UNIVERSITY INTERSCHOLASTIC LEAGUE

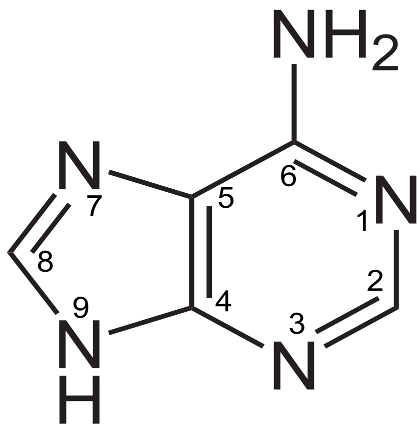
Science

State • 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. Identify the structure below.



A) adenine
B) guanine
C) cytosine
D) thymine
E) uracil

B02. Some bacteria run the citric acid cycle in reverse, which is called the reductive TCA. Which of the following occurs during the reductive TCA?
A) Carbon dioxide is released.
B) $FADH_2$ and NADH remain reduced.
C) Organic compounds are synthesized.
D) The reactions are catabolic.
E) Organic compounds are oxidized.

B03. Water can move across plasma membranes through specialized channel proteins called
A) osmosis.
B) active transport.
C) peripheral proteins.
D) aquaporins.
E) carrier proteins.

B04. Which genome editing tool has the following characteristics?

- Uses a restriction endonuclease, such as *FokI*, covalently linked to an engineered DNA recognition sequence.
- Requires two DNA recognition sequences, each linked to *FokI* catalytic domain.
- Each DNA recognition sequence is made of repeating units of 33-35 amino acids with repeat diresidues at positions 12 and 13.
- Originally derived from a plant pathogenic bacterium, *Xanthomonas*.
- Introduces double-stranded breaks and used to edit DNA only.

A) ZFN
B) CRISPR/Cas9
C) Meganucleases
D) TALEN
E) Restriction enzymes

B05. The physical points of contact during crossing over in meiosis generate an X-shaped structure that is visible under the microscope. This structure is called a/an
A) sister chromatid.
B) chiasmata.
C) recombinant chromatid.
D) non-homologous chromosome.
E) plasmodesmata.

B06. The ribosome and spliceosome are examples of
A) enzymes involved in catabolic reactions.
B) ribozymes.
C) DNA-binding structural proteins.
D) proteins complexed with DNA.
E) RNA-dependent DNA polymerases.

B07. Organisms that are well-suited to hot, dry climates might have any of the following adaptations (depends upon the organism) except
A) the organism might use a burrow or undergo estivation.
B) the organism might be nocturnal.
C) the organism might have large leaves to increase surface area.
D) the organism might undergo specialized photosynthesis
E) the ability to store water in their tissues.

B08. Which of the following would be found in both plant cells and bacteria?
A) DNA
B) ribosomes
C) cytosol
D) plasma membrane
E) All of the above are found in all cells.

B09. Ticks, fleas, and lice are best characterized as
A) ectoparasites.
B) commensals.
C) endoparasites.
D) mutualists.
E) reservoirs.

B10. Which of the following is not true?
A) Some plasmids undergo rolling circle replication, which is bidirectional.
B) DNA-dependent DNA polymerases include DNA Polymerase III.
C) DNA ligase catalyzes phosphodiester bonds.
D) HIV requires an RNA-dependent DNA polymerase before its genome can be inserted into the human genome as a provirus.
E) DNA replication occurs within the S-phase of the cell cycle in eukaryotes.

B11. Assuming Mendelian genetics, what percent of the following cross will exhibit the dominant phenotype for gene A and the recessive phenotype for gene B?

AaBb x AaBb

A) 0%
B) 6.25%
C) 18.75%
D) 56.25%
E) 100%

B12. The human genes *BRCA1* and *BRCA2* are most commonly associated with
A) Alzheimer's.
B) breast cancer.
C) kidney disease.
D) liver cancer.
E) atherosclerosis.

B13. The matrix of blood tissue is called
A) marrow.
B) solid matrix.
C) plasma.
D) cytosol.
E) osteoid.

B14. In the structure of a ribosome, there are three possible binding sites for tRNAs. An incoming aminoacyl-tRNA binds to the
A) DNA site.
B) E site.
C) P site.
D) anticodon.
E) A site.

B15. In a population at Hardy-Weinberg equilibrium, 452 individuals express the dominant phenotype out of 671 total individuals in the population. What percent of the population have at least one dominant allele?
A) 32.6%
B) 42.9%
C) 49.0%
D) 57.1%
E) 67.4%

B16. The exchange of respiratory gases in humans occurs across sacs in the lungs called
A) bronchi.
B) tubules.
C) medulla.
D) alveoli.
E) bronchiole.

B17. Sexual reproduction of *Plasmodium falciparum* occurs within
A) the *Anopheles* gut.
B) the *Anopheles* salivary gland.
C) human erythrocytes.
D) human hepatocytes.
E) human blood plasma.

B18. In February 2025, the Centers for Disease Control and Prevention began investigating a multistate outbreak of *Salmonella* linked to
A) turtles.
B) pet geckos.
C) backyard chickens.
D) ice cream.
E) spinach.

B19. Which of the following is most closely related to animals?
A) plants
B) Archaea
C) bacteria
D) viruses
E) fungi

B20. Which one of the following includes all of the others listed below in biological hierarchy?
A) organelles
B) macromolecules
C) tissues
D) organisms
E) cells

C01. 5.00 g of potassium sulfide is dissolved in 100 mL of water and a solution of a metal nitrate is slowly added until all of the sulfide is precipitated out of solution as a metal sulfide. If the dried metal sulfide precipitate has a mass of 3.99 g, what is the chemical formula of the metal nitrate?

A) FeS B) CoS C) NiS D) CuS E) ZnS

C02. A 156-liter gas sample at 1 atm pressure and 25 °C is made up of a mixture of propane (C_3H_8) and methane (CH_4). The gas mixture is combusted and gives off 7933 kJ of energy. If the sample contains 100.0 grams of propane, how many grams of methane does it contain?

A) 58.0 B) 62.0 C) 66.0 D) 70.0 E) 74.0 g

C03. You have five hydrogen atoms, A-E. Each hydrogen atom has one electron. In each atom the electron starts off in an initial energy level. The electron then makes two energy level transitions as shown in the table below: the electron will either jump to a higher energy level and then from there fall to a lower one or fall to a lower energy level and then from there jump to a higher one. Each energy level transition is accompanied by the absorbance or emission of a photon of light, so each hydrogen atom will absorb one photon and give off one photon during this process.

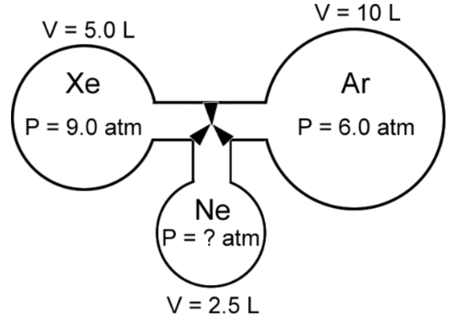
Which of these atoms will give off a photon with a shorter wavelength than the photon it absorbs?

Atom	Initial Energy Level	Transition to Level	Final Energy Level
A	1	5	2
B	2	3	1
C	3	5	4
D	4	6	5
E	5	4	6

C04. All four of the iodine atoms in Red Dye Number 3 (see the image on the Data Page) have the same electron orbital hybridization in valence bond theory. What is the electron orbital hybridization on the iodine atoms in this molecule?

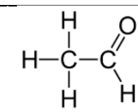
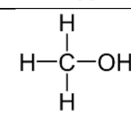
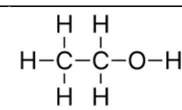
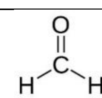
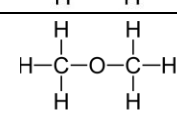
A) *s* B) *sp* C) sp^2 D) sp^3 E) Nonhybridized

C05. In the following three-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. The bulb in the center has a volume of 2.5 L and contains neon gas at an unknown pressure. After the value is opened and all three gases are allowed to mix, the final pressure of the system is 7.0 atm. How many moles of neon were in the center bulb before the valve was opened? Assume ideal behavior by all the gases.



A) 0.39 B) 0.55 C) 0.62 D) 0.78 E) 0.90

C06. Samples of these five pure liquids are cooled until all five samples have the same vapor pressure. Which liquid is the coldest?

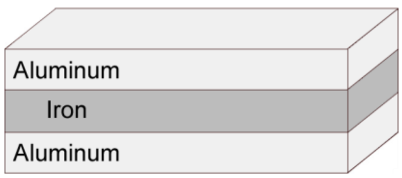
Compound		Boiling Point (°C)
A) Acetaldehyde		20.2
B) Methanol		64.7
C) Ethanol		78.4
D) Formaldehyde		–19
E) Dimethyl ether		–24

C07. What is the overall sum of the oxidation states of all the metal atoms in these compounds?

VO_4^{3-} $KMnO_4$ N_2O_4 $NaHCO_3$ $LiAlH_4$

A) 18 B) 11 C) 20 D) 14 E) 17

C08. You have three metal plates, each one 10 cm long, 4.0 cm wide, and 1.0 cm thick. Two of the plates are made of aluminum and one is made of iron. The aluminum plates are heated to 260.0 °C and the iron plate is cooled to –45.0 °C. If the iron plate is placed between the aluminum plates in an insulated container, what will the final temperature of the iron plate be? (Assume the densities of the metals remain constant throughout the temperature changes.)



A) –22.7 °C B) 131.5 °C C) 250.0 °C
D) 56.3 °C E) 169.4 °C

C09. What is the pH of pure water at 60.0°C?

A) 5.8 B) 6.2 C) 6.5 D) 6.8
E) 7.2 F) 7.5 G) 7.8 H) 8.0

C10. If a 3.42 L saturated solution of A_2B_3 contains 0.300 moles of A^{3+} in solution at equilibrium, how many moles of B^{2-} will be in solution at equilibrium in a 46.0 L saturated solution of A_2B_3?

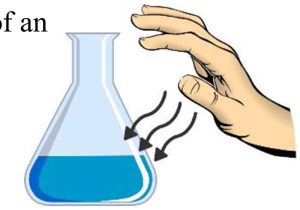
A) 4.14 B) 7.16 C) 5.21 D) 3.39 E) 6.05

C11. How many of the statements below about catalysts in chemical reactions are true?

i. Catalysts lower the activation energy for a chemical reaction.
ii. Catalysts increase the overall rate of chemical reactions.
iii. Catalysts do not interact with the reactants or products in a chemical reaction.
iv. Catalysts increase the amount of heat given off by a reaction.
v. Catalysts increase the equilibrium constant in equilibrium reactions to produce more product at equilibrium.

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

C12. Another student tells you, "If the reaction flask of an aqueous reaction feels increasingly colder as the reaction proceeds, that means the change in enthalpy for the reaction must be negative." Is his statement true or false, and why?



A) True, because at constant pressure enthalpy is the same as heat, and if it's getting colder it's losing heat so the change in enthalpy is negative.
B) True, because breaking chemical bonds releases energy as heat, making the change in enthalpy for the process negative.
C) False, because the reaction is increasing in cold energy so the change in enthalpy is positive.
D) False, because a negative change in enthalpy means the reaction is giving off heat, so it would feel warm, not cold.
E) False, because enthalpy is always conserved in a chemical reaction.

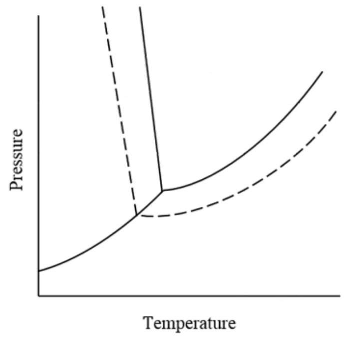
C13. An unknown amount of propane gas is added to a 100-liter rigid container containing O_2 gas at STP, and the gas is ignited. If 1130 kJ of heat is given off by the combustion reaction, what is the partial pressure of the O_2 gas remaining in the container when the reaction is over and the temperature returns to STP?

A) 0.38 atm B) 0.43 atm C) 0.63 atm
D) 0.71 atm E) 0.79 atm

C14. Aqueous solutions of potassium carbonate and copper(II) sulfate are mixed, producing one solid product and one aqueous product. The solid product is then dried and added to a solution of hydrochloric acid, where a subsequent reaction occurs. What is the sum of the coefficients in the balanced equation for the reaction between the solid product from the first reaction and the hydrochloric acid?

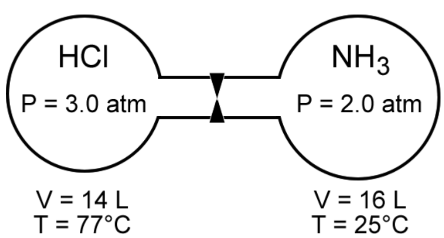
A) 4 B) 5 C) 6 D) 8 E) 9

C15. In an ancient, tattered, chemistry textbook you find this image of the phase diagram for water, but the caption beneath it has been torn from the book. Another student asks you what that mysterious dotted line on the graph is supposed to mean. Which response below would be the best answer to that question?



A) The dotted line is the phase diagram for water at an elevated temperature.
B) The dotted line is the phase diagram for water at a reduced temperature.
C) The dotted line is the phase diagram for some other substance other than water.
D) The dotted line is the phase diagram for a solution made up using water as the solvent.
E) The dotted line is the phase diagram for water in the ground state and the higher up solid line is the phase diagram for water in the excited state.

C16. You have the following two-bulb system. The HCl gas has a volume of 14.0 L and a pressure of 3.0 atm at 77°C. The NH_3 has a volume of 16.0 L and a pressure of 2.0 atm at 25°C. If the valve is opened allowing the gases to mix, and if the reaction goes to completion, how many grams of solid NH_4Cl will be formed?



A) 52 B) 61 C) 70 D) 78 E) 81

C17. 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 625 mL of 0.25 M $AgNO_3$. What is the chloride ion concentration in the mixed solution?

A) 0.263 M B) 0.390 M C) 0.456 M
D) 0.522 M E) 0.676 M

C18. If 6.00 L of A react with 3.00 L of B at STP in a flexible-walled container according to the following reaction, what will the volume of the container be when the reaction is over?

$$A(g) + 2B(g) \rightarrow 2C(g) + D(s)$$

A) 6.0 L B) 6.5 L C) 7.5 L D) 8.5 L E) 9.0 L

C19. You prepared 555 mL of a $Ba(OH)_2$ solution with a pH of 11.50, but overnight a saboteur snuck into your lab, removed an unknown volume of the solution, and then added an equal volume of water to the resulting solution. The solution you were left with was 555 mL with a pH of 11.31. What volume of solution did the saboteur remove from to your solution before adding an equal volume of water to try to hide his fiendish trick?

A) 62.0 mL B) 98.5 mL C) 124 mL
D) 35.8 mL E) 197 mL

C20. Epsom salts are used in the bathtub to help relieve muscle soreness. The chemical name for Epsom salts is magnesium sulfate heptahydrate. What percent of Epsom salts by mass is made up of water?

A) 51.2 B) 17.1 C) 29.1 D) 42.2 E) 36.0

P01. According to Orzel, if you watch Nero the cat fall into a black hole, approximately how long, from your point of view, does it take for Nero to cross from just outside the event horizon to just inside the event horizon?
A) microseconds
B) seconds
C) hours
D) years
E) an infinitely long time

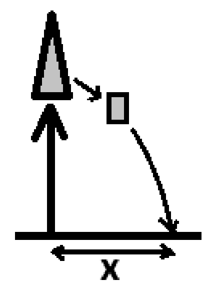
P02. According to Orzel, some time after the Big Bang, the universe cooled enough for atoms to form. At this point, the universe became transparent, and photons were free to travel vast distances without being absorbed. Some of these original photons can still be detected today. In which part of the electromagnetic spectrum are these original photons found?
A) microwave
B) infrared
C) visible
D) ultraviolet
E) gamma

P03. According to Orzel, the most promising candidate for a unified theory of quantum gravity is string theory. In string theory, all particles are represented by subatomic "strings." What characteristic of the strings distinguishes one type of particle from another?
A) string length
B) string vibration
C) string dimensionality
D) string thickness
E) string color

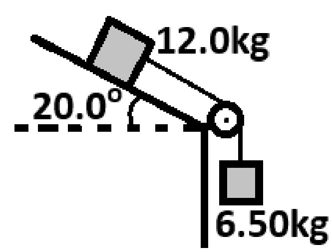
P04. Dark comets are celestial objects that exhibit motion like ordinary comets, but do not have a visible tail. Two distinct groups of dark comets have been identified, one group in the outer solar system, and one group in the inner solar system. Other than their distance from the Sun, what is the most obvious difference that distinguishes the outer group of dark comets from the inner group?
A) Water content
B) Nongravitational acceleration
C) Surface composition
D) Diameter
E) Outgassing rate

P05. You have a cube of pure copper that is 14.0 inches on a side. You melt the copper and mix it with enough tin to make an alloy that is 75% copper by volume. From the alloy, you create coins that are 2.00mm thick and have a diameter of 2.80cm. How many coins can you make from the material? Ignore any volume shrinkage resulting from the creation of the alloy.
A) 12200 coins
B) 24400 coins
C) 36500 coins
D) 48700 coins
E) 60000 coins

P06. A rocket that starts on the ground at rest launches upward, travelling straight up with an acceleration of 8.50m/s². Exactly 12.0 seconds after launch, a panel ejects from the side of the rocket. In the reference frame of the rocket, the panel has an initial velocity of 55.0m/s in a direction of 54.0° below horizontal (as illustrated). Determine the distance from the launch site to the location where the panel lands on the ground (X). Ignore air resistance.
A) 243 m
B) 537 m
C) 598 m
D) 830 m
E) 1090 m

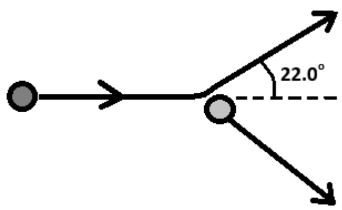


P07. A 12.0kg box of potatoes rests on an incline that is angled at 20.0° with respect to horizontal, as shown. The coefficient of friction between the box and the incline is 0.240. A rope that is tied to the box passes over a frictionless pulley and connects to a dangling 6.50kg mass. When the system is released, what is the acceleration of the box of potatoes?
A) 2.01 m/s²
B) 2.70 m/s²
C) 4.18 m/s²
D) 4.88 m/s²
E) 5.62 m/s²



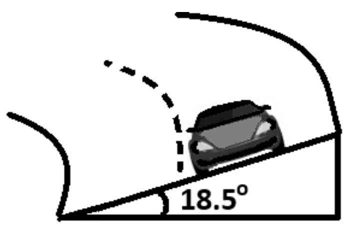
P08. A 450g steel ball is initially travelling due east with a velocity of 3.20m/s. The steel ball strikes a 170g billiard ball which is initially at rest. After the collision, the steel ball is traveling at a speed of 2.20m/s and at an angle of 22.0° north of east, as shown. What is the speed of the billiard ball after the collision?

A) 3.07 m/s
B) 3.77 m/s
C) 5.40 m/s
D) 5.82 m/s
E) 8.47 m/s



P09. A 1200kg car travels along a banked, curved road. The radius of curvature of the road is 80.0m, and the banking is angled at 18.5°, as shown. The coefficient of friction between the car's tires and the road is 0.670. What is the maximum speed that the car can travel around the curve without sliding up and off the road?

A) 14.7 m/s
B) 18.4 m/s
C) 25.4 m/s
D) 31.9 m/s
E) 35.2 m/s

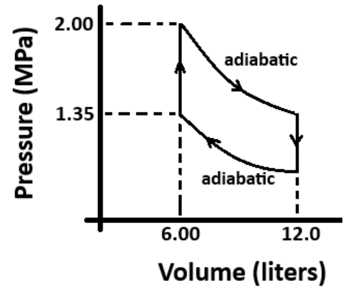


P10. When stationary, the horn on a train emits sound at a frequency of 560Hz. While driving east at 30.0m/s, you observe the train traveling west and coming toward you. You hear the train's horn sound at 754Hz. At what speed is the train traveling? Assume the air temperature is 20.0°C.

A) 66.0 m/s
B) 78.3 m/s
C) 88.2 m/s
D) 110 m/s
E) 159 m/s

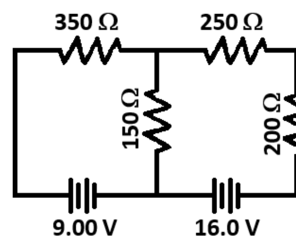
P11. An engine cycle consists of two isovolumetric processes separated by two adiabatic processes, as shown. The isovolumetric processes occur at volumes of 6.00 liters and 12.0 liters, respectively. 1.50mols of a diatomic ideal gas is taken through the cycle. How much work is done by the gas in one engine cycle?

A) 2350 J
B) 2710 J
C) 3290 J
D) 4910 J
E) 5610 J
F) 7260 J
G) 8320 J



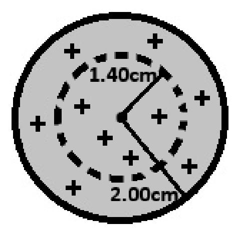
P12. For the circuit shown below, determine the current flowing in the 150Ω resistor.

A) 5.59 mA
B) 10.9 mA
C) 21.1 mA
D) 28.1 mA
E) 33.7 mA



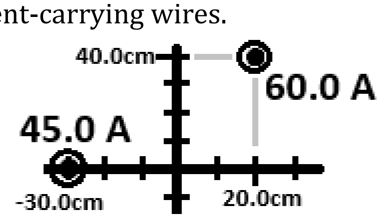
P13. A solid sphere has a charge density that varies radially according to the equation $\rho(r) = \rho_0(.0004 - r^2)$ where the units of r are meters, and $\rho_0 = 8.00\ C/m^5$. The radius of the sphere is 2.00cm. Find the magnitude of the electric field at a point that is 1.40cm from the center of the sphere.

A) 5.83×10^5 N/C
B) 6.75×10^5 N/C
C) 1.19×10^6 N/C
D) 1.31×10^6 N/C
E) 2.58×10^6 N/C



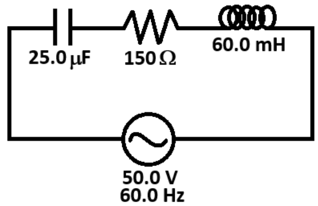
P14. Two long straight wires carry currents in the +z-direction (out of the page), as shown below. The first wire carries 60.0A and intersects the x-y plane at the point (20.0, 40.0)cm. The second wire carries 45.0A and intersects the x-y plane at the point (−30.0, 0.0)cm. Determine the direction (angle) of the magnetic field at the origin (0.0, 0.0) due to these current-carrying wires.

A) −52.1°
B) −26.6°
C) +29.7°
D) +36.9°
E) +63.4°



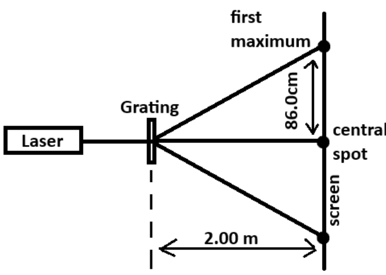
P15. For the series AC-RLC circuit shown below, determine the phase of the current relative to the voltage source.

A) 78.0° lagging
B) 78.0° leading
C) 40.6° lagging
D) 40.6° leading
E) 29.1° lagging
F) 29.1° leading



P16. A laser is directed through a diffraction grating that has 600lines/mm. On a screen that is 2.00m away from the grating, the first maximum is located 86.0cm from the central spot, as illustrated.
The grating is then replaced with a single slit. The single slit pattern appears on the same screen 2.00m away. The width of the central maximum of the single-slit pattern measures to be 2.60cm. What is the width of the single slit?

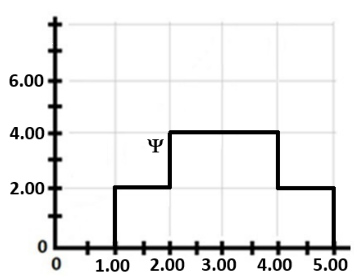
A) 50.0 μm
B) 100 μm
C) 170 μm
D) 280 μm
E) 660 μm



P17. A non-normalized wavefunction, Ψ, is described by the step function written and illustrated below. Determine the normalization constant for this wavefunction.

$$\begin{cases} \Psi = 2 \; for \; 1 \le x < 2 \\ \Psi = 4 \; for \; 2 \le x < 4 \\ \Psi = 2 \; for \; 4 \le x < 5 \end{cases}$$

A) $\frac{1}{4}$
B) $\frac{1}{12}$
C) $\frac{1}{\sqrt{12}}$
D) $\frac{1}{40}$
E) $\frac{1}{\sqrt{40}}$

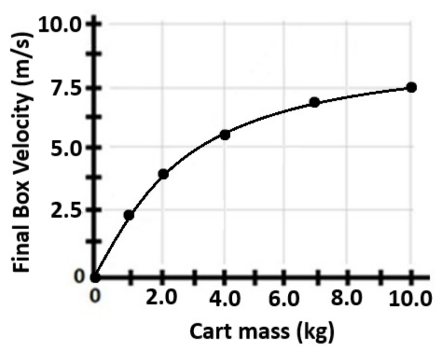


P18. You discover a new element that contains 126 protons and has a mass number of 321. The exact mass of a neutral atom of this element is measured to be 321.2321u. What is the total binding energy of a nucleus of this new element?

A) 7.09 MeV
B) 216 MeV
C) 1860 MeV
D) 2280 MeV
E) 2490 MeV

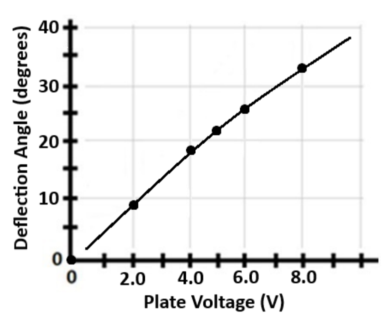
P19. A cart with a variable mass is propelled at 5.00m/s along a frictionless track. The cart impacts a box that is initially at rest in an elastic one-dimensional collision. After the collision, the final velocity of the box is measured. Each time the experiment is run, the cart is set to a different mass. The data are plotted below. Based on these data, determine the mass of the box.

A) 2.0 kg
B) 3.2 kg
C) 5.0 kg
D) 10.6 kg
E) 13.0 kg
F) 18.2 kg



P20. A beam of electrons is directed horizontally into the region between two deflection plates. The plates are separated by 4.00cm and the length of each plate is 6.00cm. The beam is deflected upward at an angle, and the angle of deflection is measured for different values of the voltage across the plates. The data are plotted below. Based on these data, what is the horizontal velocity of the electron beam?

A) 6.0×10^5 m/s
B) 1.2×10^6 m/s
C) 1.8×10^6 m/s
D) 2.5×10^6 m/s
E) 3.2×10^6 m/s



Chemistry

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

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

Water Data

T_{mp} = 0°C
T_{bp} = 100°C
c_{ice} = 2.09 J/g·K
c_{water} = 4.184 J/g·K
c_{steam} = 2.03 J/g·K
ΔH_{fus} = 334 J/g
ΔH_{vap} = 2260 J/g
K_f = 1.86 °C/m
K_b = 0.512 °C/m

Constants

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

Heats of Combustion (kJ/mol)

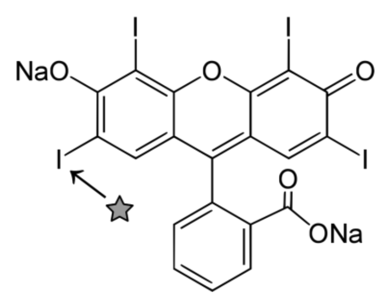
Propane C_3H_8 2044
Methane CH_4 802.3

K_{sp} for $PbCl_2$ = 1.7×10^{-5}
K_{sp} for AgCl = 1.8×10^{-10}

Iron and Aluminum Data

Density of iron = 7.874 g/cm^3
Density of aluminum = 2.710 g/cm^3
c_{Al} = 0.90 J/g°C c_{Fe} = 0.451 J/g°C

Red Dye Number 3 (4 iodine atoms)



Autoionization of water

$\Delta H°_{rxn}$ = 56.78 kJ/mol

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 STATE

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

CHEMISTRY SOLUTIONS – UIL STATE 2025

C01. (A) Since all of the answer choices here are compounds with a 1:1 metal:sulfide ratio, you know that the moles of sulfide in solution is equal to the moles of metal sulfide formed. Moles of sulfide = 5.00 g / 110.27 g/mol = 0.04534 moles of metal sulfide precipitate. Therefore the molar mass of the metal sulfide is 3.99 g / 0.04534 mol = 88.00 g/mol. Subtracting 32.07 for the sulfur leaves the molar mass of the metal as 55.93 g/mol, which is close to the molar mass of iron, 55.85 g/mol. You do not need the volume of the K_2S solution to solve the problem. (For the more abstract thinkers, you could also take the ratio of the masses (final/initial) and multiply by the molar mass of K_2S to get the molar mass of the metal sulfide, then subtract 32.07 to get the molar mass of the metal. This is mathematically equivalent to the first way of solving.)

C02. (C) You can solve this problem in two completely different ways. You can treat it as a gas law problem and ignore the thermodynamic data, or you can treat it as a thermodynamics problem and ignore the gas law data. As a gas law problem, 156 liters of gas at 25 °C (298 K) and 1 atm pressure contains 6.379 moles of gas. If 100 grams of that is propane (molar mass 44.11), then propane makes up 2.267 moles, and methane makes up the rest, or 4.112 moles. 4.112 moles × 16.05 g/mol = 66.0 grams of methane. As a thermodynamics problem, 100 grams of propane (mole mass 44.11 g/mol) is 2.267 moles. 2.267 moles × 2044 kJ/mol = 4634 kJ of energy. That means the rest of the energy (3299 kJ) came from the methane. 3299 kJ/802.3 kJ/mol = 4.112 moles of methane. 4.112 moles of methane × 16.05 g/mol = 66.0 grams of methane.

C03. (B). You are looking for an atom where the energy level drop is larger than the energy level jump. A goes from 1 to 5, then 5 to 2, so the drop is less than the jump. B goes from 2 to 3 then from 3 to 1, so the drop is larger than the jump, and B will give off a photon with higher energy (shorter wavelength) than the photon it absorbed. Like atom A, atoms C, D, and E all have a drop that is less than the jump, so those will also absorb a photon with higher energy (shorter wavelength) than the photon they emit.

C04. (D) The iodine atoms each have four regions of electron density surrounding the nucleus – three lone pairs and a single bond – and that makes the hybridization sp^3.

C05. (D) Although opening the valve mixes all of the gases, you can solve the problem by imagining the process happening step by step. First open the Ar and Xe valve and calculate the final pressure when those gases mix, then treat the problem as a two-bulb problem where the Ar/Xe system is one bulb and the neon gas is the second bulb, and solve for the pressure of the neon gas. Once you have P_{Ne} you have P, V, and T for the neon bulb and you can solve for moles of neon. When solved this way,

$$P_{\mathrm{Ar}}V_{\mathrm{Ar}} + P_{\mathrm{Xe}}V_{\mathrm{Xe}} = P_{\mathrm{final}}V_{\mathrm{total}}$$
$$6 \times 10 + 9 \times 5 = P_{\mathrm{final}} \times 15$$

P_{final} = 7.0 atm. Now mix the 15 L, 7.0 atm gas mixture with the 2.5 L neon gas, knowing that the final pressure of this mixing is 7.0 atm:

$$P_{\mathrm{Ar/Xe}}V_{\mathrm{Ar/Xe}} + P_{\mathrm{Ne}}V_{\mathrm{Ne}} = P_{\mathrm{final}}V_{\mathrm{total}}$$
$$7 \times 15 + P_{Ne} \times 2.5 = 7.0 \times 17.5$$

P_{Ne} = 7.0 atm For the original neon bulb, $PV = nRT$, $n = PV/RT$ = (7.0)(2.5)/(0.08206)(273) = 0.78 moles

Alternatively, you can use conservation of energy to solve this problem using the equation

$$P_{\mathrm{Xe}}V_{\mathrm{Xe}} + P_{\mathrm{Ar}}V_{\mathrm{Ar}} + P_{\mathrm{Ne}}V_{\mathrm{Ne}} = P_{\mathrm{final}}V_{\mathrm{total}}$$

The problem gives you all the variables except P_{Ne}, which comes out to 7.0 atm, and the rest of the solution is the same as above.

C06. (E) Vapor pressure and boiling point have an inverse relationship – a liquid with a high boiling point has a low vapor pressure, and a liquid with a low boiling point has a high vapor pressure. Cooling a liquid lowers its vapor pressure, so in order for all these liquids to have the same vapor pressure the liquid that would have to be cooled the most is the one with the lowest boiling point.

C07. (A) The V in VO_4^{3-} is +5. The K in $KMnO_4$ is +1 and the Mn is +7. There is no metal in N_2O_4. The Na in $NaHCO_3$ is +1. The Li in $LiAlH_4$ is +1 and the Al is +3. These add up to 18.

C08. (B) This is a calorimetry problem, so you need the masses of the iron and aluminum, which are not given in the problem but which can be calculated from the metals' densities and dimensions provided.

Mass of Fe = 10 cm × 4 cm × 1 cm × 7.874 g/cm^3 = 314.96 g

Mass of Al = 2 × (10 cm × 4 cm × 1 cm × 2.710 g/cm^3) = 216.80 g

$-m_{Al}c_{Al}(T_{final} - T_{Al}) = m_{Fe}c_{AFe}(T_{final} - T_{Fe})$

c_{Al} = 0.90 J/g°C $\qquad$ c_{Fe} = 0.451 J/g°C

T_{Al} = 260.0 + 273 = 533 K $\qquad$ T_{Fe} = –45.0 + 273 = 228 K

m_{Al} = 216.80 g $\qquad$ m_{Fe} = 314.96 g

[Note: This problem can be solved using T in either K or °C. Whichever temperature scale you use in the calculation, your final temperature will come out in those units. The reason you get the same answer either way is that you are really calculating a *change* in temperature ($T_f - T_i$), and the change in temperature is the same in °C as it is in K. I have used K in the solution because I expect most students probably did it that way.]

$-(216.80)(0.90)(T_{final} - 533) = (314.96)(0.451)(T_{final} - T_{Fe})$

$-195.12T_{final} + 103999 = 142.05T_{final} - 32387$

$136386 = 337.2\ T_{final}$

T_{final} = 136386/337.2 = 404.5 K

404.5 K – 273 = 131.5 °C

[One final note is that you don't actually need to calculate the masses of the iron and aluminum in order to do this problem. All you need is the correct ratio of masses. So you could assume you have 1 cm^3 of iron and 2 cm^3 of aluminum, calculate the masses of those from their densities, and use those numbers in your calculation and you would get the same final answer.]

C09. (C) To solve this problem you first have to calculate the autoionization constant for water at 60.0°C, and that requires some information that is not given in the problem, but which most students who have made it this far in the contest probably know: the pH of neutral water at 25.0°C is 7.00, and the chemical equation or the autoionization of water is 2 $H_2O(\ell) \leftrightharpoons H_3O^+(aq) + OH^-(aq)$. Armed with that knowledge you can use the van't Hoff equation to calculate K at 60.0°C, and from there calculate $[OH^-]$ at 60.0°C:

T_1 = 298K $\qquad$ $K_1 = 1.0 \times 10^{-14}$

T_2 = 333K $\qquad$ K_2 = ?

$\Delta H°_{rxn}$ (from the data page) = 56.78 kJ/mol

R = 8.314 J/mol·K

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

$$\frac{K_2}{K_1} = e^{\frac{\Delta H^{o}_{rxn}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

$$K_2 = (K_1) \cdot e^{\frac{\Delta H^{o}_{rxn}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

$$K_2 = (1.0 \times 10^{-14}) \cdot e^{\frac{56780\ \mathrm{J/mol}}{8.314\ \mathrm{J/mol \cdot K}}\left(\frac{1}{298} - \frac{1}{333}\right)}$$

$$K_2 = (1.0 \times 10^{-14}) \cdot e^{(6829.4)(0.0003527)}$$

$$K_2 = (1.0 \times 10^{-14}) \cdot 11.12$$
$$K_2 = 1.11 \times 10^{-13}$$

$K_2 = [H^+][OH^-]$ and in pure water $[H^+] = [OH^-]$ so

$$[\mathrm{H}^+] = \sqrt{1.11 \times 10^{-13}}$$

$[H^+] = [OH^-] = 3.3347 \times 10^{-7}$ pH = 6.48 This does not mean hot water is acidic. Neutral water has a pH of 7 only at 25°C. At higher temperatures the pH of neutral water moves lower, so at 60°C anything below 6.48 would be acidic and anything above 6.48 is basic.

C10. (E) There are a couple different ways you can solve this problem. The concentration at equilibrium will always be the same regardless of the volume, so one way is to calculate the equilibrium concentration of A^{3+} from the information given. $[A^{3+}] = 0.300/3.42 = 0.087719$ M. Since the ratio of B to A in the compound is 3/2, at equilibrium in a saturated solution $[B^{2-}] = [A^{3+}] \times 3/2 = 0.13158$ M. In a 46.0 L saturated solution, the moles of B in solution will therefore be 0.13158 mol/L × 46.0 L = 6.05 moles. Alternatively, you could calculate the moles of A^{3+} in the 46 L solution as 0.300 mol × (46.0 L / 3.42 L) = 4.03508 mol A and multiply this by 3/2 to get moles of B^{2-}, then divide by 46 L to get $[B^{2-}]$.

C11. (B) Only i and ii are true. Catalysts speed up reactions by providing a new pathway for the reaction to proceed which has a lower activation energy. Although catalysts are not used up in the overall reaction, they often react directly with the reactants during the course of the reaction and are then regenerated later on as products. Catalysts do not change the amount of heat given off or absorbed by a reaction – that is determined by what the reactants and the products are, and the reactants and products remain the same with or without a catalyst. Catalysts also do not change the equilibrium constant. A catalyst can help a reaction reach equilibrium faster, but it will be the same equilibrium ratio of products to reactants with or without the catalyst.

C12. (D) If the reaction feels increasingly colder as it proceeds, that means the reaction is absorbing heat from the surroundings and is using that heat energy to break chemical bonds. It is an endothermic reaction with an increase in enthalpy, so ΔH is positive.

C13. (A) Calculate the initial moles of O_2, then calculate moles of C_3H_8 from the thermodynamic data. Each mole of C_3H_8 will use up 5 moles of O_2, so calculate the moles of O_2 used up and the moles of O_2 remaining. The balanced equation for the reaction is $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$.
Initial moles of O_2 = 100 L / 22.4 L/mol = 4.4643 mol O_2. Mole sof propane = 1130 kJ / 2044 kJ/mol = 0.55284 moles propane. Consuming all of the propane will use up 0.55284 mol C_3H_8 × 5 mol O_2/1 mol C_3H_8 = 2.7642 mol O_2. Moles of O_2 remaining = 4.4643 – 2.7642 = 1.700 mol O_2. $P_{O2} = nRT/V$ = (1.700×0.08206×273)/100 = 0.38 atm

C14. (C) The first reaction is the same one from the Regional exam, so the solid product formed is copper(II) carbonate, $CuCO_3(s)$: $K_2CO_3(aq) + CuSO_4(aq) \rightarrow CuCO_3(s) + K_2SO_4(aq)$ The equation for the reaction of solid copper(II) carbonate with hydrochloric acid is $CuCO_3(s) + 2HCl(aq) \rightarrow CO_2(g) + H_2O(\ell) + CuCl_2(aq)$

C15. (D) When a pure liquid becomes the solvent of a solution, the boiling point increases and the freezing point decreases. On a phase diagram this shows up as a left shift of the solid/liquid phase boundary and a right shift of the liquid/gas boundary. The amount of the shift depends on the concentration of particles in the solution, and the triple point of the solution adjusts accordingly.

C16. (C) This is a limiting reactant problem masquerading as a two-bulb gas law problem. The equation for the reaction is $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$ First calculate moles of NH_3 and moles of HCl using $n = PV/RT$. Whichever one is less, that many moles of NH_4Cl will be formed, so multiply by the molar mass of NH_4Cl top get the grams of solid formed. Moles of NH_3 = (2.0×16)/(0.08206×298) = 1.309 mol NH_3. Moles of HCl = (3.0×14)/(0.08206×350) = 1.462 mol HCl. NH_3 is the limiting reactant, so 1.309 moles of NH_4Cl will be formed. Molar mass = 53.50 g/mol. 1.309 × 53.50 = 70.03 grams NH_4Cl.

C17. (B) Add up the moles of Cl^- and subtract the moles that react with Ag^+, then divide by the total volume. Moles of Cl^- from NaCl = (0.475)(0.75)(1) = 0.3563 moles. Moles of Cl^- from $CaCl_2$ = (0.375)(0.50)(2) = 0.3750 moles. Total moles Cl^- = 0.7313 moles. Moles of Ag^+ from AgCl = (0.625)(0.25) = 0.1563 moles. AgCl is insoluble ($K_{sp} = 1.8 \times 10^{-10}$) so Ag^+ will react with Cl^- until the Ag^+ is used up, leaving 0.7313 – 0.1563 = 0.5750 moles of Cl^- in solution. (The small amount of solid AgCl that dissolves in a solution that already contains Cl^- is negligible.) Total volume = 0.375 + 0.475 + 0.625 = 1.475 L.
Final Cl^- concentration = 0.575 mol/1.475 L = 0.390 M

C18. (C) This is a limiting reactant problem where you need to calculate how much product is formed and how much of the excess reactant is left over. First calculate the moles of A and B, then determine how many moles of C are formed and how many moles of A or B are left over. Then calculate the final volume based on the final number of moles. At STP 1 mol = 22.4 L. Moles of A = 6.0/22.4 = 0.26786 mol. Moles of B = 3.0/22.4 = 0.13393 mol. Since 2 B react for every A, the moles of A that react are 0.5×0.13393 = 0.06696, leaving 0.20089 mol A left over. The number of moles of C formed are equal to the moles of A reacted × 2 = 0.13393 mol. Total moles of gas in the end = 0.20089 + 0.13393 = 0.33482 mol. 0.33482 × 22.4 L/mol = 7.5 L [Note: This problem can also be done in volume rather than moles because P and T do not change. Reacting 3 L of B will use up 1.5 L of A and produce 3 L of C. This leaves us with 4.5 + 3 = 7.5 L of gas.]

C19. (E) There are a few different ways you could solve this one. The volume of solution removed is proportional to the moles of hydroxide removed, so calculate the initial number of moles in the sample and the final number of moles, then subtract. This will tell you how many moles of hydroxide were removed. If you take the ratio of moles removed to initial moles, then multiply that by the volume, it will tell you the volume removed from the solution. Initial solution pH = 11.50, pOH = 2.50, $[OH^-]$ = 0.00316 M. Initial moles = 0.00316 M × 0.555 L = 0.001755 moles OH^-. Final solution pH = 11.31, pOH = 2.699, $[OH^-]$ = 0.002042 M 0.002042 M × 0.555 L = 0.001133 moles OH^-. Moles removed = 0.001755 – 0.001133 = 0.0006218 moles removed. (0.0006218 moles removed / 0.001755 moles) × 0.555 L = 0.1966 L = 197 mL removed. Alternatively you could calculate the initial number of moles of OH^- and then calculate what the volume would have to be for the pH of the solution to be 11.31. Then subtract 555 mL from that volume to get the volume removed.

C20. (A) Epsom salts are a hydrated salt that incorporates H_2O molecules into the crystal structure of the compound. The chemical formula is $MgSO_4{\cdot}7H_2O$. The overall molar mass including the waters of hydration is 246.52, and the mass of the 7 water molecules in each formula unit is 126.14, so the percent water by mass is 100×(126.14/246.52) = 51.168%

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P01. (E) page 239: "The time between pulses gets longer as well, stretching to seconds, then minutes, then hours. Nero's final signal before he crosses the horizon of the black hole takes an infinite amount of time to arrive…"

P02. (A) page 269: "At that point, the universe became transparent to light, and so it has remained ever since….The vast numbers of photons flying around the early universe at that time are still around today. As the universe has expanded, though, these photons have redshifted… and are now found in the microwave region of the electromagnetic spectrum."

P03. (B) page 292: "In this picture, all fundamental particles… are described as short lengths of 'string.' The different particle types are distinguished by their vibrations, so the same bit of string can be either an up quark or a top quark, depending on how it vibrates."

P04. (D) Dark comets are bodies that resemble asteroids but exhibit nongravitational acceleration similar to comets. All dark comets are defined by their nongravitational acceleration. They all have similarly low levels of outgassing - not enough to create a coma or tail typical of ordinary comets, but enough to affect their motion. The outgassing rates indicate water content below the surface of all dark comets. The exposed surfaces of the dark comets are similar and resemble asteroids. The most obvious differences between the two groups of dark comets are their distance from the Sun, and their overall size (diameter). Dark comets in the inner solar system are approximately one hundred times smaller than dark comets identified in the outer solar system.

P05. (D) First, we find the volume of copper in metric units. Converting, $L = 14.0in * \frac{2.54cm}{1.00in} = 35.56cm$. Then $V_{Cu} = L^3 = (35.56)^3 = 44966.1cm^3$. Now, adding tin to create the alloy gives a total volume of $V_A = \frac{4}{3}V_{Cu} = \frac{4}{3}(44966.1) = 59954.8cm^3$. Converting the dimensions of the coins, we get $r = \frac{d}{2} = \frac{2.80cm}{2} = 1.40cm$, and $h = 2.00mm = 0.200cm$. Each cylindrical coin requires a volume of $V_c = \pi r^2 h = \pi(1.40cm)^2(0.200cm) = 1.2315cm^3$. So, finally, the total number of coins that can be made from this volume of alloy is $N = \frac{V_A}{V_c} = \frac{59954.8}{1.2315} = 48684 \approx 48700$ coins.

P06. (C) We first find the height and velocity of the rocket when the panel is ejected. The height is $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 = 0 + (0)(12.0) + (0.5)(8.50)(12.0)^2 = 612\text{m}$. The velocity of the rocket at that point is entirely vertical and equals $v_{ry} = v_{iy} + at = 0 + (8.50)(12.0) = 102\text{m/s}$. These are the height and velocity of the panel just prior to it being ejected. In the reference frame of the rocket, the panel is ejected at 55.0m/s downward at an angle of 54.0°. The panel's velocity components (in the frame of the rocket) are $v_{px} = (55.0)\cos(-54.0) = 32.33\text{m/s}$, and $v_{py} = (55.0)\sin(-54.0) = -44.50\text{m/s}$. From the reference frame of the Earth, the components of the initial velocity of the panel are $v_{ipx} = 32.33\text{m/s}$ and $v_{ipy} = 102 - 44.50 = 57.50\text{m/s}$. The initial height of the panel is $y_{ip} = 612\text{m}$.

Now the panel is in free fall. Using $y_{fp} = y_{ip} + v_{ipy}t + \frac{1}{2}a_y t^2$ gives $0 = 612 + 57.5t - (0.5)(9.80)t^2$ leading to the quadratic $4.9t^2 - 57.5t - 612 = 0$. The solutions to this quadratic are $t = \frac{57.5 \pm \sqrt{(57.5)^2+4(4.9)(612)}}{2(4.9)} \rightarrow t = -6.76s, or\ 18.49s$. Since negative time is not valid, we conclude that the panel was in free fall for 18.49 seconds. Finally, we determine the horizontal distance that the panel travelled during this time: $x = x_{ip} + v_{ipx}t + \frac{1}{2}a_x t^2 = 0 + (32.33)(18.49) + 0 = 598\text{m}$.

P07. (C) The force diagram for the box includes four forces: gravity ($m_b g$, downward), the normal force (F_N, up and right, perpendicular to the incline), tension (T, down and right, parallel to the incline), and friction (F_f, up and left, parallel to the incline). We tilt the coordinate system so that the normal force is in the positive y-direction, the tension is in the positive x-direction, and the friction is in the negative x-direction. The gravitational force must be divided into components: $m_b g \sin\theta$ is in the positive x-direction, and $m_b g \cos\theta$ is in the negative y-direction. There is no motion in the y-direction, so:
$\sum F_y = 0 = F_N - m_b g\cos\theta \ \rightarrow \ F_N = m_b g\cos\theta = (12.0)(9.80)\cos(20.0°) = 110.5\text{N}$. From this we can find the frictional force: $F_f = \mu F_N = (0.24)(110.5) = 26.52\text{N}$. For the x-direction, we have non-zero acceleration, so: $\sum F_x = m_b a \ \rightarrow \ T - F_f + m_b g\sin\theta = m_b a$. This gives $T - 26.52 + (12.0)(9.8)\sin(20.0°) = (12.0)a$, which simplifies to $T + 13.70 = 12a$ or $T = 12a - 13.70$.
For the hanging mass, the force diagram has only two forces, both in the y-direction: gravity (Mg, downward), and the tension (T, upward). The acceleration is the same as the box, and directed downward, giving

$\sum F_y = Mg - T = Ma$. This leads to $(6.5)(9.8) - T = (6.5)a \;\rightarrow\; 63.7 - T = 6.5a$. Substituting in the expression found earlier for the tension, we obtain
$63.7 - (12a - 13.70) = 6.5a \;\rightarrow\; 77.4 = 18.5a \;\rightarrow\; a = 4.18$ m/s^2.

P08. (B) The initial momentum of the steel ball is entirely in the x-direction and is given by $p_{six} = m_s v_{six} = (0.450)(3.20) = 1.44$ kgm/s. The initial momentum of the billiard ball is zero for both directions since it starts at rest. So, $p_{bix} = 0$, $p_{biy} = 0$, along with $p_{siy} = 0$. After the collision, the steel ball has a total momentum of $p_{sf} = (0.450)(2.20) = 0.990$ kgm/s. This momentum has components in both the x- and y-directions: $p_{sfx} = p_{sf}\cos(22.0) = 0.918$ kgm/s, and $p_{sfy} = p_{sf}\sin(22.0) = 0.371$ kgm/s. Conservation of momentum in the x-direction gives:
$p_{six} + p_{bix} = p_{sfx} + p_{bfx} \;\rightarrow\; 1.44 + 0 = 0.918 + p_{bfx}$. This gives $p_{bfx} = 0.522$ kgm/s. For conservation of momentum in the y-direction we get
$p_{siy} + p_{biy} = p_{sfy} + p_{bfy} \;\rightarrow\; 0 + 0 = 0.371 + p_{bfy} \rightarrow p_{bfy} = -0.371$ kgm/s. Thus, the total momentum of the billiard ball after the collision is $p_{bf} = \sqrt{(0.522)^2 + (0.371)^2} = 0.640$ kgm/s. Lastly, the speed of the billiard ball after the collision is $v_{bf} = \frac{0.640\ kgm/s}{0.170kg} = 3.77$ m/s.

P09. (D) The free-body force diagram for a car on a banked curve has three forces: gravity (mg, downward), the normal force (F_N, up and left, perpendicular to the road), and friction (F_f, down and left, parallel to the road). In this special case, we will *not* tilt our coordinate system. Instead, we will decompose both the normal force and frictional force into components. The gravitational force is entirely in the negative y-direction. In the negative x-direction we have the components $F_N \sin\theta$ and $F_f \cos\theta$. In the positive y-direction we have $F_N \cos\theta$, and in the negative y-direction we have $F_f \sin\theta$. There is no acceleration in the y-direction, so we obtain: $\sum F_y = F_N\cos\theta - F_f \sin\theta - mg = 0$. Inserting the expression relating the frictional force to the normal force gives us $F_N\cos\theta - \mu F_N \sin\theta - mg = 0$. This leads to
$F_N\cos(18.5) - (0.670)F_N\sin(18.5) - (1200)(9.80) = 0 \;\rightarrow\; 0.7357F_N = 11760$, which gives a normal force of $F_N = 15984$N. The frictional force is then $F_f = \mu F_N = (0.67)(15984) = 10709$N. In the x-direction, the forces are all directed towards the center of the circle defined by the curve of the road (that is, the negative x-direction). The sum of these forces must equal the centripetal force needed to keep the car moving in a circle. Thus, we have $|\sum F_x| = F_N\sin\theta + F_f\cos\theta = F_c \;\rightarrow$
$(15984)\sin(18.5) + (10709)\cos(18.5) = \frac{mv^2}{R}$. This leads to $15227 = \frac{(1200)}{80}v^2 \;\rightarrow$
$v = \sqrt{1015} = 31.9$m/s. This is the maximum speed the car can travel without slipping off the road.

P10. (A) The Doppler effect is described by the equation $f' = f_0\frac{(v \pm v_L)}{(v \mp v_S)}$ where v is the speed of sound, v_L is the speed of the listener, and v_S is the speed of the source. Because you (the listener) are moving towards the train, the sign in the numerator is positive. Because the train (the source) is moving towards you, the sign in the denominator is negative. Finally, at 20.0°C, the speed of sound is 343m/s. Putting it all together, we get:
$754 = (560)\frac{(343+30)}{(343-v_S)} \;\rightarrow\; 1.346 = \frac{373}{343-v_S} \;\rightarrow\; 343 - v_S = 277.0$. So, the speed of the train is $v_S = 66.0$m/s.

P11. (A) First, we find the temperature at each vertex of the cycle. For the lower left vertex we get $PV = nRT \;\rightarrow$
$(1.35\times10^6\ Pa)(6.00\times10^{-3}\ m^3) = (1.50)(8.314)T_A \;\rightarrow\; T_A = 649.5K$. Similarly, the temperature at the upper left vertex can be found to be $T_B = 962K$. The gas is diatomic, so the specific heat ratio is $\gamma = 1.40$. This allows us to find the pressures at the vertices on the right. For the top adiabatic process, we get
$P_B V_B^\gamma = P_C V_C^\gamma \;\rightarrow\; (2.00\times10^6)(6.00\times10^{-3})^{1.40} = P_C(12.0\times10^{-3})^{1.40} \;\rightarrow\; P_C = 0.758MPa$ at the top right vertex. Similarly, the pressure at the lower right vertex is $P_D = 0.512MPa$. Turning back to the ideal gas law for the upper right vertex, we can obtain the temperature: $PV = nRT \;\rightarrow$
$(0.758\times10^6\ Pa)(12.0\times10^{-3}\ m^3) = (1.50)(8.314)T_C \;\rightarrow\; T_C = 729K$. Likewise, for the lower right vertex we obtain a temperature of $T_D = 492K$. No work is done by the gas during an isovolumetric process, so we only need to consider the adiabatic processes. For an adiabatic process, the work done by the gas is $W = -nC_v\Delta T$. For a diatomic gas, the specific heat capacity at constant volume is $C_v = \frac{5}{2}R$. So, for the upper adiabatic process, the work done is $W_U = -n\frac{5}{2}R(T_C - T_B) = -(1.50)(2.5)(8.314)(729 - 962) = 7260$ J.
For the lower adiabatic process, the work done is
$W_L = -n\frac{5}{2}R(T_A - T_D) = -(1.50)(2.5)(8.314)(649.5 - 492) = -4910$ J. Thus, the total work done by the gas in one cycle of this engine is $W = W_U + W_L = 7260 - 4910 = 2350$ J.

P12. (A) We will label the currents first: I_1 is the current in the left branch (going up), I_2 is the current in the middle branch (going up), and I_3 is the current in the right branch (going down). For the top node, we obtain the equation $I_1 + I_2 = I_3$. We will go clockwise around the two smaller loops. For the left loop, we obtain the equation $9.00 - 350I_1 + 150I_2 = 0$. And for the right loop we obtain $16.0 - 150I_2 - 250I_3 - 200I_3 = 0 \rightarrow$ $16 - 150I_2 - 450I_3 = 0$. Using the node equation to substitute for I_3 in the second loop equation gives $16 - 150I_2 - 450(I_1 + I_2) = 0 \rightarrow 16 - 450I_1 - 600I_2 = 0$. Multiplying both sides of the first loop equation by four gives: $36.0 - 1400I_1 + 600I_2 = 0$. Now, adding these two loop equations gives us: $16 - 450I_1 - 600I_2 + 36.0 - 1400I_1 + 600I_2 = 0 + 0 \rightarrow 52.0 - 1850I_1 = 0 \rightarrow I_1 = 0.0281A = 28.1mA$. Plugging this back into our first loop equation gives $9.00 - 350(0.0281) + 150I_2 = 0 \rightarrow$ $I_2 = 0.00559 = 5.59mA$. This is the current that we seek. [Note, in case you are curious, $I_3 = 33.7mA$.]

P13. (C) By Gauss' Law, we have $\oint E \cdot dA = \frac{Q_{inside}}{\epsilon_0}$. Since the charge density varies radially, we have spherical symmetry, and the surface integral simplifies to $\oint E \cdot dA = EA = \frac{Q_{inside}}{\epsilon_0}$. Here the area A is the surface area of the Gaussian sphere, which is $A = 4\pi b^2$ where $b = 1.40cm$. The charge contained inside the Gaussian sphere, Q_{inside}, is given by $Q_{inside} = \iiint \rho dV$. Again, thanks to the spherical symmetry, this simplifies to $Q_{inside} = \int_0^b 4\pi r^2 \rho(r) dr = \int_0^b 4\pi r^2 \rho_0 (0.0004 - r^2) dr = 4\pi\rho_0 \int_0^b (0.0004r^2 - r^4) dr$. This integrates to $Q_{inside} = 4\pi\rho_0 \left(\frac{0.0004}{3} r^3 - \frac{1}{5} r^5\right)\Big|_0^b = 4\pi\rho_0 \left(\frac{0.0004}{3} b^3 - \frac{1}{5} b^5\right) = 4\pi\rho_0 b^3 \left(\frac{0.0004}{3} - \frac{1}{5} b^2\right)$. Putting this all together, we obtain $E(4\pi b^2) = \frac{4\pi\rho_0 b^3}{\epsilon_0}\left(\frac{0.0004}{3} - \frac{1}{5} b^2\right) \rightarrow E = \frac{\rho_0 b}{\epsilon_0}\left(\frac{0.0004}{3} - \frac{1}{5} b^2\right)$. Now we insert the values $b = 1.40cm = 0.014m$ and $\rho_0 = 8.00\ C/m^5$, and we get an electric field of $E = \frac{(8.00)(0.014)}{(8.854 \times 10^{-12})}\left(\frac{0.0004}{3} - \frac{1}{5}(0.014)^2\right) = 1.19 \times 10^6$ N/C.

P14. (D) The magnetic field produced by a long straight current carrying wire is $|B| = \frac{\mu_0 I}{2\pi r}$. The distance from the first wire to the origin is $r_1 = \sqrt{(20.0)^2 + (40.0)^2} = 44.72cm = 0.4472m$. The distance from the second wire to the origin is $r_2 = 30.0cm = 0.300m$. Thus, the magnitude of the magnetic field at the origin due to the first wire is $|B_1| = \frac{\mu_0 I_1}{2\pi r_1} = (2.0 \times 10^{-7})\frac{(60.0)}{0.4472} = 2.68 \times 10^{-5}T = 26.8\mu T$. The magnitude of the magnetic field at the origin due to the second wire is $|B_2| = \frac{\mu_0 I_2}{2\pi r_2} = (2.0 \times 10^{-7})\frac{(45.0)}{0.300} = 3.00 \times 10^{-5}T = 30.0\mu T$. Now we consider the direction of each field. Both currents are in the +z direction, so the magnetic fields go in counterclockwise circles around the wires. For both wires, the orientation of the magnetic field is perpendicular to a line drawn from the origin to the wire. Thus, the vector direction of the first wire's magnetic field is $\overrightarrow{V_1} = 40\hat{\imath} - 20\hat{\jmath}$. Normalizing gives a unit vector of $\widehat{V_1} = \frac{1}{44.72}(40\hat{\imath} - 20\hat{\jmath}) = 0.8944\hat{\imath} + 0.4472\hat{\jmath}$. Thus, the first wire's vector magnetic field is $\overrightarrow{B_1} = 26.8\mu T(0.8944\hat{\imath} + 0.4472\hat{\jmath}) = 24.0\hat{\imath} - 12.0\hat{\jmath}\ [\mu T]$. Similarly, the second wire's unit vector is $\widehat{V_1} = \hat{\jmath}$ and the vector magnetic field is $\overrightarrow{B_2} = 30.0\hat{\jmath}\ [\mu T]$. Combining these vector magnetic fields gives us a total magnetic field of $\vec{B} = 24.0\hat{\imath} - 12.0\hat{\jmath} + 30.0\hat{\jmath} = 24.0\hat{\imath} + 18.0\hat{\jmath}\ [\mu T]$. The direction of the total magnetic field at the origin is $\tan^{-1}\left(\frac{B_y}{B_x}\right) = \tan^{-1}\left(\frac{18.0}{24.0}\right) = +36.9°$.

P15. (F) At 60Hz, the capacitive reactance is $X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(60)(25.0 \times 10^{-6})} = 106.1\Omega$ and the inductive reactance is $X_L = 2\pi f L = 2\pi(60)(0.060) = 22.6\Omega$. The phase of the current, relative to the voltage source, is given by $\phi = \tan^{-1}\left(\frac{X_C - X_L}{R}\right) = \tan^{-1}\left(\frac{106.1 - 22.6}{150}\right) = 29.1°$. Since the capacitive reactance is larger than the inductive reactance, then the phase of the current is positive, which means that the current leads the voltage. So, the phase of the current is 29.1° leading. [This AC-RLC circuit is not at resonance.]

P16. (B) First, we determine the wavelength of the laser using the data from the grating: $\tan\theta = \frac{y}{L} = \frac{0.860m}{2.00m} = 0.430 \rightarrow \theta = 23.3°$. The grating spacing is $d = \frac{1}{G} = \frac{1mm}{600 lines} = 1.67 \times 10^{-3}mm = 1.67 \times 10^{-6}m$. Then, $d\sin\theta = m\lambda \rightarrow (1.67 \times 10^{-6})\sin(23.3°) = \lambda = 6.58 \times 10^{-7}\ m = 658nm$ [Note: this is red in color]. Now we consider the single slit. The width of the central maximum represents twice the distance from the central spot to the first minimum. In other words, the important distance is one half of the width of the central maximum: $y = \frac{1}{2}(2.60cm) = 1.30cm$. Now, as before $\tan\theta = \frac{y}{L} = \frac{0.0130}{2.00} = 0.0065$. This gives $\theta = 0.372°$. For a single slit, $a\sin\theta = m\lambda \rightarrow a\sin(0.372°) = 658nm \rightarrow$ $a = 101230nm = 101\mu m \approx 100\mu m$.

P17. (E) Normalization requires that $\int_{-\infty}^{\infty} \Psi^* \Psi dx = 1$. We write the normalization constant, A, separately and obtain $\int_{-\infty}^{\infty} A\Psi^* A\Psi dx = \int_{-\infty}^{\infty} A^2 \Psi^* \Psi dx = 1$. The wavefunction is not complex, and it extends over a limited range, so the integration simplifies to $A^2 \int_1^5 \Psi^2 dx = 1$. At this point, we divide the integration up over the steps of the wavefunction: $A^2 \int_1^2 \Psi^2 dx + A^2 \int_2^4 \Psi^2 dx + A^2 \int_4^5 \Psi^2 dx = 1$. Putting in the values of the stepwise function gives: $A^2 \int_1^2 (2)^2 dx + A^2 \int_2^4 (4)^2 dx + A^2 \int_4^5 (2)^2 dx = 1$. This leads to

$$4A^2 \int_1^2 dx + 16A^2 \int_2^4 dx + 4A^2 \int_4^5 dx = 4A^2(2-1) + 16A^2(4-2) + 4A^2(5-4) = 1 \;\; \rightarrow$$

$4A^2 + 32A^2 + 4A^2 = 40A^2 = 1$. Thus, the normalization constant is $A^2 = \frac{1}{40} \;\; \rightarrow \;\; A = \frac{1}{\sqrt{40}}$.

P18. (D) The number of neutrons in this isotope is $N = A - Z = 321 - 126 = 195$. The combined mass of the protons, neutrons and electrons is
$M = 126m_p + 195m_n + 126m_e = 126(1.007276u) + 195(1.008665u) + 126(0.000549u) = 323.6756u$.
[The electrons don't add enough mass to make much difference – you will still get close enough to the correct answer without including them.] The mass defect is $\Delta m = M - m = 323.6756 - 321.2321 = 2.4435u$.
Converting the mass defect to energy gives a total binding energy of
$BE = (2.4435)(931.5) = 2276MeV \approx 2280MeV$.

P19. (B) Let's derive an equation for this experiment. The initial momentum is given by $p_i = m_c v_{ci} = 5.00m_c$, and the initial kinetic energy is given by $KE_i = \frac{1}{2} m_c v_{ci}^2 = (0.5)m_c(5.00)^2 = 12.5m_c$. The final momentum is given by $p_f = m_c v_{cf} + m_b v_{bf}$, and the final kinetic energy is given by $KE_f = \frac{1}{2} m_c v_{cf}^2 + \frac{1}{2} m_b v_{bf}^2$. Momentum is conserved in any collision, and because the collision is elastic, the kinetic energy is also conserved. Thus, $p_i = p_f$ and $KE_i = KE_f$, which gives $5.00m_c = m_c v_{cf} + m_b v_{bf}$ and $12.5m_c = \frac{1}{2} m_c v_{cf}^2 + \frac{1}{2} m_b v_{bf}^2$. Using the momentum equation to solve for the final velocity of the cart, we get: $5.00 = v_{cf} + \frac{m_b}{m_c} v_{bf} \;\; \rightarrow \;\; v_{cf} = 5 - \frac{m_b}{m_c} v_{bf}$. Thus,
$v_{cf}^2 = \left(5 - \frac{m_b}{m_c} v_{bf}\right)^2 = 25 - 10\frac{m_b}{m_c} v_{bf} + \left(\frac{m_b}{m_c} v_{bf}\right)^2$. Putting this into the energy equation gives
$12.5m_c = \frac{1}{2} m_c v_{cf}^2 + \frac{1}{2} m_b v_{bf}^2 \;\; \rightarrow \;\; 25 = v_{cf}^2 + \frac{m_b}{m_c} v_{bf}^2 \;\; \rightarrow \;\; 25 = 25 - 10\frac{m_b}{m_c} v_{bf} + \left(\frac{m_b}{m_c} v_{bf}\right)^2 + \frac{m_b}{m_c} v_{bf}^2$.
This simplifies to $0 = -10\frac{m_b}{m_c} v_{bf} + \left(\frac{m_b}{m_c}\right)^2 v_{bf}^2 + \frac{m_b}{m_c} v_{bf}^2 \;\; \rightarrow \;\; 0 = -10 + \frac{m_b}{m_c} v_{bf} + v_{bf} \;\; \rightarrow \;\; v_{bf} = \frac{10}{\left(1+\frac{m_b}{m_c}\right)}$.
This is the functional equation for our data. We can see that it is not linear, so we choose a single data point to estimate the mass of the box. I'll choose the point (2.0kg, 3.8m/s).
This gives $v_{bf} = \frac{10}{\left(1+\frac{m_b}{m_c}\right)} \;\; \rightarrow \;\; 3.8 = \frac{10}{\left(1+\frac{m_b}{2.0}\right)} \;\; \rightarrow \;\; m_b = 3.26kg \approx 3.2kg$.

P20. (C) Let's derive an equation for this situation. The electric field between the plates is given by $E = \frac{V}{d}$, and the force acting on the electrons is $F = qE = q\frac{V}{d}$. The vertical acceleration of the electrons is $a_y = \frac{F}{m} = \frac{qV}{md}$, and the final vertical velocity of the electrons is $v_y = v_{iy} + a_y t = 0 + \frac{qV}{md} t = \frac{qV}{md} t$. Here t is the time that an electron takes to pass between the plates. This is found using the length of the plates and the horizontal velocity of the electrons: $x = x_i + v_x t + \frac{1}{2} a_x t^2 \;\; \rightarrow \;\; L = v_x t \;\; \rightarrow \;\; t = \frac{L}{v_x}$. This gives a formula for the final vertical velocity of the electrons: $v_y = \frac{qV}{md} t = \frac{qV}{md}\frac{L}{v_x} = \frac{qVL}{mdv_x}$. The deflection angle is found from the velocities using $\tan\theta = \frac{v_y}{v_x} = \frac{qVL}{mdv_x^2}$. Plugging in the charge and mass of an electron, and the length and separation of the deflection plates, we obtain $\tan\theta = \frac{qVL}{mdv_x^2} = \frac{(1.602 \times 10^{-19})(0.06)V}{(9.11 \times 10^{-31})(0.04)v_x^2} = (2.638 \times 10^{11})\frac{V}{v_x^2}$.
Although the plot appears almost linear, our derived equation shows that it is not. Thus, I'll choose a single data point and plug it into this derived equation to estimate the horizontal velocity of the electron beam. I'll choose the point (6.0V, 26°). This gives $\tan(26°) = (2.638 \times 10^{11})\frac{(6.0)}{v_x^2} \;\; \rightarrow v_x = 1.8 \times 10^6$ m/s.