UNIVERSITY INTERSCHOLASTIC LEAGUE

Science

Region • 2023

GENERAL DIRECTIONS:

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

B01. An organic macromolecule that contains a five-carbon sugar, three phosphates, and a nitrogenous base would best be classified into which major macromolecular group?
A) carbohydrates
B) proteins
C) nucleic acids
D) ATP
E) lipids

B02. Eukaryotic cells contain several different types of RNA polymerases. Which RNA polymerase specifically synthesizes 28S, 18S, and 5.8S rRNA molecules?
A) RNA Polymerase I
B) RNA Polymerase II
C) RNA Polymerase III
D) None of the above are correct.
E) All of the above transcribe all rRNA genes.

B03. In vertebrates, glucose can be generated from non-carbohydrate substrates in the liver, and to a lesser extent, the kidneys, in a process called
A) glycogenolysis.
B) cellular respiration.
C) glycolysis.
D) gluconeogenesis.
E) pyruvate oxidation.

B04. A male child is completely colorblind but neither of his parents is colorblind. What is the genotype of his mother?
A) X^CX^c
B) X^CX^C
C) X^cX^c
D) X^CY
E) X^cY

B05. Cytokinins are plant hormones that are primarily responsible for
A) phototropism.
B) plant growth inhibition.
C) fruit ripening.
D) resistance to fungal or bacterial invaders.
E) cell growth/division and differentiation.

B06. The pathophysiology of the Gram-positive pathogen, _______, involves the global dissemination of the toxin that interferes with the release of inhibitory neurotransmitters, particularly GABA and glycine.
A) *Clostridium botulinum*
B) *Clostridium tetani*
C) *Clostridium perfringens*
D) *Clostridium difficile*
E) *Bacillus anthracis*

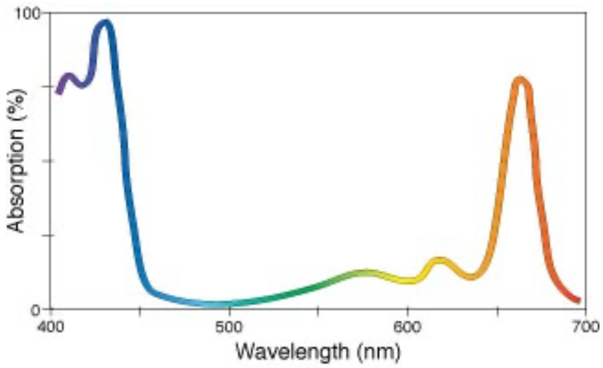
B07. In a population at Hardy-Weinberg equilibrium, 3% of the population express the recessive phenotype. What percent of the population is heterozygous?
A) 17.3%
B) 28.6%
C) 68.4%
D) 82.7%
E) 98.5%

B08. The tissue that includes loose and dense examples and collagenous, reticular, or elastic fibers is classified as ________ tissue.
A) muscle
B) epithelial
C) nervous
D) connective
E) none of the above

B09. Which organ is primarily responsible for maintaining potassium homeostasis in the human body?
A) kidney
B) liver
C) thyroid
D) pancreas
E) skin

B10. The oxidation of ammonium to dinitrogen gas using nitrite as the anaerobic electron acceptor is called
A) denitrification.
B) nitrogen fixation.
C) anammox.
D) ammonification.
E) nitrification.

B11. Examine the absorption spectrum for a given pigment. At which wavelength is transmittance highest?

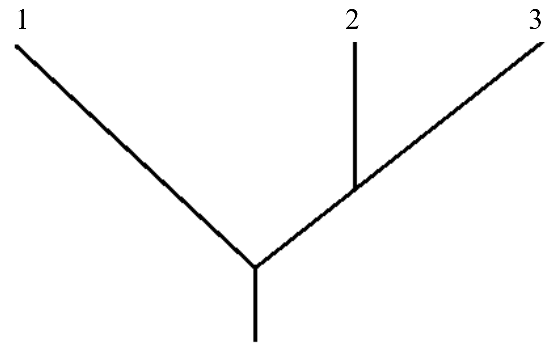


A) 410 nm
B) 425 nm
C) 495 nm
D) 620 nm
E) 660 nm

B12. The resistance mechanism employed by the *Pseudomonas aeruginosa* strain identified by the Centers for Disease Control and Prevention and the Food and Drug Administration in artificial tears in February 2023 is
A) limitation of the influx of the antimicrobial agent into the cell.
B) rapid efflux of the antibiotic from the inside of the cell.
C) modification of the drug target.
D) imitation of human proteins on the cell surface of the pathogen to prevent recognition by the immune system.
E) inactivation of the antimicrobial agent through enzymatic action.

B13. DNA wrapped approximately two times around a core of eight histone proteins is called a
A) chromatosome.
B) chromatid.
C) nucleosome.
D) 30-nm fiber.
E) 300-nm fiber.

B14. Examine the currently accepted evolutionary tree for the three Domains of life. Which is paired correctly?



A) 1=Bacteria; 2=Archaea; 3=Eukarya
B) 1=Archaea; 2=Eukarya; 3=Bacteria
C) 1=Eukarya; 2=Bacteria; 3=Archaea
D) 1=Prokarya; 2=Eukarya; 3=Archaea
E) 1=Archaea; 2=Bacteria; 3=Eukarya

B15. Given the following normal and mutated chromosomal sequences, where the asterisk represents the centromere, what type of chromosomal mutation has occurred?

Normal: ABC*DEFGH
Mutant: ABC*FEDGH

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

B16. Analogous structures in biology
A) refer to structures that have an evolutionary relationship.
B) are the result of similar evolutionary pressures.
C) include the forelimbs of mammals, as examples.
D) have no similarity in function.
E) are derived from a common ancestral feature.

B17. In a population that includes both white- and brown-haired rabbits, white-haired rabbits prefer to mate with other white-haired rabbits, and brown-haired rabbits prefer to mate with other brown-haired rabbits. This situation
A) increases gene flow in the population.
B) would have no effect on evolution.
C) always results in speciation.
D) is considered random mating.
E) might lead to microevolution due to the non-random mating.

B18. A researcher is examining three genes that are known to be linked in *Drosophila*. If the researcher crosses a fly that carries at least one dominant allele for each of the three genes with a fly that is homozygous recessive for all three genes, which of the following genotypes in the progeny would indicate a double crossover recombination event has occurred? Assume the genes are in the correct order on the chromosome.

Parent 1: *A_B_C_*
Parent 2: *a_b_c_*

A) *A_B_C_*
B) *A_b_C_*
C) *a_b_c_*
D) *a_B_C_*
E) *a_b_C_*

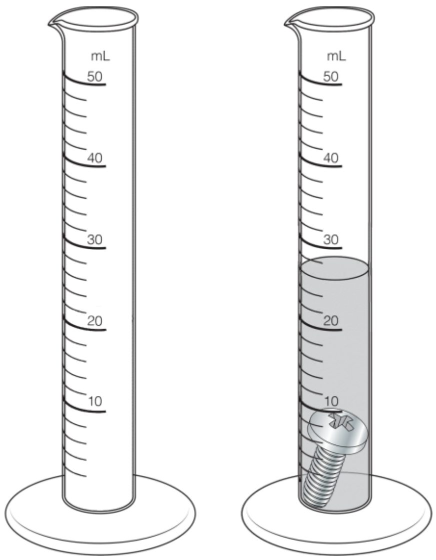
B19. The chemical reactions occurring within the peroxisome include all of the following except
A) β-oxidation of fatty acids.
B) some steps in the photorespiration pathways in plant cells.
C) synthesis of bile acids in the liver.
D) oxidation of glucose.
E) production of hydrogen peroxide.

B20. Mouse coat color is controlled by two unlinked genes. Wild-type agouti color (*A*) is dominant to solid black fur color (*a*). The second gene (*C*) controls pigment production. A cross between two agouti mice that are heterozygous for both genes would yield a ratio of:

__ agouti: __black:__albino.

A) 9:7:0
B) 3:9:4
C) 4:3:9
D) 9:4:3
E) 9:3:4

C01. The empty 50 mL graduated cylinder weighs 172.6 grams. If the graduated cylinder with the screw and the liquid has a total mass of 228.0 grams and the screw has a density of 4.9 g/mL, what is the density of the liquid?



A) 0.95 g/mL
B) 1.0 g/mL
C) 1.1 g/mL
D) 1.2 g/mL
E) 1.3 g/mL

C02. Nitroglycerin decomposes violently according to the following (unbalanced) equation. When this equation is balanced using the smallest whole numbers, what is the coefficient on CO_2?

___ $C_3H_5(NO_3)_3(\ell) \longrightarrow$

___ $CO_2(g)$ + ___ $H_2O(\ell)$ + ___ $N_2(g)$ + ___ $O_2(g)$

A) 3
B) 6
C) 9
D) 12
E) 15

C03. 0.100 moles of C_3H_8 gas and 0.500 moles of O_2 gas are placed in a 2.00 liter rigid container at 25.0 °C and a complete combustion reaction occurs, producing CO_2 and H_2O gas. After the reaction is complete the container is heated to 190.0 °C. What will the final pressure of the gas inside the container be?

A) 11.4 atm
B) 5.45 atm
C) 13.3 atm
D) 7.8 atm
E) 4.68 atm

C04. If the gas phase reaction $2A + B \rightleftharpoons 3C + D$ is at equilibrium and you heat the container, what will happen to the ratio of products to reactants in the container?

A) The reaction will shift to the left, so the ratio of products to reactants will go down
B) The reaction will shift to the right, so the ratio of products to reactants will go up
C) The reaction will shift to the right, so the ratio of products to reactants will go down
D) The reaction will shift to the left, so the ratio of products to reactants will go up
E) There will be no change in the ratio of products to reactants

C05. On the District exam, a scientist titrated a 50.0 mL sample of 0.100 M benzoic acid using 0.500 M NaOH. He now decides to do a second trial to verify his results, but he runs out of 0.500 M NaOH after adding only 3.65 mL to the benzoic acid solution. What is the pH of the solution at this point? For benzoic acid $K_a = 6.3 \times 10^{-5}$.

A) 3.96
B) 4.20
C) 5.66
D) 7.28
E) 9.06

C06. The mechanism for the gas-phase reaction $A_2(g) + B_2(g) \rightarrow 2AB(g)$ is as follows:

1) $A_2(g) \rightarrow 2A(g)$ (*slow*)
2) $A(g) + B_2(g) \rightarrow AB_2(g)$ (*fast*)
3) $AB_2(g) \rightarrow AB(g) + B(g)$ (*fast*)
4) $A(g) + B(g) \rightarrow AB(g)$ (*fast*)

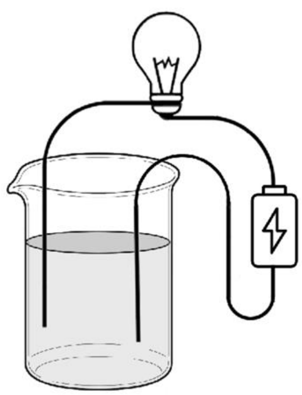
Which of the following changes is likely to make the reaction go faster?

A) Lower the temperature of the reaction container
B) Increase the volume of the reaction container
C) Increase the pressure of gas B_2
D) Increase the pressure of gas A_2
E) Add an inert gas such as He to the reaction container

C07. Which of the following isotopes contains the most neutrons in its nucleus?

A) U-238
B) Np-237
C) Pu-244
D) Am-243
E) Cm-245

C08. A sample of a white crystalline solid is added to water, and upon stirring is found to completely dissolve. When the solution is incorporated into an electrical circuit, the light bulb does not light up at all. Which of these compounds could possibly be the white crystalline solid?



A) NH_4Cl
B) K_2CO_3
C) $NaHCO_3$
D) $C_6H_{12}O_6$
E) $AgNO_3$

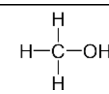
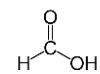
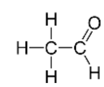
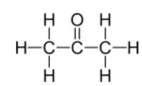
C09. If 125 grams of ice at –15.0°C is added to 500. mL of water at 35.0°C, what will the final temperature of the water be?

A) 21.8 °C
B) 12.0 °C
C) 17.5 °C
D) 13.2 °C
E) 10.5 °C

C10. If you add 25.0 grams of $Ca(OH)_2$ to 9.00 L of water and then dilute it to a final volume of 10.0 L and let it reach equilibrium, how many grams of solid $Ca(OH)_2$ will remain undissolved in the container? K_{sp} for $Ca(OH)_2 = 5.00 \times 10^{-6}$.

A) 17.0 g
B) 7.98 g
C) 18.8 g
D) 6.15 g
E) 12.5 g

C11. A friend asks you to check his chemistry homework for him before he turns it in. The assignment is to identify the strongest intermolecular force that is present in each of the following compounds when they are in the liquid state. How many of his answers (in the third column) are incorrect?

Compound Name	Compound Structure	Strongest IMF in the liquid state
Methanol		Hydrogen bonds
Formic Acid		Hydrogen bonds
Acetaldehyde		Hydrogen bonds
Acetylene	$H-C\equiv C-H$	Dispersion forces
Acetone		Hydrogen bonds

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

C12. For an equal mass of water, which of these phase changes is the most exothermic?

A) Freezing
B) Melting
C) Vaporization
D) Condensation
E) Sublimation

C13. You intended to dilute 300. mL of 0.015 M solution of hydrochloric acid to twice the original volume, then add 0.15 grams of NaOH, but instead of diluting the solution with deionized water you accidentally diluted it with 0.0050 M hydrochloric acid instead. What will the pH of the final solution be after you add the NaOH?

A) 2.43
B) 3.55
C) 7.00
D) 10.45
E) 12.75

C14. What is the sum of the oxidation numbers of all the atoms in the five compounds and ions below?

$AlCl_3$ SO_4^{2-} Ni^{2+} N_2O_4 NO_3^{-}

A) –2
B) –1
C) 0
D) +1
E) +2

C15. When a ball of copper wire is added to concentrated nitric acid, the following redox reaction occurs:

$$Cu(s) + 2HNO_3(aq) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(\ell)$$

If you dropped a 123 gram piece of copper into 135.5 mL of 15.7 M nitric acid and the reaction went to completion, how many grams of solid copper metal would be left over?

A) 65 g
B) 55 g
C) 37 g
D) 83 g
E) 17 g

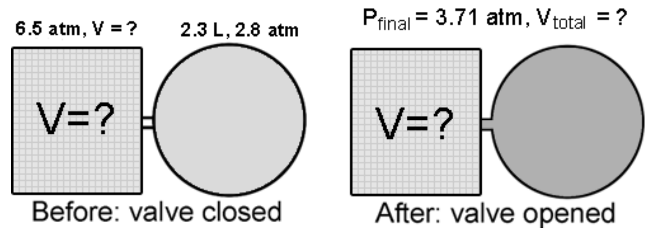
C16. What is the molar mass of phosphorous acid?

A) 31.98
B) 32.99
C) 34.00
D) 82.00
E) 98.00

C17. Your incompetent lab partner was supposed to mix up 1200 mL of a NaOH solution with a pH of 12.00, but when you measured the pH it was only 11.50. How many more grams of NaOH should you add to the solution to bring the pH up to pH 12.00? Assume the volume doesn't change when adding solid NaOH.

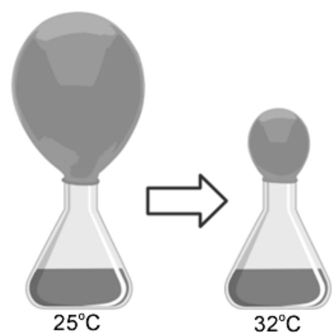
A) 0.33 g
B) 0.48 g
C) 0.40 g
D) 0.29 g
E) 0.13 g

C18. Two bulbs are connected by a valve. One bulb contains 2.3 L of Cl_2 gas at 2.8 atm and the other bulb, whose volume is unknown, contains Cl_2 gas at 6.5 atm. When the valve is opened, the final pressure in the combined system is 3.71 atm. What was the volume of the second bulb? Assume the volume of the valve tube is negligible.



A) 0.75 L
B) 1.50 L
C) 2.25 L
D) 3.00 L
E) 3.75 L

C19. Which of the following reactions could be taking place inside the flask?



A) $X_2(g) + Y_2(g) \rightarrow 2\ XY(aq)$ $\Delta H = -15kJ$
B) $X_2(g) + Y_2(g) \rightarrow 2\ XY(aq)$ $\Delta H = +15kJ$
C) $2\ XY(aq) \rightarrow X_2(g) + Y_2(g)$ $\Delta H = -15kJ$
D) $2\ XY(aq) \rightarrow X_2(g) + Y_2(g)$ $\Delta H = +15kJ$
E) $2\ XY(aq) \rightarrow X_2(\ell) + Y_2(\ell)$ $\Delta H = -15kJ$

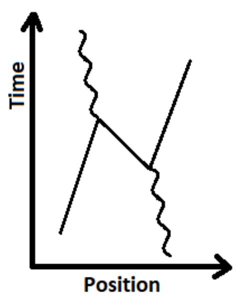
C20. Which of these properties is most closely associated with the polarity of a molecule?

A) Reactivity toward acids
B) Boiling point
C) Temperature
D) Density
E) Odor

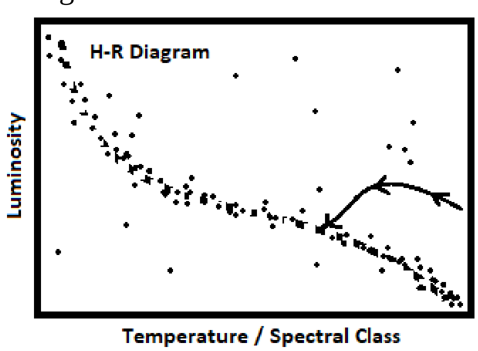
P01. According to Feynman, how many basic actions are needed to produce all of the phenomena associated with light and electrons?
A) two
B) three
C) four
D) six
E) ten

P02. According to Feynman, the junction number is the amplitude to emit or absorb a photon. It is labelled j and has a value of about -0.1. With what physical property is this number associated?
A) mass
B) magnetic moment
C) spin
D) charge
E) polarization

P03. According to Feynman, the diagram shown includes an electron moving backwards in time. What does a backwards-moving electron represent when viewed with time moving forwards?
A) a neutrino
B) an electron
C) a photon
D) a proton
E) a positron



P04. The path shown on this H-R diagram illustrates what stage of stellar evolution?



A) a protostar becoming a main sequence star
B) a main sequence star becoming a red giant star
C) a main sequence star becoming a supergiant star.
D) a red giant star becoming a white dwarf
E) a supergiant star becoming a neutron star

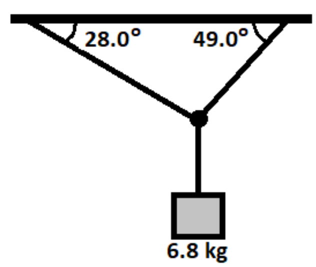
P05. For this equation, E is in [Volts]/[meter]; a is in [meters]/[second^2], and Q is in [Coulombs]. What are the units of W?

$$W = \frac{Q^2 E}{a}$$

A) [kilogram][Coulomb][second]
B) [kilogram][Ampere][second]
C) [meter][kilogram][Coulomb]
D) [meter][kilogram][Ampere]
E) [meter][Ampere][second]

P06. A rocket, starting from rest at ground level, accelerates upward at a rate of 16.5m/s^2. Exactly 3.50seconds after launch, a metal plate detaches from the rocket and falls back to Earth. How fast is the plate moving when it impacts the ground?
A) 36.8 m/s
B) 48.4 m/s
C) 57.8 m/s
D) 65.8 m/s
E) 72.9 m/s

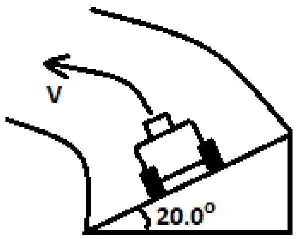
P07. A 6.80kg box is held aloft by an arrangement of ropes, as shown. The upper left rope makes an angle of 28.0° with respect to the horizontal, and the upper right rope makes an angle of 49.0° with respect to the horizontal. The lower rope is vertical and attaches to the box. What is the tension in the upper left rope?
A) 66.6 N
B) 60.4 N
C) 48.1 N
D) 44.9 N
E) 32.1 N



P08. A sphere with a mass of 12.0kg sits in equilibrium atop a vertical spring. The sphere is pressed down, compressing the spring by 39.0cm, and released. Once released, the sphere launches upward, achieving a maximum height of 1.24m above its original equilibrium position. What is the spring constant of the spring?
A) 2520 N/m
B) 1920 N/m
C) 1260 N/m
D) 960 N/m
E) 660 N/m

P09. A car drives around a banked circular track that has a radius of curvature of 250.0m. The track is banked at an angle of 20.0° with respect to horizontal and the coefficient of friction between the car's tires and the track is 0.67. What is the maximum speed at which the car can travel without slipping?

A) 31.5 m/s
B) 48.3 m/s
C) 57.9 m/s
D) 62.0 m/s
E) 84.6 m/s



P10. You have a pendulum whose normal period of oscillation is 1.35seconds. You enter an elevator with your pendulum, and when the elevator accelerates upward, the pendulum swings with a period of oscillation of 1.12seconds. What is the acceleration of the elevator?

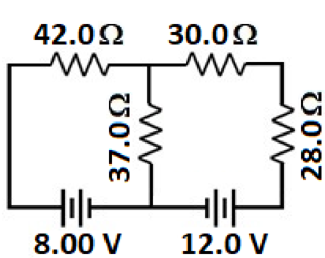
A) 5.02 m/s^2
B) 4.44 m/s^2
C) 3.23 m/s^2
D) 2.01 m/s^2
E) 0.96 m/s^2

P11. 0.55 moles of an ideal gas starts at a temperature of 45.0°C and a volume of 1.20 liters. First, the gas is expanded under constant pressure until its volume is 1.60 liters. Then the gas is compressed under constant temperature until it is back to its original volume of 1.20 liters. What is the final pressure of the gas?

A) 1.71×10^5 Pa
B) 2.28×10^5 Pa
C) 9.08×10^5 Pa
D) 1.21×10^6 Pa
E) 1.62×10^6 Pa

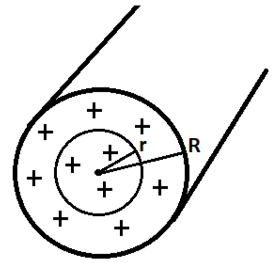
P12. For the circuit shown, determine the current flowing in the 37.0Ω resistor.

A) 51.5 mA
B) 106 mA
C) 126 mA
D) 158 mA
E) 310 mA



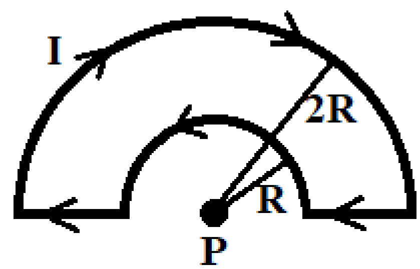
P13. A solid plastic cylinder has a radius of 1.30cm and holds a linear charge density of 45.0nC/m. The charge is spread evenly throughout the volume of the cylinder. What is the magnitude of the electric field at a distance of 1.00cm from the center of the cylinder?

A) 28300 N/C
B) 36800 N/C
C) 47900 N/C
D) 62200 N/C
E) 80900 N/C



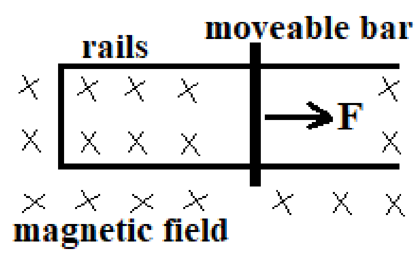
P14. A current, I, flows around two semicircular loops, as shown. The inner loop has a radius of R and the outer loop has a radius of 2R. What expression would correctly give the strength of the magnetic field at the center point of the two loops (the point P)?

A) $\frac{\mu_0 I}{2R}$
B) $\frac{3\mu_0 I}{8R}$
C) $\frac{\mu_0 I}{4R}$
D) $\frac{\mu_0 I}{8R}$
E) $\frac{\mu_0 I}{16R}$

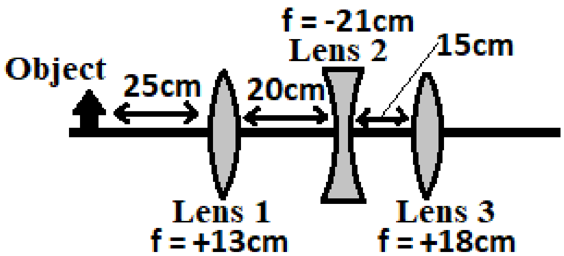


P15. Two parallel conductive rails are connected at one end by a fixed bar, and at the other end by a moveable bar, as shown. The rails are 45.0cm apart and have an internal resistance of 0.600Ω. A magnetic field of 0.650T, oriented perpendicular to the rails, permeates the area. What magnitude of force, F, is needed to pull the bar along the rails at a constant speed of 15.0m/s?

A) 2.14 N
B) 3.57 N
C) 4.39 N
D) 4.78 N
E) 7.31 N



P16. Three lenses are arranged as shown. The first lens has a focal length of +13.0cm. The second lens, located 20.0cm to the right of the first lens, has a focal length of -21.0cm. The third lens, located 15.0cm to the right of the second lens, has a focal length of +18.0cm. An object is placed 25.0cm to the left of the first lens. Where is the final image located?



A) 4.31cm left of the third lens
B) 5.67cm left of the third lens
C) 7.14cm right of the third lens
D) 9.54cm right of the third lens
E) 22.3cm right of the third lens

P17. As seen from Earth, an exploding star sends a shockwave of expanding debris towards your spaceship at a speed of 0.750c. You rush away from the explosion at the maximum velocity of your ship, which is 0.680c (as seen from Earth). How fast is the wave of debris approaching you as seen from your spaceship?
A) 0.143c
B) 0.100c
C) 0.070c
D) 0.057c
E) 0.046c

P18. An atom of Oganesson (element 118) undergoes fission, splitting into two smaller nuclei and two free neutrons, as shown. How much energy is released in this fission reaction?

$$^{294}_{118}Og \rightarrow \ ^{116}_{47}Ag + \ ^{176}_{71}Lu + \ ^{1}_{0}n + \ ^{1}_{0}n$$

The atomic mass of Og-294 is 294.213979u, the atomic mass of Ag-116 is 115.911387u, and the atomic mass of Lu-176 is 175.942686u

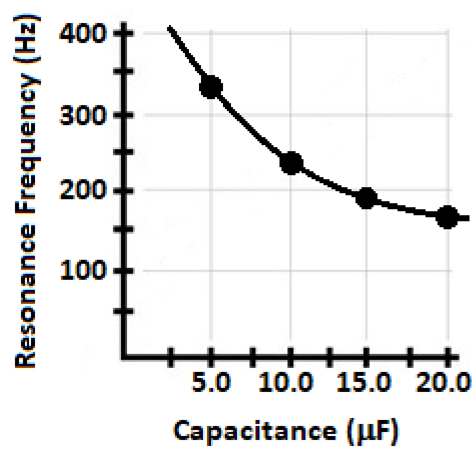
A) 294 MeV
B) 319 MeV
C) 373 MeV
D) 445 MeV
E) 615 MeV

P19. A resonance tube is an open-closed tube that has an adjustable position for the closed end. A tuning fork with a frequency of 1024 Hz is held above a resonance tube, and the closed end is adjusted until resonances are achieved. The table below gives the location of the closed end for three resonances. Using this data, determine the approximate temperature of the air in the tube.

Resonance #1	13.2cm
Resonance #2	29.5cm
Resonance #3	45.8cm

A) -5°C
B) 0°C
C) 5°C
D) 10°C
E) 15°C

P20. You construct an AC-RLC circuit in which the capacitance is adjustable. For several values of capacitance, you determine the resonance frequency of the circuit. The data are plotted below. From your data, determine the approximate value of the inductance, L, in the RLC circuit.



A) 10 mH
B) 25 mH
C) 45 mH
D) 65 mH
E) 100 mH

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)

<u>Water Data</u>

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*

<u>Constants</u>

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

All the information necessary to do the problems can be found either in the box to the left or in the problems themselves.

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Physics

Useful Constants

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

DO NOT DISTRIBUTE TO STUDENTS BEFORE OR DURING THE CONTEST!

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2023 REGIONAL

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

CHEMISTRY SOLUTIONS – UIL REGIONAL 2023

C01. (E) The mass of the screw is 4.9 g/mL × 6.0 mL = 29.4 grams. The mass of the liquid is the mass of the cylinder, liquid, and screw minus the mass of the cylinder and the screw.
Mass of liquid = 228.0 – 172.6 – 29.4 = 26.0 g. Density of liquid = 26.0 g / 20.0 mL = 1.30 g/mL

C02. (D) The balanced equation is $4\ C_3H_5(NO_3)_3(\ell) \longrightarrow 12\ CO_2(g) + 10\ H_2O(\ell) + 6\ N_2(g) + 1\ O_2(g)$

C03. (C) $1\ C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$ 0.100 mol of propane and 0.500 mol of O_2 will produce 0.300 mol of CO_2 and 0.400 mol of H_2O gas with no reactants left over. There are therefore 0.300 + 0.400 = 0.700 moles of gas in the container when the combustion is over.
PV=nRT P = nRT/V = (0.700)(0.08206)(190+273)/2.00 = 13.3 atm

C04. (A) There are more moles of gas on the product side than on the reactant side, so when the container is heated the pressure of the products will increase faster than the pressure of the reactants. That makes Q > K, so the reaction shifts to the left, decreasing the ratio of products to reactants.

C05. (A) You can calculate the moles of each species in the solution using a RICE table:

Reaction	HBenz	+	NaOH	→	NaBenz	+	H_2O
Initial moles	0.00500 mol		0.001825 mol		0		—
Change	*–0.001825 mol*		*–0.001825 mol*		*+0.001825 mol*		—
Ending moles	0.003175 mol		0		0.001825 mol		—

After adding the NaOH the solution contains some benzoic acid and some conjugate base benzoate ion, so it is a buffer solution. You can calculate the pH of a buffer solution using the Henderson-Hasselbalch equation or by using the K_a expression. In either case, because the weak acid and conjugate base are in the same volume and we are taking a ratio of the concentrations, you can use the moles of each one in the calculation instead of calculating the new concentration.

Using the K_a expression,

$$K_a = \frac{[H^+][Benz^-]}{[HBenz]}$$

$$[H^+] = \frac{K_a \times [HBenz]}{[Benz^-]} = \frac{(6.3 \times 10^{-5})(0.003175)}{(0.001825)} = 1.096 \times 10^{-4}\ M$$

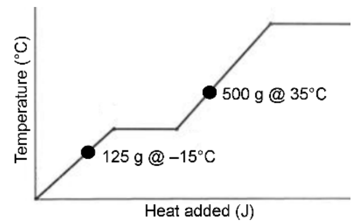
$$pH = -\log(1.096 \times 10^{-4}) = 3.96$$

C06. (D) Since the rate-limiting step depends on A2, increasing the pressure of A2 will speed up the slow step and therefore speed up the entire reaction.

C07. (C) The number of neutrons is the mass number of the isotope minus its atomic number. The number of neutrons in these isotopes are: U-238 146, Np-237 144, Pu-244 150, Am-243 148, and Cm-245 149.

C08. (D) Since the bulb does not light up at all, the white crystalline solid cannot be an ionic compound because ionic compounds produce ions in solution when they dissolve in water. Of these answer choices all of them are ionic except (D), glucose.

C09. (E) There are many ways to do this kind of problem, but the method that is most flexible and can be used in a wide array of problems like this is to move the top dot down to the bottom dot and calculate all the heat given off by that process. Then put all of that heat into the combined mass dot and see where it ends up. Moving the water down to –15°C gives off this much heat:



1) cool the water to 0°C: q = mcΔT = (500)(4.184)(–35) = –73,220 J
2) freeze the water: q = $-m\Delta H_{fus}$ = (500)(334) = –167,000 J
3) cool the ice to –15°C: q = mcΔT = (500)(2.09)(–15) = –15,675 J
Total heat given off = 255,895 J.

Now add all that heat back to 625 g of ice at –15°C:

1) warm the ice to 0°C: q = mcΔT = (625)(2.09)(15) = 19,594 J
2) melt the ice: q = $m\Delta H_{fus}$ = (625)(334) = 208,750 J
That adds up to 228,344 J and leaves us 27,551 joules to heat the water.
3) warm the water: q = mcΔT, so ΔT = q/mc = 27551/(625)(4.184) = 10.5°C.

C10. (A) $K_{sp} = [Ca^{2+}][OH^-]^2 = 4x^3$, where $x = [Ca^{2+}]$. $x = [\mathrm{Ca}^{2+}] = \left(\frac{K_{sp}}{4}\right)^{1/3} = \left(\frac{5.00\times10^{-6}}{4}\right)^{1/3} = 0.010772\ M$

Moles of $Ca(OH)_2$ dissolved in 10.0 L = 0.010772 M × 10.0 L = 0.10772 moles dissolved.
Grams of $Ca(OH)_2$ dissolved = 0.10772 moles × 74.10 g/mol = 7.9821 grams
Grams undissolved = 25.0 – 7.9821 = 17.0 g

C11. (C) Although acetaldehyde and acetone contain hydrogen and oxygen atoms, the hydrogen atoms are not bonded directly to the oxygen atom, so they are not capable of hydrogen bonding. The other three answers are correct.

C12. (D). Since it takes 2260 J/g to vaporize water from liquid to gas, water given off 2260 J/g when it condenses from gas to liquid. The only other exothermic process listed here is freezing, which gives off 334 J/g. The other answer choices are all endothermic, not exothermic.

C13. (A) This is an acid-base reaction, but you have two sources of H^+. Add the moles of H+ from both sources, then calculate whether H^+ or OH^- is in excess, and then calculate the resulting $[H^+]$ or $[OH^-]$ and the pH.

Moles of H^+ from original solution = 0.300 L × 0.015 mol/L = 0.0045 mol H^+
Moles of H^+ from mistaken dilution = 0.300 L × 0.005 mol/L = 0.0015 mol H^+
Total moles of H^+ = 0.0045 + 0.0015 = 0.0060 mol H^+
Moles of OH^- = 0.15 g × (1 mol / 40.0 g) = 0.00375 mol OH^-
H^+ is in excess, with 0.0060 – 0.00375 = 0.00225 moles H^+ remaining.
The volume is now 600 mL, so $[H^+]$ = 0.00225 mol/0.600 L = 0.00375 M
pH = $-\log[H^+]$ = –log(0.00375) = 2.43

C14. (B) The sum of the oxidation states in any polyatomic species ion is simply the charge on the species, so there is no need to determine the individual oxidation states here, you can just add up all the charges. 0 + (–2) + (+2) + 0 + (–1) = –1

C15. (B) moles of HNO3 = M×V = (15.7)(0.1355) = 2.1274 mol
moles of Cu = ½moles of HNO3 = 1.0637 mol of Cu
1.0637 mol × 63.55 g/mol = 67.6 grams of Cu reacted. 123 g – 67.6 g = 55 g Cu remaining

C16. (D) Phosphorous acid, H_3PO_3, is the acid form of the phosphite ion, PO_3^{3-}. (Polyatomic ions that end in *–ite* become *–ous* acids, and polyatomic ions that end in *–ate* become *–ic* acids.) The molar mass is (1.01 × 3) + (30.97 × 1) + (16.00 × 3) = 82.00.

C17. (A) To have a sodium hydroxide solution with a pH of 12.0, you need a pOH = 14 – 12 = 2.0, which is $[OH^-] = 10^{-2} = 1.00 \times 10^{-2}$ M. 1.00×10^{-2} M × 1.200 L = 0.012 moles of NaOH. 0.012 mol × 40 g/mol = 0.48 grams of NaOH needed.

Do the same calculation again using pH 11.5 to find out how many grams your lab partner already added. It comes out to 0.152 g. The mass of NaOH still needed is 0.48 – 0.152 = 0.33 g.

C18. (A) $P_1 = 2.8$ atm, $V_1 = 2.3$ L, $P_2 = 6.5$ atm, $V_2 = ?$ $P_{FINAL} = 3.71$ atm, $V_{TOTAL} = V_1 + V_2$.
$P_1V_1 + P_2V_2, = P_{FINAL}V_{TOTAL}$. $V_{TOTAL} = 2.3 + V_2$
$P_1V_1 + P_2V_2, = P_{FINAL}(2.3 + V_2)$.

Rearranging to solve for V_2 yields

$$V_2 = \frac{P_1V_1 - P_TV_1}{P_T - P_2} = \frac{(2.8)(2.3) - (3.71)(2.3)}{3.71 - 6.5} = 0.75 \text{ L}$$

If you didn't know how to do this problem you could also just try the various answer choices in $P_1V_1 + P_2V_2, = P_{FINAL}V_{TOTAL}$ until you got the one that works, and it turns out to be the first one.

C19. (C) The temperature of the solution rises, so the reaction is exothermic and the ΔH must be (–), so B and D are wrong. The volume is increasing, so more moles of gas are being produced than consumed by the reaction, so A and E are wrong. Only C is producing more gas as a product and is also exothermic.

C20. (B) Polar molecules have stronger intermolecular forces than non-polar molecules, so for molecules of similar size, a polar molecule will have a higher boiling point than a nonpolar molecule.

PHYSICS SOLUTIONS – UIL REGIONAL 2023

P01. (B) pages 84-85: “The answer is yes; the number is three. There are only three basic actions needed to produce all of the phenomena associated with light and electrons.” “So now, I present to you the three basic actions, from which all the phenomena of light and electrons arise.”

P02. (D) page 91: “This junction number I will call j – its value is about -0.1: a shrink to about one-tenth, and half a turn.[4]” Footnote: “[4] This number, the amplitude to emit or absorb a photon, is sometimes called the ‘charge’ of a particle.”

P03. (E) pages 97-98: “Figure 63… The example in (c) shows a strange but real possibility: the electron emits a photon, rushes backwards in time to absorb a photon, and then continues forwards in time.” “The backwards-moving electron when viewed with time moving forwards appears the same as an ordinary electron, except it’s attracted to normal electrons – we say it has a ‘positive charge’…. For this reason it’s called a ‘positron.’”

P04. (A) The path enters the H-R diagram from the right, drifts left and down until it ends at the main sequence. This represents a large deep-red object heating up and shrinking into a smaller, but hotter, object. This exactly describes the evolution of a loosely formed protostar collapsing and heating up to become a main sequence star. Notably, this path does not go near the locations of white dwarfs, neutron stars, or supergiant stars on the H-R diagram. It does pass through the red giant star region, but the path ends at the main sequence rather than beginning at it.

P05. (B) Let’s write the equation in unit notation: $W = \frac{Q^2E}{a} = \frac{[Coulomb]^2[Volts/meter]}{[meter/seconds^2]}$. Expanding, we get $W = \frac{[Coulomb][Coulomb][Volt][second][second]}{[meter][meter]}$. Recalling that a $[Volt]$ is a $[Joule]/[Coulomb]$, we convert this to $W = \frac{[Coulomb][Coulomb][Joule][second][second]}{[meter][meter][Coulomb]} = \frac{[Coulomb][Joule][second][second]}{[meter][meter]}$. Also, we know that a Joule is a $\frac{[kilogram][meter]^2}{[second]^2}$, giving: $W = \frac{[Coulomb][kilogram][meter]^2[second][second]}{[meter][meter][second]^2}$, which reduces to $W = [Coulomb][kilogram]$. Finally, we know that an $[Ampere]$ equals a $\frac{[Coulomb]}{[second]}$, which means a $[Coulomb]$ equals an $[Ampere][second]$, which leads to our final answer: $W = [kilogram][Ampere][second]$

P06. (E) First, we need to know the position and velocity of the rocket at the instant when the plate of metal detaches from it. To find that, we start with the kinematics of the rocket itself: for the position, we use: $y = y_i + v_{iy}t + \frac{1}{2}at^2 \ \rightarrow \ y = 0 + 0 + (0.5)(16.5)(3.50)^2 = 101.1$m. For the velocity, we have: $v_y = v_{iy} + at \ \rightarrow \ 0 + (16.5)(3.50) = 57.75$m/s (upward). This is the position and velocity of the rocket when the metal detaches, so this represents the initial position and initial velocity of the metal plate. Now we turn our attention to the metal plate itself. It has an initial velocity of 57.75m/s (upward) and an initial position of 101.1m. It falls under the influence of gravity, so its acceleration is -9.80m/s^2 (taking downward to be negative). Now we turn to one more kinematic equation: $v_{fy}^2 = v_{iy}^2 + 2a(y_f - y_i)$. Noting that the initial position is above the ground ($y_i = 101.1$m) and the final position is ground level ($y_f = 0$), we can determine the final velocity: $v_{fy}^2 = (57.75)^2 + 2(-9.8)(0 - 101.1) \ \rightarrow v_{fy}^2 = 3335 + 1982 = 5317 \ \rightarrow \ v_{fy} = 72.9$m/s. Note: the final velocity is technically negative since the metal plate is travelling downward, but the question only asks for the speed of the metal, which is a positive number.

P07. (D) The whole system is in static equilibrium, which means that the vector forces will sum to zero. Using this fact at the box allows us to find the tension in the lower rope. There are two forces acting on the box – the tension (T_1, directed upward) and gravity (mg, directed downward). These will sum to zero, so we get $\sum F_{box} = T_1 - mg = 0 \;\rightarrow\; T_1 = mg = (6.80)(9.80) = 66.64$N.

Now, we focus on the knot where the three ropes connect to one another. Three forces act on the knot: the lower rope tension (T_1, directed downward), the upper left rope tension (T_2, directed up and left), and the upper right rope tension (T_3, directed up and right). The upper rope tensions must be broken into horizontal and vertical components. For the upper left rope, we have a horizontal component of $T_2\cos(28.0)$ left and a vertical component of $T_2\sin(28.0)$ up. Similarly, for the upper right rope, we have a horizontal component of $T_3\cos(49.0)$ right and a vertical component of $T_3\sin(49.0)$ up. Taking left to be negative and summing the horizontal forces gives: $\sum F_x = T_3\cos(49.0) - T_2\cos(28.0) = 0 \;\rightarrow\; T_3\cos(49.0) = T_2\cos(28.0)$. This leads to the relation $T_3 = (1.346)T_2$. Taking down to be negative and summing the forces in the vertical gives us: $\sum F_y = T_2\sin(28.0) + T_3\sin(49.0) - T_1 = 0$. Substituting in the value for T_1 and using the relation we found for T_3 gives: $T_2\sin(28.0) + (1.346)T_2\sin(49.0) - 66.64 = 0$. This leads to: $(1.485)T_2 = 66.64 \;\rightarrow\; T_2 = 44.9$N, which is the tension in the upper left rope.

P08. (A) To solve this, we will use conservation of energy. In this case, elastic potential energy in the spring is converted to the gravitational potential energy of the sphere. The only thing to be careful about is the location of the sphere from equilibrium. If we take the equilibrium position of the sphere on the spring to be $h = 0$, then when the sphere is pressed down, it launches from an initial position of $h_i = -39.0cm = -0.39m$. After it is launched, the sphere reaches a maximum height (the final position) of $h_f = 1.24m$. The spring was initially compressed by an amount of $x_i = 0.39m$, and is not compressed at all after the sphere is launched ($x_f = 0$). Now we can apply conservation of energy: $EPE_i + GPE_i = EPE_f + GPE_f \;\rightarrow\; \frac{1}{2}kx_i^2 + mgh_i = \frac{1}{2}kx_f^2 + mgh_f$.
Plugging in the known values gives:
$\frac{1}{2}k(0.39)^2 + (12.0)(9.80)(-0.39) = \frac{1}{2}k(0)^2 + (12.0)(9.80)(1.24)$.
Then, $.07605k - 45.864 = 145.824 \;\rightarrow\; .07605k = 191.7 \;\rightarrow\; k = 2520$N/m.

P09. (C) For any object moving in a circle, we need to identify the net force directed towards the center of the circular path. First, let's look at the forces acting on the car. There are three forces: gravity (mg, directed downward), the normal force (F_N, directed up and left, perpendicular to the track), and friction (F_f, directed down and left, parallel to the track). We need to stay in a standard coordinate system, so we will break the normal force and the frictional force into components. In the vertical are the components $F_N\cos\theta$ (upward) and $F_f\sin\theta$ (downward) as well as the entire gravitational force mg (downward). Here we note that the car has no motion in the vertical, so these forces must sum to zero: $\sum F_y = F_N\cos\theta - F_f\sin\theta - mg = 0$. Utilizing the mathematical relationship between the frictional force and the normal force $F_f = \mu F_N$, we obtain $F_N\cos\theta - \mu F_N\sin\theta - mg = 0$, which leads to $F_N(\cos\theta - \mu\sin\theta) = mg \;\rightarrow\; F_N(\cos 20 - (0.67)\sin 20) = m(9.8)$. From this, we determine $F_N(0.7105) = 9.8m \;\rightarrow\; F_N = 13.79m$, and $F_f = \mu F_N = (0.67)(13.79)m = 9.24m$.

For the horizontal, we have two components that are both directed towards the center of the circular path: the horizontal component of the normal force $F_N\sin\theta$ and the horizontal component of the frictional force $F_f\cos\theta$. Together these components provide the centripetal force needed to keep the car moving in a circle around the track without slipping. Mathematically, $\sum F_x = F_N\sin\theta + F_f\cos\theta = \frac{mv^2}{R}$. Plugging in the expressions we derived earlier, we get: $(13.79m)\sin 20 + (9.24m)\cos 20 = \frac{mv^2}{250.0} \;\rightarrow\; 13.40m = \frac{mv^2}{250.0}$. Conveniently, the mass of the car cancels out, and we are left with $13.40 = \frac{v^2}{250.0} \;\rightarrow\; v^2 = 3350 \;\rightarrow\; v = 57.9$m/s.

P10. (B) First, we use the normal oscillation period to find the length of the pendulum. Using $T = 2\pi\sqrt{\frac{L}{g}}$, we get: $1.35 = 2\pi\sqrt{\frac{L}{9.8}} \rightarrow L = 9.8\left(\frac{1.35}{2\pi}\right)^2 = 0.452$m. Now, using this equation again, we can determine the acceleration of the elevator: $T' = 2\pi\sqrt{\frac{L}{g+a}} \rightarrow 1.12 = 2\pi\sqrt{\frac{0.452}{9.8+a}}$. This rearranges to $9.8 + a = 0.452\left(\frac{2\pi}{1.12}\right)^2 \rightarrow a = 14.24 - 9.8 = 4.44$m/s^2.

P11. (E) For an isobaric (constant pressure) process, we can use the relation $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (Charles' Law). First, we convert the initial temperature to Kelvin: $T_1 = 45 + 273 = 318$K; and then we use Charles' Law to find the temperature after the isobaric expansion: $\frac{1.20L}{318K} = \frac{1.60L}{T_2} \rightarrow T_2 = 424K$. Now, we use the ideal gas law to find the pressure. For this, we also convert the volume to cubic meters: $P_2V_2 = nRT_2 \rightarrow P_2(1.60 \times 10^{-3}\ m^3) = (0.55)(8.314)(424) \rightarrow P_2 = 1.21 \times 10^6$ Pa. The second process is isothermal (constant temperature), which means that we can use the relation: $P_2V_2 = P_3V_3$ (Boyle's Law). This gives the final pressure: $(1.21 \times 10^6 Pa)(1.60 \times 10^{-3} m^3) = P_3(1.20 \times 10^{-3} m^3) \rightarrow P_3 = 1.62 \times 10^6$ Pa.

P12. (D) Because there are batteries in two different branches of the circuit, we must solve this using Kirchhoff's Laws. To begin, we define the currents in each branch: I_1 in the left branch (going up), I_2 in the middle branch (going down), and I_3 in the right branch (going up). Using the node rule at the top node, we obtain a relationship between these currents: $I_1 + I_3 = I_2$. For the loop rule, we will use the two small loops. For the left side loop, going clockwise around the loop, we obtain: $8.00 - 42.0I_1 - 37.0I_2 = 0$. For the right side loop, and going counterclockwise around the loop, we get: $12.0 - 28.0I_3 - 30.0I_3 - 37.0I_2 = 0$. Now we have some algebra to do. Using the node equation to substitute for I_2 and rearranging, we obtain these two expressions: $79.0I_1 + 37.0I_3 = 8.00$ and $37.0I_1 + 95.0I_3 = 12.0$. You can solve these several different ways, but the result is $I_3 = 0.1063A$ and $I_1 = 0.0515A$. Plugging back into the node equation we obtain the current that we seek: $I_2 = 0.1063A + 0.0515A = 0.158A = 158mA$.

P13. (C) To solve this problem we will use Gauss' Law. In integral form Gauss' Law states: $\oint E \cdot dA = \frac{Q_{inside}}{\epsilon_0}$. This law applies to the Gaussian surface, which we choose to be the same shape as the system itself (a cylinder) but with its edge at the point of interest. In other words, our Gaussian surface will be a cylinder with a radius of 1.00cm, while the real cylinder has a radius of 1.30cm. Fortunately, the symmetry of the cylindrical system allows us to avoid the surface integral, with the mathematics simplifying to $EA = \frac{Q_{inside}}{\epsilon_0}$. The hard part is finding the charge contained inside the Gaussian surface (Q_{inside}). This step can often involve calculus, but since the problem states that the charge is spread evenly throughout the cylinder, we can use a simple ratio. The ratio of charge contained inside the Gaussian surface to the total charge equals the ratio of the volume inside the Gaussian surface to the total volume. Mathematically: $\frac{Q_{inside}}{Q_{total}} = \frac{V_{inside}}{V_{total}}$. Recalling that the volume of a cylinder is $V = \pi r^2 L$, we get: $\frac{Q_{inside}}{Q_{total}} = \frac{\pi r^2 L}{\pi R^2 L}$. Dividing by the length of the cylinder, L, changes the charge ratio to a linear charge density ratio: $\frac{\lambda_{inside}}{\lambda_{total}} = \frac{r^2}{R^2} \rightarrow \frac{\lambda_{inside}}{45.0nC/m} = \frac{(1.00cm)^2}{(1.30cm)^2} = 0.592$. Thus, the linear charge density contained inside the Gaussian cylinder is $\lambda_{inside} = 26.63nC/m$. Finally, we return to Gauss' Law itself. Inserting the surface area of the Gaussian cylinder, we obtain: $EA = \frac{Q_{inside}}{\epsilon_0} \rightarrow E(2\pi rL) = \frac{Q_{inside}}{\epsilon_0} \rightarrow E = \frac{Q_{inside}}{2\pi rL\epsilon_0} = \frac{\lambda_{inside}}{2\pi r\epsilon_0} = \frac{26.63 \times 10^{-9}\ C/m}{2\pi(1.00 \times 10^{-2}\ m)(8.854 \times 10^{-12}\ C^2/Nm^2)}$. Thus, $E = 47863 \approx 47900$ N/C.

P14. (D) The formula for the magnetic field produced at the center of a current-carrying circular loop of radius R is $B=\frac{\mu_0 I}{2R}$. What we have, however, are semicircular loops. A semicircular loop will produce half as much magnetic field as a complete circular loop, so for a semicircular loop of radius R, we get a magnetic field of $B=\frac{\mu_0 I}{4R}$. Also, the field produced by the outer loop, which has a radius of $2R$, will be $B=\frac{\mu_0 I}{4(2R)}=\frac{\mu_0 I}{8R}$. Now, the inner semicircular loop has a current flowing counterclockwise, which produces a magnetic field in the +z direction; while the outer semicircular loop has a current flowing clockwise, which produces a magnetic field in the -z direction. Since the semicircular loops produce fields in opposite directions, we must subtract their magnitudes to obtain the total field at the point P. Thus, the magnitude of the magnetic field at the point P is $B=\frac{\mu_0 I}{4R}-\frac{\mu_0 I}{8R}=\frac{\mu_0 I}{8R}$.

P15. (A) As the bar moves through the magnetic field, a current will be induced in it. The induced current in the bar will then experience a force acting on it from the same magnetic field. This is the force that we must overcome to keep the bar moving. First, then, we need to find the induced current. Starting with Faraday's Law, we find the induced voltage in the rails and bar: $\mathcal{E}=-\frac{d\Phi}{dt}=-\frac{d(BA)}{dt}$. The magnetic field, B, is constant, so this becomes $\mathcal{E}=-\frac{BdA}{dt}$. The area enclosed by the rails and bar is a rectangle with a fixed height of $y=45.0cm$ (the separation of the rails). So, we have $\mathcal{E}=-\frac{Bd(xy)}{dt}=-By\frac{dx}{dt}$. The quantity, $\frac{dx}{dt}$, is equal to the velocity, v, of the bar. Thus, the induced voltage in the bar and rails is $\mathcal{E}=-Byv=-(0.650T)(0.450m)(15.0m/s)$ which equals $\mathcal{E}=-4.39V$. The negative sign gives the orientation of the voltage, but we don't need that, so we will use $|\mathcal{E}|=4.39V$. We find the induced current by using Ohm's Law: $I=\frac{|\mathcal{E}|}{R}=\frac{4.39V}{0.600\Omega}=7.31A$. Now, we can calculate the force of the magnetic field acting on this current. Since the field and current are perpendicular, we use: $F=ILB$. The length, L, is the length of the current-carrying part of the bar, which equals the separation of the rails, y. Thus we get a force of $F=(7.31A)(0.450m)(0.650T)=2.14N$. This is the force that we must provide to keep the bar moving at constant speed.

P16. (B) In a compound lens system we treat each lens independently, with the image from the n^{th} lens becoming the object for the $(n+1)^{th}$ lens. In each case, object locations are labeled p, image locations are labeled q, focal lengths of lenses are labeled f, and the distances between lenses are labeled D. Let's start by considering the image formed by the first lens: $\frac{1}{p_1}+\frac{1}{q_1}=\frac{1}{f_1} \rightarrow \frac{1}{25.0}+\frac{1}{q_1}=\frac{1}{13.0} \rightarrow q_1=27.08cm$. This gives the location relative to the first lens of the first image. This is the object for the second lens. Translating over to the second lens, we get a 'second object' location of $p_2=D_{1\rightarrow 2}-q_1=20.0cm-27.08cm=-7.08cm$. The fact that this is negative is fine, and means that the light reaches the second lens prior to actually forming the first image. Now, we go through the second lens and find the location of the second image: $\frac{1}{p_2}+\frac{1}{q_2}=\frac{1}{f_2} \rightarrow \frac{1}{-7.08}+\frac{1}{q_2}=\frac{1}{-21.0} \rightarrow q_2=10.69cm$. This is the location (relative to the second lens) of the second image. This becomes the object for the third lens. Translating over to the third lens: $p_3=D_{2\rightarrow 3}-q_2=15.0cm-10.69cm=4.311cm$. Finally, we go through the third lens: : $\frac{1}{p_3}+\frac{1}{q_3}=\frac{1}{f_3} \rightarrow \frac{1}{4.311}+\frac{1}{q_3}=\frac{1}{18.0} \rightarrow q_3=-5.67cm$. The negative on the image location means that this image is to the left of the lens; so, the final image is located 5.67cm left of the third lens.

P17. (A) Both the speed of the debris and the speed of your spaceship are close to the speed of light, so to find their relative velocity requires more than just a simple subtraction. Combining these relativistic velocities requires the formula: $u' = \frac{u+v}{\left(1+\frac{uv}{c^2}\right)}$. In this problem, one velocity is positive, and the other is negative, so the result is $u' = \frac{0.750c-0.680c}{\left(1+\frac{(0.750c)(-0.680c)}{c^2}\right)} = \frac{0.070c}{(1-0.51)} = 0.143c$. This is the velocity of the approaching debris as seen from your ship.

P18. (B) The energy released is based on the difference in mass between the left side and the right side of the fission equation. On the left side, we have only Og-294 with a mass of $M_L = 294.213979u$. On the right side we have two isotopes and two neutrons with a combined mass of: $M_R = 115.911387 + 175.942686 + 2(1.008665) = 293.871403u$. Thus, the mass difference between the left and right sides is $\Delta M = 294.213979 - 293.871403 = 0.3426u$. Converting this mass difference into energy gives us the energy released by the fission reaction: $E = (0.3426u)(931.5MeV/u) = 319MeV$.

P19. (C) The distance between adjacent resonance locations is equal to one-half of a wavelength of the sound waves. That is $\frac{1}{2}\lambda = 45.8 - 29.5 = 29.5 - 13.2 = 16.3cm$. This gives a wavelength of $\lambda = 32.6cm = 0.326m$. We know the frequency, so the speed of sound in the resonance tube is $v = f\lambda = (1024Hz)(0.326m) = 333.8m/s$. Now, the speed of sound varies with temperature according to the equation: $v = 331\sqrt{1+\frac{T}{273}}$ where T is in Celsius. Putting in the speed of sound that we found earlier, we get: $333.8 = 331\sqrt{1+\frac{T}{273}} \rightarrow 1.00853 = \sqrt{1+\frac{T}{273}} \rightarrow \frac{T}{273} = 0.0171 \rightarrow T = 4.7 \approx 5°\text{C}$

P20. (C) Since the plot is not linear, we will simply use data points on the curve to obtain an approximate answer. I chose (5.0μF, 335Hz) and (15.0μF, 190Hz) as my test points, though any points on the curve should give about the same result. For an AC-RLC circuit, the resonance frequency is $f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$. Solving for the inductance, we obtain $\frac{1}{LC} = 4\pi^2 f^2 \rightarrow L = \frac{1}{4\pi^2 f^2 C}$. For the points that I chose, we get $L_1 = \frac{1}{4\pi^2(335)^2(5.0\times10^{-6})} = 0.0451H = 45mH$ and $L_2 = \frac{1}{4\pi^2(190)^2(15.0\times10^{-6})} = 0.0468H = 47mH$.

For either of my points, it is clear that the closest choice is $L \approx 45mH$.