (744.8 - 76a) - (34a + 106.6) = 12a \;\rightarrow$
$638.2 - 110a = 12a \;\rightarrow\; 122a = 638.2 \;\rightarrow\; a = 5.23$m/s^2.

P10. (C) First, the mass per length of the string is $\mu = \frac{m}{L} = \frac{0.900 \times 10^{-3}}{0.360} = 0.0025\ kg/m$. Then, the frequency is related to the speed of the wave by $f_n = \frac{nv}{2L} \;\rightarrow\; 780.0 = \frac{(4)v}{2(0.360)} \;\rightarrow\; v = 140.4\,m/s$. Finally, we relate the speed of the wave to the tension: $v = \sqrt{\frac{T}{\mu}} \;\rightarrow\; 140.4 = \sqrt{\frac{T}{0.0025}} \;\rightarrow\; T = 49.3\ N$.

P11. (E) The mass of a molecule of water is $m = (18u)(1.66 \times 10^{-27}) = 2.99 \times 10^{-26}\ kg$. Room temperature in Kelvin is $T = 20 + 273 = 293\ K$. Kinetic theory gives the relation that for a gas molecule in three dimensions, we have: $\frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_B T$. Inserting Boltzmann's constant and the molecular mass, we get:
$(0.5)(2.99 \times 10^{-26})v_{rms}^2 = (1.5)(1.38 \times 10^{-23})(293) \;\rightarrow$
$(1.495 \times 10^{-26})v_{rms}^2 = 6.065 \times 10^{-21}$. This gives an r-m-s velocity of $v_{rms} = \sqrt{405960} = 637\ m/s$.

P12. (C) Combining the two series capacitors in the top branch gives: $\frac{1}{C_A} = \frac{1}{45} + \frac{1}{60} \;\rightarrow\; C_A = 25.71\mu F$. We then combine the top branch in parallel with the bottom branch capacitor: $C_B = 25.71 + 30 = 55.71\mu F$. Finally, we combine the group capacitance in series with the lone capacitor on the right:
$\frac{1}{C_T} = \frac{1}{55.71} + \frac{1}{50} \;\rightarrow\; C_T = 26.35\mu F$. This is the total circuit capacitance. The total charge stored in the circuit is: $Q_T = C_T V_T = (26.35)(24.0) = 632.4\mu C$. This same charge is stored on the lone 50.0μF capacitor

($Q_{50} = 632.4\mu C$) and on the group capacitance ($Q_B = 632.4\mu C$). Thus, the voltage across the group capacitance is $V_B = \frac{Q_B}{C_B} = \frac{632.4}{55.71} = 11.35V$. This voltage is the same for the bottom branch ($V_{30} = 11.35V$) and the top branch ($V_A = 11.35V$). Lastly, we find the charge stored on the top branch: $Q_A = C_A V_A = (25.71)(11.35) = 291.9\mu C$. This is the same value for both capacitors, including the 45.0μF capacitor. Thus, $Q_{45} = 291.9 \approx 292\mu C$.

P13. (D) The magnitude of the electric field at the origin due to each charge is given by the equation $|E| = \left|\frac{kQ}{r^2}\right|$. So, we first need the distance from the origin to each charge. For Q_1 the distance is $r_1 = 30.0cm = 0.300m$. For charge Q_2, the distance is $r_2 = \sqrt{40.0^2 + 30.0^2} = 50.0cm = 0.500m$. Thus, the magnitude of the electric field at the origin due to charge Q_1 is $|E_1| = \left|\frac{(8.99\times10^9)(-50.0\times10^{-9})}{(0.300)^2}\right| = 4994N/C$. Similarly, the magnitude of the electric field at the origin due to charge Q_2 is $|E_2| = \left|\frac{(8.99\times10^9)(60.0\times10^{-9})}{(0.500)^2}\right| = 2158N/C$. Now we must consider the directions of these electric fields. Since Q_1 is negative, the electric field E_1 is directed towards the charge. At the origin, this is entirely in the positive x-direction. In vector notation, we would write this first electric field as $\vec{E}_1 = 4994\hat{\imath} + 0\hat{\jmath}\ [N/C]$. Charge Q_2 is positive, so E_2 is directed away from the charge. At the origin, this is down and left (into the third quadrant). Based on the right triangle formed with the origin, Q_2, and the x-axis, we can see that the x-component of the second electric field will point in the negative x-direction and have a magnitude of $|E_{2x}| = \frac{40}{50}|E_2| = 0.80|E_2|$. Similarly, the y-component of the second electric field will point in the negative y-direction and have a magnitude of $|E_{2y}| = \frac{30}{50}|E_2| = 0.60|E_2|$. Thus, $E_{2x} = -0.80(2158) = -1726N/C$ and $E_{2y} = -0.60(2158) = -1295N/C$. Therefore, in vector notation, the second electric field is $\vec{E}_2 = -1726\hat{\imath} - 1295\hat{\jmath}\ [N/C]$. Combining the first and second electric fields gives us the total electric field at the origin. In vector notation, this is $\vec{E} = \vec{E}_1 + \vec{E}_2 = 4994\hat{\imath} + 0\hat{\jmath} - 1726\hat{\imath} - 1295\hat{\jmath} = 3268\hat{\imath} - 1295\hat{\jmath}$. The magnitude of this total electric field is $|E| = \sqrt{(3268)^2 + (-1295)^2} = 3515 \approx 3510\ N/C$.

P14. (A) The four different peaks indicate that there will be four different types of ions produced by this compound. From the masses of these ion types, we can work backward to the composition of the original compound. The velocity selector has an electric field of $E = \frac{V}{d} = \frac{5.00V}{0.100m} = 50.0V/m$. This gives a selected velocity for all of the various ions of $v = \frac{E}{B} = \frac{50.0V/m}{0.008T} = 6250m/s$. The relevant equation for the mass spectrometer is $r = \frac{mv}{qB}$. Solving for the mass and converting radius to diameter gives: $m = \frac{qBr}{v} = \frac{qBd}{2v}$. Since we assume that all of the ions are singly ionized, we have $q = 1.602\times10^{-19}C$ for all of the ions. Starting with the largest diameter, we obtain a mass of $m_1 = \frac{(1.602\times10^{-19})(0.008)(0.712)}{2(6250)} = 7.30\times10^{-26}kg$. Converting this to atomic mass units gives: $m_1 = 44.0amu$. Using the same equation with the other peaks in the spectrum gives ion masses of $m_2 = 28.0amu$, $m_3 = 16.0amu$, and $m_4 = 12.0amu$. Now we interpret these data: the smaller masses clearly are C (12amu) and O (16amu). We can also conclude that the next masses are CO (28amu) and CO_2 (44amu). There is no sign of hydrogen, but clear signal for carbon and oxygen. We conclude that the original compound is CO_2 since all of the ion types are logical fragments of this parent compound.

P15. (E) We reach terminal speed when the magnetic force acting on the induced current in the bar is equal to the applied force pulling the bar. We start with Faraday's Law: $\mathcal{E} = \frac{\Delta\Phi_B}{\Delta t}$. Here the magnetic flux is given by $\Phi_B = BA$. The magnetic field B is constant, but the area is increasing as the bar is pulled along the rails. The area is a rectangle, so it can be written as $A = \ell w$. The width (the distance between the rails) is also constant – only the length of the area is changing. Putting all of this into Faraday's Law gives $\mathcal{E} = \frac{\Delta(BA)}{\Delta t} = \frac{Bw\Delta\ell}{\Delta t} = Bwv$ where v is the velocity of the bar on the rails. The induced current is then $I = \frac{\mathcal{E}}{R} = \frac{Bwv}{R}$. Since the current is perpendicular to the magnetic field, the force acting on the

induced current is $F = IwB = \frac{Bwv}{R}wB = \frac{w^2B^2v}{R}$. Finally, we set this expression for the force on the induced current equal to the applied force, and solve for the velocity:
$F = F_{app} = 16.5 = \frac{w^2B^2v}{R} = \frac{(0.450)^2(1.90)^2v}{1.30} = 0.5623v \;\rightarrow\; v = 29.3m/s.$

P16. (C) As with all compound optical systems, we deal with each element separately. Starting with the lens, we use $\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$ to find the location of the first image. Thus, $\frac{1}{20.0}+\frac{1}{q_1}=\frac{1}{24.0} \;\rightarrow$ $q_1 = -120cm$. This image formed by the lens is the object for the refracting surface. The distance of this image from the surface is $p_2 = D - q_1 = 45.0 — 120 = 165cm$. For finding the image resulting from a refracting surface, the equation is $\frac{n_1}{p}+\frac{n_2}{q}=\frac{n_2-n_1}{R}$. The indices of refraction are that of air ($n_1 = 1.00$) and the refracting material ($n_2 = 1.68$). For a convex refracting surface, the radius of curvature is positive. Putting this together gives: $\frac{1}{165}+\frac{1.68}{q_2}=\frac{1.68-1.00}{40.0}=\frac{0.68}{40.0} \;\rightarrow$ $q_2 = 154cm$. This is the final image location relative to the refracting surface.

P17. (D) There are several frames of reference in this problem, but the best frame to work in is that of the observer on the Moon. First, we determine the speed of the missile as seen by the observer on the Moon. Transforming from the battleship frame to the Moon frame gives a missile velocity of $v' = \frac{u+v}{1+\frac{uv}{c^2}} = \frac{0.65c+0.92c}{1+\frac{(0.65c)(0.92c)}{c^2}} = \frac{1.57c}{1.598} = 0.9825c$. In this case, the signs of the velocities are both positive since the missile moves to the right and the Moon moves to the left, as seen by the UrQuan battleship. Now, converting the Moon frame velocity into the frame of reference of the Earth Federation cruiser, we get a missile velocity of $v'' = \frac{w+v'}{1+\frac{wv'}{c^2}} = \frac{0.9825c-0.81c}{1-\frac{(0.9825c)(0.81c)}{c^2}} = \frac{0.1725c}{0.2042} = 0.84c$. Here, one sign is negative since both the missile and Federation spaceship are moving to the right as seen by the observer on the Moon.

P18. (D) The particle is a baryon, so its decay products must include exactly one baryon (since baryon number is a conserved quantity). This eliminates choices A, B, and E since the decay products of A and B are all mesons (no baryons), and the decay products of E include two baryons. Strangeness and Charm numbers are not helpful since neither are conserved quantities. However, the total charge is conserved. The original particle has a charge of +1, so the decay products must also add up to a total charge of +1. This eliminates choice C since its decay products add up to a total charge of 0. Therefore, the choice that conserves both baryon number and charge is the only correct choice - D.

P19. (B) The equation for the frequency of sound produced by the first harmonic of an open-closed pipe is $f_1 = \frac{(1)v}{4L} = \frac{v}{4L}$. The speed of sound also varies with temperature, according to the equation $v = (331m/s)\sqrt{1+\frac{T}{273}}$ where the temperature T is in Celsius. Putting these together, we obtain $f_1 = \frac{331}{4L}\sqrt{1+\frac{T}{273}}$. Although the plot looks linear, it is not. It represents a small segment of a larger curve, so it only looks linear. Therefore, I will simply use a data point to plug into the equation and answer the question. I'll choose (20°, 132Hz). This gives
$132 = \frac{331}{4L}\sqrt{1+\frac{20}{273}} \;\rightarrow\; 528L = 343 \;\rightarrow\; L = 0.65m = 65cm.$

P20. (B) The resonant frequency for an AC-RLC series circuit is given by the equation $f = \frac{1}{2\pi}\frac{1}{\sqrt{LC}}$. The plot is clearly not linear, so it is easiest to use a data point to estimate the answer. I'll use (150mH, 95Hz). Inserting this into the equation gives: $95 = \frac{1}{2\pi}\frac{1}{\sqrt{(0.150)C}} \;\rightarrow\; 356000C = 6.67 \;\rightarrow\; C = 1.9\times10^{-5}F = 19\mu F \approx 20\mu F.$