UNIVERSITY INTERSCHOLASTIC LEAGUE
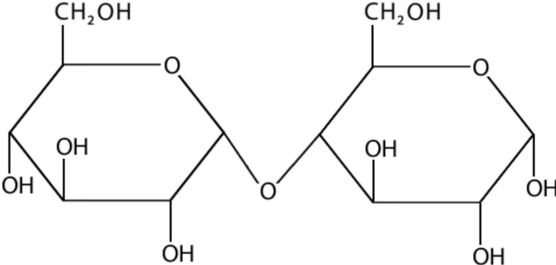
Science

State • 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. During anaerobic respiration,
A) a respiratory electron transport chain is used and a proton motive force is established.
B) oxygen could be used as the final electron acceptor.
C) lactate and/or ethanol and carbon dioxide are products.
D) is more efficient than aerobic respiration in terms of energy transfer.
E) ATP is produced via substrate-level phosphorylation.

B02. Examine the following image. This molecule would be classified into which major macromolecular group?

A) disaccharides
B) carbohydrates
C) nucleic acids
D) proteins
E) amino acids
F) lipids
G) nucleotides

B03. DnaA is to _____ as initiator tRNA is to
A) *oriC*; AUG.
B) transcription; translation.
C) +1; AUG.
D) promoter; Shine-Dalgarno.
E) *oriC*; transcription.

B04. Cellular components that perform chemical reactions and are made of RNA are specifically called
A) inorganic catalysts.
B) enzymes.
C) proteins.
D) ribozymes.
E) nucleic acids.

B05. Two different closely related species of flowers exist in the same forest. Each flower blooms for only 12 hours, one during the night and the other during the day, and pollination occurs during that time. This is an example of
A) post-zygotic isolation.
B) behavioral isolation.
C) geographic isolation.
D) temporal isolation.
E) gene flow.

B06. Antisense RNAs modulate gene expression by
A) binding to mRNA targets to prevent translation.
B) binding to complementary DNA sequences to prevent transcription through chromatin remodeling.
C) binding to mRNA targets to initiate degradation.
D) binding to mRNAs to prevent splicing (RNA processing) in eukaryotes.
E) all of the above mechanisms.

B07. The flattened, pancake-shaped cells of the skin that shed from the outermost layer and are responsible for the epidermal water barrier are called
A) basal cells.
B) melanocytes.
C) keratinocytes.
D) mast cells.
E) Langerhans cells.

B08. MRSA is caused by
A) *Streptococcus pneumoniae*.
B) *Bacillus anthracis*.
C) *Clostridium tetani*.
D) *Staphylococcus aureus*.
E) *Salmonella sp*.

B09. Histone modification includes all of the following except
A) phosphorylation.
B) methylation.
C) acetylation.
D) ubiquitination.
E) All of the above are histone modifications.

B10. Cells that lack a nucleus and are found in extreme environments, such as high salt, high or low temperatures, acidic and alkaline pH, probably belong to
A) Domain Archaea.
B) Domain Prokarya.
C) Domain Eukarya.
D) Domain Bacteria.
E) Domain Eubacteria.

B11. In March 2023, the Centers for Disease Control and Prevention advised against eating raw _____ due to recent infections with *Salmonella*.
A) oysters
B) eggs
C) flour
D) spinach
E) mushrooms

B12. Which of the following is not an example of adaptive radiation?
A) Darwin's finches on the Galapagos.
B) The Cambrian explosion.
C) Drosophilid flies on the Hawaiian Islands.
D) Mammalian evolution after the extinction of non-avian dinosaurs 65.5 mya.
E) All of these are examples of adaptive radiation.

B13. Mushrooms are members of Supergroup
A) Rhizaria.
B) Chromalveolata.
C) Opisthokonta.
D) Excavata.
E) Archaeplastida.

B14. Hemophilia is X-linked and recessive. What percent of the male offspring will have hemophilia from the following genetic cross?

$X^H X^h$ x $X^H Y$
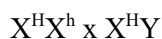
A) 0%
B) 25%
C) 50%
D) 75%
E) 100%

B15. Dialysis tubing allows the movement of water into and out of the membrane but other molecules, especially larger ones, do not move through the tubing. A researcher fills dialysis tubing with a NaCl solution of unknown concentration, seals the tubing, and places it into a beaker containing a NaCl solution of unknown concentration. The mass of the tubing and its contents is measured immediately before dropping the tubing into the beaker and every 15 minutes for 1.5 hours. Examine the data in this table and identify the correct interpretation of the results.

Time (minutes)	Mass (grams)
0	94.4
15	92.7
30	90.9
45	88.8
60	87.2
75	86.0
90	85.1

A) The solution in the dialysis tubing is hypertonic and water is moving out of the tubing and into the beaker.
B) The solution in the beaker is hypertonic and water is moving out of the tubing and into the beaker.
C) The solution in the dialysis tubing is hypotonic and water is moving into the tubing from the beaker.
D) The solution in the beaker is hypotonic and water is moving out of the tubing and into the beaker.
E) The solution inside the dialysis tubing is isotonic and water is moving out of the tubing and into the beaker.

B16. In terms of microanatomy of the kidney, most of the filtered K^+ is reabsorbed in the
A) proximal convoluted tubule.
B) descending limb of the loop of Henle.
C) distal convoluted tubule.
D) glomerulus.
E) collection duct.

B17. A researcher is interested in the expression patterns of a bacterial protein with unknown function. She grows the same bacteria in liquid culture under different temperatures, including 60°C, 15°C, 37°C, and 42°C (S1-S4, respectively). She loads the SDS-PAGE with equivalent protein concentration per well and then performs a Western blot using an antibody against the protein-of-interest. Examine the image of the Western blot and choose the interpretation that is the *least* likely.
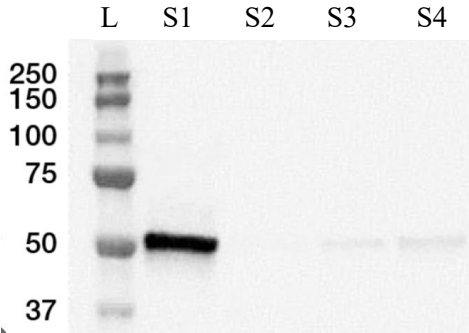
A) The protein is expressed at minimal levels at 37°C and 42°C.
B) The protein is not expressed during mesophilic growth.
C) The protein functions in the cell under high temperature.
D) The protein could be a heat shock protein.
E) The bacteria probably grow best at higher temperatures.

B18. In a population at Hardy-Weinberg equilibrium, 17% of the population carry at least one dominant allele. What is the frequency of the recessive allele?
A) 0.008
B) 0.089
C) 0.162
D) 0.830
E) 0.911

B19. Genes A, B, C, and D are linked and located on the same chromosome. The map units between the genes were determined and are reported below. What is the most likely order of the genes on the chromosome?

Relationship	Distance (m.u.)
A—C	15
A—B	3
B—C	12
C—D	25
A—D	10

A) CABD
B) CBAD
C) ABCD
D) ACBD
E) BCDA

B20. The zone of a lake that is closest to the shoreline is called the _____ zone.
A) pelagic
B) limnetic
C) profundal
D) littoral
E) benthic

C01. The empty graduated cylinder has a mass of 172.6 grams. Each screw has a density of 5.91 g/mL and a volume of 4.90 mL. Five screws are added to the empty graduated cylinder, and then a liquid with a density of 1.23 g/mL is added to the cylinder. How many mL of the liquid must be added to bring the total mass of the entire system (cylinder, screws, and liquid) to 335.0 g?
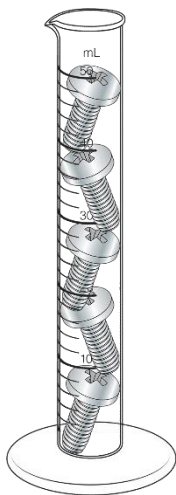
A) 17.6 mL
B) 14.3 mL
C) 13.2 mL
D) 11.1 mL
E) 10.5 mL

C02. Ordinary table sugar can be used as a rocket fuel in model rockets when it is oxidized using potassium nitrate. The unbalanced equation for the reaction is

$$KNO_3(s) + C_{12}H_{22}O_{11}(s) \rightarrow$$
$$N_2(g) + CO_2(g) + H_2O(g) + K_2CO_3(s)$$
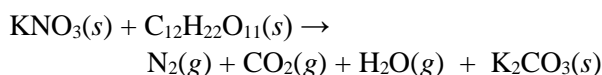
How many moles of gas are generated from the oxidation of 30 grams of sugar using this reaction?

A) 0.5   B) 1.0   C) 1.5   D) 2.0   E) 3.0

C03. Four students who never agree on anything are asked to make a water sample at exactly 50.0°C. One student runs 500. mL of water from the faucet and checks the temperature. It is 23.3°C. "That's too cold," says the second student, who then adds 525 mL of 90.5°C water to the mix. "Now it's too hot," says the third student, who dumps in 25 grams of ice at –5°C. The fourth student shrugs his shoulders and adds another 165 mL of water from the faucet. What is the final temperature of the water? (Assume the density of water is 1 g/mL.)

A) 33.5 °C
B) 42.5 °C
C) 50.2 °C
D) 56.7 °C
E) 68.8 °C

C04. If a fission reaction of a U-235 nucleus produces I-131 and three neutrons, which other isotope will be formed?

A) Kr-98
B) Kr-101
C) Y-98
D) Y-101
E) Y-104

C05. Five circuits similar to the one shown here were made, each one using a different aqueous solution in the beaker. Which of the solutions below would result in the light bulb glowing the brightest?
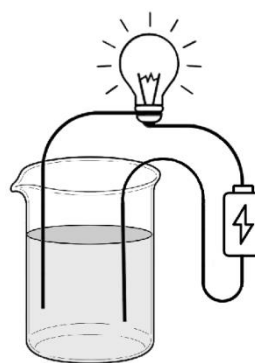
A) 1.0 M NaCl
B) 3.0 M CH₃COOH
C) 1.5 M NaOH
D) 2.0 M $C_6H_{12}O_6$
E) 1.0 M AlCl₃

C06. 0.100 moles of propane gas (C_3H_8), 0.100 moles of methane gas (CH₄), and 0.900 moles of O₂ gas are placed in a flexible-walled container at 25.0 °C and 1.00 atm pressure and a complete combustion reaction occurs. After the reaction is complete the container is heated to 190.0 °C. What will the final volume of the gas inside the container be?

A) 45.6 L
B) 41.5 L
C) 37.4 L
D) 33.3 L
E) 29.2 L

C07. How many milligrams of magnesium would remain dissolved in solution if 500. L of 0.10 M Mg(NO₃)₂ is mixed with 225 L of 0.45 M NaOH? The K_{sp} for Mg(OH)₂ is 5.6×10^{-12}.

A) 5.72 mg
B) 17.4 mg
C) 33.2 mg
D) 41.1 mg
E) 48.9 mg

C08. Which of these compounds would you expect to have the largest a constant in the van der Waals equation:

$$\left(P + a\frac{n^2}{V^2}\right)(V - nb) = nRT$$

A) H_2O
B) CH_4
C) C_4H_{10}
D) XeF_6
E) H_2

C09. The standard enthalpy of combustion for pentane (C_5H_{12}) is –3,509 kJ/mol. What is the change in internal energy of the system for the combustion of one mole of liquid pentane at 25°C and 1 atm pressure? (Ignore the volume of any liquids in the reaction.)

A) –3488 kJ
B) –3502 kJ
C) –3509 kJ
D) –3516 kJ
E) –3530 kJ

C10. The gas phase reaction $2A + B \rightleftharpoons 3C + D$ has a ΔH of 25.5 kJ and an equilibrium constant K of 2.40×10^{-3} at 25°C. What is the equilibrium constant for this reaction at 200°C?

A) 1.08×10^{-1}
B) 4.65×10^{-1}
C) 1.92×10^{-2}
D) 2.40×10^{-3}
E) 3.01×10^{-4}
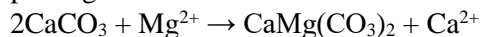
C11. If you add 25.0 grams of $Ca(OH)_2$ to 9.00 L of water and then dilute it to a final volume of 10.0 L using 0.50 M HCl and let it reach equilibrium, how many grams of solid $Ca(OH)_2$ will remain undissolved in the container?

A) 6.48
B) 5.48
C) 4.24
D) 2.48
E) 1.24

C12. You intended to dilute 30.0 mL of 0.015 M solution of hydrochloric acid to twice the original volume, then add 0.015 grams of NaOH, but instead of diluting the solution with deionized water you accidentally diluted it with 0.0050 M sodium acetate instead. What will the pH of the final solution be after you add the NaOH?

A) 4.74
B) 5.92
C) 7.00
D) 8.15
E) 9.21

C13. Dolomite is a calcium magnesium carbonate mineral that occurs widely in pre-Cenozoic sedimentary rocks, but is much less common in Cenozoic sedimentary rock beds. One mechanism for its formation involves magnesium ions replacing calcium ions in calcite:
    $2CaCO_3 + Mg^{2+} \rightarrow CaMg(CO_3)_2 + Ca^{2+}$
What is the oxidation state of the carbon atom in dolomite, $CaMg(CO_3)_2$?

A) –2   B) 0   C) +1   D) +2   E) +4

C14. A 1.5 L bulb and a 2.3 L bulb are connected by a valve. At 25°C the larger bulb contains Cl_2 gas at 2.8 atm and the smaller bulb contains Cl_2 gas at an unknown pressure. When the valve is opened and the entire system is heated to 265°C, the final pressure in the combined system is 5.2 atm. What was the initial pressure of Cl_2 in the smaller bulb at 25°C before the valve was opened? Assume the volume of the valve tube is negligible.


Before: valve closed
T = 25°C

After: valve opened
T = 265°C
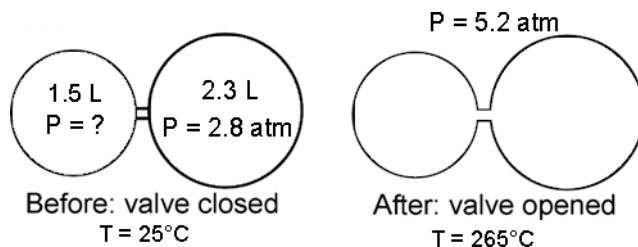
A) 0.25 atm
B) 1.19
C) 1.96
D) 3.00
E) 10.5

C15. The exothermic reaction $A + B + C \rightarrow D + E$ exhibits first order kinetics with respect to each reactant and is third order overall. Under which of these reaction conditions would the reaction exhibit first-order kinetics?

A) At very high temperatures
B) At very low temperatures
C) When $[A]_0 = [B]_0 = [C]_0$
D) When $[A]_0 = [B]_0 \gg [C]_0$
E) When $[A]_0 \gg [B]_0 = [C]_0$

C16. Phase changes A, B, C, D, E, and F are the six usual phase changes that any matter such as H_2O undergoes. Use the clues below to determine which phase change corresponds to vaporization.

I. Phase change E is exothermic.
II. Phase changes E and C are equal in magnitude and have the lowest magnitude of the phase changes.
III. Phase change A is greater in magnitude than phase change F and both are exothermic.
IV. Phase change B is equal in magnitude to phase change F.

A) A   B) B   C) C   D) D   E) E   F) F

C17. You have just finished up a titration of HCl with NaOH and reached a beautiful faint pink phenolphthalein endpoint when a vile prankster creeps up behind you, throws some NaOH pellets into your titration flask, and runs away. You add 25.00 mL of 1.50 M HCl to the flask to turn the bright pink solution clear again, and then you continue the titration. If it takes an additional 17.88 mL of 1.20 M NaOH to reach the endpoint, and if each NaOH pellet has a mass of 0.1605 grams, how many pellets did the prankster throw into your flask?

A) 3
B) 4
C) 5
D) 6
E) 7

C18. In basic solution metallic zinc reacts with the permanganate ion to produce solid manganese dioxide and insoluble zinc hydroxide. If you add a 96.0 g piece of zinc to large beaker containing 2.50 L of a 0.177 M solution of potassium permanganate and the reaction goes to completion, how many grams of solid will there be in the beaker when the reaction is finished?

A) 52.6 g
B) 91.1 g
C) 38.5 g
D) 66.0 g
E) 157 g

C19. You are making propanol molecules (C_3H_8O) out of elemental carbon, hydrogen, and oxygen. You have 1.75 moles of H_2, 6.45×10^{23} carbon atoms, and 15.4 grams of O_2. You make as many propanol molecules as you can, and then you decide to combust the propanol you made using the remaining O_2. How many CO_2 molecules result from the combustion?

A) 6.45×10^{23}
B) 2.15×10^{23}
C) 1.22×10^{23}
D) 8.55×10^{22}
E) 5.91×10^{22}

C20. Based on the following experimental data, what is the value of the rate constant for the reaction $2A_2 + B \rightarrow C$?

Trial Number	$[A_2]_0$	$[B]_0$	rate (M/s)
1	1.15 M	2.20 M	0.0212
2	1.75 M	3.75 M	0.0935
3	2.45 M	2.20 M	0.0451

A) 8.38×10^{-3}
B) 3.80×10^{-3}
C) 1.42×10^{-2}
D) 7.29×10^{-3}
E) 8.14×10^{-3}

P01. According to Feynman, when calculating terms with couplings, we must consider situations when two coupling points are directly on top of each other. What happens when we try to calculate using zero distance between coupling points?
A) the result is imaginary
B) the result produces negative energies
C) the result gives probabilities greater than 100%
D) the result is infinite
E) the result is zero

P02. According to Feynman, we have a simple, definite theory to explain the properties of protons and neutrons. Unfortunately, we can't use the theory to calculate to any great accuracy because …
A) protons and neutrons are massive.
B) protons are made of quarks.
C) the strong force has such a short range.
D) quarks have the polarization we call color.
E) the coupling constant for gluons is large.

P03. According to Feynman, a d-quark can change into a u-quark. This specific quark flavor change is caused by which particle?
A) a photon
B) a gluon
C) an electron
D) a W particle
E) a Z particle

P04. You discovered an exoplanet that passes in front of its host star. During transit, the light output from the system drops by 0.570%. The star has a diameter of 2.78×10^9m. What is the diameter of the exoplanet as compared to that of Jupiter (1.40×10^8m)?
A) 0.57 times the diameter of Jupiter
B) 1.0 times the diameter of Jupiter
C) 1.5 times the diameter of Jupiter
D) 1.8 times the diameter of Jupiter
E) 3.1 times the diameter of Jupiter

P05. The current flowing in a resistor is measured to be $I = 0.135 \pm 0.004$ A. The resistance is given as $R = 470 \pm 10 \ \Omega$. Thus, you calculate the power dissipated by the resistor to be $P = 8.566 \pm \delta P$ W. What is the propagated error on the power, δP?
A) 3 W
B) 2 W
C) 1 W
D) 0.7 W
E) 0.4 W

P06. A skier starts from rest at the top of a slope. The slope is 120.0m long and is angled downward at 22.0° with respect to horizontal. At the end of the slope is a 30.0m drop to ground level, as shown. Ignoring friction, how far from the edge of the drop does the skier land (distance d)?
A) 31.2m
B) 43.7m
C) 68.1m
D) 74.9m
E) 106m
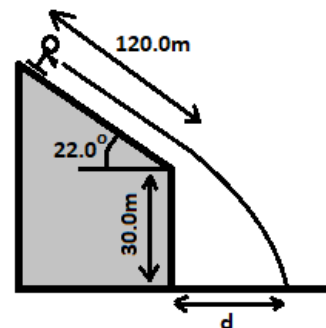
P07. You pull a 22.0kg bag of sawdust across the floor. The coefficient of friction between the bag and the floor is 0.158. You pull with a force that is angled at 35.0° above the horizontal. What magnitude of force, F, is needed to accelerate the bag horizontally at a rate of 2.00m/s^2?
A) 85.8 N
B) 78.1 N
C) 53.7 N
D) 44.0 N
E) 34.1 N
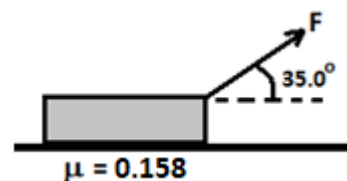
P08. A 900.0kg speedboat travelling at 25.0m/s East (at an angle of 0.0°) impacts a 2200.0kg tugboat that is travelling at 15.0m/s North-West (at an angle of 125.0°). After the collision, the tugboat is moving at 10.0m/s North-East (at an angle of 60.0°). What is the velocity (magnitude v and direction θ) of the speedboat after the collision?
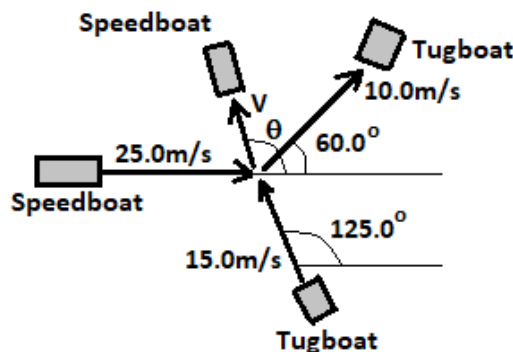
A) 8.98m/s at 99.2°
B) 21.2m/s at 99.2°
C) 4.96m/s at 133°
D) 12.1m/s at 133°
E) 18.5m/s at 151°

P09. A flagpole with uniform density is 1.40m long and has a mass of 4.00kg. The flagpole is attached to the side of a building and droops downward, so that it makes an angle of 65.0° with respect to the building wall, as shown. A cable is attached to the flagpole at a point 1.20m along the pole; the other end of the cable is attached to the building and makes an angle of 50.0° with respect to the building wall. A sign with a mass of 8.20kg hangs vertically from the end of the flagpole. What is the magnitude of the total force acting on the base of the flagpole, where it attaches to the building?

A) 189 N
B) 248 N
C) 344 N
D) 408 N
E) 558 N
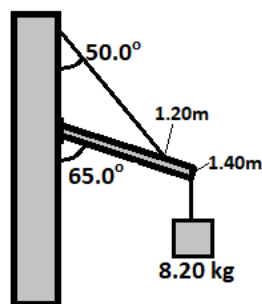
P10. You are driving on the highway at a speed of 33.0m/s when you hear a siren from an ambulance. The ambulance is coming towards you, and the frequency you hear is at 886Hz. You know that all ambulances have a siren that (at rest) produces sound at a frequency of 678Hz. How fast is the ambulance moving towards you? Assume the air temperature is 20.0°C.

A) 48.5 m/s
B) 55.3 m/s
C) 62.1 m/s
D) 72.2 m/s
E) 106 m/s

P11. A solid iron rod has a diameter of 2.50cm and is 65.0cm long. One end of the rod is placed in contact with a heater that maintains a constant temperature of 86.0°C. The other end of the rod is placed against 1.50kg of ice at 0.00°C. Assuming the rod remains in contact with the ice, how long does it take for the ice to completely melt? The heat of fusion of ice is 3.33×10^5 J/kg and the thermal conductivity of solid iron is 79.5 W/Km.

A) 10.1 minutes
B) 6.72 hours
C) 13.9 hours
D) 21.1 hours
E) 26.9 hours

P12. For the capacitor network shown, determine the energy stored in the 120μF capacitor.

A) 7.26 mJ
B) 5.80 mJ
C) 5.40 mJ
D) 2.60 mJ
E) 1.42 mJ
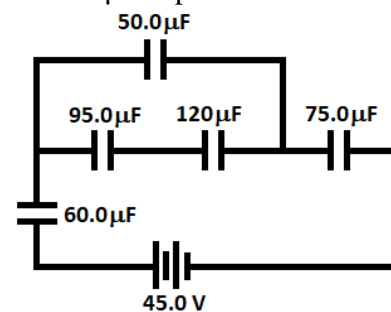
P13. Consider an electric field that is constant and is described by the vector expression:

$\vec{E} = 1700\hat{\imath} + 2400\hat{\jmath}$ [N/C]. How much energy is needed to move a +180μC charge through this electric field from the point (+10.0cm, +40.0cm) to the point (-30.0cm, -20.0cm)?

A) 0.382 J
B) 0.680 J
C) 1.44 J
D) 2.03 J
E) 2.59 J

P14. The current in a cylindrical wire is distributed in the wire with a current density described by the expression $J(r) = (6.50 \times 10^9)r^2$. The radius of the wire is $R = 1.40$mm. What is the magnitude of the magnetic field at a distance of $a = 1.60$mm from the center of the wire?

A) 1.39 μT
B) 2.14 μT
C) 4.90 μT
D) 7.43 μT
E) 11.1 μT
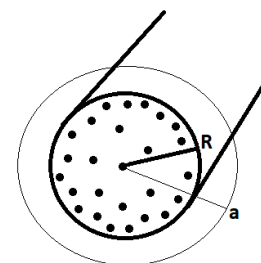
P15. Determine the magnitude of the AC voltage (RMS) across the 40.0mH inductor in this circuit.

A) 9.03 V
B) 12.4 V
C) 14.5 V
D) 20.6 V
E) 23.7 V
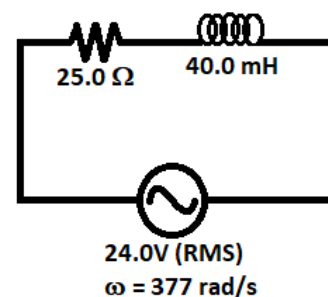
P16. A solid glass ornament has a transparent front surface with a radius of curvature of 36.0cm, and a mirrored back surface with a radius of curvature of 22.0cm (as shown). The ornament is 31.0cm thick, and the glass has an index of refraction of 1.67. If an object is placed 23.0cm left of the front surface of the ornament, then where is the location of the final image?
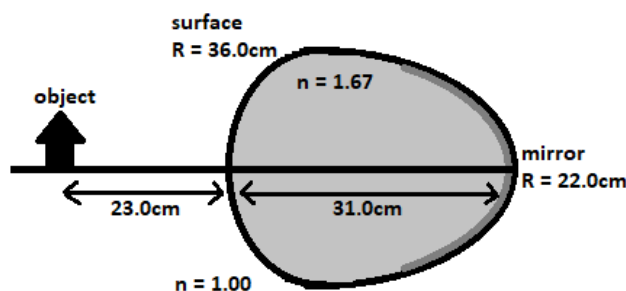
A) 14.1cm right of the front surface
B) 16.2cm right of the front surface
C) 18.0cm right of the front surface
D) 24.1cm right of the front surface
E) 27.1cm right of the front surface

P17. The following wavefunction describes a mixed state of a quantum system:

$$\Psi_{mixed} = 0.60\Psi_1 + 0.80\Psi_2$$

Here Ψ_1 and Ψ_2 represent normalized pure states of the system. The energy of the pure state Ψ_1 is 1.40eV, and the energy of the other pure state, Ψ_2, is 4.40eV. What is the expectation value of the energy for the mixed-state of the system, Ψ_{mixed}?

A) 2.90 eV
B) 3.11 eV
C) 3.32 eV
D) 3.76 eV
E) 4.36 eV

P18. According to Electroweak Theory, the massive vector bosons ($W^{\pm}, Z^0$) and the massless photon (γ) arise from the spontaneous symmetry breaking of the Electroweak field. This symmetry breaking originates from the interaction of the Electroweak field with…

A) the Higgs field
B) the Quark-Gluon field
C) the Lepton field
D) Gauge supersymmetry
E) Electromagnetic supersymmetry

P19. An ideal gas is kept in a rigid container at a constant volume of 1.50 liters. The pressure of the gas is measured at different temperatures, and the data are plotted below. Based on the data, how many moles of the ideal gas are in the container?
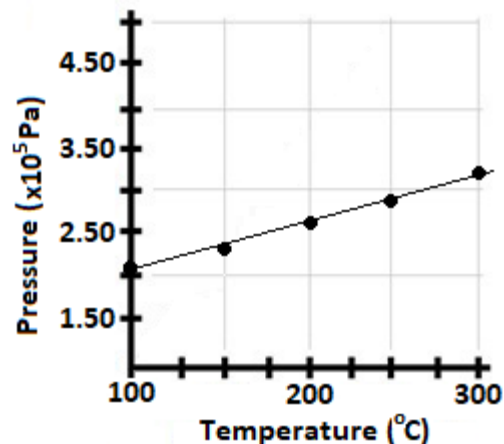
A) 0.1 moles
B) 0.2 moles
C) 0.4 moles
D) 0.7 moles
E) 1.0 moles

P20. The following table gives the object and image distances for a strong converging lens by itself (lens 1), and for the combination of the strong converging lens in close contact with a diverging lens (lens 1+2). From the data, determine the focal length of the diverging lens (lens 2).

Object	Lens 1 image	Lens 1+2 image
20cm	20cm	100cm
25cm	17cm	50cm
30cm	15cm	38cm
40cm	13cm	29cm

A) -75cm
B) -50cm
C) -40cm
D) -25cm
E) -15cm

Chemistry

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

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

Water Data

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

Constants

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

Equilibrium constants

$Ca(OH)_2$ $K_{sp} = 5.00 \times 10^{-6}$
Acetic acid $K_a = 1.8 \times 10^{-5}$

Conversion factors

1 L·atm = 101.325 J

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}	$1000.0 \, kg/m^3$

UIL HIGH SCHOOL SCIENCE CONTEST
ANSWER KEY
2023 STATE

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

C01. (B) The mass of liquid needed is the total mass minus the mass of the cylinder and the mass of the screws. Mass of liquid = 335.0 – 172.6 – (5×4.90×5.91) = 17.605 grams. 17.506 g / 1.23 g/mL = 14.3 mL

C02. (D) The balanced equation is 48 $KNO_3(s)$ + 5 $C_{12}H_{22}O_{11}(s)$ → 24 $N_2(g)$ + 36 $CO_2(g)$ + 55 $H_2O(g)$ + 24 $K_2CO_3(s)$. The total number of moles of gas in this equation is 24 + 36 + 55 = 115, which is produced from 5 moles of sugar. The moles of gas produced from one mole of sugar is 115/5 = 23 moles of gas. 30 grams of sugar (molar mass 342.34 g/mol) is 0.0876 moles, so 0.0876 mol × 23 moles of gas/mol of sugar = 2.01 moles of gas.

C03. (C) There are many ways to do this problem, but the easiest is to collapse all the water samples to one volume and temperature, and then add the ice. At that point the problem is essentially the same as the one on the Regional exam. There are two water samples at 23.3°C, so you can just add those directly: 500 mL + 165 mL = 665 mL of water at 23.3°C.
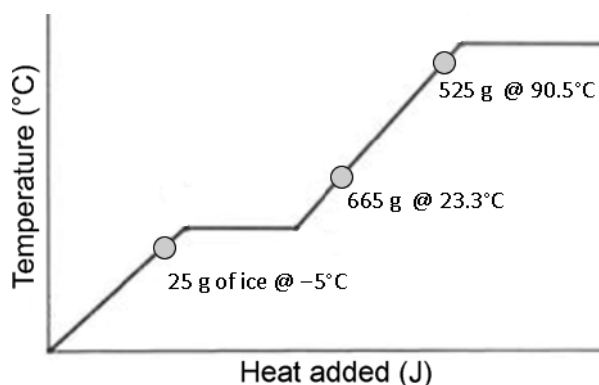
Mixing the hot water with the 23.3° water will result in a weighted average temperature:

$$T_{final} = \frac{(V_1 T_1) + (V_2 T_2)}{V_{total}} = \frac{(665 \times 23.3) + (525 \times 90.5)}{1190} = 52.95°C$$

Now we have 1190 mL at 52.95°C and we have to add 25 g of ice at –5°C. Calculate the heat required to warm the ice to 0°C and melt it. This gives us 25 g of water at 0°C. Remove that same amount of heat from the water, and that leaves us again with two different water samples that we have to find the weighted average of the temperature.
Warming the ice: q = mcΔT = (25)(2.09)(5) = 261.25 J
Melting the ice: q = mΔHfus = (25)(334) = 8350 J
Total heat to warm and melt the ice = 8611.3 J
Remove that much heat from the water: q = –mcΔT, so ΔT = –q/mc = –8611.3/(1190×4.184) = –1.73°C
The new water temperature is 52.95 – 1.73 = 51.22°C.
Now we have to mix this with the melted ice (25 g of water at 0°C).

$$T_{final} = \frac{(V_1 T_1) + (V_2 T_2)}{V_{total}} = \frac{(1190 \times 51.22) + (25 \times 0)}{1215} = 50.2°C$$

1

C04. (D) U-235 has 92 protons and 235-92 = 143 neutrons. I-131 accounts for 53 protons, so the other isotope is atomic number 92-53 = 39, or Yttrium. The I-131 also accounts for 131-53=78 neutrons. The number of neutrons in the Y isotope is 143 – 78 – 3 = 62, so the mass number of the Yttrium isotope is 39+62 = 101.

C05. (E) The solution with the highest ion concentration will conduct electricity the best. 1.0 M NaCl has an ion concentration of 2.0 M. 1.5 M NaOH has an ion concentration of 3.0 M, $C_6H_{12}O_6$ is a nonelectrolyte and will not produce any ions in solution. 1.0 M $AlCl_3$ has an ion concentration of 4.0 M. CH_3COOH is a weak acid and only partially dissociates, so without doing any calculations we can say the ion concentration in that solution is less than 3.0 M.

C06. (A) Combustion of the propane gas: $C_3H_8(g) + 5\ O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$
Combustion of the methane gas: $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
0.100 mol $C_3H_8(g)$ will use up 0.500 mol O_2 and produce 0.300 mol CO_2 and 0.400 mol H_2O
0.100 mol $CH_4(g)$ will use up 0.200 mol O_2 and produce 0.100 mol CO_2 and 0.200 mol H_2O
All of the C_3H_8 and CH_4 are used up. 0.200 mol O_2 is left over. 0.400 mol CO_2 is produced and 0.600 mol H_2O is produced. The total moles of gas in the container at the end of the reaction is 0.200 + 0.400 + 0.600 = 1.200 moles of gas. PV = nRT so V = nRT/P = (1.200)(0.08206)(463)/1 = 45.6 L

C07. (C) Moles of Mg^{2+} = 500 L × 0.100 M = 50.0 moles
Moles of OH^- = 225 L × 0.45 M = 101.25 moles
The precipitation reaction will use up all the Mg^{2+} and 100 moles of OH^-, leaving 1.25 moles OH^- in 725 L of solution, so $[OH^-] = 1.724 \times 10^{-3}$ M
$K_{sp} = [Mg^{2+}][OH^-]^2$ $[Mg^{2+}] = K_{sp}/[OH^-]^2 = 5.6 \times 10^{-12}/(.001724)^2 = 1.884 \times 10^{-6}$ M
1.884×10^{-6} M × 725 L = 1.366×10^{-3} moles Mg × 24.31 g/mol = 3.3×10^{-2} grams = 33.2 mg

C08. (A) The a constant in the van der Waals equation is a measure of how strong the intermolecular forces are in a real gas. The gas among the answer choices that has the strongest intermolecular forces is H_2O.

C09. (B) The balanced equation for the reaction is $C_5H_{12}(\ell) + 8\ O_2(g) \rightarrow 5\ CO_2(g) + 6\ H_2O(\ell)$
$\Delta U = q + w = \Delta H - P\Delta V$
Using $PV = nRT$, $V_{initial} = (8)(0.08206)(298)/1 = 195.63$ L
$V_{final} = (5)(0.08206)(298)/1 = 122.27$ L
$\Delta V = 122.27 - 195.63 = -73.36$ L
$P\Delta V = -73.36$ L·atm
Convert $P\Delta V$ from L·atm to J: -73.36 L·atm × 101.325 J/L·atm = -7433.2 J = -7.433 kJ
$\Delta U = \Delta H - P\Delta V = -3,509$ kJ – (–7.433 kJ) = –3502 kJ

C10. (A) Use the van't Hoff equation to calculate K at a second temperature.

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

$$\ln\left(\frac{K_2}{2.40 \times 10^{13}}\right) = \frac{25,500\ J}{8.314\ J/mol \cdot K}\left(\frac{1}{298} - \frac{1}{473}\right)$$

Solving the equation yields $K_2 = 1.08 \times 10^{-1}$.

2

C11. (E) There are two steps to this process. Each one will remove some of the solid $Ca(OH)_2$ from the container: 1) $Ca(OH)_2$ reacts with HCl, and 2) $Ca(OH)_2$ dissolves in the resulting solution. Although the problem says we're going to dissolve the $Ca(OH)_2$ and *then* add the acid, equilibrium problems can be solved in any order, and it's usually easiest to do the acid-base reaction first.
Adding 1.00 L of 0.50 M HCl means adding 0.50 moles of H^+ to the reaction. Since the acid reacts 2:1 with the base: $2H^+(aq) + Ca(OH)_2(s) \rightarrow Ca^{2+}(aq) + 2H_2O(\ell)$
This means 0.50 moles of HCl is enough to dissolve 0.25 moles of $Ca(OH)_2$.
So the acid part of this process dissolves 0.25 mol × 74.1 g/mol = 18.525 grams $Ca(OH)_2$ dissolved, leaving 6.475 grams of solid $Ca(OH)_2$ behind. This was answer A, which was a very good wrong answer if you picked it, but some of the $Ca(OH)_2$ is still going to dissolve just through solubility.
Now we have solid $Ca(OH)_2$ dissolving in 10 L of solution that is already 0.25 mol/10.0 L = 0.025 M Ca^{2+}. This is a common ion problem. $K_{sp} = [Ca^{2+}][OH^-]^2$, so $[OH^-] = (K_{sp}/[Ca^{2+}])^{\frac{1}{2}}$
$[OH^-] = (5.00×10^{-6}/0.025)^{\frac{1}{2}} = 0.014142$ M. This is 0.014142 mol/L × 10.0 L = 0.14142 mol OH^-. Since there are two OH– for every $Ca(OH)_2$ that dissolves, the amount of additional $Ca(OH)_2$ that dissolves into the solution is 0.07071 moles of $Ca(OH)_2$. 0.07071 mol × 74.1 g/mol = 5.2397 grams.
So the total amount of $Ca(OH)_2$ that dissolves is 18.525 g + 5.2397 g = 23.76 g dissolved, and the mass that remains as undissolved solid is 25.0 g – 23.76 g = 1.24 g $Ca(OH)_2$.

C12. (A) In this problem you're mixing a strong acid, a strong base, and a weak base. Since they all end up in the same solution, you can do the calculations in whatever order you want. The easiest way is to react the strong acid and strong base first, then add that solution to the weak base.
Moles of H^+ from original solution = 0.300 L × 0.015 mol/L = 0.0045 mol H^+
Moles of OH^- = 0.15 g × (1 mol / 40.0 g) = 0.00375 mol OH^-
H^+ is in excess, with 0.0045 – 0.00375 = 0.00075 moles H^+ remaining.
The moles of sodium acetate in the solution is 0.300 × 0.0050 M = 0.0015 mol acetate
You can calculate the moles of each species in the solution using a RICE table:

Reaction	HCl	+	CH₃COONa	→	CH₃COOH	+	NaCl
Initial moles	0.00075 mol		0.0015 mol		—		–
Change	*–0.00075 mol*		*–0.00075 mol*		*+0.00075 mol*		*+0.00075 mol*
Equilibrium	0		0.00075 mol		0.00075 mol		0.00075 mol

The final solution therefore contains 0.00075 moles of acetate and an equal number of moles of acetic acid, so it is a 1:1 buffer solution. You can calculate the pH using the Henderson-Hasselbalch equation or you can calculate $[H^+]$ using the K_a expression for acetic acid, or you can calculate $[OH^-]$ using the K_b expression for the acetate ion, or maybe you know that when a weak acid and its conjugate base are equal concentrations, $pH = pK_a$. $K_a = 1.80 × 10^{-5}$, so pH = –log(1.80 × 10⁻⁵) = 4.74

C13. (E) This question is just asking for the oxidation state of the carbon atom in a carbonate ion: the ion is –2 overall and the three oxygen atoms are –2 each for a total of –6, so the carbon atom has to be +4.

C14. (D) Total moles of gas = (3.8 L)(5.2 atm)/(0.08206)(538 K) = 0.4476 moles
Moles of gas in the large bulb = (2.3 L)(2.8 atm)/(0.0826)(298) = 0.2634 moles
Moles of gas in the small bulb = 0.4476 – 0.2634 = 0.1842 moles
Pressure in the small bulb at 25°C = (0.1842)(0.08206)(298)/1.5 = 3.00 atm

C15. (D) A higher order kinetic reaction can be made to mimic a lower order kinetic reaction by having one or more of the reactant concentrations be much greater than another. In this case if the initial concentrations of A and B are much higher than that of C, the concentrations of A and B will remain approximately constant and the reaction rate will depend only on [C], making this a pseudo first order reaction. Changing the temperature of the reaction has no effect on the order of the reaction.

C16. (B) From clues I and III, E, A, and F are exothermic, so they are freezing, condensation, and deposition in some order. That leaves B, C, and D as possible correct answers. Clue II says C and E are the lowest magnitude phase changes, and we already know E is exothermic, so C and E correspond to melting and freezing respectively. That leaves B and D as vaporization and sublimation. Clue III says A is greater in magnitude than F, and we already know these are condensation and deposition, so A is deposition and F is condensation. Finally, clue IV says B is equal in magnitude to F, and since F is condensation, B must be vaporization.

C17. (B) The added moles of HCl = moles of NaOH from the continued titration + moles of NaOH from the pellets.
moles of HCl = 0.0250 L × 1.50 M = 0.03750 moles H+
moles of NaOH from the titration = .01788 L × 1.20 M = 0.02145 moles OH–
moles of NaOH from pellets = 0.03750 – 0.02146 = 0.01604 moles.
each pellet is 0.1605 grams. 0.1605 g / 40 g/mol = .0040125 moles each
0.01604 moles NaOH / 0.0040125 moles/pellet = 3.9975 pellets = 4 pellets

C18. (E) The balanced equation for the reaction is $2MnO_4^- + 4H_2O + 3Zn \rightarrow 2MnO_2(s) + 3Zn(OH)_2(s) + 2OH^-$
moles of MnO_4^- = 2.50 L × 0.177 M = 0.4425 moles
moles of Zn used up = 0.4425 × (3 Zn/2 MnO_4^-) = 0.66375 moles
grams of Zn used up = 0.66375 mol × 65.38 g/mol = 43.396 grams used up
grams of Zn remaining = 96.0 – 43.396 = 52.6 g Zn remain
all MnO_4^- is converted to MnO_2, so 0.4425 moles of MnO_2 formed
0.4425 mol MnO_2 × 86.94 g/mol = 38.47 g MnO_2 formed
0.4425 mol MnO2 × ($3Zn(OH)_2$ / $2MnO_4^-$) = 0.66375 moles $Zn(OH)_2$ produced
0.66375 moles $Zn(OH)_2$ × 99.40 g/mol = 65.98 g $Zn(OH)_2$
total mass of solids = solid Zn + MnO_2 + $Zn(OH)_2$ = 52.6 g + 38.47 + 65.98 = 157 g of solid

C19. (C) Determining how much propanol can be made is a compositional stoichiometry limiting reactant problem. Burning the propanol is a reaction stoichiometry limiting reactant problem.
How many moles of propanol can you make?

Carbon: 6.45×10^{23} C atoms $\times \frac{1 \text{ propanol}}{3 \text{ C atoms}} \times \frac{1 \text{ mole}}{6.022 \times 10^{23} \text{ molecules}} = 0.3570$ moles propanol

Hydrogen: 1.75 moles $H_2 \times \frac{2 \text{ H atoms}}{1 \text{ H}_2} \times \frac{1 \text{ propanol}}{8 \text{ H atoms}} = 0.4375$ moles propanol

Oxygen: 15.4 g $O_2 \times \frac{1 \text{ mol O}_2}{32.0 \text{ g O}_2} \times \frac{2 \text{ O atoms}}{1 \text{ mol O}_2} \times \frac{1 \text{ propanol}}{1 \text{ O atom}} = 0.9625$ moles propanol

C is the limiting reactant. 0.3570 moles of propanol are formed, using up 0.3570 moles of O atoms and leaving 0.6055 moles of O atoms, or 0.30275 moles of O_2, left over.
Combusting the propanol $2C_3H_8O + 9O_2 \rightarrow 6CO_2 + 8H_2O$
To burn 0.3570 moles of propanol you need 9/2 × 0.3570 = 1.607 moles of O_2, but you don't have that

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much. You started with 0.9625 moles of O and used 0.3570 to make the propanol, so you have 0.6055 moles of O, or 0.3028 moles of O_2 remaining. With that much O_2 you can combust 0.3028×2 propane/9 O_2 = 0.0673 moles of C_3H_8O, yielding 0.2018 moles of CO_2. That is 1.22×10^{23} CO_2 molecules.

C20. (B) First the rate law must be determined from the data. The rate law is rate = $k[A_2]^x[B]^y$. x can be determined from trials 1 and 3, where $[B]_0$ is held constant. Taking the ratio of the rate law for trial 3 to trial 1 and canceling out k and [B] from top and bottom,

$$\frac{0.0451}{0.0212} = \left(\frac{2.45}{1.15}\right)^x$$

$$2.12 = (2.13)^x$$

$x = 1$. Now you can choose trial 2 and either of the other two trials to determine the exponent y. I'll use trials 1 and 2:

$$\frac{0.0935}{0.0212} = \left(\frac{1.75}{1.15}\right)\left(\frac{3.75}{2.20}\right)^y$$

$$2.90 = (1.70)^y$$

$y = 2$. Now you can choose any trial and plug the rate, $[A_2]_0$, and $[B]_0$ into the rate law and calculate k. Using trial 1, $0.0212 = k=(1.15)(2.20)^2$, so $k = 3.81 \times 10^{-3}$. The other two trials yield 3.80×10^{-3} for k.

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PHYSICS SOLUTIONS – UIL STATE 2023

P01. (D) page 127: "When calculating terms with couplings, we must consider (as always) all the possible points where couplings can occur, right down to cases where the two coupling points are on top of each other – with zero distance between them. The problem is, when we try to calculate all the way down to zero distance, the equation blows up in our face and gives meaningless answers – things like infinity….People were getting infinity for every problem they tried to calculate!."

P02. (E) page 138: "We have a simple, definite theory that is supposed to explain all the properties of protons and neutrons, yet we can't calculate anything with it, because the mathematics is too hard for us…. The reason we can't calculate to any great accuracy is because the coupling constant for gluons, g, is so much larger than for electrons."

P03. (D) page 139-140: "…what really happens is that one of the neutron's d-type quarks changes into a u-type quark. Here's how it happens: the d-quark emits a new thing like a photon called a W…. The W is a spin 1 type particle (like the photon and the gluon), that changes the 'flavor' of a quark…"

P04. (C) The percent drop is light output is directly proportional to the percent area of the star that is blocked by the planet. Since the disk of the star is a circle, the area of the star's disk can be found from the diameter: $A_{star} = \pi r^2 = \pi \left(\frac{1}{2}(2.78 \times 10^9)\right)^2 = 6.07 \times 10^{18} \text{m}^2$. The amount of area blocked by the planet is then $A_{planet} = (0.57\%)A_{star} = (0.0057)(6.07 \times 10^{18}) = 3.46 \times 10^{16} \text{m}^2$. From this planetary disk area, we can determine the diameter of the planet: $A_{planet} = \pi a^2 = 3.46 \times 10^{16}$. This gives a planet radius of $a = \sqrt{3.46 \times 10^{16}/\pi} = 1.05 \times 10^8 \text{m}$. Thus, the diameter of the planet is $D = 2a = 2.10 \times 10^8 \text{m}$. Dividing by the diameter of Jupiter, we get: $\frac{2.10 \times 10^8}{1.40 \times 10^8} = 1.5$ times the diameter of Jupiter.

P05. (D) There are some nice formulas for doing error propagation, but I'll show a little more of the basic mathematics. We write our variables in terms of their value and error as $I + \delta I$ and $R + \delta R$. The errors, δI and δR, are small quantities. Now, to calculate power we utilize the formula $P = I^2 R$. Including the errors, we have $P + \delta P = (I + \delta I)^2(R + \delta R) = (I^2 + 2I\delta I + \delta I^2)(R + \delta R)$. This expands to $P + \delta P = I^2 R + I^2 \delta R + 2IR\delta I + 2I\delta I\delta R + \delta I^2 R + \delta I^2 \delta R$. Because the errors are small, any term containing a higher order of errors than first order can be consider essentially zero. In other words, $P + \delta P \approx I^2 R + I^2 \delta R + 2IR\delta I$. Thus, the error in the power calculation is $\delta P \approx I^2 \delta R + 2IR\delta I = (0.135)^2(10) + 2(0.135)(470)(0.004) = 0.69 \approx 0.7 \text{W}$.

P06. (B) First, we need to know the velocity of the skier at the end of the slope. Because we ignore friction, we know the acceleration down an inclined slope is $a = g \sin \theta = (9.80) \sin(22.0) = 3.67 \text{m/s}^2$. Now, we can find the speed of the skier at the end of the slope: $v^2 = v_i^2 + 2a\Delta x = 0 + 2(3.67)(120) = 881 \rightarrow v = 29.7 \text{m/s}$. The direction for the skier is down and right at an angle of 22.0° below the horizontal. So, the components of the velocity are as follows: for the horizontal, we have $v_x = v \cos \theta = (29.7) \cos(-22.0) = 27.5 \text{m/s}$. And for the vertical, we get $v_y = v \sin \theta = (29.7) \sin(-22.0) = -11.1 \text{m/s}$.

These are the initial velocities for the next part, in which the skier is in free fall. For this second part, the acceleration is downward at 9.80m/s², the initial vertical position is 30.0m, and the final vertical position is 0.0m. We can now find the time that the skier is in the air: $y = y_i + v_{iy}t + \frac{1}{2}a_y t^2 \rightarrow 0 = 30 + (-11.1)t + (0.5)(-9.8)t^2 \rightarrow 4.9t^2 + 11.1t - 30 = 0$. Solving the quadratic gives two options for the time: $t = 1.59s, -3.86s$. We can ignore the negative option, so the actual time is $t = 1.59s$. Finally, we can find the location at which the skier lands: $x = x_i + v_{ix}t + \frac{1}{2}a_x t^2 \rightarrow x = 0 + (27.5)(1.59) + 0 = 43.7 \text{m}$.

P07.   (A) The force diagram for this problem includes four forces: the gravitational force (mg, downward), the normal force (F_N, upward), the frictional force (F_f, to the left), and the pulling force (F, up and right). The pulling force is at an angle, so it will need to be broken into components. In the horizontal, we have $F_h = F \cos\theta$ and in the vertical we have $F_v = F \sin\theta$. Since the bag of sawdust does not move in the vertical, the vertical forces must sum to zero: $\sum F_y = F_N + F \sin\theta - mg = 0$. This leads to a relationship between the pulling force and the normal force: $F_N = -F \sin\theta + mg \rightarrow F_N = -F \sin 35.0 + (22.0)(9.8) \rightarrow F_N = 215.6 - 0.5736F$. In the horizontal, we have a net acceleration of $a_x = 2.00\text{m/s}^2$. Mathematically, $\sum F_x = ma_x \rightarrow \sum F_x = F \cos\theta - F_f = ma_x$. Utilizing the formula for the frictional force, $F_f = \mu F_N$, we get $F \cos\theta - \mu F_N = ma_x$. Now, putting in the given values: $F \cos 35.0 - (0.158)F_N = (22.0)(2.00) \rightarrow 0.8192F - 0.158F_N = 44.0$. Now we substitute the expression for F_N that we obtained previously from the vertical: $0.8192F - 0.158(215.6 - 0.5736F) = 44.0$. This simplifies to $0.8192F - 34.06 + 0.0906F = 44.0 \rightarrow 0.9098F = 78.06 \rightarrow F = 85.8\text{N}$.

P08.   (D) Because there is a collision involved, this problem is solved using conservation of momentum. The initial momentum in each direction must equal the final momentum in those same directions. In other words, $p_{ix} = p_{fx}$ and $p_{iy} = p_{fy}$. Let's begin with the horizontal momenta. We have to consider the horizontal components for each boat, both before and after the collision: $p_{ixs} + p_{ixt} = p_{fxs} + p_{fxt} \rightarrow m_s v_{is} \cos(0) + m_t v_{it} \cos 125 = m_s v_{fs} \cos\theta + m_t v_{ft} \cos 60$. Plugging in the given masses and velocities: $(900)(25)(1) + (2200)(15)(-0.5736) = (900)v \cos\theta + (2200)(10)(0.5)$. This leads to $22500 - 18928 = 900v \cos\theta + 11000 \rightarrow v \cos\theta = -8.253\text{m/s}$.

Now we consider the vertical direction: $p_{iys} + p_{iyt} = p_{fys} + p_{fyt}$. This leads to: $m_s v_{is} \sin(0) + m_t v_{it} \sin 125 = m_s v_{fs} \sin\theta + m_t v_{ft} \sin 60$. Plugging in the given values: $(900)(25)(0) + (2200)(15)(0.8192) = (900)v \sin\theta + (2200)(10)(0.8660) \rightarrow 27032 = 900v \sin\theta + 19053$. Finally, we have $v \sin\theta = 8.866\text{m/s}$. Dividing our two results allows us to find the angle: $\frac{v \sin\theta}{v \cos\theta} = \frac{8.866}{-8.253} \rightarrow \tan\theta = -1.074$. This gives an angle of $\theta = 133°$. Now we can use either one of these to find the speed: $v \sin(133) = 8.866 \rightarrow v = 12.1\text{m/s}$. So, the final velocity of the speedboat is 12.1m/s at an angle of 133°

P09.   (C) This system is in equilibrium, so all forces and all torques will sum to zero. The force diagram for this system includes five forces: the weight of the sign (Mg, downward, acting on the end of the flagpole), the weight of the flagpole (mg, downward, acting at the middle of the flagpole), the tension in the cable (T, up and left, acting 1.20m from the base of the flagpole), the vertical force at the building wall (F_v, upward, acting at the base of the flagpole), the horizontal force at the building wall (F_h, to the right, acting at the base of the flagpole). Torque is defined as a force multiplied by a distance from an axis multiplied by the sine of the angle between the torque-arm and the force. The torque arm is the flagpole, so the angle for the weights and the vertical wall force are all $\theta_1 = 65.0°$, while the angle for the horizontal wall force is $\theta_2 = 90 - 65 = 25.0°$. The angle for the tension is based on the triangle formed by the flagpole, the wall, and the cable: $\theta_3 = 180 - 50 - 115 = 15°$. Now, we must choose the location of the axis: we will use the base of the flagpole, where it connects to the wall, to be the axis. The torques are then: $Mg(1.40)\sin(65)$ (clockwise), $mg(0.70)\sin(65)$ (clockwise), $T(1.20)\sin(15)$ (counterclockwise). Neither of the forces acting at the base of the flagpole contribute to the torque because they are located at the axis (a torque-arm distance of zero). Recalling that counterclockwise torques are positive, we can sum the torques and set the total equal to zero: $\sum \tau = T(1.20)\sin(15) - Mg(1.40)\sin(65) - mg(0.70)\sin(65) = 0$. This leads to $T(1.20)(0.2588) - (8.20)(9.80)(1.40)0.9063) - (4.00)(9.80)(0.70)(0.9063) = 0$. This simplifies: $0.3106T = 101.96 + 24.87 \rightarrow T = 408.3\text{N}$.

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Now that we have a value for the tension, we can look at summing the vertical forces and setting that to zero. Both weights and the vertical force at the base are completely vertical, but the tension makes and angle of 50.0° with respect to vertical. Summing, we get $\sum F_y = F_v + T \cos 50 - Mg - mg = 0$. This gives: $F_v + (408.3)(06428) = (8.20)(9.8) + (4.00)(9.8)$. This simplifies to $F_v + 262.5 = 119.6 \rightarrow F_v = -142.9$N. It's negative because it's actually directed downward instead of upward. Now for the horizontal forces, which includes the horizontal force at the base as well as a component of the tension: $\sum F_x = F_h - T \sin 50 = 0 \rightarrow F_h = (408.3)(0.7660) = 312.8$N. Finally, we can determine the magnitude of the total force at the base of the flagpole: $F = \sqrt{F_v^2 + F_h^2} = \sqrt{(-142.9)^2 + (312.8)^2} = 344$N.

P10. (B) This Doppler shift is caused by both the motion of the source (the ambulance) and the motion of the observer. Given the temperature, we know the speed of sound is $v = 343$m/s. The equation for the Doppler effect is $f_{obs} = \frac{v \pm v_o}{v \mp v_s} f_s$. You are moving towards the ambulance, so v_o will be added in the numerator. Likewise, since the ambulance is moving towards you, v_s will be subtracted in the denominator. Putting in the known values and signs, we have: $886 = \frac{343+33}{343-v_s}(678) \rightarrow$ $886(343 - v_s) = (376)(678)$. This leads to $303898 - 886v_s = 254928 \rightarrow 886v_s = 48970 \rightarrow$ $v_s = 55.3$m/s.

P11. (E) The ice melts because of the flow of heat energy through the iron rod. This flow of heat energy results from conduction, for which the equation is $P = \frac{kA\Delta T}{L}$. The length of the rod is given, as is the thermal conductivity. We also need the cross-sectional area, which we can find from the diameter. First, the radius is $r = \frac{1}{2}d = 1.25$cm. Now, the area is $A = \pi r^2 = \pi(0.0125)^2 = 4.91 \times 10^{-4}$m^2. So, the heat energy per second flowing to the ice is $P = \frac{(79.5)(4.91 \times 10^{-4})(86.0-0.00)}{(0.650)} = 5.16$ J/s. The total amount of energy needed to completely melt the ice is $Q = mL_f = (1.50)(3.33 \times 10^5) \rightarrow$ $Q = 5.00 \times 10^5$J. Thus, we can determine the time needed to flow that amount of heat energy through the iron rod to melt the ice: $t = \frac{Q}{P} = \frac{5.00 \times 10^5}{5.16} = 96,800s = 1613min = 26.9$hours.

P12. (E) First, we combine the capacitors to find a single equivalent capacitance for the circuit. We combine the 95.0µF and the 120µF in series: $\frac{1}{C_a} = \frac{1}{95.0} + \frac{1}{120} \rightarrow C_a = 53.0$µF. This series group is in parallel with the 50.0µF capacitor giving: $C_b = 53.0 + 50.0 = 103.0$µF. This parallel group capacitance is in series with both the 75.0µF and the 60.0µF, leading to a total circuit capacitance of $\frac{1}{C_T} = \frac{1}{103.0} + \frac{1}{75.0} + \frac{1}{60.0} \rightarrow C_T = 25.2$µF. Now, the total charge stored in the circuit is $Q_T = C_T V_T = (25.2)(45.0) = 1133$µC. This is the charge stored on the 75.0µF capacitor, the 60.0µF capacitor, and the parallel group. Therefore, the voltage across the parallel group can be found $V_b = \frac{Q_T}{C_b} = \frac{1133}{103} = 11.0$V. This is the same voltage across the 50.0µF capacitor and across the initial series group. Thus, the charge stored on the initial series group is $Q_a = C_a V_b = (53.0)(11.0) = 583$µC. This equals the charge stored on the 95.0µF capacitor and on the 120µF capacitor. Thus, the energy stored on the 120µF capacitor can be calculated: $U = \frac{Q^2}{2C} = \frac{(583)^2}{2(120)} = 1417$µJ = 1.42mJ.

P13. (A) The displacement of the charge can be described in vector notation as $\Delta s = ((-30.0) - 10.0)\hat{\imath} + ((-20.0) - 40.0)\hat{\jmath} = -40.0\hat{\imath} - 60.0\hat{\jmath}$ [cm] $= -0.400\hat{\imath} - 0.600\hat{\jmath}$ [m]. The voltage difference between the starting and ending points of the charge is given by the vector dot product: $\Delta V = -E \cdot \Delta s$. This gives a result of: $\Delta V = -(1700\hat{\imath} + 2400\hat{\jmath}) \cdot (-0.400\hat{\imath} - 0.600\hat{\jmath}) \rightarrow$ $\Delta V = -(1700)(-0.400) - (2400)(-0.600) = 2120$V. Finally, the energy needed to move the charge through that voltage difference is $U = Q\Delta V = (180 \times 10^{-6}C)(2120V) = 0.382$J.

P14. (C) We use Ampere's Law to solve this problem. In integral form, Ampere's Law is $\oint B \cdot ds = \mu_0 I_{in}$. Fortunately, the cylindrical/circular symmetry of the system allows us to get rid of the integral, simplifying the law to $Bs = \mu_0 I_{in} \rightarrow B(2\pi a) = \mu_0 I_{in}$. Here, I_{in} is the current flowing through the Amperean path, which is the circle of radius a. The point of interest lies at a distance of $a = 1.60$mm from the center of the wire, which is a location outside of the wire itself. Thus, the current inside the Amperean path (I_{in}) is simply the total current flowing in the wire. To find this total current flowing in the wire, we need to use calculus: $I_{in} = I = \iint J \cdot dA$. Because of the symmetry of the current density (it depends only on the radial variable, r), we can simplify this integration to:
$I = \int 2\pi r J(r) dr = \int 2\pi r((6.50 \times 10^9)r^2)dr = 2\pi(6.50 \times 10^9) \int_0^{1.40mm} r^3 dr$. This leads to
$I = 2\pi(6.50 \times 10^9)\frac{1}{4}r^4|_0^{0.00140} = 2\pi(6.50 \times 10^9)\frac{1}{4}(3.84 \times 10^{-12}) = 0.03922$A. Note that we stop the integration at the edge of the wire ($R = 1.40$mm). Now we return to Ampere's Law to find the magnetic field strength: $B(2\pi)(1.60 \times 10^{-3}) = (4\pi \times 10^{-7})(0.03922) \rightarrow B = 4.90 \times 10^{-6}T = 4.90\mu T$.

P15. (B) First, we determine the inductive reactance in the circuit: $X_L = \omega L = (377)(0.040) = 15.1\Omega$. Combining this with the resistance allows us to calculate the total impedance of the circuit. Resistances and reactances are combined using a Pythagorean sum: $Z = \sqrt{X^2 + R^2}$. Thus, in our circuit the impedance is $Z = \sqrt{(15.1)^2 + (25.0)^2} = 29.2\Omega$. Now, we use the AC version of Ohm's Law to find the current flowing in the circuit: $I = \frac{V}{Z} = \frac{24.0}{29.2} = 0.822$A. Lastly, we can use this current to determine the voltage drop across the inductor: $V_L = IX_L = (0.822)(15.1) = 12.4$V. Note: this simplified treatment of an AC circuit, which avoids phasors, works because everything in this circuit is in series in a single loop. This would not work with a more complex circuit.

P16. (A) In this problem, the light will pass through the front refracting surface from left to right, reflect from the mirrored back surface, and then pass back through the front refracting surface from right to left. Each step can be calculated independently, with the image from one step becoming the object for the next step. The refracting surface as seen by the object is convex, which means it has a positive radius of curvature, so we begin with $\frac{n_1}{p_1} + \frac{n_2}{q_1} = \frac{n_2 - n_1}{R} \rightarrow \frac{1.00}{23.0} + \frac{1.67}{q_1} = \frac{1.67 - 1.00}{36.0}$. This gives a first image location of $q_1 = -67.16$cm (that is, 67.16cm left of the refracting surface). This now becomes the object for the mirror: $p_2 = D - q_1 = 31.0cm - (-67.16cm) = 98.16$cm. Reflecting off of the mirror gives the second image location: $\frac{1}{p_2} + \frac{1}{q_2} = \frac{2}{R}$. The mirror is concave, so its radius of curvature is also considered positive: $\frac{1}{98.16} + \frac{1}{q_2} = \frac{2}{22.0} \rightarrow q_2 = 12.39$cm. This second image becomes the object for going back through the refracting surface:
$p_3 = D - q_2 = 31.0 - 12.39 = 18.61$cm. This light is now travelling from the glass back into the air, and goes towards the concave side of the refracting surface. So, this time we use 1.67 for n_1 and 1.00 for n_2, and we will have a negative radius of curvature for the surface. Mathematically, $\frac{n_1}{p_3} + \frac{n_2}{q_3} = \frac{n_2 - n_1}{R} \rightarrow \frac{1.67}{18.61} + \frac{1.00}{q_3} = \frac{1.00 - 1.67}{-36.0}$. This gives a third, and final, image location of $q_3 = -14.1$cm. That is, 14.1cm to the right of the front refracting surface.

P17. (C) For a mixed state, the expectation value of the energy is based on the mixing coefficients and on the energies of the pure states. First, though, we must make sure that the mixed state is normalized. We know the pure states are normalized, so we check the mixed state by combining the mixing coefficients in a Pythagorean sum: $\sqrt{a^2 + b^2} = \sqrt{(0.60)^2 + (0.80)^2} = 1$. Having shown the mixed state is properly normalized, we can now determine the expectation value of energy for the mixed state: $\langle E \rangle = a^2 E_1 + b^2 E_2 = (0.60)^2(1.40eV) + (0.80)^2(4.40) = 3.32eV$.

P18.   (A) In perfect Electroweak symmetry, the weak bosons ($W^\pm, Z^0$) and the photon (γ) are all massless particles. In fact, the neutral boson, Z^0, behaves essentially just like a photon. However, spontaneous symmetry breaking occurs when the electroweak field interacts with the Higgs field. It is the coupling of the Higgs field to the weak bosons that gives the $W^\pm$ and Z^0 their very large masses; while the photon, which does not couple to the Higgs field, remains massless.

P19.   (A) The Pressure versus Temperature plot shows the relationship to be linear. Thus, we will start by finding the slope of the line. I'll use two points on the line to determine the slope: ($265°C, 3.00 \times 10^5 Pa$) and ($175°C, 2.50 \times 10^5 Pa$). The slope is then:
$slope = \frac{3.00 \times 10^5 - 2.50 \times 10^5}{265 - 175} = 556$Pa/°C. Because the unit of Kelvin has the same magnitude as a degree Celsius, we can change the units of this slope to 556Pa/K. From the ideal gas law, we can see the relationship between pressure and temperature: $PV = nRT \rightarrow P = \frac{nR}{V}T$. Thus, the slope equals the quantity $\frac{nR}{V}$. Equating this to our calculated slope and putting in the known values gives:
$\frac{nR}{V} = 556 = \frac{n(8.314)}{1.50 \times 10^{-3}} \rightarrow n = 0.100$ moles.

P20.   (D) Using one of the object distances and the corresponding Lens 1 image distance, we can find the focal length of the strong converging lens: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \rightarrow \frac{1}{20} + \frac{1}{20} = 0.1 = \frac{1}{f_1} \rightarrow f_1 = 10cm$. Note: You'll get the same result for all of the object locations. Now, we repeat the calculation with the Lens 1+2 image. This will give the focal length of the close-contact combination of lenses 1 and 2.
$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \rightarrow \frac{1}{25} + \frac{1}{50} = 0.06 = \frac{1}{f_{12}} \rightarrow f_{12} = 16.7cm$. Lastly, we use the formula for combining the focal lengths of lenses that are in close contact: $\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{f_{12}} \rightarrow \frac{1}{10} + \frac{1}{f_2} = \frac{1}{16.7}$. This gives $f_2 = -25cm$, which is the focal length of the diverging lens.